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Resilience of traditional rice-dominated agricultural communities to precipitation variability in the North China Plain

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ABSTRACT: This study used the concept of resilience as a framework to explore the response of a traditional rice-dominated agricultural society to past climatic variability in the Hai River Basin, North China Plain. In agriculture-based communities, the performance of resilience refers to the functions of cropping and water systems and the flexibility to respond to an uncertain climate. With limited water inflow, the responses to the recent historical precipitation variability in this case study demonstrated that the local people were adjusting to both interannual variability and extreme drought through their collective and individual actions. In the short term, the local people coped by adjusting the planting area and individually switching from planting paddy rice to less water-intensive crops in order to adapt to a severe, continuing drought. However, because of poor management of the water system by community leaders and the lack of an adequate budget for the collective action of rice cropping, the shift in land use to rice cropping as an adaptation to the recent increased precipitation was not usually reversible. In the long term, the agricultural production of most villages became less resilient to current precipitation variability, despite the intention of most villagers to change the current cropping system to improve their low household staple food self-sufficiency. This study indicated that over the long term the social resilience and adaptive capacity of agricultural communities and their associated stakeholders must be built on and enhanced to better cope with the constraints and opportunities of current climate variability. New institutional arrangements, including collective irrigation regimes and community leadership capabilities, are required to build social resilience and to enhance adaptive capacity for future uncertainties.

KEY WORDS: Precipitation variability · Agricultural production · Adaptation · Resilience · Institution · North China Plain

1. INTRODUCTION

Climate change has emerged as one of the most multifaceted manifestations of global change (Dessai et al. 2007) and is expected to affect many economic sectors, including forestry, energy consumption and tourism; however, climate change particularly affects the agricultural sector (Moriondo et al. 2010). The current vulnerabilities to climate are strongly correlated with climate variability, particularly precipitation variability (Cruz et al. 2007). These vulnerabilities are greatest in arid and semi-arid, low-income

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areas, where precipitation and stream flow are concentrated over a few months and the year-to-year variation is high (Lenton 2004, Kundzewicz et al. 2007). This year-to-year variation is of great concern in agricultural sectors (Thomas 2008). Although humans and natural ecosystems in many river basins suffer from a lack of water, in water-scarce areas the people and ecosystems are particularly vulnerable to the decreasing or variable precipitation that results from climate change (Kundzewicz et al. 2007).

Several recent studies have assessed the vulnerability to global environmental change and the adaptive capacity to cope with these changes on local and global scales (Dessai & Hulme 2007, Acosta-Michlik & Espaldon 2008, Kelkar et al. 2008, Saldaña-Zorrilla 2008, Nunn 2009, Podestá et al. 2009). Recently, the concept of resilience has been increasingly used in studies of the human dimension of global environmental change science (Janssen et al. 2006, Vogel et al. 2007, Cutter et al. 2008, Young 2010). The resilience-based approach was developed to understand the changing dynamics of the integrated social–ecological systems (SES), and can provide insights into potential management options during conditions of uncertainty and change (Allison & Hobbs 2004, Folke 2006, Cutter et al. 2008, Resilience Alliance 2010). This approach is particularly appropriate for managing the effects of climate change, because the future climate and climate predictions are inherently uncertain (Dessai et al. 2007, Marshall 2010).

1.1. Definition of resilience

This paper utilises the definition given by the Resilience Alliance (2010) that resilience is the capacity of a system to absorb disturbances and to reorganise itself, while undergoing change to retain essentially the same function, structure, identity and feedback. Simply, resilience has 2 qualities — (1) it is inherent (resilience functions well during non-disturbance periods) and (2) adaptive (resilience is flexible in its responses during disturbances) — and these qualities can be measured by referencing some level of system performance (or system function) (McDaniels et al. 2008). Resilience indicators for sustainable development are usually defined under the environment, economy, organisation and resources, as well as (qualitatively) technology and operation dimensions (Schluter & Pahl-Wostl 2007). Few quantitative methodologies have been introduced to explore the system characteristics and mechanisms of resilience, e.g. the computable general equilibrium model and fuzzy Delphi method (Rose 2004, Chan et al. 2014). Depending on the magnitude of the disturbances, resilience is not only related to being persistent or robust to a disturbance. In a resilient SES, disturbance has the potential to create the opportunity to do new things, to innovate and to develop (Folke 2006). This alternate state may be desirable or undesirable (Carpenter et al. 2001, Resilience Alliance 2010).

The development of resilient agricultural systems is an essential topic of study because many communities greatly depend on the services provided by such systems for their livelihood; these 'provision services' include food, fodder, fuel and other bio-resources (Lin 2011). On a year-to-year basis, agricultural systems at the community level are often highly resilient (Marcus 2005); the people are able to absorb the small disturbances, including droughts, floods, economic fluctuations and pest attacks, whereas the agricultural system retains its core structural features. In fact, this resilience reflects the history of the agricultural process in many agricultural areas throughout the world (Marcus 2005). However, severe disturbances, such as long-term drought or tsunamis, may provide people with the incentive to adopt new states of agricultural structural dynamics, thereby affecting the reliability of provision services. Such alternate states may be desirable or undesirable for the continued production by sectors.

