REPORT

Impacts of Nomad Sedentarization on Social and Ecological Systems at Multiple Scales in Xinjiang Uyghur Autonomous Region, China

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Abstract China's government is now promoting the Nomad Sedentarization Project (NSP) in large areas of grassland as a solution for ecological restoration and poverty alleviation. To examine the effects of this policy, we conducted in-depth interviews at two of the project's sites and examined the social and ecological systems at village, county, and catchment scales in Jinghe County of Xinjiang. We found that (1) the NSP in one village greatly improved the household standard of living and changed their resource utilization modes; (2) the success in this village can be attributed to resources imported from the social and ecological systems at larger scales, and could not be repeated in a second nearby village with different constraints; and (3) the NSP is poorly adapted to local ecosystem characteristics, and may therefore have negative impacts at larger scales. To avoid these problems, holistic assessments are necessary to judge the NSP's impacts on social and ecological systems at multiple scales, and the program must be implemented cautiously to account for the potential risks in ecologically vulnerable areas.

Keywords Social and ecological systems · Scale · Sedentarization · Arid area · Xinjiang

INTRODUCTION

Complex interactions and feedback mechanisms exist between human and natural systems within coupled social and ecological systems (Liu et al. 2007; Li and Li 2012). As a result of these mechanisms, human society is a major driving force that changes ecosystem dynamics at scales ranging from the local environment to the whole biosphere (Kirch 2005; Liu et al. 2007). In turn, human society is affected by changes in ecosystems, including a growing

scarcity of resources such as water (Millennium Ecosystem Assessment 2005; Janssen et al. 2007; Kok and Veldkamp 2011). Social and ecological problems also cannot be simply separated into local, national, or global scales; the interactions among different scales are becoming increasingly important (Gibson et al. 2000). Because of this complexity of social and ecological systems, many sustainability problems arise from “scale” problems (Costanza et al. 2001).

“Scale” can be defined as “the spatial, temporal, quantitative, or analytical dimensions used to measure and study any phenomenon” (Gibson et al. 2000). In the past decade, the scale concept has been increasingly introduced into the field of natural resource management (Lovell et al. 2002; Adger et al. 2005; Berkes 2006; Borgström et al. 2006; Young 2006; Biggs et al. 2007; Olsson et al. 2007; Papaik et al. 2008). Large-scale social and ecological systems consist of subsystems at smaller scales, and changes that occur at a given focal scale may have unexpected impacts at larger and smaller scales (Pelosi et al. 2010). The results of any study will therefore vary according to the scale or scales chosen for the analysis (Gunderson and Holling 2003; Cash et al. 2006; Cumming et al. 2006; Zurlini et al. 2006; Wiens and Bachelet 2010). For instance, management practices that are effective at a certain scale may be unable to achieve the same results at other scales. However, there has been little empirical research about the interactions between social and ecological systems and vulnerable natural environments across a range of scales. This kind of research is important because such systems are sensitive, and any changes at a certain scale may have consequences ranging from subtle to obvious at larger or smaller scales.

In this paper, we used the grassland social and ecological system of China's Xinjiang Uyghur Autonomous

Region as a case study to analyze the impacts of cross-scale interactions on environmental management. Grassland covers 41.7 % of China's territory, and about 1.5 million pastoralists and agro-pastoralists live in these grasslands. These grasslands are ecologically vulnerable arid and semi-arid ecosystems that sustain large populations of livestock despite the fragile vegetation communities and harsh biophysical environment. The interactions between the pastoralists and their environment can be considered an example of a social and ecological system (Robinson 2009). As the problems of declining ecosystem services and poverty in pastoral areas have attracted increasing attention from China's government and society, Nomad Sedentarization Projects (NSPs) have been implemented as a development strategy in pastoral areas in an attempt to solve ecological and social problems. Subsidized by the government, these projects are intended to improve the pastoralists' standard of living by building houses, providing services such as tap water and electricity, and encouraging them to enter other professions. At the same time, the goal is to restore the region's grasslands by reducing the utilization of natural grassland and replacing grazing with fodder planted at the sedentary sites and by breeding to improve the livestock. NSPs have been part of the 11th and 12th 5-year plans in China's six largest pastoral areas. In 2011 alone, the central government budgeted 1.7×10^9 RMB for implementing NSPs in the Xinjiang Uyghur, Inner Mongolia, and Tibet regions (Ministry of Finance 2011).

Sedentarization has been advocated in pastoral areas of China and other parts of the world by development agencies, conservation groups, and national governments, supported by discussions among anthropologists and sociologists. From their perspective, pastoralism is inefficient and damaging to the environment, and sedentarization appears to be beneficial because it can integrate former pastoralists with the rest of the national economy, thereby improving their material well-being (Fratkin et al. 2006). Some national governments encourage sedentarization because it permits better control and taxation, while also eliminating cross-border migrations (Scott 1998). Government-imposed sedentarization may jeopardize important cultural aspects of the nomadic society and lead to dependence on governmental subsidies (Ptackova 2011; Li and Huntsinger 2011). Scoones (1994) noted that some of these policies are nothing more than Western ranching models that have failed in pastoral areas with different ecological and social backgrounds, such as East Africa.

