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ORIGINAL ARTICLE

Multi-stage evolution of social response to flood/drought in the North China Plain during 1644–1911

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Abstract How the past human society responded to climatic disasters could provide better understanding on the nature of climate–human–ecosystem interactions and the knowledge of the vulnerability for the society in the context of changing climate. In this paper, the North China Plain in the Qing dynasty (1644–1911) is selected as a typical regional social-ecological system; with historical information kept in official documents, social responsive behavior and measures to flood/drought (e.g., reclamation, disaster relief, migration, revolt) are quantitatively described with proxy indicator time-series. It is found that the dominant responsive strategy altered significantly in different stages: (1) stage of cropland expansion (1644–1720); (2) stage of governmental disaster relief (1721–1780); (3) stage of increasing climate refugees (1781–1860); (4) stage of revolt and emigration (1861–1911). The multi-stage evolution of social response was impacted by various natural and social factors: (1) regional population–food balance and governmental finance were the most important limiting factors; (2) the interaction between the governmental policy and refugees' behavior in disasters affected the social consequences to a certain extent; (3) decadal-to-multi-decadal climate change would also impact the social response measures, even directly trigger the shift of dominant responsive strategy. This study would be helpful for deeper understanding of social resilience and better responding to climate change and extreme events in the present and future.

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Introduction

Against the background of climate change, natural disasters caused by rapid variation of climatic factors (e.g., flood, drought, heat wave, cold injury, etc.) have shown a tendency to enhance, which severely challenge the human society for the present and future (Parry et al. 2007). According to the theoretical framework of risk managing, the social impact of climatic disaster is a result of the interaction between the variation of climatic factors as an external perturbation and the vulnerable exposure of a social-ecological system, and the vulnerability is defined as its sensitivity to climate change and its capacity of to respond (Gallopín 2006; Lebel et al. 2011). Reasonably, the strategy that human adopt for responding to climatic disasters would affect social vulnerability to a great extent, and consequently the social consequences of disasters.

The past is a key to the present and future. In the pre-industrial era, climate change had always played an important role in social development (Zhang et al. 2008; Büntgen et al. 2011), and many precedents have been dug out that regional society declined or even collapsed under the pressure of abrupt climate change and extreme climatic disasters (Cullen et al. 2000; Haug et al. 2003; Amesbury et al. 2008). On the other hand, how human coped with climatic pressure has also been proved a crucial factor in the past climate–society interaction (Diamond 2005). For example, the Greenland and Iceland, two of Viking colonies rising in the Medieval Warm Period, both suffered from colder climate in the Little Ice Age. The former did not change its traditional way of living by pasture and hunting, and finally collapsed under ecological

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deterioration and heavy weather in the early fifteenth century; while in contrast, Iceland took full advantage of its local fishery resources to develop the fishing industry and trade goods with Europe, so that successfully saved their society.

There were various factors that affected the decision on the response strategies of a past regional society, such as its geographical location, ecological environment in and around the region, variety and abundance of available natural resources, economic and financial situation, internal class contradiction, relations with neighboring societies (friends or enemies), decision-making capacity of rulers, and so on (Diamond 2005). Historical empirical study on a regional scale that reconstructing social response to climate change and extreme meteorological disasters in a given historical period and analyzing the limiting factors in the decision making of dominant strategy (Endfield et al. 2004; Kumara et al. 2006) could provide better understanding on the nature of climate–human–ecosystem interactions and the knowledge of the vulnerability for the society in the context of changing climate (PAGES 2009; IHOPE 2010).

As an ancient civilization with written records for over 3,000 years, there are really close relationships between the formation and development of Chinese civilization and environmental changes, especially climate change (Fang et al. 2004). With most of its core region in the East Asia Monsoon Region, the rise and prosperity of Chinese farming culture benefited from the climate characterized by four distinct seasons and warm and wet crop growing season, whereas since its origin, this huge agricultural society has been severely threatened by floods and droughts caused by the violent fluctuation of annual and inter-annual precipitation. Fighting against the two natural disasters has become a dominant theme in Chinese history. The establishment of the first dynasty, Xia (about 2000–1600 BC), has been related with the need for integrating social resources to regulate an extraordinary flood (Wang 2005; Wu and Ge 2005). Since the first centralized state, the Qin dynasty (221–206 BC), was established, disaster relief has always been one of the most important functions of every central government in the last more than 2,000 years (Huang 1997). The efficiency and effectiveness of governmental response to natural disasters (especially flood and drought) could be a decisive factor in the rise and fall of a dynasty. It has been proved that a vital reason of the collapse of the Ming dynasty (1368–1644) was that the court gave up its responsibility of disaster relief in the tremendous drought in the early seventeenth century, which led to country-wide famine and social unrests (Mote and Twitchett 1998). The deep involvement of government in social response to disasters could significantly distinguish China from other ancient civilizations (e.g., the medieval Europe). According to the studies of the governmental disaster relief in the Qing dynasty (1644–1911), either the scale or efficiency of the relief activities was fairly prominent, considering that it occurred in a traditional agricultural society (Will 1990; Li 2007). These historical experiences would be meaningful to modern society in which the governmental policy making and emergency management are regarded as important assessment indicators of the capacity of social response to climate change.

At present, by means of reconstructing proxy indicator series based on Chinese historical documents, researchers have achieved quantitative analysis on the past social response to climate change and extreme disasters. Some of these studies focus on a terminal or extreme response, such as population fluctuation (Lee et al. 2008), revolts (Xiao et al. 2011a) and war (Zhang et al. 2007) and reconstruct a macro and intuitive spatio-temporal correspondence between the proxy indicator series and climatic factors (e.g., temperature), which might inevitably lead to a lack of some intermediate links in the climate–society interactive chain (especially the governmental response). Some others dig out more human responsive behaviors to the past climate change on a smaller spatio-temporal scale; make a distinction between the governmental (e.g., migration policy) and civil response (e.g., migration, reclamation, and revolt); and analyze the interaction among extreme climate events (disasters), human behavior, and policies, as well as its temporal change (Ye et al. 2004; Fang et al 2007). In these cases, the governmental response was generally the implementation of migration policy, while disaster relief, as another crucial measure of response, has not attracted enough attention.