The factors that enable social systems to proactively respond to environmental change have emerged as a core domain of global change research (Marshall 2010, Conway & Schipper 2011, Frank et al. 2011, Larsen et al. 2011). A society's ability to manage resilience resides in its sectors, social networks and institutions (Lebel et al. 2006). Terms, such as property regimes, community coping strategies, governance and institutional factors are important aspects for understanding the resilience of agricultural communities that have the ability to respond to disturbances, including both individually and collectively (Tompkins 2005, Fraser & Stringer 2009, Engle & Lemos 2010, Larsen et al. 2011). Other aspects of maintaining the resilience of agriculture-based communities include crop diversity and a resilient environment (Fraser & Stringer 2009, Lin 2011).

1.2. Water and cropping systems in the North China Plain

Both the Fourth and Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) mentioned that the water and agricultural sectors are likely to be the most sensitive to climate change-induced effects in Asia (Cruz et al. 2007, Hijioka et al. 2014). Rice is the principle staple crop of Asia, and any deterioration in the rice production systems caused by climate change would severely impair the food security in this continent (Wassmann et al. 2009). Water availability is the primary factor that determines the success of rice cropping. Although the production of rice has increased over time in the wake of the Green Revolution, the production of rice in the past few decades has declined in many parts of Asia because of the increasing water stress that has arisen partly from climate variability and change (Cruz et al. 2007). Therefore, the vulnerability of the rice-dominated agricultural system to water stress has become a key concern in Asia.

In China, rice is the largest cereal crop; it accounts for 25% of the cultivated land, is primarily grown in the southeast and is secondarily grown in the northeast. The North China Plain (NCP) is a major agricultural production area in China, where water scarcity is already a big issue; its mean precipitation is 500 to 600 mm yr^{-1}, and the actual crop evapotranspiration is 800 to 900 mm yr^{-1}. The NCP includes 3 main river basins, those of the Yellow River, the Hai River and the Huai River. For many years, a shortage of water resources in the NCP has been a key concern for sustainable crop production (Liu & Xia 2004, Liu et al. 2008, Tao & Zhang 2010). Rice cultivation in the NCP will be highly sensitive to future climate change if no adaptation measures are implemented (Xiong et al. 2009). Extensive studies have used crop models and several climate change scenarios to simulate the effects of climate change on rice production in Asia (Matthews & Wassmann 2003, Asada & Matsumoto 2009, Masutomi et al. 2009) and specifically in China (Tao et al. 2008, Chavas et al. 2009, Xiong et al. 2009). However, there have been only limited local studies regarding the effects of stakeholders' responses to climate change and to socio-economic development on rice production in the NCP or in other areas in China.

This study used the concept of resilience as a framework to understand the dynamics of the traditional rice-dominated agricultural areas in the NCP on the county, village and farm scales, and how stakeholders cope with and adapt to a changing environment. In this context, in the agriculture-based communities, the resilience performance refers to the functions of the cropping system (the area and types of the dominant planted crops) and the water system (network and condition of equipment and water service) and the flexibility to respond to an uncertain climate. This study aimed to contribute to the sustainablility of agriculture and to enhance the adaptive capacity and resilience in the context of climate change; the specific focus was on precipitation variability.

2. CASE STUDY

2.1. Study area

The Hai River Basin, northeast of the NCP, is one of the most developed regions in China; the river flows through Beijing (China's capital), Tianjin (China's third largest city), and through the primary Heibei Province into the Bohai Gulf of the Yellow Sea. This basin has the lowest annual precipitation (539 mm) in the Chinese east costal region and contains the lowest per capita water availability (305 m^3) among all of the Chinese basins (Liu et al. 2012). Recently—primarily because of the rising water demand and competition for non-agricultural water uses in the Hai River Basin—river flow has greatly decreased (Liu & Xia 2004).

This study was conducted in a traditional rice-dominated agricultural area composed of 2 administrative counties of Tianjin—Ninghe and Baodi—which are on a low-lying alluvial plain along the mouth of the Hai River (39° 18'–39° 50' N, 117° 08'–117° 56' E) (Fig. 1). It covers an area of 1414 km^2 in Ninghe and 1509 km^2 in Baodi. This area has a semi-arid monsoon climate and an average precipitation of ~530 mm yr^{-1}. The precipitation is highly irregular between seasons and from year to year, and approximately 3/5 of the precipitation occurs in July and August. The city of Tianjin has an available per capita volume of water resources that is equal to only 1/15 of the national average and 1/50 of the world average (Song et al. 2011). The major land use in this area is agricultural, and the arable land accounts for >55.6% of the area. Annual single cropping is predominant in the study area, and multiple cropping of vegetables is common. Irrigated paddy rice in paddy fields and corn or cotton in crop fields are the primary single crops; specifically, a local traditional brand of rice named 'Xiaozhan' is common. Given its distinct and popular qualities, Xiaozhan has been regarded as a geographical indication in China. Historically, wetland and paddy fields were widespread in the study area. However, because of severe water shortages, the area encompassed by wetland and paddy fields has decreased over the past 2 decades (Li et al. 2007). In 2009, the paddy fields in these 2 counties

