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Analysis

Changes in Human Well-being and Rural Livelihoods Under Natural Disasters

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ABSTRACT

Rural areas around the world are increasingly exposed to natural disasters. To guide management intervention for sustainable development after natural disasters, scientists and policymakers need a better understanding of the linkages between livelihood changes after natural disasters and recovery outcomes. Despite the growing body of disaster research, systematic evaluation of the relationship between post-disaster changes in rural livelihoods and recovery outcomes is rare, largely due to the lack of relevant data. By taking advantage of the long-term data collection and research conducted in China's Wolong Nature Reserve (Wolong), we empirically evaluated livelihood changes after the catastrophic 2008 Wenchuan Earthquake and how those changes are linked to the recovery of human well-being. Our results show that households' livelihood portfolios in Wolong conspicuously changed after the earthquake and that human well-being had been recovering. However, we found most of these livelihood changes negatively affected, instead of facilitated, human well-being recovery. The enriched understanding of the linkages between post-disaster livelihood changes and recovery outcomes has important management implications for achieving Sustainable Development Goals amid natural disasters in Wolong and beyond.

1. Introduction

Human exposure to natural disasters has been increasing rapidly over the past decades due to factors such as human-induced ecological degradation and climate change (Cutter et al., 2015; Field, 2012; Guha-Sapir et al., 2012; Simpson et al., 2016; Tuanmu et al., 2013). These disasters, like the series of hurricanes that struck the Caribbean and the North American mainland in fall 2017, can have massive local and regional effects. Besides substantial damage to ecosystems, natural disasters often cause tremendous socioeconomic losses to human communities (van den Berg, 2010; Zhang et al., 2011). This challenge is especially acute when considered in the context of global efforts to achieve Sustainable Development Goals (United Nations, 2016) in rural areas. Rural areas provide sanctuary to the majority of the world's biodiversity. However, many of these biodiversity hotspots are in rural regions with frequent natural disasters (e.g., earthquakes, hurricanes, floods, and droughts) (Myers et al., 2000; Willis et al., 2007). In addition, human populations in those areas have continued to increase in recent decades (Bacci, 2017; Williams, 2013) and households there are often poor and thus especially vulnerable to natural disasters (Masozera et al., 2007). Without effective management interventions, short-term losses due to natural disasters can easily cause long-term poverty (Hallegatte and Dumas, 2009; Hallegatte et al., 2007). This poverty may in turn prompt destructive use of natural resources and lead to poverty-environment traps in which poverty exacerbates environmental degradation and environmental degradation worsens poverty (Barrett et al., 2016; Cao et al., 2009; Carter et al., 2007; Haider et al., 2017; Rudel et al., 2013; van den Berg, 2010).

To steward human-nature interactions toward sustainable development after natural disasters, it is crucial to understand the post-disaster changes in household livelihoods and how these changes affect socioeconomic and ecological outcomes (e.g., human well-being and biodiversity) (Barrios, 2017; Ingram et al., 2006; Lawther, 2015; Resosudarmo et al., 2012). Natural disasters are not entirely “natural”. Their effects on households depend crucially on households' livelihoods which interact with changes in factors such as institutions and biophysical environment (Barrios, 2017). In biodiverse regions, efforts to respond to adverse effects of natural disasters have the added challenge of taking biodiversity into account. Conservation polices along with development of some off-farm industries such as nature-based tourism