In this paper, the North China Plain (NCP) in the Qing dynasty is selected as a typical regional social-ecological system in Chinese history; abundant historical information kept in official documents about the social responsive behavior and measures (e.g., reclamation, disaster relief, migration, revolt) that related to climate change (especially extreme flood/drought) are collected; subsequently, the stage change of dominant responsive strategy is analyzed based on the reconstructive proxy indicator time-series of social response; and finally, the main natural and social factors that affected the decision on the response strategies are discussed.

Study area

The NCP in this paper is defined as 22 prefectures (Fu) and 198 counties (Xian) that include most of Zhili (north to the Great Wall), northeastern Henan, and northwestern Shandong (according to the administrative divisions in 1820) (Fig. 1) (Tan 1987; Niu 1990). This region roughly covers modern Beijing and Tianjin, most of Hebei, and part of Henan and Shandong, which is alluvial floodplain of the Hai River and Yellow River and is surrounded by the Yan Mountains to the north, the Taihang Mountains to the west, and the Shandong Hills to the southeast.

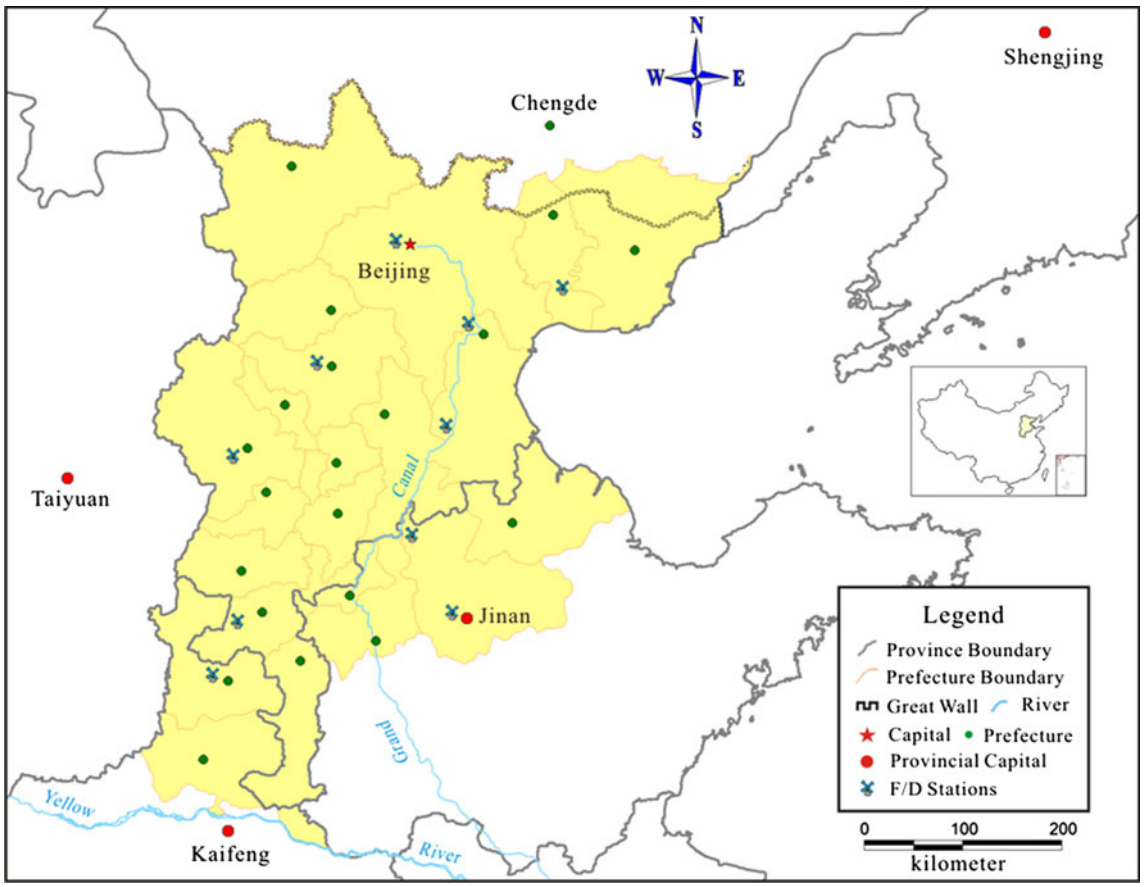

Fig. 1 Administrative division of the North China Plain in 1820. *Source* Data of digital map are from Yugong site, http://yugong.fudan.edu.cn/Ichg/Chgis_index.asp

The NCP is located in warm temperature zone with an annual precipitation of 600–700 mm. Due to the high variability of annual and inter-annual precipitation, severe flood/drought often occurs and becomes huge threat to this traditional agricultural region (Li 1990; Gu 1991). On the other hand, as the political center of the Qing Empire, disaster relief in the NCP received much attention from the court and was well organized by government; besides, civilians' large-scale emigration to north of the Great Wall could also effectively relieve the pressure of disasters. Multi-level responses from individuals to the central government allow us to reconstruct time-series of social responses during 1644–1911. In recent years, focusing on a certain social response, such as revolt (Xiao et al. 2011a), emigration to northeast China (Ye et al. 2012) or eastern Inner Mongolia (Xiao et al. 2013), and abrupt change of dominant responsive strategy in a short time (Fang et al. 2012), we have engaged in several historical empirical researches in this region, which constituted the basis of this paper.

Materials and methods

In this paper, the main data source of historical proxy indicator series is *the veritable records of the Qing dynasty* photoprinted by the Zhonghua Book Company (ZBC 1985–1987), which was a collection of official records (4433 volumes edited on a daily basis) including the archive from the Cabinet and bureaucratic ministries, the literature from the Research Institute of the Qing dynasty History, the imperial instructions and anthology, etc. The historical information collected from *the veritable records of the Qing dynasty* include governmental grain relief, gruel charity in the capital (Beijing), migration of refugees, and revolting events in the NCP. The data on population, cropland area, crop yield per unit area, and administrative division are cited from previous studies. The trend and amplitude of climate change, as well as the frequency and intensity of climatic disaster (flood/drought), was analyzed with existing reconstructions of historical climate.