In this study, we performed more than a purely sociological investigation of sedentarization. Instead, we focused on the interactions between the social and ecological systems at a range of scales. Many previous researchers who studied the impacts and sustainability of

NSPs based on empirical studies have adopted some common approaches: most studies were based on fieldwork in a single sedentary village, and focused on the social aspects of the system, such as the policy design, implementation scope, cultural change, and changes of the customs and lifestyles of the local people (Tsui 2002; Gai and Song 2005; Jiao et al. 2008; Zhao et al. 2009; Wang and Wang 2010; Li et al. 2011). A few researchers have explored the ecological impacts after the implementation of NSPs (Xu 2001; Chu and Meng 2005; Du 2011; Tsui 2012). In our study, we took a combined social and ecological system perspective and performed our research at three scales: village, county, and catchment. Our goal was to explore the impacts of the NSP at all three scales to determine the changes in the interactions between humans and their ecosystem at each scale and how changes at one scale affect the system at different scales.

MATERIALS AND METHODS

Study Area

The Ebinur Lake Catchment covers 5.06×10^4 km² (Bai et al. 2012) on the northern side of the Tianshan Mountains in China's Xinjiang Uyghur Autonomous Region (Fig. 1a). The Bortala River, Jinhe River, Kuytun River, and others flow into Ebinur Lake. The study area is arid, with an average annual precipitation of 90 mm, and the surface water originates largely from snowmelt in the Tianshan Mountains (Jinghe County Chorography Editorial Committee 1998). These rivers and the associated wetlands play a significant role in sustaining the regional populations of humans and livestock. Jinghe County is located south of Ebinur Lake, and has a typical temperate continental desert climate. The elevation ranges from 4700 m in the southern mountains to 198 m near Ebinur Lake. The precipitation decreases from 300 to 500 mm in the southwest, near the mountains, to between 60 and 80 mm in the northeast.

The population of Jinghe County is 142 544, and includes 25 nationalities. Of these, the five largest nationalities are Han (69.0 % of the population), Uyghur (12.7 %), Kazakh (9.4 %), Hui (4.0 %), and Mongolian (3.7 %). The Mongolian and Kazakh peoples are both traditionally nomadic (Jinghe County Statistical Bureau 2011). The Mongolian Tuerhute tribe moved into this region from Russia after the 1770s, whereas the Kazakh people moved into this area in the 1880s, and both groups depended on pastoralism for their survival (Jinghe County Chorography Editorial Committee 1998). Agriculture and pastoralism coexist in Jinghe County. Currently, 826 households engage in pastoralism. The region's natural grassland covers 0.72×10^6 ha, of which usable grassland

Fig. 1 Location of the Study Area (a), photos of summer pasture in Tianshan Mountains (b), and settlement site with permanent house and crops (c). Both the photographs were taken by author Mingming Fan

accounts for 96.6 %. For thousands of years, herders in this area have used the pastures seasonally by practicing vertical transhumance: from June to September, they grazed their livestock in cool alpine summer pastures (Fig. 1b) in the Tianshan Mountains at elevations of 2000 to 3000 m, where the dominant vegetation type is alpine meadow. Because of the abundant rainfall in these areas at this time of year, the summer pastures are of high quality, and were used to fatten the animals before they were sold. From September to December, the pastoralists descended to their autumn pastures, at elevations of 300 to 1700 m. The autumn pastures are found in areas with a gentle slope, where the vegetation is dominated by desert steppe communities, complemented by a few lowland meadows. From December to March, the pastoralists and their livestock stayed in winter pastures, which were located in sheltered, low-lying depressions or on slopes that receive abundant sunshine, where it was warmer than in other places. The winter pasture vegetation consisted of mountain desert steppes and mountain grassland. From March to May, livestock were moved to spring pastures where abundant

vegetation had accumulated. In the spring, ewes gave birth to lambs. There was no clear boundary between the spring and autumn pastures, but the distance between them and the winter pastures was about 30–40 km, and the distance between the winter and summer pastures was about 50 km. However, because of the large changes in elevation, the distance between the spring and summer pastures were 80–100 km. The pastoralists did not build permanent houses in these seasonal pastures, but every family owned a yurt (a portable structure made from bent wood covered by hides and other materials) that could be disassembled and moved.

The Conference for Nomad Sedentarization in Northern Xinjiang was held in 1986. At that time, the government defined a development goal for the pastoral areas in which pastoralism should be replaced by sedentary or semi-sedentary communities that both raise livestock and cultivate crops. The government encouraged pastoralists to settle down by providing a small amount of money to build permanent home and allowing break grassland to plant crops in settlement site (Fig. 1c). During the 1990s, the

government provided more financial support, and gradually began to provide roads, water, and electricity at the settlement sites. In 2000, the central government began to promote NSPs at a national scale, and implemented several plans to settle pastoralists. By 2007, 97.8 % of the pastoral households in Jinghe County had settled in these communities. In 2010, Hubei Province (situated in central China) began to invest in NSPs in Jinghe County in the form of partner assistance (partner assistance is a national western development policy, which aims to shorten the gap between eastern and western regions, eastern cities help western cities' development by investment), and built 300 new houses for the pastoralists.