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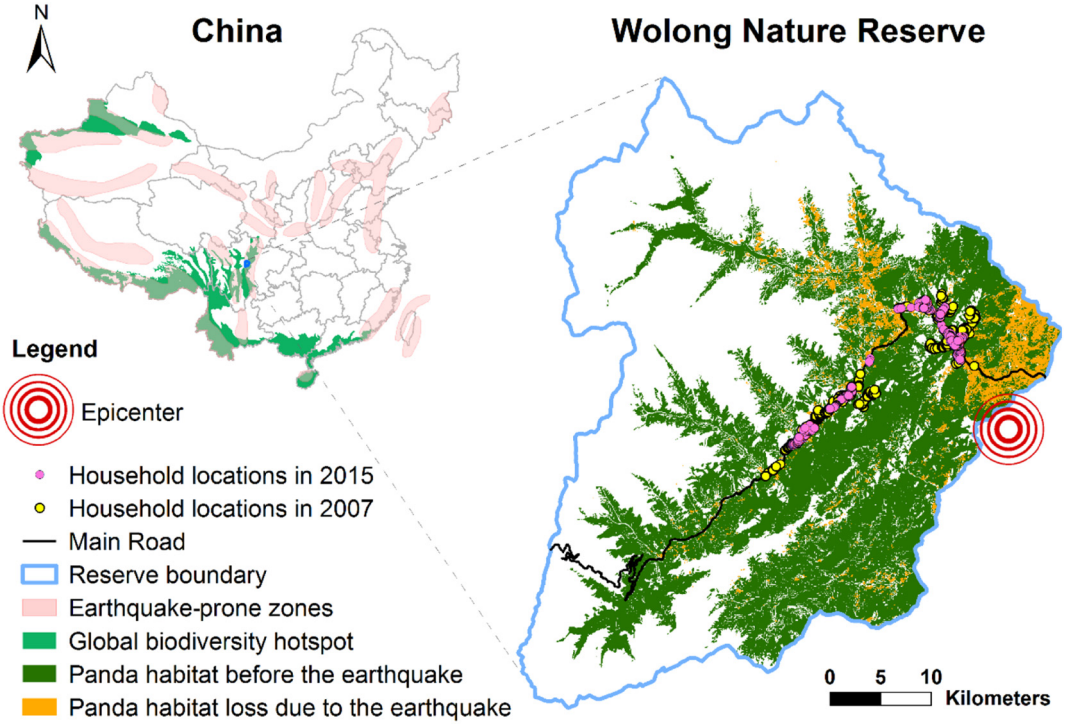

Fig. 1. Wolong Nature Reserve in Southwestern China. The reserve is located within one of the overlapped regions between an earthquake-prone zone and global biodiversity hotspots in China. The information on panda habitat and its change was obtained from the published results (Ouyang et al., 2008).

can substantially shape households' livelihood portfolios and mitigate their impacts on ecosystems (Liu et al., 2012; Yang et al., 2018). However, natural disasters may reshape livelihood portfolios and generate unexpected outcomes. A better understanding of interrelated changes in livelihood portfolios and recovery outcomes after natural disaster is therefore important for management agencies to develop better interventions that facilitate households' recovery after disasters while minimizing their impacts on ecosystems. Absent such interventions, unregulated livelihood activities (e.g., timber harvesting) after disasters may lead to serious biodiversity loss and compromise the natural capital that is essential for the long-term sustainability of local communities (Ingram et al., 2006).

While there is vast and sophisticated literature on natural disaster (Phillips, 2015; Rodríguez et al., 2007; Smith et al., 2018; Tierney, 2014), little if any of it directly addresses the linkages between post-disaster changes in livelihoods and human well-being, especially in biodiverse areas. The existing literature has examined the restoration of housing conditions, household income, and people's psychological health (e.g., Priebe et al., 2011; Rathfon et al., 2013; Yang, 2013), and how these recovery outcomes are influenced by demographic and socioeconomic characteristics, such as race and ethnicity (e.g., Finch et al., 2010; Wang et al., 2012; Wang et al., 2015; Zhang and Peacock, 2009), as well as external assistance (e.g., Msilimba, 2010; Resosudarmo et al., 2012). A recent study by Yang et al. (2015) has further examined the linkages between households' dependence on ecosystems services and the impact of natural disasters on human well-being. However, systematic evaluation of long-term changes in livelihoods and their linkages to recovery of human well-being after natural disasters is rare in existing literature (Burton, 2015; Lawther, 2015), largely due to the lack of relevant data.