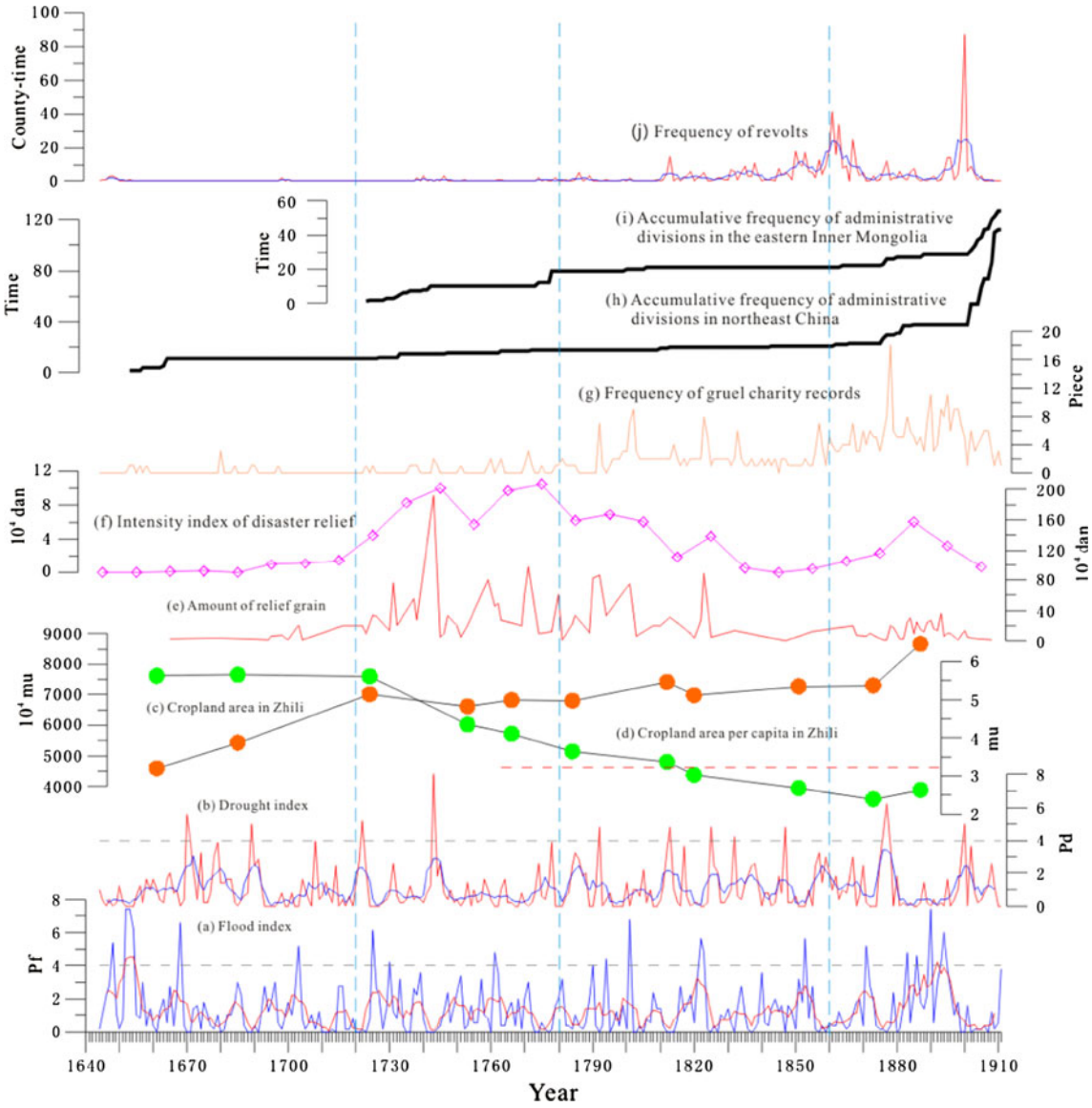

Fig. 2 Multi-stage evolution of social response to flood/drought in the North China Plain during 1644–1911

Flood/drought index

The flood/drought index indicates annual intensity of flood/drought in the NCP in 1644–1911 and is calculated using wetness/dryness grade data from 10 stations (Beijing, Tianjin, Tangshan, Baoding, Cangzhou, Shijiazhuang, Handan, Anyang, Dezhou and Jinan; Fig. 1) in the NCP, described in the *yearly charts of dryness/wetness in China for the last 500-year period* (classified into 5 grade: 1, very wet; 2, wet; 3, normal; 4, dry; 5, very dry) (CMA 1981). The annual flood index, Pf (Fig. 2a), and drought index, Pd (Fig. 2b) in the NCP are defined as $P = N1 \times W1 + N2 \times W2$, where N_1 is the number of severely affected stations (wetness/dryness grade = 1/5); N_2 is the number of minimally affected stations (2/4); W_1 and W_2 are the weights assigned as 0.8 and 0.2, respectively. Additionally, it is defined as 1 year with extreme drought/flood disaster when Pd $\geq$ 4 or Pf $\geq$ 4.

Cropland area and grain output per capita

According to the provincial cropland area and demographic data reconstructed by Liang (2008) and Cao (2001), respectively, total cropland area (Fig. 3c) and per capita (Fig. 3d) of Zhili Province (main body of the NCP) at several points of time during the Qing dynasty was estimated. With a relatively reliable estimate of crop yield per unit area in Zhili in the eighteenth century (Xue 2008),

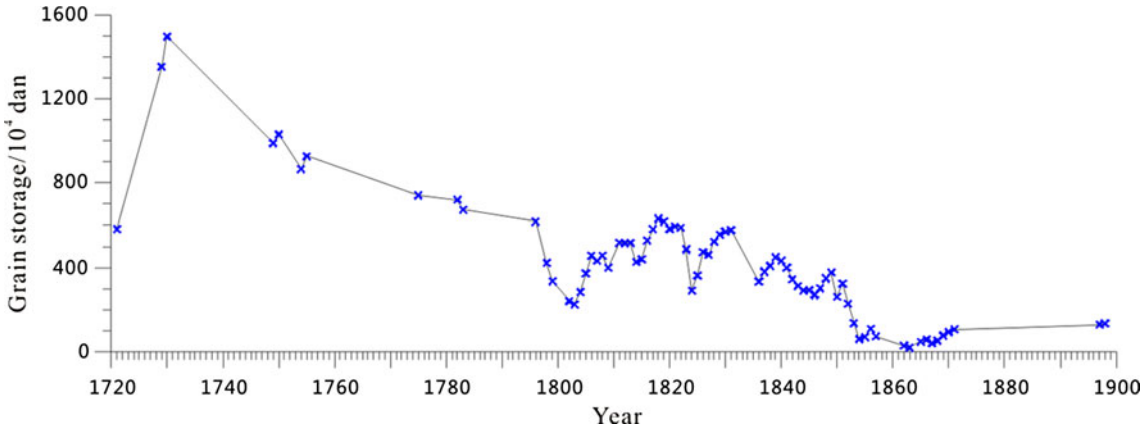

Fig. 3 Total grain storage in Beijing and Tongzhou of some years in the Qing dynasty