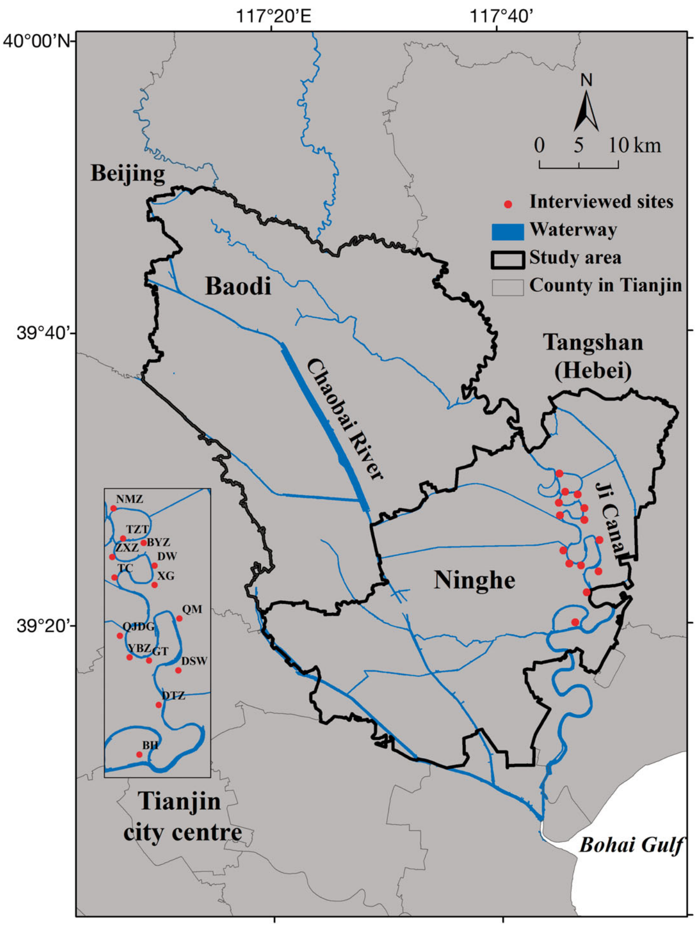

Fig. 1. Study area: Ninghe and Baodi counties, Tianjin, China. Interviews were held in 14 villages of Ninghe County— NMZ: Nanmaizu; BYZ: Beiyuezhuang; TZT: Tianzhuangtuo; ZXZ: Zhangxinzhuang; DW: Dongwo; XG: Xiguan; TC: Taci; QJDG: Qianjiedaogu; YBZ: Yangbozhuang; GT: Gaotuo; QM: Qianmi; DSW: Dashawo; DTZ: Datingzhuang; BH: Bohou

covered 112.41 km^2, accounting for ~11.4% of the entire area of paddy fields in the Hai River Basin and 82.9% of all paddy fields in the Beijing–Tianjin capital region. These 2 counties are in the remote rural area of Tianjin City where farm income remains the major source of income.

There are 2 main water couses in the study area, the Ji Canal and the Chaobai River (Fig. 1). The growth season of rice and cotton in this area is from April to October: Irrigation of crops usually occurs in spring and early summer. In spring, the rivers (swollen from rainy season rains) are used as a source of irrigation. The land is tilled and fertilised in the rainy season (June to August), when rainwater is the principal source of irrigation. In the winter, the local farmers also usually irrigate fields in order to improve soil fertility and structure and to reduce the risk of disease in the coming year. If there is not enough irrigation water available during the winter and spring, the local farmers transfer water from other rivers. Although the 2 counties are geographically adjacent, Baodi has more runoff water than Ninghe (Fig. 2) because Baodi is located upstream, near the mouth of the Chaobai River (Fig. 2). After Baodi residents have withdrawn sufficient water from the rivers, water is released from the dam to be used in Ninghe. The water stored in the rivers is the primary water source in Ninghe after the rainy season. Thus, irrigation in Ninghe relies heavily on precipitation (Fig. 2).

2.2. Statistical analysis and data collection

To understand the historical trajectories of the agricultural system and their responses to precipitation variability, it is assumed that the rice planting area (acreage) in the current year corresponds to the farmers' cropping intentions and their perception of available water, based on the precipitation over the previous year. In Tianjin, the irrigation water requirement for the optimal growth of rice is suggested to be 9000 m^3 ha^{-1}, whereas for less water-intensive crops, such as cotton, it is suggested to be 1200 m^3 ha^{-1}. Therefore, given that rice requires more water, farmers often switch to drought-tolerant crops after a bad precipitation year. Thus, it is also reasonable to expect that when these farmers suffer from crop damage from extremely low precipitation, they may then convert their paddy fields to crop fields. In the study area, several alternative crops were utilised by farmers to resist water stress, including cotton, maize and chilli peppers. Because cotton is the most common crop in this region, occupying 45.6% of the total agricultural land in 2009, this study considered cotton planting to be an alternate state of the prevailing agricultural system, which shifted from a food- to a fibre-dominated provision. Planting areas of rice and cotton were analysed and related to a historical series of annual accumulated precipitation from 1990 to 2009 in both counties, as well as their associated differential responses.