Long-term interdisciplinary research project conducted in China's Wolong Nature Reserve (Wolong hereafter), which was seriously affected by the Wenchuan Earthquake, provides an excellent opportunity to address this issue. On May 12, 2008, a catastrophic earthquake (Ms 8.0; the most devastating in China since the 1950s) struck southwestern China, with its epicenter in Wenchuan County, Sichuan Province (Viña et al., 2011; Zhang et al., 2014). The earthquake generated tremendous socioeconomic impacts in China, as it caused 69,227 deaths, 374,643 injuries, and 17,923 people missing, in addition to over 84.51 billion yuan ($12.6 billion USD) of economic loss associated with property damage (CCTV, 2009). The earthquake also caused serious impacts on biodiversity (Zhang et al., 2014; Zhang et al., 2011). It was estimated that about 1221 km^2 of forest, grassland, and wetland was lost (e.g., converted to bare land) due to the earthquake and subsequent landslides (Ouyang et al., 2008; Xu et al., 2009). In response, the Chinese government initiated hundreds of post-disaster reconstruction projects to rebuild the facilities, infrastructures, and residential houses with a massive investment of over 1700 billion yuan ($253 billion USD) (China News, 2012).

Wolong is among the areas most seriously affected by the Wenchuan Earthquake. By taking advantage of the long-term research and data collection efforts in Wolong (e.g., An et al., 2001; Chen et al., 2012b; Linderman et al., 2005; Liu et al., 1999b; Tuanmu et al., 2011), we are able to empirically evaluate livelihood changes after the earthquake and how those livelihood changes affect human well-being. We first characterized changes in local households' livelihood portfolios in response to the direct and indirect impacts of the 2008 Wenchuan earthquake using multi-year household survey data. We then used a quantitative human well-being index system to characterize changes in human well-being for each surveyed household. Finally, we built empirical models to evaluate the effects of changes in household livelihood portfolios on human well-being recovery. This allows us to discuss the management strategies that would facilitate sustainable development amid natural disasters in Wolong and beyond.

Our study is one of the first to add a focus on the households' livelihood portfolio to the overall literature on disaster recovery. It complements existing literature on a central theme in ecological economics: how households manage a portfolio of resources to generate well-being (De Sherbinin et al., 2008; Dietz, 2015; Nguyen et al., 2015; Pour et al., 2017). In addition, a natural disaster is one of many exogenous factors that shape the success of household livelihood strategies for well-being because a natural disaster's impacts are as much a result

of the social as of the natural (Barrios, 2017). Our analysis on the interrelated changes in livelihood portfolios and human well-being also complements a number of other studies that show how exogenous forces such as national policies and urban labor market shape local socioeconomic and ecological outcomes (Chen et al., 2012a; Kramer et al., 2009; Liu et al., 2015; Yang et al., 2018).

2. Materials and Methods

2.1. Study Area

Our study area is Wolong in southwestern China (102°52′ to 103°24′ E, 30°45′ to 31°25′ N), where the nature reserve was designed mainly for the conservation of giant pandas (*Ailuropoda melanoleuca*) (Fig. 1). The reserve was established in 1963 and expanded to its current size of 2000 km^2 in 1975 (Bai et al., 2018; Liu et al., 2016). It is within one of the top 25 global biodiversity hotspots and provides sanctuary to > 6000 species of plants and animals, including the iconic giant panda (Liu et al., 2003; Myers et al., 2000; Yang, 2013). Besides the diverse wildlife species, Wolong is also home to about 4900 local residents, living in around 1200 households (Liu et al., 2016).