which was 93 kg/,[1] the amount of grain output per capita at each point could be calculated. Referenced to the modern subsistence level of 300 kg (raw grain) per capita, where a critical share of food security is guaranteed (Yin et al. 2009), the deviation in the grain output per capita and the critical share during different periods are calculated to assess the regional social sensitivity to climate change and its temporal change.

Relief grain from the central granaries

In the Qing dynasty, a series of huge granaries were built in Beijing, Tongzhou (the terminal of the Grand Canal), Dezhou, Linqing (two important docks alongside the Canal in Shandong province), and other cities to store the grain shipped to Beijing from southern provinces (especially the Yangtze River basin) through the Canal, which amounted to 4 million dan[2] every year and supported the imperial family, court officials, and nobles of the Eight Banners (Li and Jiang 2008). When disasters occurred in the NCP, the most important source of relief grain was these granaries directly controlled by the central government, including the grain in transit.

The veritable records of the Qing dynasty, as a compilation of official document, kept detailed records of the allocation of relief grain from the central granaries, with which the source, destination, time, and amount (in the unit of 10 thousand dan) of grain allocation in the NCP could be identified, and the annual variation of relief grain (R) from the central granaries to the NCP could be reconstructed (Fig. 2e).

Intensity index of disaster relief

The intensity index of disaster relief (I) reflects the capacity of disaster relief that was organized by the Qing court in the NCP. It is calculated using the indexes of P and R as below:

$$I = R/(\mathrm{Pd} + \mathrm{Pf})$$

Considering that governmental relief was always launched after disaster and usually lasted from autumn to the next spring, the index (I) of a certain year could not completely represent the intensity of disaster relief in that year. In this paper, decadal average (Fig. 2f) is used to estimate the long-term variation of governmental response capability.

Gruel charity in Beijing

Gruel charity once played an important role in disaster relief activities in the Qing dynasty. It was took charge by some specialized institutions set in many cities, most of which were organized or aided by government. Regularly, they opened after autumn harvest every year, providing finite food (mainly gruel) and camp for the poor and disaster victims from surrounding area, and lasted until the next spring. Gruel charity in Beijing was directly supported by central government, with the largest scale, the most sufficient funds and efficient organization; therefore, Beijing became the most important destination for refugees in the NCP (Wang 2007). Records of gruel charity in Beijing kept in *the veritable records of the Qing dynasty*, with 475 pieces in total, could be divided into three categories:

"Regular" records (258 pieces) refer to the records about regular execution of gruel charity every year, such as the open and close of institutions on schedule, standard amount of grain and outlay allocated to every institution, etc.

[1] μ is a traditional Chinese unit of area, and 1 μ ≈ 0.067 hm^2.

[2] Dan is an ancient Chinese unit of capacity, and in the Qing dynasty, 1 dan of grain was equivalent to approximately 70 kg.

"Temporary" records (190) appear in the cases of emergency, such as large numbers of refugees arriving in Beijing when some severe natural disasters occurred, including extending duration, setting up provisional charity institutions, supplying more grain and outlay, etc., which reflected a temporarily intensified gruel charity. Other records (27) are relevant records of gruel charity affairs, like inspecting the order of institutions and counting staffs of the institution, etc.

The frequency of gruel charity records (piece/year) (Fig. 2g) could reflect the severity of refugee problem to some extent, which means that the more severely the disasters affected the victims' survival, the more refugees left for the capital to seek relief, and the more records of gruel charity could be found, the "temporary" records in particular.

Administrative division in northeast China and eastern inner Mongolia

In the early Qing dynasty, the inhabitants of the eastern Inner Mongolia were primarily Mongol herdsmen, while northeast China the Manchus. Both regions were protected by the "quarantine policy", which prohibited immigration and reclamation. However, in later centuries, they gradually became the major destinations of the refugees from the NCP. To manage them, the Qing court established a series of administrative units named Fu (equivalent to prefectures), Ting, Zhou, and Xian (equivalent to counties).

The frequency of establishment and reformation of administrative units in different periods could reflect the changes of migration policy, which means frequent administrative divisions generally took place in the period of relatively flexible policy. In many cases, the loosening of migration policy could be related to the climatic disasters in the NCP which would cause sharp increasing of destitute and homeless refugees (Ye et al. 2012; Fang et al. 2012).

During 1644–1911, there were 54 times of administrative divisions (including establishment and reformation) in the EIM, while 112 in the NC. The accumulation curves for the frequency of administrative divisions in the two regions were created respectively (Fig. 2h, i).

The staging of the evolution of the migration policy (quarantine policy) in the Qing dynasty was based on Ye et al.'s work (2012).

Frequency of revolt events in the NCP

Revolt was a more extreme response of refugees to disaster, compared with seeking for relief and inter-regional migration, which was a mark of unstable (or high risk) social status. Revolt-related records in the Veritable records of the Qing dynasty can be divided into 3 categories in line with the severity of the action against the government: mass demonstrations, banditry incidents, and peasant uprisings. With the data of the location of outbreaks, affected regions, duration, and seriousness of the revolts, the frequency of the revolts in the NCP during 1644–1911 is reported in the units of "county-time" (1 county-time signifies that one county was affected by a revolt in 1 year) (Xiao et al. 2011a). Because the records during the Boxer Movement were far from complete in *the veritable records of the Qing dynasty*, the frequency of revolts from 1899–1901, during the Boxer Movement, is calculated using the records from *brief records on Boxer Movement* (Li 1986).