The annual precipitation and acreage data were obtained from statistical yearbooks in the study area (Tianjin Municipal Bureau of Statistics 1991–2010). The correlation between the system's response and variable precipitation was examined on the county scale by comparing the acreage of water-intensive rice or drought-tolerant cotton with the long-term

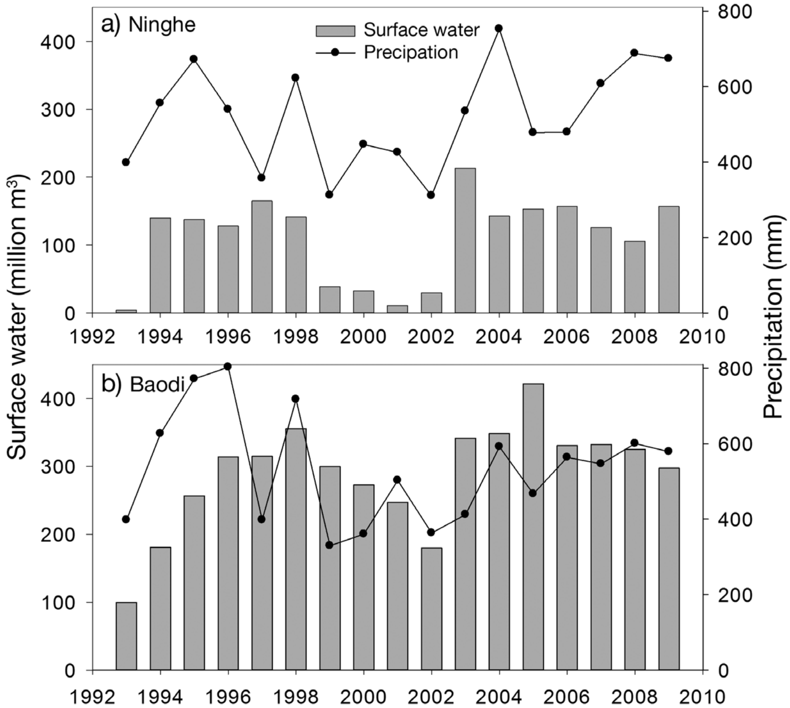

Fig. 2. Annual available surface water resources and precipitation in the study area (1993–2009), including runoff water from upstream, local precipitation that was stored in the river and the water transferred from other rivers. Source: Tianjin Statistics Yearbook (1994–2010)

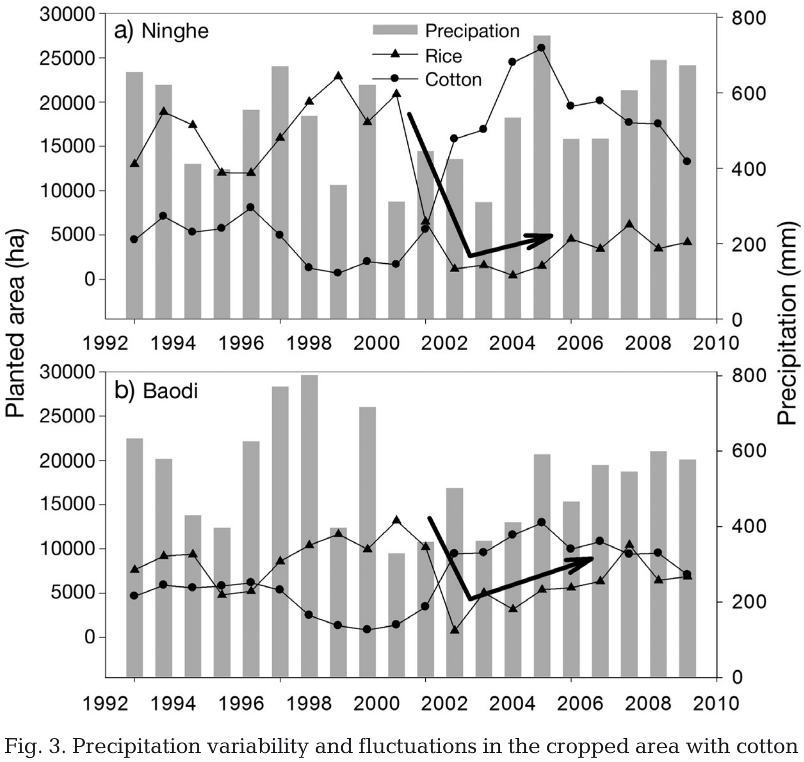

Fig. 3. Precipitation variability and fluctuations in the cropped area with cotton and rice in Ninghe and Baodi Counties (1990–2009). Solid arrows: resilience performance

variability in annual precipitation over the last 2 decades. To facilitate the observation, the study period was also separated into 2 time series for the correlation analysis: 'until drought' encompassing the years 1990–2002, and 'after drought' ranging from 2003–2009.

2.3. Responses to year-to-year precipitation variability on the county scale

The 2 counties experienced the same annual precipitation patterns during the study period (mean ± SE: Ninghe County = 527 ± 129; Baodi County = 534 ± 135); both counties encountered continuing drought from 1999 to 2002 (Fig. 2) (although in 2001, the rainfall in Baodi was very close to the average). This drought, which lasted 4 yr and was observed across much of the Northern Hemisphere's mid-latitude regions from 1998 to 2002 (Zeng et al. 2005), dramatically decreased the acreage of rice; however, rice production remained stable in both of the counties during that period.

In Ninghe, the area that was planted with rice decreased dramatically, and this decrease was accompanied by a considerable increase in the area planted with cotton during the period 1990–2009. In 1990, rice cropping was the most popular agricultural practice and accounted for 32.7% of the agricultural area; by 2009, rice cropping was performed in only 11.3% of the agricultural area (a 67.8% decline), whereas cotton cropping increased from 11.1 to 34.5% in the same period. Thus the study area transformed from a rice-dominated system to a cotton-dominated system.