Wolong is ideal for this research for several reasons. First, Wolong is within a region susceptible to natural disasters and was seriously affected by the Wenchuan Earthquake (Fig. 1). The reserve lies on the Longmen Mountain fault and has been subjected to frequent seismic activities (Zhang et al., 2014). Since 1933, there have been 10 earthquakes with the magnitude of 7.0 Ms or higher occurred around this region, including the most recent Jiuzhaigou Earthquake in 2017, Lushan Earthquake in 2013, and the Wenchuan Earthquake in 2008 (Lei et al., 2017; Xu et al., 2013; Yang et al., 2017; Zhang et al., 2014). The epicenter of the Wenchuan Earthquake was only 2 km away from the reserve's boundaries, which makes Wolong among the areas most seriously affected. The Earthquake and its associated landslides killed 129 people in Wolong, with 6 people missing and 35 people seriously injured (Wang, 2013). The earthquake also caused severe damage to local infrastructure and facilities, including residential houses, hospitals, schools, hotels, and the main road that connects Wolong to the outside world. The direct economic loss associated with the earthquake damage in Wolong was estimated up to 1.95 billion yuan (about $291.9 million USD) (Wang, 2013). Besides these socioeconomic damages, the earthquake also caused the loss of about 56 km^2 of forest (about 7% of total forest) that is critical for the habitat of giant pandas and many other wildlife species in Wolong (Ouyang et al., 2008; Viña et al., 2011).

Second, household livelihoods in Wolong before the earthquake share many common features with other rural areas around the world. In Wolong, as in many other rural areas, crop production (e.g., growing cabbage, corn and potatoes) and livestock husbandry (e.g., rearing cattle or yaks) are important livelihood strategies (Liu et al., 2016). Meanwhile, the rich natural resources in Wolong made it a famous tourism destination. The development of nature-based tourism in the 2000s benefited many local households by bringing off-farm job opportunities (He et al., 2008; Liu et al., 2012; Yang et al., 2015). In recent decades in China, a widening rural-urban disparity of job opportunities has drawn a rapidly growing number of farmers from rural areas to urban centers (Rush, 2011). Wolong has not been an exception, and a growing number of households having members out-migrate to cities for temporary jobs (Chen et al., 2012a). Since these livelihood activities in Wolong are commonly found in other rural areas around the world, methods and findings from this study may guide research and management not only in Wolong, but also many other places around the world (Kramer et al., 2009; Pulido-Fernandez et al., 2015).

Our research team has been conducting long-term interdisciplinary research on coupled human and natural systems in Wolong since the mid-1990s (e.g., Hull et al., 2011; Liu et al., 2001; Liu et al., 1999a; Tuanmu et al., 2011; Yang et al., 2013b). This lays an essential foundation for examining the linkages between changes in livelihoods and human well-being after the earthquake (Liu et al., 2016). For example, the detailed household information collected before and after the earthquake constitutes an excellent dataset for characterizing the changes of local livelihood portfolios. In addition, Yang et al. (2013a) developed a survey-based approach to quantify human well-being as conceptualized in the Millennium Ecosystem Assessment, which offers a feasible way to evaluate human well-being changes of local households.

2.2. Characterizing Changes in Livelihood Portfolios

In this study, we focus on the changes of four major types of livelihood activities after the earthquake in Wolong, including local off-farm labor, crop production, labor migration (temporary out-migration to work in cities), and livestock husbandry. We chose these livelihood types because they encompass almost all income activities in Wolong (Liu et al., 2013b) and were common in many other rural areas. Since household members often make joint or coordinated decisions regarding livelihood strategies, all data characterizing changes in livelihood portfolios were collected at the household level.

We used household survey data collected in Wolong in 2007, 2010, and 2015. It contains detailed demographic (e.g., household size, members' age, education, and occupation) and socioeconomic (e.g., cropland area, number of livestock, livestock selling prices, and income sources) information of local households at three important time steps: 2007 (just before the earthquake), 2009 (soon after the earthquake) and 2014 (six years after the earthquake), respectively. To understand reasons behind cropland change after the earthquake, we added questions to the survey for 2014 to collect information on amount of cropland lost due to earthquake and post-disaster reconstruction. We conducted these three surveys in the form of face-to-face interviews. During these interviews, we selected household heads or their spouses as interviewees because they usually have the best knowledge about their households' affairs. Before performing the formal surveys, we conducted pretests to assess respondents' comprehension of our survey questions and how difficult they feel it was to answer. Based on interviewees' responses in pretests, we iteratively revised our survey instruments to ensure that interviewees understood and were able to answer our questions correctly. In total, 199, 287, and 245 randomly sampled households completed these three formal surveys, with a response rate of 93%, 95%, and 96%, respectively.