Temperature change

The temperature change in the NCP in the Qing dynasty is analyzed based on previous studies also, more specifically, the temperature anomaly series in north China since 1380s (Wang 1991) and the winter half-year temperature anomaly series in eastern China over the past 2,000 years (Ge et al. 2003) (both in 10 years resolution).

Results

Proxy indicator series of flood/drought and its social response in the NCP during 1644–1911 are shown in Fig. 2. Multi-stage evolution of social response could be found, which means that in different period, the dominant responsive strategy would be different. 4 stages have been identified as follows.

Stage of cropland expansion (1644–1720)

Having experienced the large-scale wars and famines in the late Ming dynasty, population in the NCP sharply decreased in the early Qing. For instance, in Zhili Province, the population in 1644 was approximately 7.3 million, excluding the Manchus and the original inhabitants of northeast China that followed them, which was 1/3 less than that in 1630 (Cao 2000); the cropland area was 45.98 million μ in 1661 (Liang 2008), which was 74.7 % of the peak of the Ming dynasty (61.58 million μ in 1583) (Fan 1984). In this period, the immediate concern of the Qing court was to restore agricultural production. During the first several emperors' reign, encouraging reclamation had always been one of the most important policies. Newly reclaimed cropland could get tax cut for many years, and the amount of new cropland was taken as a key assessment index of provincial officials' achievements (Peng 1990). For suffering from severe financial difficulties (insufficient revenues and lasting unification wars), the new government

did very little in disaster relief when flood/drought occurred (Fig. 2e, f) except for land tax cut. Under these policies, the more cropland peasants owned, the less vulnerable their households were to disasters to flood/drought. That was why peasants' enthusiasm for reclaiming was enhanced and cropland area in the NCP had sustained rapid growth in this stage (Fig. 2c).

In the same time, for agriculture in northeast China (particularly in eastern Liaoning Province) declined due to most local peasants' emigration following the Manchu army; the Qing court encouraged the immigration for a short time (1653–1667) and established some prefectures and counties in this area (Fig. 2h). In the late seventeenth century, there were three migratory peaks in northeast China corresponding to three drought events in north China, respectively, which means that inter-regional migration was a responsive measure to climatic disasters (Fang et al. 2007; Ye et al. 2012) in the NCP, although not the main measure for limited scale of migrants. After the encouraging-migration policy was canceled in 1668, the population increase in northeast China slowed down and there were no more administrative divisions in 1665–1726 (Fig. 2h). Low frequency of gruel charity records in Beijing (Fig. 2g), and revolts' (Fig. 2j) records also implies that survival in the NCP was not critical, though extreme flood/drought occurred frequently in this stage (Fig. 2a, b).

Stage of governmental disaster relief (1721–1780)

By the early eighteenth century, the expansion of cropland in the NCP gradually stagnated. Cropland area of Zhili exceeded 70 million μ in 1724, and in the later 150 years, its fluctuation range was never more than 4 million μ (Liang 2008). Subsequently, cropland area per capita decreased continuously since 1720s (Fig. 2c) accompanying population growth.

In this stage, governmental financial circumstances had been greatly improved because of national unification and economic prosperity. The most significant change of social response to flood/drought in the NCP was the rapid reinforcement of governmental disaster relief with abundant grain storage and efficient water transportation. Since 1720s, relief grain from the central granaries sharply increased (Fig. 2e), as well as the intensity index of disaster relief (Fig. 2f), which reached its peak in 1770s (10.5 on average). On decadal scale, the amount of relief grain allocated to disaster areas achieved its peak in 1740s (2.6 million dan) and on annual scale in 1743 (1.9 million dan). In many disaster cases, such as the drought of 1743 and flood of 1761, both the intensity and efficiency of governmental disaster relief were unprecedented in Chinese history (Will 1990; Li 2007; Xiao et al. 2012). The government played a positive role in disaster relief.

The scale of refugees caused by disasters in this period was a little larger than that in the early Qing. During the flood of 1725 and drought of 1743, there were thousands of refugees pouring into Beijing for relief.[3] Accordingly, frequency of gruel charity records increased a little although most of them concentrated in some years of extreme disaster, which indicates that gruel charity was just a subsidiary and temporary relief measure then (Fig. 2g).

Despite the immigration into northeast China was more strictly forbidden since 1740 (Ye et al. 2012), when flood/drought occurred in the NCP, under the pressure of refugees, the government often acquiesced in their inter-regional migration, such as in the drought of 1743.[4]Meanwhile, the quarantine policy in eastern Inner Mongolia was more liberal than that in northeast China. In this stage, permanent inter-regional migration from NCP (mainly to eastern Inner Mongolia) driven by flood/drought was relatively active. There were 19 types of administrative division in eastern Inner Mongolia (Fig. 2i), out of which 16 took place around Chengde, and only 7 in northeast China (Fig. 2h). The migration to the north of the Great Wall and reclamation around Chengde could be taken as another important responsive measure to disasters in the NCP in this stage (Xiao et al. 2013). Nevertheless, the scale of migration was still limited. In 1782, nearly a century after the initial agricultural exploitation, the population in Chengde Prefecture was just 0.55 million (Cao 2001), while 0.95 million in northeast China in 1780, increasing by 0.42 million relative to 1724 (Zhao 2004).

During 1721–1780, under the efficient governmental disaster relief, there was no large-scale survival crisis in the NCP, and most disaster victims chose to stay at their residence waiting for relief, rather than emigration (temporary or permanent) or revolt (Fig. 2j).

Stage of increasing climate refugees (1781–1860)

Since 1780s, the intensity of governmental disaster relief had been continuously weakened. Relative to the average intensity index of 8.13 in 1720–1770s, it decreased by 21.6 % (6.37 on average) in the next 30 years (1780–1800s), and even 82.3 % (1.44 on average) in 1810–1850s. The golden age of the Qing had gone with the severe financial crisis caused by rampant corruption of

[3] *The Veritable Records of the Qing Dynasty*, Vol. 11: 647-a. "今年流民亦只三四千之数，较之雍正二三年数至盈万者，尚为减少" (1744-1-14).