The link between precipitation variability and cropping over time in Ninghe is shown in Fig. 3. The acreage of rice production was significantly negatively correlated with the acreage of cotton during the last 2 decades ($y = 19325.289 - 0.837x$, N = 20, r = −0.894 at the p = 0.01 level). No significant relation was found between the acreage of rice production and precipitation, with a 1 yr lag over the entire study period ($y = 1736.751 + 16.007x$, N = 19, r = 0.268). However, the lagged correlation was significant when the data after 2003 were removed ($y = -4844.746 + 37.448x$, N = 12, r = 0.631 at the p = 0.05 level).

In Baodi County, the paddy fields declined from 9.8 to 9.0% during the study period, and the cotton fields increased from 6.0 to 9.3%. Similar to Ninghe County, the acreage of rice production was also significantly negatively correlated with the acreage of cotton during the same period ($y = 11674.202 - 0.022x$, N = 20, r = −0.730 at the p = 0.01 level). A significant positive relation was found between the acreage of rice production and precipitation with a 1 yr lag over the entire study period ($y = -60.405 + 14.267x$, N = 19, r = 0.638 at the p = 0.01) (Fig. 3).

The significant negative correlations between the rice and cotton cropping areas and the positive association between precipitation and rice production showed that local farmers responded to the precipitation fluctuation by adjusting the planting area and by switching crops. The different results of the correlation analyses of rice cropping and precipitation during different periods showed that precipitation is not currently perceived as a limiting factor for rice cropping in Ninghe, even when the precipitation levels were greater than normal. Although rice cropping in Baodi also experienced dramatic decreases during the continuous period of low precipitation from 1999 to 2002, its production recovered (showing that resilience was maintained) after the extreme precipitation low. The comparable evidence from Baodi helped us exclude the possibility of any larger-scale external disturbances, such as a consumption pattern or wider economic changes, in these 2 counties. We hypothesize that some internal disturbances may have occurred in Ninghe, and that these disturbances may have caused the failure of recovery to the previous state of rice cropping and the loss of resilience. Therefore, 2 questions were asked. (1) Why did Ninghe fail to recover to the previous planting state, even when precipitation was sufficient? (2) Did cropping and water system functions of the agricultural system fail, resulting in a loss of flexibility? The aim of the next section is to answer these questions by examining the farmers' responses to the variable year-to-year precipitation at the village community scale and at the farm scale in Ninghe.

3. FARMERS' COPING STRATEGIES AND ADAPTATION CAPACITIES

3.1. Interview survey

The semi-structured interviews were performed in 14 village communities located along the Ji Canal of Ninghe County in December 2010 (Fig. 1). All of these villages are typical agricultural villages in the study area and have the same free access to water in the canal. For the purpose of ths study, a village was regarded as synonymous with a community. There are 30 km between the Ninghe County town and the mouth of the river where the canal flows into the Bohai Gulf. The surveyed villages were selected according to the distance from the town along the Ji Canal, the main production patterns, and the changes that occurred during the study period. The survey focused on farm characteristics, reasons for the current cropping state, crop changes, the rationale for abandoning the previous crop and the households' future willingness to continue with the current crop. An average of 3 to 4 households were randomly selected to be interviewed in each sample village. In total, 53 households were interviewed. Key informant interviews with 14 village leaders were simultaneously conducted to determine the community's take up of adaptive measures. Additional in-depth interviews were conducted with the local officers of water and agriculture authorities to obtain information regarding local runoff and water consumption of agricultural production.

3.2. Coping strategies following extreme events

The interviews with the individual households and with village committee leaders in 14 communities along the Ji Canal confirmed the above estimation of the implications of this variable precipitation for production in each village. The majority of village committee leaders (12/14) reported that their conversion from paddy field to crop fields started in 1998 and was concentrated in 2000 and 2001 because of the harvest loss caused by the continuing extreme drought that was followed by a high water salinity level.

The extremely low precipitation from 1999 to 2002 caused dramatic shortages in the surface water and ground water that were used for irrigation in Ninghe County (Fig. 2). The lack of freshwater runoff coupled with the intrusion of coastal sea water accelerated an extreme rise in the water salinity. Without freshwater to rinse the Ji Canal and its reaches, sea water encroached further up the Ji Canal through the broken sluice gate, which was distorted by the Great Tangshan Earthquake in 1976. Saline water entered as far inland as 100 km in Yutian County, Hebei Province, according to the local officer of water authority, who also reported that the maximum water salinity level in the Ji Canal reached 15 ppm, with a 1998–2003 average ranging from 5 to 8 ppm. Although rice favours relatively saline soils, it is not tolerant to such excess salinity. The high salt content threatened the agricultural water supplies that depended on freshwater from rivers, preventing the farmers in some areas from irrigating their crops.

Our interview results indicated that the farmers shifted from rice to cotton because they needed to adapt to reduced rainfall and to the use of salt water. The farmers also mentioned soil salinity as a reason for their conversion to cotton. In the coastal area near the lower reaches of the Hai River, there is a large area of both saline and saline-alkali soils. Cotton is quite tolerant of saline soils, and consumes less water than rice.