The household livelihood information in 2007, 2009 and 2014 comprises an excellent dataset to characterize changes in livelihood portfolio after the Wenchuan Earthquake. As is true of most rural households in developing countries, households rely on a diverse set of resources to generate livelihoods and our surveys capture considerable variation from household to household and within households over time (Barrett et al., 2001; Chen et al., 2012a; Yang et al., 2016a).

We operationalized local off-farm labor in Wolong as the number of household member(s) working in local off-farm sectors (e.g., construction, operating restaurants). Crop production was operationalized as the amount of cultivated cropland owned by each local household. Labor migration was operationalized as the number of labor migrants in each household, while livestock husbandry was operationalized as the average number of livestock raised by each household. To make different types of livestock (sheep, yak, cattle, and horses) comparable, the livestock number we used in this study is the equivalent number of sheep calculated by converting the data on other types of livestock to that of sheep based on the ratios of their average selling prices derived from our survey.

2.3. Measuring Human Well-being Changes

The survey instrument we used (Table S1) was designed based on the framework of human well-being proposed in the Millennium Ecosystem Assessment (MA, 2005; Yang et al., 2013a). Human well-

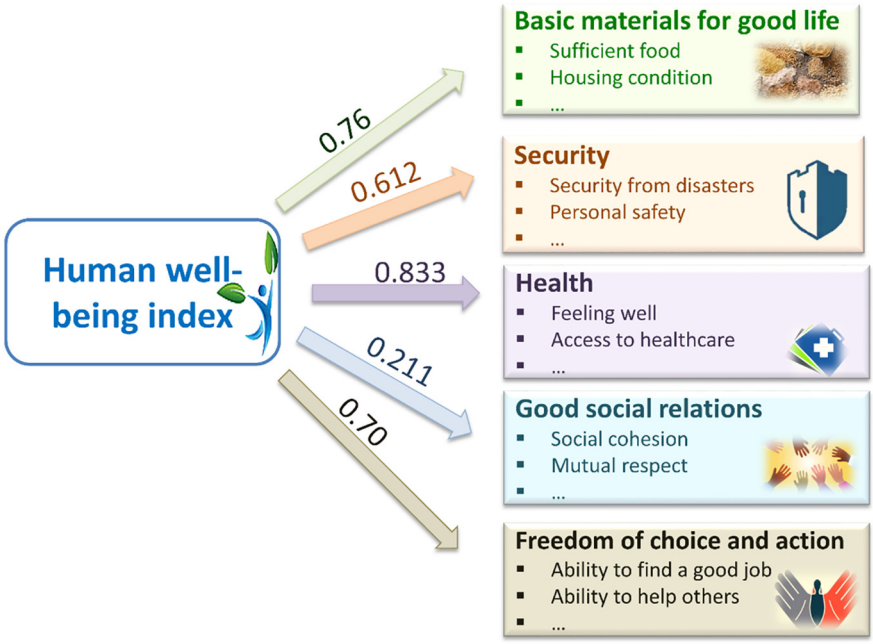

Fig. 2. The structure of human well-being index system. Besides the overall human well-being (the blue in the left), it has five sub-indecies corresponding to the five demensions of human well-being as proposed in the Millineum Ecosystem Assessment, including basic materials for good life, security, health, good social relation, freedom of choice and action. For each sub-index, we designed a set of indicators measured with five-category Likert-style scale as presented in our survey instrument (Table S1). We estimated these indices using confirmatory factor analysis. The single-headed arrows represent direction of causal influence. Number along each arrow is the standardized coefficient indicating the strength of the empirical relationship between overall human well-being and the corresponding sub-dimension of it. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