We selected two villages (Fig. 1a) as our case study sites. Village A achieved considerable success under the NSP, and became a model for implementation of this program elsewhere, whereas Village B gained little attention from the government. Both villages are located in the middle of Jinghe County, and are less than 50 km from the southeastern shore of Ebinur Lake. The two villages were similar in terms of the areas of grassland available to them in each season (Table 1), although Village A had smaller area of autumn pasture, when the NSP was implemented, and they had similar standards of living before sedentarization, average livestock numbers per household were 406 ± 142 in A and 308 ± 142 in B. In Village A, 76 households were engaged in pastoralism, and 75 of these families were Mongolian; the other family was Kazakh. In Village B, 38 families (all of them Kazakh) were engaged in pastoralism. The income of herders in both villages was derived entirely from herding sheep, goats, cattle, horses, yaks, and camels. Encouraged by the government of Jinghe County in 1990, the pastoralists in both villages gradually settled in their autumn pastures, and government policies for both villages were similar. Each household that participated in the NSP was allowed to reclaim a parcel of land near their sedentary site where they could cultivate forage crops and they received some money from the local government to build houses. They retained their right to use the natural grassland throughout the year. By the time we conducted our fieldwork in 2011, most of the pastoralists had built permanent houses in their former autumn pasture. The main difference between the two villages was

the area of farmland: Village A received 13.4 ha for each family, whereas Village B received 5.4 ha because some of their pastures were subsequently included in the Ebinur Lake reserve, where reclamation for agriculture was forbidden.

Data Collection

We performed field surveys in the study area in the summer of 2011, from July to August. Our survey included 23 pastoral households in Village A and 16 pastoral households in Village B, covering a range of livestock populations. These samples represented 30.3 and 42.1 % of the total number of pastoral households in each village. Because we did not speak the Mongolian or Kazakh languages, we hired two translators (a Mongolian in Village A and a Kazakh in Village B). As the interviews were conducted privately, with only the members of a given household present during the interview, we believe that the information was reliable. As pastoralism represented the major source of income for the pastoralists (75.9 % in Village A and 67.4 % in Village B in 2010), we chose the number of livestock as a direct indicator of their standard of living. Based on the number of livestock, the households in Village B had much less wealth than the households in Village A. We therefore used the number of livestock as an indicator of wealth, and divided the households into four groups (Table 2): Poor, middle, better-off, and wealthy to help us select samples reflecting the overall situation of each village, so the criterion were different for the two villages. The categorization was conducted with the help of a local leader who was familiar with the situations in the villages. We then randomly sampled several households in each group for detailed interviews.

By conducting structured interviews, we obtained information about: (1) the basic characteristics of each family, such as the family size, number of livestock, income structure, area of grassland, and cultivation of forage crops; (2) the mode of production, such as transhumance before settlement versus animal husbandry and forage and cash crop cultivation after settlement; and (3) resource utilization, such as changes in the use of natural

Table 1 Time of settlement and areas of seasonal pasture per household in villages A and B. *Source* pasture area data from Jinghe County Grassland Monitoring Station, and livestock numbers data from interviews of Villages A ($N = 23$) and B ($N = 16$)

	Time of settlement (years)	Average number of livestock per household (sheep units)	Areas of seasonal pastures (ha per household)			
			Spring pasture	Summer pasture	Autumn pasture	Winter pasture
Village A	1990	406 ± 142	234.2	96.0	13.4	127.9
Village B	1990	308 ± 142	308.5	156.5	76.5	117.8

Table 2 Wealth distribution for the pastoralists in villages A and B

Wealth level	Sheep units in July ^a	Number of households	Proportion of total samples (%)	Proportion of total households (%)
Village A (<i>N</i> = 23)				
Wealthy	1501–2000	2	8.7	10
Better-off	801–1500	7	30.4	40
Middle	301–800	11	47.9	40
Poor	0–300	3	13.0	10
Village B (<i>N</i> = 16)				
Wealthy	601–800	2	12.5	10
Better-off	401–600	4	25.0	40
Middle	101–400	7	43.7	40
Poor	0–100	3	18.8	10

^a The total number of livestock is calculated based on sheep units: 1 cow, horse, camel, or yak = 5 sheep units. The number of livestock after sedentarization is the number reported in 2011. The number before sedentarization differed among the households because they settled in the villages in different years. The earliest settled household was in 1991, and the latest was in 2010; 12 families settled after 2000

grassland, forage fields, and water resources before and after settlement. We also conducted open-ended interviews to learn about the settlement process the pastoralists have experienced and their feelings about changes in the local ecology and in their livelihood. In addition, we interviewed officials from the Jinghe Animal Husbandry Bureau (1 interview), the Jinghe Grassland Monitoring Station (2 interviews), the Bortala Animal Husbandry Bureau (1 interview), and the Bortala Water Affairs Bureau (1 interview) to learn about the background of the NSP and local natural resource conditions, and to collect related documents and meteorological data. Because the quality and quantity of the information obtained from these officials was limited, we mainly used it to understand the background and for an overview of each area.