[4] *The Veritable Records of the Qing Dynasty*, Vol. 11: 508-b. "本年天津、河间等处较旱，　闻得两府所属失业流民……出喜峰口、古北口、山海关者颇多。……若仍照向例拦阻，不准出口，……恐贫苦小民愈致狼狈。……如有贫民出口者，门上不必拦阻，即时放出；但不可将遵奏谕旨、不禁伊等出口情节令众知之，……倘有声言令众得知，恐贫民成群结夥，投往口外者，愈致众多矣" (1743-8-15).

bureaucratic group and the White Lotus Rebellion in 1796–1804. The increasingly empty central granaries could not provide enough relief grain to the NCP (Fig. 2e).

Because the insufficient governmental disaster relief could no longer ease the food shortage caused by disasters, survival crisis were more and more common in the NCP and the "climate refugee" problem began to emerged, which could be illustrated in large-scale migration after flood/drought, including migration inside the NCP and inter-regional migration.

During the drought of 1792 and flood of 1801, tens of thousands of refugees crowded into Beijing,[5] which forced the Qing court to greatly reinforce gruel charity (Fig. 2g). Since then, gruel charity, used to be a subsidiary measure in the disaster relief system, became more and more important, even for a time was the only governmental relief measure.

During and after the drought of 1792, the quarantine policy was significantly relaxed (especially for northeast China) to ease the pressure of refugees. Around the turn of the nineteenth century, a large number of refugees from the NCP migrated and settled down along the Willow Palisade in northeast China. Just in 1792, there were more than a hundred thousand persons emigrating from the NCP.[6] Compared with 1780, the population in northeast China in 1820 sharply increased by 160 %, to 2.47 million, with an annual growth of 24.2 ‰. Most of the increased population was exactly the refugees from the NCP. In order to govern these immigrants, a series of administrative units were established here (Fig. 2h).

In 1803, the Qing court decided to reaffirm the quarantine policy and forbid further migration and reclamation to northeast China to protect Manchu's homeland (Fang et al. 2012). After the 1810s, as the quarantine policy came into effect, the population growth in northeast China slowed down again. During 1820–1860, annual growth rate decreased to 10.1 ‰. As the refugees' emigration was blocked, refugee problem in the NCP gradually became uncontrollable and the refugees' behavior became increasingly violent. The frequency of revolts in the NCP significantly rose with fluctuation in the early nineteenth century, and extreme flood/drought became an important trigger of revolts (Fig. 2j). The first large-scale peasant uprising in the NCP in the Qing dynasty broke out in the drought of 1813 (Xiao et al. 2011a).

[5] *The Veritable Records of the Qing Dynasty*, Vol. 26: 919-a. "京城粥厂现在远来领赈者竟有二万余人(1792-8-17)"; *The Veritable Records of the Qing Dynasty*, Vol. 29: 262-b. "近日京城附近地方饥民领赈者至二万五六千人(1802-3-27)".

[6] *The Veritable Records of the Qing Dynasty*, Vol. 27: 461-b. 1792年旱灾期间,灾民"前赴盛京、吉林及蒙古地方就食,不下数十万人"(1794-9-4).

Stage of revolt and emigration (1861–1911)

The climate refugee problem in the NCP emerged in the late eighteenth century and reached its climax during late 1850–1860s. After the Yellow River changed its course at Tongwaxiang in 1855, drought and plague of locusts occurred and lasted for several years. Subsequently, peasant uprisings spread over most areas of the NCP and had not been suppressed until late 1860s (Fig. 2j).

Famines and wars resulted in much larger number of refugees. The frequency of gruel charity records in Beijing sharply increased (280 pieces of records during 1860–1900s, 58.9 % of total), indicating the unprecedented scale of refugees pouring into Beijing and the duration of their stay (Fig. 2g). In 1860, under the great external and internal stress, the Qing court eased the quarantine policy again, for the purpose of resisting the Russian invasion from the northeast by immigration and reclamation, as well as resolving the serious social contradictions in the NCP. Thereafter, the migration from the NCP to northeast China turned much more active, especially in the years of extreme flood/drought. In particular, during and after the drought of 1876–1878, millions of refugees from disaster areas in North China (Zhili, Shandong, Shanxi and Henan) immigrated in northeast China (Hao et al 2010). During 1876–1882, there were 14 times of administrative division in northeast China (Fig. 2h) and 4 in eastern Inner Mongolia (Fig. 2i). Intensive administrative division could reflect the massive immigration in the corresponding period. In 1900, the population of northeast China was 12 million, triple of 1860 (Zhao 2004). Taking 10 ‰ as annual natural growth rate during 1860–1900, it could be estimated that 6 million, a half of total population, were new immigrants.

After the Taiping Rebellion (1851–1864) and Nianjun Uprising (1852–1868) were put down in 1860s, the south–north transportation resumed, and the governmental financial situation recovered for a short time, which allowed more relief grain to be allocated in the NCP (Fig. 2e). In the late nineteenth century, especially in 1880s, the intensity of governmental disaster relief rebounded significantly (Fig. 2f).

But in 1890s, due to continual floods in the NCP (Fig. 2a) and the Qing's fiasco in the First Sino-Japanese War (1894–1895), the government completely lost control of social order. During 1899–1900, the Boxer Movement broke out in the background of drought (Fig. 2b, j). After that, a mass exodus from the NCP to northeast China and eastern Inner Mongolia occurred, which was reflected in the unprecedentedly rapid increase in administrative division in the latter two regions (Fig. 2h, i), under the New Policies of the Qing court which finally terminated the quarantine policy and encouraged immigration and

agricultural exploitation in the areas north of the Great Wall.

In the last 50 years of the Qing, the NCP suffered from severe social upheaval. Large-scale emigration (such as in the drought of 1876–1878) and revolts (like in the drought of 1899–1900) were both the most important social responsive measures to extreme flood/drought in the NCP.

Discussion

The dominant responsive strategy to flood/drought in the NCP in the Qing dynasty evolved from the reclamation in the early days, to large-scale governmental disaster relief in the mid-eighteenth century and finally to intensifying population migration and armed revolts in the nineteenth century. It appeared to be a process of stage change from positive to negative, as well from peace to violent. The shift of dominant response was impacted by various natural and social factors, some of which were universal in Chinese history, and others were specific to the NCP in the Qing dynasty.