being encompasses five interrelated dimensions: basic material for good life, security, health, good social relations, and freedom of choice and action (MA, 2005). Fig. 2 presents the structural relations between the overall human well-being index and its five sub-indices representing each of the five dimensions. For each sub-index, our survey instrument includes a set of questions to generate indicators to construct it (Table S1). In collecting retrospective information, we followed standard practices of life history calendars to enhance respondents' recall accuracy (Axinn et al., 1999; Freedman et al., 1988).

We used confirmatory factor analysis (CFA) with Mplus, version 7 (Muthén and Muthén, 2010) to estimate the overall human well-being index and its five sub-indices. We evaluated the validity of these human well-being indices using a set of standard criteria for CFA (Table S2). The validation results indicate that the overall index and sub-indices of human well-being have high reliability (Table S2). To allow cross-year comparisons, we normalized the overall index and the sub-indices to the range from 0 to 1 using maximum-minimum normalization method as suggested by Yang et al. (2015). A higher value of the index value suggests higher satisfaction of corresponding human needs. More technical details regarding construction, validation, and application of the indices can be found in previous studies (e.g., Yang et al., 2013a; Yang et al., 2015).

2.4. Modeling the Linkages Between Changes in Livelihoods and Human Well-being

One of our major goals is to evaluate the relationship between changes in household livelihood portfolio after the earthquake and the recovery of human well-being. Previous work has examined the short-term impacts of the earthquake per se (Yang et al., 2016b); our emphasis is what happened during the recovery period, that is, the year following the earthquake (2009) to six years after the earthquake (2014). We used changes in the overall human well-being index and its five sub-indices between 2009 and 2014 as our measures of recovery outcomes. We hypothesize that the human well-being changes after the earthquake are affected by the portfolio of livelihood activities of households in 2009 and their changes during the recovery period (2009 to 2014).

To develop indicators characterizing changes in livelihood portfolios within households over time (Table 1), we compiled panel data using socioeconomic information on households in 2009 and 2014. In total, there are186 households surveyed in both years. With these panel data, we constructed linear regression models to relate changes in overall human well-being index and its five sub-indices between 2009 and 2014 to changes in household livelihood activities during the same period as well as their values in 2009.

To control for potential confounding effects, our models included some other socioeconomic and demographic factors that may affect human well-being changes (Table 1). Similar to livelihood activities, some of these factors (e.g., number of laborers in a household) may change during the recovery period (i.e., 2009 to 2014). We thus included variables measuring these socioeconomic and demographic conditions in 2009 and their changes between 2009 and 2014 in our models (Table 1). Our models also included the changes in human well-being indices between 2007 and 2009 as independent variables because the short-term impact of the earthquake on human well-being may have legacy effect on the long-term recovery. The general form of the models can be given as

$$\mathbf{H}_{\Delta} = \beta_0 + \beta_1\mathbf{H}_{2009} + \beta_2\mathbf{H}_{2007-2009} + \beta_3\mathbf{L}_{2009} + \beta_4\mathbf{L}_{\Delta} + \beta_5\mathbf{X}_{2009} + \beta_6\mathbf{X}_{\Delta} + \varepsilon$$

where $\mathbf{H}_{\Delta}$ refers to the vector of changes in overall human well-being index and the sub-indices between 2009 and 2014; $\mathbf{H}_{2009}$ refers to the vector of corresponding indices in 2009; $\mathbf{H}_{2007-2009}$ represents the vector of changes in corresponding indices between 2007 and 2009; $\mathbf{L}_{2009}$ and $\mathbf{L}_{\Delta}$ represent the vectors of livelihood activity variables in 2009 and their changes between 2009 and 2014 respectively; $\mathbf{X}_{2009}$ and $\mathbf{X}_{\Delta}$ represent the vectors of other socioeconomic and demographic variables in 2009 and their changes between 2009 and 2014 respectively; $\boldsymbol{\beta}_0$ is the vector of intercept; $\boldsymbol{\beta}_1 - \boldsymbol{\beta}_6$ are the vectors of coefficients to be estimated; ε is the vector of error term, in which each error term is assumed to be normally distributed with a mean of zero. We conducted the modeling analyses using Stata 13.1 (StataCorp, College Station, Texas, USA).