Analytical Framework

From the perspective of multiple-scale social and ecological systems, we can regard the NSP implemented in Jinghe County as a multi-scale process (Fig. 2): a model program at village A, it spread to the county scale based on the village-level experience, then the broader watershed scale. In our analysis, “scale” includes both spatial and temporal aspects, and is not a precise concept. We attempted to answer the three questions shown in the right part of Fig. 2: (1) At the village scale, we used a “successful” sedentary site, Village A, as a model to analyze the changes in the social and ecological system, and especially the changes in resource utilization that reflected the interactions between the local society and its supporting ecosystem. (2) At the county scale, we added Village B to study whether new connections emerged between the sedentary sites and the systems surrounding them at a larger scale. To support policy development the goal was to learn whether the

success of one village could be generalized to other villages. (3) At the catchment scale, we investigated whether sedentarization was suitable for the local ecological conditions and was therefore sustainable. We also asked whether we could predict the impacts at a larger scale. Our answers to these questions revealed the changes within and across scales. Our goal was to examine whether NSPs have impacts on both the social system and the ecological system, the impacts differed among the scales, and the interactions between humans and nature changed during the sedentarization process.

RESULTS

Scale I: Village Scale (Village A)

Village A became the model for a successful NSP in Jinghe County. In this section, we will analyze changes within the social and ecological systems before and after sedentarization for this village.

Social Aspects: Change of Lifestyle

Households in Village A have adapted to their lifestyle after sedentarization. After 1990, when the government began to promote the benefits of sedentarization, it took 10 years for the pastoralists to begin accepting this radical change in their lifestyle. Figure 3 shows that sedentarization did not become significant until 1998. By 2011, when our survey was conducted, all of the households in Village A had settled down.

All of the 23 households we interviewed preferred their present sedentary lifestyle to their previous nomadic lifestyle (Table 3): they felt that they had better housing,

Fig. 2 The analytical framework used in the present study, showing the relationships among scales and research questions at each scale

Fig. 3 Numbers of pastoralist households that settled in Village A from 1990 to 2011 (our total sample size was 23 households)

improved access to basic services, and a more convenient daily life. Their household income had also increased and they found better conditions for animal husbandry.

Each family's mode of operation and sources of income became diversified. During the traditional nomadic period, all family members depended on pastoralism, and all income was derived from the sales of livestock and livestock products such as cashmere. After the sedentarization, the family's income was still mainly derived from animal husbandry (75.9 %). However, other income sources became significant. Land rent (12.1 %), agriculture

(4.7 %), income from other types of work (0.6 %), and government grassland subsidies (6.7 %) accounted for the remaining 24.1 % of the household income (Table 4).

The families earned income from their 13.4 ha of arable land in two ways: planting cash crops, and renting their excess land to others. The average planting area for each crop: 1.8 ha of alfalfa, 0.5 ha of corn, and 0.3 ha of cotton. The corn and alfalfa are prepared as fodder for the livestock in winter, especially for pregnant ewes and lambs. Three families planted cotton as a cash crop: in 2010, the price of cotton was high, at about 1.6 USD kg⁻¹, and the average yield was about 4478 kg ha⁻¹, yielding a net income of at least 3640.3 USD ha⁻¹. Due to a lack of labor and water, most families cannot use the rest of their land (10.9 ha per household), so they rent the land to contractors from outside the village, most of whom are Han farmers from Henan Province (situated in central China). These farmers plant cotton in this land, because the price has been good in recent years and they are more skilled at farming than the local people. In general, three to five adjacent families rent their land to the same contractor, who can afford to drill wells to access the water required for large-scale cultivation of this crop. (The government requires a spacing of at least 800 m between wells, so these farmers must rent adjacent land to drill sufficient wells.)

Table 3 Opinions of herders from a village about their lives before and after sedentarization. *Source* Interviews in Village A

	Description
Housing	It was too cold on the mountains. It's much better now
Infrastructure	The settlement is near many important places such as the hospital, school, and market. Previously, we were forced to travel a long distance to see the doctor It was cold in the mountains, and difficult to transport fodder to our animals. Now, we have houses and warm shelters for our livestock We also have tap water and electricity in our settlement, and paved roads. Our lives are more convenient than before
Income	People were lazy before they moved to the village, and spent their days watching their animals. Now, we are trying to find ways to make more money and improve our standard of living
Livestock production	Our income is improving each year, and we can afford to own more livestock The lambs can be born earlier, grow faster, and earn a good price at the market We can plant crops here and keep more livestock Now we have more grass and plant crops for our livestock It was hard to travel the long distance to the mountains to feed our animals; it's much more convenient to feed our livestock in the village In the mountains, we often encountered snowstorms that killed many of our animals

The rents vary according to the suitability of the land (which often has saline or alkali soil before reclamation), and depends on the duration of the reclamation required, which involves large investments of labor, material, and water resources. The rent is 48.6 to 72.8 USD ha⁻¹ before reclamation and increases to between 970.7 and 1213.5 USD ha⁻¹ when the land is suitable for planting cash crops. As shown in Table 4, the average rental income per household is 3019.3 USD.