Regional population–food balance and governmental finance

The shift of social responsive strategy took place in the background of a complete dynastic cycle (from social harmony to crisis), and many factors which had more or less impacted the governmental policy decision or civilian spontaneous behavior in other cycles in Chinese history could also be identified in this process. Regional population–food balance and governmental finance could be regarded as two of the most important limiting factors of the changing of social response measures.

The NCP in the Qing dynasty was still a traditional agriculture society with no great technical innovation in agriculture and transportation, which meant that crop yield per unit area increased very little during the more than 200 years (Wang 2009), and it was also unrealistic to solve food shortage by large-scale inter-regional trading market. Consequently, natural growth of population became the main motivation for altering population–food balance in regional scale.

With the data of cropland area, population, and crop yield per unit area (93 kg/μ) in Zhili, the capacity of food supply in different periods could be estimated. Before 1720s, annual grain output per capita maintained over 500 kg owing to the cropland reclamation; after that, it began to decline. Around the turn of the nineteenth century, the population-food balance came to a critical turning point that annual grain output per capita decreased from about 339 kg (1784) to less than 300 kg in 1810s, which was lower than the subsistence level of 300 kg per capita for the first time (Fig. 2d, the red dotted line represents the crop area per capita equivalent to 300 kg grain output per capita). The food shortage continuously deteriorated in the nineteenth century, and by 1870s, annual grain output per capita had been below 230 kg. Food crisis contributed to a sharp rise in the social sensitivity to external perturbation, such as extreme floods or droughts. When disasters occurred, famine or even bankruptcy would be inevitable for most of the peasants who already had no surplus grain. That was why "climate refugee" problem emerged in the late eighteenth century and reached its climax in the mid-late nineteenth century.

Compared with other regions, government played a more important role in social response to disasters in the NCP. In particular, the relief grain supplied by government could directly ease food shortage and maintain social order after disaster. During 1720–1911, the Pearson correlation coefficient between the 5-year running averages of intensity index of disaster relief, and frequency of revolts was −0.349 (with the significant level of 0.01), which meant that efficient governmental disaster relief could significantly reduce the risk of social disorder after disasters. However, as discussed above, large-scale grain relief played as the dominant relief measure only in the mid-eighteenth century; in other stages, the multiple shifts of main governmental relief measures was restricted by its financial situations, which was visually reflected in grain storage controlled by the Qing court.

Let us take the total grain storage in Beijing and Tongzhou for example (Fig. 3) (Li and Jiang 2008), where the largest central granaries were located and the most relief grain was contributed. In the early Qing, these granaries were in the course of construction, and grain storage was insignificant. Therefore, the government usually adopted tax cut as the main relief measure. As the agricultural production resumed and developed, the governmental grain storage rapidly increased since the turn of the eighteenth century and reached its peak around 1730. Abundant grain storage allowed the government to broadly distribute relief grain to disaster victims. However, the grain storage sharply decreased since the end of eighteenth century, keeping pace with the end of the so-called Kong and Qian Eras. The capacity of governmental relief decreased immediately. In 1850–1860s, the Yellow River's changing course and peasant uprisings suspended the grain transportation along the Grand Canal, and the central grain storage was minimized. In the late Qing, the government just maintained its disaster relief by reinforcing gruel charity and easing the quarantine policy (Fang et al. 2012; Xiao et al. 2012).

Interaction between the government and refugees

Social response to flood/drought in the NCP in the Qing dynasty occurred at two levels, governmental and civilian.

The interaction between the governmental policy and refugees' behavior in disasters also affected the social consequences to a certain extent. When the interaction was benign, the negative impacts of disaster would be well relieved, and vice versa.

The inter-regional emigration from the NCP to the north of the Great Wall (northeast China and eastern Inner Mongolia) embodied a concentrated reflection of the interaction between government and refugees. For the refugees in the NCP, temporary or permanent emigration to the north of the Great Wall where was sparsely inhabited was a reasonable response measure to reduce food demand of disaster area; however, for the Manchu rulers, too many Han immigrants would be a threat to the Manchus and Mongolian original inhabitants' privileges (e.g., priority of access to natural resources). The conflicts and compromises on migration problem between the government and refugees ran through the whole Qing dynasty. Since the early Qing, the quarantine policy for "Manchuria" and Mongolia had been adjusted for many times; by the turn of the eighteenth century, it had been developed into a so-called "semi- quarantine" policy (restrictive immigration), which meant that in years of flood/drought, refugees from the NCP would be allowed to move to the north of the Great Wall, while in normal years, the ban was strictly enforced, and no one could pass through the tollgates along the Great Wall (Ye et al. 2012; Xiao et al. 2013). In the eighteenth century, this policy eased the pressure of disaster relief in the NCP, promoted the agricultural exploitation in nomadic regions, and protected the vulnerable local ecosystem because the scale of immigration and exploitation was limited.

The benign interaction turned into its opposite since the late eighteenth century. Under the pressure of severe imbalance between food demand and supply in the NCP, large-scale emigration became the only viable option for the government to resolve the emerging climate refugee problem; however, the governmental policy decision always lagged behind the refugees' spontaneous behavior. In the beginning, the Qing court inappropriately reaffirmed the quarantine policy and tried to shut out the refugees' emigration (the early nineteenth century); then, in 1860s, it was forced to ease the quarantine policy and just let the refugees drift; when it made the New Policies and consciously organize the emigration and reclamation, it had been too late to benefit the government. The negative interaction between the government and refugees resulted in severe social consequences. On the one hand, the refugee problem in the NCP gradually became uncontrollable and the refugees' behavior became increasingly violent (Xiao et al. 2011a; Fang et al. 2012); on the other hand, refugees who had immigrated into northeast China and eastern Inner Mongolia also turned to be grave threat to local social order due to the lack of efficient administration (Ye et al. 2012; Xiao et al. 2013).

Decadal and multi-decadal climate change

Social response measures in this paper were discussed mainly on annual time-scale because they occurred after a specific extreme precipitation event, which lasted not very long. The social impacts of decadal and multi-decadal climate change (e.g., cooling, warming, increase or decrease in frequency and intensity of disaster) were relatively difficult to identify in a short period; however, after a continuous accumulation, the impact would be significant enough to affect the shift of social response measure by changing the population–food balance. In particular, when climate shifted from mild to harsh and the rate exceeded the capacity of human adaptation, climate change might greatly accelerate the shift of dominant responsive strategy to disaster.