3.3. Long-term resilience loss and adaptive capacity

3.3.1. Stakeholder responses

The interviews with the individual households and village committee leaders made it clear that 2 stakeholders were involved in this response: the households and the collective community committees. In rural areas of China, land is defined as collectively owned, and the institutional units are the rural collective, e.g. villagers' committees, village economic cooperatives or township collective economic entities. In the study area, individual households were free to make decisions regarding cropping pattern (which crop and how much to plant), and these farmers preferred to plant in their own crop fields; however, rice cropping was the exception to this practice (McGee 2008). Only the villagers' committee could plan and initiate rice cropping because of the collective irrigation scheme. The rice irrigation system is collectively owned, operated and maintained by the villagers' community, and operates on a self-financed basis. The villagers' committee are formally in charge of the decisions concerning water distribution through 'ditch riders', who takes care of ditches during the irrigation season, when rice is harvested. Typically, approximately 4 ditch riders are employed for one cropping season, and these ditch riders are charged with ensuring the delivery of water from the river to the secondary channels, and finally to the paddy fields for the farmers of their village.

3.3.2. An undesirable alternate state

Although cotton was more profitable and used less water, our interviews indicated that the current state was undesirable, and when asked concerning their plan for future agriculture adaptation, the local farmers intended to change their crops to rice. Of the interviewed farmers, 62.3% (33/53) intended to revert to the previous rice cropping state. The 2 most common reasons for this contradiction were 'rotation for preventing pests and diseases and improving the soil' (18/33) and 'self-production for family consumption' (13/33). One farmer explained, 'I would like to eat rice produced by myself. Yes, although I would buy it using the money I earn from growing cotton … or, simply speaking, if I need to take one cup of rice per meal, I can eat 2 cups if I grew it myself, but I may only eat half a cup if I bought it from the market.' Moreover, another stated, 'I want to grow rice for family consumption, then I will be not afraid of the rice price rising.'

Most of the respondents considered the higher occurrence of pests and diseases, particularly *Fusarium* and cotton wilt, to be a major problem of the current cropping state. An average of 4.5 yr of continuous cotton cropping practiced by 58.5% of the interviewed farmers (31/53, i.e. 31 out of 53 resondents) led to the more virulent pest and disease in cotton.

3.3.3. Social institutions and barriers to maintain the system's resilience

An increase in the supply of available irrigation water after 2002 was observed from both the meteorological data and from the survey respondents. However, only a slight increase in rice cropping was observed in the study area. Although the local farmers intended to change crops, particularly reverting to the previous rice cropping state, this decision was made by the village committee leaders.

The results of interviews with village committee leaders indicate that there are considerable differences between each village community along the Ji Canal with respect to the current climatic situation (Table 1).

Within the 14 interviewed villages, 2 villages (Gaotuo and Qianmi) continued cropping rice, even dur-

Table 1. Profiles of interviewed villages (NMZ: Nanmaizu; BYZ: Beiyuezhuang; TZT: Tianzhuangtuo; ZXZ: Zhangxinzhuang; DW: Dongwo; XG: Xiguan; TC: Taci; QJDG: Qianjiedaogu; YBZ: Yangbozhuang; GT: Gaotuo; QM: Qianmi; DSW: Dashawo; DTZ: Datingzhuang; BH: Bohou). I: Individually grown; NG: Not grown; C: Collectively grown

Village	Population (inhabitants)	Total agr. land (ha)	Agr. land per person (inhabitants ha^{-1})	Rice cropping	Reason for rice cropping
NMZ	2102	280	0.107	I	Fishpond; accumulated water easily
BYZ	1760	246	0.100	NG	
TZT	1210	199	0.107	NG	
ZXZ	620	57	0.047	NG	
DW	265	59	0.167	C; at intervals[a]	Improve soil and disease resistance
XG	860	156	0.133	C; at intervals[b]	Improve soil; good price
TC	454	109	0.200	NG	
QJDG	299	43	0.133	NG	
YBZ	1315	152	0.113	I	Easily flooded
GT	938	100	0.047	C; continuously	Limited arable land; family consumption
QM	814	54	0.047	C; continuously	Limited arable land; family consumption
DSW	2033	273	0.093	NG	
DTZ	2074	169	0.053	I	Low-lying plots; easily flooded
BH	1458	37	0.037	NG	

[a]In 2009 and 2010; [b]in 2007, 2009, and 2010

ing the extreme drought. All of the interviewed households in these 2 villages mentioned that it could not possibly be profitable to change their limited land per person into a cash crop because of the economics of the input scale and because of their village's small area of agricultural land. Therefore, both the village committee leaders and the village members preferred to crop rice. In 2005, these 2 villages dug wells as an alternative water resource, and when the surface water was insufficient or at a high salinity level, the villages mixed the underground water with surface water from the Ji Canal.

Dongwo and Xiguan, 2 other interviewed villages, changed their rice cropping during the extreme drought periods; however, these villages recently returned to the previous planting state. In 2007 (Xiguan) or 2008 (Dongwo), these villages resumed rice planting because of the more recent increased precipitation. The interviewed village members and committee leaders in these 2 villages all mentioned that they made this switch to improve the soil quality and to enhance soil disease resistance by rotation. Another reason, which was mentioned by one farmer in Xiguan, was that the cost of buying rice for consumption was increasing. Both committee leaders of the 2 villages recently stated that when the canal had sufficient water in the early spring of each year, the villages collected and transported the surface water to the local agricultural technical support station to test the salt content. If the salinity level was below the regulation (1.5 ppm), then the leaders decided whether to plant rice that year. The committee leader in Dongwo still remembered that the test result in early 2010 was 0.8 ppm.