The government provides grassland subsidies to compensate herders for reducing their usage of grassland after sedentarization. This is paid per unit grassland area owned by each household, and averages more than 1600 USD per household. In addition, the central location of the village and the convenient access to transportation provide

many opportunities for villagers to operate a side business. In our survey, two households operated small shops, one purchased agricultural equipment that could be rented, and two households owned vehicles that they used to earn additional income by providing transportation services.

The number of livestock increased rapidly after sedentarization, thereby increasing the household income. Animal husbandry provides the majority of the family income, so we considered the change in livestock numbers to be a key issue. In our survey, 17 of the 23 families remembered the exact number of sheep units before sedentarization (406 ± 142), versus 1002 ± 548 after sedentarization, for a ratio of 2.5 ± 1.2 . Most households increased their number of livestock after sedentarization: 18 % (3/17) quadrupled the number, 41 % (7/17) at least doubled the number, and the average number of livestock was 2.5 times the number before sedentarization. Only two families had fewer livestock after sedentarization, and this was because they continued selling large numbers of lambs, and even the ewes that could have been used for lamb production, to pay for marriages, medical care, or the education of family members. In short, from 1997 to 2011, the number of livestock increased rapidly, resulting in an overall improvement of the household standard of living. All families that we interviewed therefore believed that sedentarization was better for both them and their livestock; they did not need to move to a new location each season, and the livestock had enough fodder to last them through the winter, which is the hardest time of year for animal husbandry.

The improved rearing conditions also improved the survival rate of the lambs. This rate was only 60–70 % before sedentarization because of insufficient forage or fodder and the region's harsh climate, and birth of the lambs began at the end of March or early April. After sedentarization, the households constructed brick shelters and prepared fodder for the winter by planting their own supply and buying additional fodder from the market. As a result, the lamb survival rate had increased to more than 95 % and the birth months shifted to mid-February or early March. This improvement both increased the number of livestock and increased opportunities for slaughtering the lambs to provide a source of meat.

After sedentarization, the family division of labor changed, and the labor intensity decreased. In the

Table 4 Household income structure of the families in Village A in 2010 ($N = 21$). *Source* Interviews with the families in Village A

	Income source (USD year ⁻¹)					Total
	Animal husbandry	Land rent	Agriculture	Income from other types of work	Grassland subsidies	
Money (RMB)	18 934.3	3019.3	1161.3	154.8	1667.6	24 937.3
Proportion of total (%)	75.9	12.1	4.7	0.6	6.7	100

traditional way of life, the livestock were cared for by one or two main workers, and because the whole family moved with the livestock each season, family members could not take other jobs because the pastures were far from the nearest town. After sedentarization, the families spent less time in areas of natural grassland, so preparing fodder for the winter and caring for newborn lambs became important forms of labor, and the main workers stayed at the village to do this work. The livestock are often looked after by hired workers; 19 of the 23 families hired Kazakh workers from neighboring towns that were also located in pastoral areas. In general, each household hired one person or a family composed of two persons, with an average salary of 243.9 USD per month and some sheep provided for meat. After sedentarization, during April and October, when the livestock are herded on the mountain slopes, one of the household workers is responsible for delivering food and some daily necessities to the workers twice per month. Because moving around is less often necessary or unnecessary, most of the households believed that their life is easier than before. In addition, the other workers can more easily find jobs because there are more employment opportunities in the village, which is near the town and more people. In our interviews with families from Village A, four families performed other jobs, such as operating shops, renting agricultural equipment, or providing transportation services.

Ecological Aspects: Impact on Patterns of Resource Use

Resource utilization patterns changed from a complete dependence on natural resources to a dependence on farmland. The traditional grazing pattern used different areas of natural grassland in different seasons, with only a small amount of fodder supplied during the lambing season. After sedentarization, the traditional grazing pattern changed greatly; livestock spent the winter at the village site because farmers could provide sufficient forage or fodder from the surrounding

farmland. All of the households we interviewed built brick sheds for their livestock; they also bought some fodder from the market before the winter. Figure 4 shows that the livestock spent almost 6 months at the sedentary site, and the other 6 months in natural grasslands.

The traditional four nomadic seasons changed into two nomadic seasons. The herders leave the sedentary site around April 20, and arrive at the summer pasture around June after spending 1 month each in the spring and winter pastures. In early September, they return to the sedentary site from the summer pastures along the same route, again spending 1 month each in the spring and winter pastures. The livestock rely increasingly on crop residues from agricultural areas and stayed near the sedentary site until the next April. Compared with the traditional pattern, the use of summer pasture did not change, but the time spent at the sedentary site (which was formerly the autumn pasture) increased.