For example, the turn of the nineteenth century was a period when climate shifted from a relatively warm period of the eighteenth century to the last cold period of the Little Ice Age (Wang 1991; Ge et al. 2003). In north China, temperature dropped by approximately 1 °C during 1790–1810s (Wang 1991); meanwhile, the frequency of extreme flood/drought during 1780–1810s significantly increased relative to 1740–1770s (Fig. 2a, b, above the dotted lines), which were both harmful to local agricultural production. According to our previous estimation, just the cooling and more frequent extreme disasters could reduce the average crop yield during 1780–1810s decrease by at least 11.75 % compared with normal years; considering that the growth of population in the 40 years was about 25 %, the extent of climatic impact on regional population–food balance had approximated 50 % of that caused by population growth, which could accelerate the outbreak of the food crisis in the NCP by about 20 years (marked by large-scale peasant uprising in the 1810s) (Fang et al. 2012). It could be inferred that the emergence of "climate refugee" problem and the shift of the refugees' behavior from peaceful to violent around the turn of the nineteenth century could also be related to the climatic deterioration in the corresponding period.

Additionally, similar response measures might lead to different social consequences in different climatic background. For example, during 1870–1890s, governmental disaster relief in the NCP had been recovered, although only to a limited extent (Fig. 2e). In 1880s, 1.76 million dan of relief grain were provided, which was nearly equivalent to the level of the mid-eighteenth century (decadal average of 1720–1770s was 1.78 million dan). However, the last decades of the Qing was a period with the most frequent and severe disasters in the NCP. In 1870–1890s, average annual frequency of extreme flood/drought

was 2.83 station-times (1 station-time signifies that one station was affected by extreme disasters in 1 year), which was 1.65 in 1720–1770s; and there were 9 extreme disaster years in this 30 years (Fig. 2a, b), which was 5 in 1720–1770s. Relatively cold climate and frequent disasters led to the lowest crop yield during 1736–1911 (Zhang 1996). Due to the poor climatic condition, more relief grain did not increase the intensity index significantly (Fig. 2f), thus did not work as well as that in the mid-eighteenth century (Xiao et al. 2012). Another case was the inter-regional migration between the NCP and eastern Inner Mongolia. The agro-pastoral transitional zone of northern China moved northward in the background of climatic warming in the early and mid-eighteenth century, which allowed greater agricultural exploitation and environmental capacity in the former nomadic regions. That was why eastern Inner Mongolia could accept numerous refugees from the NCP, and local agriculture became prosperous in this period; however, as the climatic deterioration since the late eighteenth century, the boundary between agricultural and pastoral land was moved toward southeast, agriculture in eastern Inner Mongolia declined, local environmental capacity decreased, and conflicts between refugees from the NCP and local inhabitants were aggravated (Xiao et al. 2011b, 2013; Fang et al. 2012).

Conclusion

Based on historical official documents and previous relevant researches, the social (governmental and civilian) responsive behavior and measures to flood/drought (e.g., reclamation, disaster relief, migration, revolt) in the North China Plain in the Qing dynasty are quantitatively described with proxy indicator time-series. It is found that the dominant responsive strategy altered significantly in different periods.

(1) In 1644–1720, the dominant responsive strategy was reclamation which was reflected in continuous expansion of cropland in the NCP, while very small-scale migration and few revolts could be identified though extreme flood/drought occurred frequently. (2) In 1721–1780, large-scale governmental disaster relief became the most significant response measure, accompanied by mild regional and inter-regional migration. (3) In 1782–1860, governmental disaster relief sharply declined and climate refugee problem emerged, characterized by increasing events of migration and revolt related to flood/drought. (4) In 1861–1911, large-scale emigration and revolts were both the most important social responsive measures. According to the interactions (positive or negative) between the governmental emergency management and civilian spontaneous behavior in and after flood/drought and the social consequences, the four stages of social response could be summarized as recovery, prosperity, decline, and collapse, respectively.

As a regional social-ecological system based on traditional agriculture, the multi-stage evolution of social response to disasters in the NCP in the Qing dynasty was very typical in Chinese history: under the precondition of lack of large-scale interregional trade and technical revolution, the shifting regional population–food balance driven by natural population growth was a determinative factor that affected the main social response measures in different periods. On the other hand, the important role government played in the social response system, especially the unprecedentedly large-scale and long-lasting grain relief, could be a distinguishing characteristic of the NCP in the Qing dynasty. Consequently, the intensity and social effects of governmental disaster relief depended on the governmental finance and grain storage.

The temporary or permanent emigration to eastern Inner Mongolia and northeast China was another important social response measure in the NCP. Its scale and social impacts both on the source and destination was affected by the interaction between disaster refugees' willing and governmental decision on migration policy.

The shift of dominant responsive strategy was also affected by decadal-to-multi-decadal climate change, such as temperature fluctuation, trends of the frequency and intensity of flood/drought, etc. The emergence of climate refugee problem around the turn of the nineteenth century, and increasingly violent behavior of the refugees was triggered by abrupt climatic deterioration in the corresponding period. Additionally, similar response measures (e.g., grain relief, migration) might lead to different social consequences in different climatic background.

Social resilience to climate change, especially extreme events (climatic disasters) which may lead to regime shifts in ecological systems, is an active area of research and practice (Carpenter et al. 2012). The interaction between human society and natural environment in the past can provide a basis for a deeper understanding of the present and for forecasting the future (Costanza et al. 2007). How humans in the past responded to climate change and extreme events was a key issue for estimating the resilience. However, as mentioned in the introduction, most of the existing studies focus on a single responsive behavior or measure, which could not completely describe the capacity of social response, and increased the uncertainty of results. In this paper, with the proxy indicator time-series of the main social responsive behavior and measures, interactions of the ecological and the social systems amidst the changing climate was detailed and quantitatively described, and the major drivers that shaped the dominant coping strategy in the NCP in the Qing dynasty was suggested. This coevolving human–environment system could

be compared with the case studies in resilience across continents and societies in different periods made by the Resilience Alliance.[7] In the future, based on more accurate quantification of indicators of human responses and influencing factors, an integrated estimation of resilience of the past regional society will be provided.

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