The remaining 10 villages no longer cropped rice because of the extreme drought periods. Of the interviewed farmers in these 4 villages, 28.9% (11/38) were not concerned regarding the change; however, these farmers mentioned that the decision was made by the village committee. Overall, 31.6% of the interviewed farmers (12/38) complained, 'Our village could not crop rice anymore' because the community members and leaders did not maintain their equipment, which now was rusty or was sold as an asset; the ditches were also full of weeds or occupied as commons by surrounding farmers to increase their own land. Thus, the irrigation and drainage (I&D) system was disabled. Additionally, 23.7% (9/38) also complained that the village committee leaders did not want to concern themselves with or spend time initiating and managing rice cropping. Only 15.8% (6/38) of farmers mentioned the lack of irrigation water for rice cropping. Overall, 40% (4/10) of the village committee leaders stated that the committee did not have an adequate budget for rice cropping, and that it was difficult to collect the cost for rice cropping from individual households. During the survey, the authors also interviewed 3 farmers who individually planted rice in 3 of the 10 villages. All of the farmers cropped on land leased from the villagers' committee, e.g. the land along the canal bank or a previous fish pond. No crop other than rice can be grown well under the adverse conditions of unstable water levels during the rainy season.

To determine the actual costs of cropping rice for a community, the costs and sources of payment were requested from the leaders of the 4 villages that currently crop rice (Table 2). On average, the cost of rice cropping that was paid by the village committee was 2445 CNY ha^{-1}; this money was primarily used for electricity, labour payments and for ditch cleaning. These costs accounted for nearly half of the entire operational cost, and were equivalent to 10% of the revenue for the individual households if the households sold their rough rice at the average price in Autumn 2009 (2.4 CNY kg^{-1}, 9000 kg ha^{-1}). This operational cost was paid from different sources among the 4 villages; however, this cost was primarily derived from the money that was obtained from leased fishponds or from the lease of agricultural land to farmers. Despite this revenue, the leaders also mentioned that the lack of operational costs still restrained their annual rice cropping. The committee leader of the Xiguan village mentioned, 'We planned and succeeded to plant rice in 2007. The committee members collected the operation fee from most of the households (2250 CNY ha^{-1}). Only 3 households did not pay but still planted and harvested. Some other villagers felt that this was unfair. When we planned to plant rice again in 2008, we failed to collect the money. So, our committee had to find another source of money for planting.' The committee leader of the Dongwo village said that the village did not plan to plant rice in 2011, that all their savings had been used up and the village needed to save money for approximately 2 years to obtain the future rice operation costs.

All 4 villages that currently crop rice maintain a good irrigation infrastructure, which is now generally managed by a few farmers that were hired by the community committee. Commonly, because of the poor irrigation infrastructure and the limited budget, a loss of resilience followed. The local farmers were confident that rice is the most desirable rotational crop to improve the soil and to prevent pests and diseases. However, given the above-mentioned limitations, the villages failed to maintain or to return to the previous planting state. This short-term coping strategy may eventually result in long-term maladaptation. Thus, the agricultural systems lost their resilience even when the rainfall was sufficient.

4. RESULTS AND DISCUSSION

By focusing on precipitation variability and by comparing communities at both county and village scales, this study presents valuable evidence regarding the short-term adaptation and long-term resilience of the agricultural communities, which are measured in terms of the crop systems and water systems in the study area. The responses to recent historical precipitation variability in this case study demonstrate that local people adjusted to both an interannual variability and a multi-year drought through their short-term collective and individual actions vis-à-vis the planting area and their choice of crops. Annual precipitation and water flow show that a serious, continuing drought occurred from 1999 to 2002; this drought compelled the farmers to convert their paddies to field crops. The comparison of 2 adjacent counties showed that the agricultural system of the upstream county had a high resilience, even during severe drought; this resilience was due

Table 2. Balance sheet of involved villages for rice cropping in 2009. Amount unit: 10^3 CNY (at the time of the survey, the exchange rate was ~1 CNY = 0.1167 EUR). GT: Gaotuo; QM: Qianmi; DW: Dongwo; XG: Xiguan; Agr: agricultural

Village	Area [ha] (Density [people ha^{-1}])	Paid: Items	Paid: Amount [10^3 CNY]	Received: Items	Received: Amount [10^3 CNY]
GT	26.7 (0.028)	Electricity & payment of wages	70	Leased Agr. land fee (35 ha, 4800 CNY ha^{-1})	156
				Leased fishpond fee (2 ha)20	
QM	40.0 (0.049)	Electricity & payment of wages	10	Leased Agr. land fee (20 ha, 6000 CNY ha^{-1})	120
				Leased fishpond fee (2 ha)20	
DW	40.0 (0.151)	Electricity & payment of wages	90	Accumulated profit brought forward	10
				Leased Agr. land fee (10 ha, 1500 CNY ha^{-1})	15
				Leased built-up land fee (village enterprise)	20
				Rice subsidy (40 ha, 1095 CNY ha^{-1})	45
XG	66.7 (0.078)	Electricity & payment of wages	150	Leased Agr. land fee (13.3 ha)	7
		Ditch cleaning	10	Leased fishpond fee (13.3 ha)	100
				Rice subsidy (67 ha, 1095 CNY ha^{-1})	73