After sedentarization, the dependence on local water resources increased. The traditional animal husbandry relied on natural water resources in the autumn, and was referred to as the “three springs” system (from the Mongolian name for the autumn pasture, *kaerwenbulage*, which means three springs); however, agricultural reclamation has led to excessive exploitation of groundwater, and the three springs have disappeared. The spring pasture has a small spring that provides drinking water for the livestock, the summer pasture is rich in glacial meltwater and is used during the time of year with the highest precipitation, and winter pasture provides water in the form of snow. After 1995, reclamation of the area surrounding the sedentary site has made livestock feeding depend increasingly on agriculture. However, because Jinghe County is an arid region with insufficient annual precipitation and unstable levels of precipitation, natural rainfall cannot meet the irrigation demand to support agricultural production. Thus, sedentarization requires a stable and adequate supply of irrigation water. All of the families we

Fig. 4 Seasonal patterns for the use of grassland resources before and after the sedentarization of Village A (*Spr P* spring pasture, *Sum P* summer pasture, *Aut P* autumn pasture, *Win P* winter pasture, *Far Set* farmland surrounding sedentary site)

interviewed used water from alkaline drainage for irrigation. In 1998, Jinghe County reclaimed large areas of grassland for crop cultivation. To improve the alkaline soil, huge amounts of water were used to flush the soil. The drainage water became an important water source used to reclaim the grassland. This explains why most of the herders only settled in the village after 1998. Four families used well water from wells drilled by contractors who rented their land.

The families expressed diverse opinions about pasture conditions, but generally believed that the goal of improving natural pastures by reducing the pressure on this vegetation had not been achieved. Most of the interviewees (11/19) believed that the pasture's condition depended primarily on rainfall, so they could not say whether its condition was improving. Most of the others believed that the pasture's condition was declining (7/19), but for different reasons: three believed that increasing livestock numbers increased the pressure on the grassland, and four believed that a combination of drought and livestock pressure was responsible for the decline. Only one believed that the pasture was improving, possibly due to decreased grazing in their pastures.

In summary, there appear to have been tremendous changes in both the resource utilization patterns and the living conditions of the households. Village A changed from relying on natural pasture to depending increasingly on cultivation of forage crops, the transition time for movement among the different seasonal pastures changed to account for the timing of these crops, the dependence on wells and irrigation channels increased, and few believed that the settlement process had improved pasture conditions. However, the sources of income increased after sedentarization, the number of livestock increased, and the labor intensity decreased. Overall, the herdsman and the local government had a positive attitude about the impacts of sedentarization. As a result, Village A became a model for the region, and the approach was expanded for use at other sedentary sites.

Scale II: County Scale

Although the results of sedentarization appear promising at the village scale, the changes depend heavily on interaction with the larger-scale social and ecological systems that surround a village. Village B has experienced changes of lifestyle and production mode that are mostly similar to those of Village A, such as increased dependence on farmland, and we will not restate the changes that are the same. In this section, we will instead emphasize the differences between the two villages. Using a larger-scale comparison revealed the causes of the differences between the two villages in their responses to sedentarization. The results will provide insights into whether the successful

model of Village A can be expanded throughout the county.

The Linkage Between the Village Scale and Larger Scales

Even though the natural ecological conditions for the two villages, including the pasture area, environmental conditions, and the social conditions, were similar before sedentarization, the process produced different results. Figure 5 shows that Village B had fewer livestock, with most families (69 %) having fewer than 500 sheep units (the average livestock numbers per household are 335 ± 192); this data shows no significant change compared with the conditions before sedentarization (308 ± 142). Compared with Table 4, Table 5 shows income structures are similar, but total income of Village B is less than 50 % of Village A. In addition, more of the families required bank loans in Village B (87.5 %, versus only 8.7 % in Village A). Our interviews revealed that the loans were used to maintain a family's standard of living rather than to expand production. The families in Village B generally obtain loans in March or April, when they start planting crops, and pay off the loan when they sell their livestock in October. So, why the outcomes happened in these two villages?