to the county's geographic location. The possibility of external disturbances at a larger scale was excluded. However, because of the limited water flow from the outside to the downstream county, the paddy fields faced high water stress and relied heavily on precipitation, displaying a low resilience to precipitation variability. By focusing on the county with a low resilience at the village scale, it was determined that farmers who switched to less water-intensive crops, e.g. cotton, appeared to create a more robust adaptation to water stress. However, in the long-term, this short-term adaptation caused many farmers to become more vulnerable to a worsening pest and disease management problem, and to low staple food self-sufficiency, because of the inflexible cropping system and disabled water system. Most villages lost the resilience of their agricultural production to current precipitation variability because of poor community leadership and because of the institutional failure with regards to collective action, despite the main intention of most villagers to change the current cropping system to improve their low household staple food self-sufficiency. Only a few villages, which maintained their properties well and possessed leaders who had the awareness to practice the traditional crop for rotation, had a high resilience and succeeded in recovering from the variable precipitation to resume their traditional cropping system. The difference between individual and community decisions has large implications for long-term resilience. The initiation and support of local institutions, such as the collective irrigation system and the role of village committees, caused the local farmers to fail to replant rice, even if these farmers intended to do so, and even if there was normal precipitation.

Most Asian megacities are in rich alluvial deltas that have long served as the 'rice-baskets' of their respective regions (McGee 2008). Recently in China, many paddy fields have been converted into other types of agricultural land to increase revenue. This conversion is the result of the influence of market mechanisms, such as the conversion of paddy fields into aquaculture and mulberry fields for silk production in the Yangtze Delta (Wu et al. 2009), and the transformation to cash crops, fruits and aquaculture in the Pearl River Delta (Li & Yeh 2004). However, in the study area, water shortages and unreliable rainfall compelled the farmers to shift their paddies to field crops.

Adaptations are often place- and context-specific (Adger et al. 2005, Conway 2005, Nunn 2009, Podestá et al. 2009). The disturbance regimes can also change over time and can contain an inherent degree of uncertainty. The combination of the disturbances and the timing of the events can cause synergistic effects (Cutter et al. 2008, Resilience Alliance 2010). It has been assumed that traditional and subsistence farmers are the most vulnerable to the effects of globalisation and climate change (Conway 2005, Acosta-Michlik & Espaldon 2008). The community-based rice production in the areas of this study was mostly for the consumption of the farmer's family or for farmers living in neighbouring villages who did not grow rice. Few croppings by individual households were for commercial use. This finding presents the following evidence contrary to the notion that subsistence farmers are vulnerable to globalization and climate change: given the limited amount of agricultural land per person in the Gaotuo and Qianmi villages (0.028 and 0.049 ha person^{-1}, respectively), the marginal profit of shifting land use from subsistence rice cropping to cropping the more valuable cash crops, such as cotton, is not much higher because of the higher production inputs. Instead, farmers consistently crop paddy fields for family consumption to maintain their staple food sufficiency even in the presence of water stress. Food security is a necessary part of adaptation capacity for individual households locally, not only enhancing resilience to environmental change, but also increasing economic flexibility.

Governance and institutions are critical determinants of adaptive capacity and resilience (Engle & Lemos 2010). Institutions include sets of working rules (Ostrom 1990). A robust institution tends to enhance the capacity of both individuals and communities to use resources in a sustainable way over long periods (Becker & Ostrom 1995). The community-managed irrigation schemes have essentially two sets of stakeholdsers: the households and the collective community committees; however, resilience of the agricultural system to environmental fluctuations is controlled only by the community committee. The difference between the individual and community decisions has large implications for long-term resilience in this study. There is growing interest in identifying public policies and institutional arrangements that currently impede adaptation to environmental conditions; the goal is to remove such impediments (Smithers & Smit 1997). The original purpose of the community irrigation institution was to work together as a village unit and to effectively use water when rice cropping. However, collective action only on the village scale failed when the entire basin faced water scarcity, because of the poor management of the water system by community leaders, and because of the lack of an adequate budget for the collective action of rice cropping. Poor leadership led to fewer options for the community in an uncertain future. The village leaders' awareness and efforts to maintain the facility and to operate traditional rice planting are a useful institution to enhance resilience. To address these current water topics, governments and water managers must also notice the importance of both community and individual decisions, and the importance of community leadership in rebuilding resilience. Although water shortages may frequently occur in the future, these local communities should be able plant rice, at least in turn, by more effectively managing water allocation and distribution.

This study relays several lessons to other agricultural systems experiencing climate change. (1) Resilience-building must be integrated into the adaptation measures to climate and global environmental change for sustainable agricultural development strategies. (2) The local institution plays a vital role in building resilience. A fundamental shift in thinking is required for a community to move away from a short-term view of coping measures and profit gains to a long-term perspective that emphasises sustainable agriculture. New institutional arrangements, including collective irrigation regimes and community leadership capacities (e.g. organizational, managerial coordination, mentoring), are necessary for building resilience. It is important to consider both climate fluctuation and collective irrigation regimes for rice production in the Asian 'rice-basket'.

During the preparation of our manuscript, the authors experienced the devastating 2011 Tōhoku earthquake and tsunami in Japan, which allowed us to recognise that in the face of uncertain environmental change and disaster in the future, it is important to build the resilience of social-ecological systems to be proactive. An improved understanding of individual and societal resilience not only provides insights for estimating future adjustment but also helps to address the current problems of sustainable development in light of our variable and uncertain environment.

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