Village A appears to be better able to transfer its pressure on the natural grassland to social and ecological systems at other scales. Table 1 shows that the area of seasonal pasture is larger for Village B, except for a smaller area of winter pasture. However, the summer pasture of Village A is adjacent to grasslands in Yining County and Nileke County that currently sustain few livestock. This is because the high altitude, low temperatures, and frequent snow disasters cause herders in these counties to maintain fewer livestock, and because of the long distance from their

Fig. 5 Frequency distribution for livestock numbers in Villages A and B

Table 5 Household income structure of the families in Village B in 2010 ($N = 16$). *Source* Interviews with the families in Village B

	Income source (USD year ⁻¹)					Total
	Animal husbandry	Land rent	Agriculture	Income from other types of work	Grassland subsidies	
Money (RMB)	8677.9	425.9	6286.7	349.1	1372.1	11 848.9
Proportion of total (%)	73.2	3.6	8.6	3.0	11.6	100

summer pastures, they seldom use the summer pastures, and instead usually rent them to herders from Jinghe County to earn additional income. We found that 18 families in Village A (78.3 % of the total) rent summer pasture in these counties. Generally, livestock fed in a household's own pasture for more than 1 month, then moved to the leased pastures for 1 month, and then returned to their own pastures for half a month. In this way, herders from Village A can fatten their livestock without limiting the livestock number based on the lower carrying capacity of their own pastures. However, no such pastures are available for herders from Village B, so they cannot transfer the grazing pressure to other pastures. As a result, they must maintain fewer livestock.

Based on this finding, Village A can take advantage of the larger-scale social and ecological system more easily. After settlement, the livestock typically stay at the sedentary site for 5–6 months, the herders plant forage crops, and the remainder of the surrounding farmland is used as a primary source of livestock fodder through the winter and to support the mothers of newborn lambs in the spring. Reclamation of the land for farmland requires both enough water and sufficient funds to pay for the workers, equipment, and essential materials such as fertilizer. (The funds are mainly used for drilling wells, hiring employees, and installing drip irrigation systems. The farmers must also bear these high startup costs, with no earnings for the first 3–5 years, while they wait for sufficient soil improvement to permit cultivation of crops.) During the last decade, local farmers and businessman from other regions have planted cotton (Fig. 6) because of its higher economic value; the area of cotton in Jinghe County increased by 258 % from 1990 to 2007. Contractors and farmers from other regions of China harvest only the cotton; the cotton shells, seeds, and stalks can be eaten by livestock. Each household in Village A owns only 13.4 ha of farmland, but they are surrounded by a large area of cultivated farmland owned by other farmers. This situation greatly increases the stability of the food supply for the livestock of Village A in the winter and spring, allowing more stable livestock development.

In contrast, each household in Village B has only 5.4 ha of arable land, and this land is more dispersed, which makes it more economically difficult for investors to drill sufficient wells. Among the 16 households we interviewed,

Fig. 6 Areas of cotton and other crops in Jinghe County from 1978 to 2010. *Sources* Jinghe County Statistical Bureau and Jinghe County Development and Reform Bureau

only 3 (18.8 %) rented their land to investors; the other households planted some cotton or used the land to grow grass for fodder. Because some of the pastures of Village B lie within the Ebinur Lake National Nature Reserve, this part of the land cannot be reclaimed for agriculture, which further compresses the available farmland area and limits the number of livestock that can be maintained. When we asked residents of Village B why they developed more slowly than residents of Village A, most complained that it was because they had less farmland and they could not reclaim more land because of the nature reserve adjacent to their land.

Village A also has better access to water resources. The farmland of Village B is more difficult to rent because of its dispersion, so there is not enough capital to invest in drilling wells. Although the village drilled two motor-pumped wells, they are difficult to use because the households are dispersed over a wide area. For example, for one household it takes 6 h for the well water to reach their land, and much of the water is lost to evaporation; as a result, water charges accounted for more than 50 % of the cost of agricultural production. Therefore, limited water resources are an important constraint on Village B's agriculture, further limiting livestock development.

In summary, Villages A and B are no longer closed systems, as they were before sedentarization; instead, they have established various connections with social and ecological systems at larger scales, and experience different constraints as a result of these connections. Our comparison of Villages A and B reveals that a village's development potential depends strongly on its ability to import resources from larger-scale systems.

Expansion of the Sedentarization Model at the County Scale

As our analysis shows, the success of Village A depended on the input of resources from larger-scale systems, but at the county scale, there are many differences in pasture area, arable land, water availability, and other resource endowments among the villages in the region. Thus, Village A has many advantages that Village B lacks, preventing Village B from taking advantage of the potential benefits of sedentarization. This difference provides a strong warning about the effectiveness of extending the model of Village A to larger scales without a careful consideration of the constraints faced by other villages.

Scale III: Ebinur Lake Catchment scale

The natural social and ecological characteristics at the catchment scale define the background within which the smaller-scale social and ecological systems operate. Thus, any consideration of the sustainability of development at one scale requires a careful consideration of the constraints imposed by the social and ecological characteristics of larger-scale systems.

Ecological Consequences of the Ebinur Lake Catchment

The source water for the Ebinur Lake Catchment has three main sources: precipitation, flows of surface water, and groundwater into the lake. Ebinur Lake plays a vital role for the natural ecosystems of the northern Xinjiang Uyghur Autonomous Region. However, increasing human activities in the region are causing dramatic changes in the ecosystem.

Ebinur Lake is shrinking rapidly and the river flows are decreasing or even disappearing in recent decades. In 1950, the lake covered about 1.2×10^5 ha, but by the 1970s, the area had decreased to less than half of the area in 1950 (Fig. 7). Although the lake's area increased from the late 1990s to 2003, it has never reached more than 77 % of the 1950 area, and the area has decreased steadily since 2003. Changes in both precipitation and human activities explain this trend (Zhou et al. 2010), but most researchers estimate that drought accounts for only 2–5 % of the shrinkage

(Yuan 1990). In the 1970s, human activities became the prime factor (Qian et al. 2004). Agriculture consumes most of the water (Cheng and Hong 2011), and from 1970 to 2009, the area under cultivation increased at an average rate of about 5.2 % (Fig. 7), and most of the agricultural land was produced by reclamation of natural grassland (Bai et al. 2012). The cultivation area is negatively correlated with the lake area (Sun and Gao 2010). Ebinur Lake shrinks by 2.25 km² for each 666.7 ha increase in the cultivation area (Liu et al. 2010). As the area of salinized lakebed expands, highly erodible sediments are exposed, and combined with the bare farmland surface in the spring and the reduction in the cover by native vegetation, which can protect the soil, sandstorm weather has been increasing as the lake shrinks (Su et al. 2002; Yang et al. 2003). In addition to the decreased water quantity, researchers have begun to notice that water quality is deteriorating. The water in the Ebinur Lake Basin during even periods of high inflow is moderately polluted, agricultural non-point-source pollution was the main cause of pollution of the Bortala River, and the N concentrations in the Kuytun River and the Jinghe River were higher than those in other rivers (Mi et al. 2010). These ecological consequences are threatening agricultural production, economic development, and the safety of the living environment for the people in this area.

The Sustainability of Nomad Sedentarization at a Catchment Scale

The process of sedentarization makes the village-scale social and ecological system shift from a dependence on natural ecosystems to a dependence on artificial agro-ecosystems; therefore, the sustainability of sedentarization depends on the sustainability of the agro-ecosystems. Many studies have confirmed the linkage between significant agricultural expansion in this region and decreased flows of water into the lake (Su et al. 2002; Qian et al. 2004). In addition, our survey revealed that during the farming period, it was becoming more difficult to obtain water from the shallow wells used to supply drinking water, and that the water level in these and other wells has dropped greatly in recent years. (Unfortunately, measurements of these changes are not currently available.) At present, the local government is taking many measures to limit water consumption in agricultural land and to improve water-use efficiency, as they recognize that the region is facing a growing and potentially severe water scarcity. Therefore, the sustainability of sedentarization will increasingly be constrained by the water resources in this arid area. In the aspects of SES, the economy may improve in a short-term in small villages like village A. However, in the long run, because these changes reinforce

Fig. 7 The relationship between the cultivated area in the Ebinur Catchment and the area of Ebinur Lake from 1950 to 2009. Based on data from Sun and Gao (2010)

the scarcity of water, this may lead to less sustainable in the catchment scale.

CONCLUSIONS AND SUGGESTIONS

Our study shows that we obtained different results at different scales, and demonstrates the importance of studying social and ecological systems at multiple scales. At the village scale, shifting the dependence on natural resources to a dependence on agricultural resources has allowed some of the formerly nomadic households to expand their livestock numbers, earn more income, and improve their living conditions. However, our comparison of the two villages at the county scale revealed that the success of Village A depends on the import of resources from the larger-scale system, and that even in the same county, there are so many differences among the villages that the model of Village A cannot be expanded to all villages throughout the county. At the catchment scale, the sustainability of sedentarization depends strongly on the limited water resources, and from a long-term perspective, this constraint suggests it will be difficult to sustainably develop the region's social and ecological systems further. It is therefore necessary to carefully reconsider the current pattern of sedentarization.

The NSP has been implemented in China for almost two decades, and investments in this approach by local and central governments is increasing rapidly. However, our research suggests that this approach cannot guarantee short- or long-term improvements in the standard of living of the formerly nomadic people, and creates a high risk of severe ecological damage when the approach is not adapted to account for local constraints. Our results suggest that sedentarization, accompanied by house construction and supported by the provision of public services and modernized animal husbandry practices, may only create short-term prosperity for some portion of the nomadic peoples, and may come at the cost of ecological damage and the loss of their 1000-year-old culture in the longer term. This suggests an urgent need for a discussion and reconsideration of the role of pastoralism in such areas and careful determination of whether the NSP approach will be broadly sustainable. We argue that, a system of food production that was sustainable with using very little water is the best choice, such as pastoralism. In that case, what the governments need to do are to provide policy, technical, and other supports for pastoralism improvement and development instead of replacement with livelihoods using more water.

Scale is an important consideration in analyses of the management of natural resources and related issues. Social

and ecological systems function at a range of scales, and interact with each other across these scales. The characteristics of larger-scale systems constrain smaller-scale systems, but the smaller-scale systems also create feedbacks that will affect the larger-scale system. Environmental policy is usually developed to solve problems at a certain scale, and the policy is evaluated only at that scale. This approach ignores the potentially crucial interactions among different scales, and this may lead to solving a problem at one scale but causing another, potentially more serious, problem at another scale.

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