3. Results

3.1. Changes in Livelihood Portfolios After the Earthquake

After the earthquake, all the four major types of livelihood activities in Wolong experienced conspicuous changes in response to the direct

Table 1
Summary of variables included in the linear regression models that relate changes of human well-being index and sub-indices after the earthquake to different livelihood changes and other socioeconomic factors (sample size = 186).

Variables	Description	Mean (SD)
Outcome variables		
Well-being change	Change in the overall human well-being index value from 2009 to 2014.	0.271 (0.182)
Change in basic material	Change in value of sub-index representing basic materials for good life from 2009 to 2014.	0.32 (0.279)
Change in security	Change in value of sub-index representing security from 2009 to 2014.	0.382 (0.191)
Change in health	Change in value of sub-index representing health from 2009 to 2014.	0.225 (0.186)
Change in social relations	Change in value of sub-index representing social relations from 2009 to 2014.	0.013 (0.081)
Change in freedom	Change in value of sub-index representing freedom of choice and action from 2009 to 2014.	0.195 (0.191)
Livelihood activities and their changes		
Labor work inside 09	The number of laborers earned income through working in local off-farm sectors in 2009.	1.102 (0.775)
Change in labor work inside	Change in the number of laborers working in local off-farm sectors from 2009 to 2014.	−0.054 (1.089)
Labor work outside 09	The number of laborers earned income through working outside the reserve in 2009.	0.409 (0.739)
Change in labor work outside	Change in the number of laborers working outside the reserve from 2009 to 2014.	0.317 (1.081)
Crop production 09	The area of the household's cropland in 2009. (Mu[a])	3.491 (3.228)
Change in crop production	Change in household's cropland area from 2009 to 2014. (Mu)	−0.481 (3.016)
Livestock husbandry 09	The number of livestock (as measured by equivalent number of sheep) raised in 2009.	33.578 (111.317)
Change in livestock husbandry	Change in the number of livestock from 2009 to 2014.	4.056 (18.71)
Socioeconomic and demographic characteristics		
Human well-being 09	Overall human well-being index value in 2009.	0.363 (0.15)
Change in well-being 07–09	Change in the overall human well-being index value from 2007 to 2009.	−0.247 (0.166)
Basic materials 09	Sub-index value of basic material in 2009.	0.374 (0.215)
Change in basic materials 07–09	Change in sub-index value of basic material from 2007 to 2009.	−0.235 (0.247)
Security 09	Sub-index value of security in 2009.	0.189 (0.128)
Change in security 07–09	Change in sub-index value of security from 2007 to 2009.	−0.449 (0.208)
Health 09	Sub-index value of health in 2009.	0.432 (0.179)
Change in health 07–09	Change in sub-index value of security from 2007 to 2009.	−0.232 (0.186)
Social relations 09	Sub-index value of social relations in 2009.	0.682 (0.144)
Change in social relations 07–09	Change in sub-index value of social relations from 2007 to 2009.	−0.033 (0.085)
Freedom of choice and action 09	Sub-index value of freedom of choice and action in 2009.	0.322 (0.173)
Change in freedom 07–09	Change in sub-index value of freedom of choice and action from 2007 to 2009.	−0.136 (0.153)
Total income 09	Log-transformed gross income in 2009. (Yuan[b])	10.033 (1.391)
Household size 09	The number of members in the household in 2009.	4.796 (1.525)
Change in household size	Household house size change from 2009 to 2014.	−0.215 (1.626)
Laborers 09	The number of members involved in income-earning activities in 2009.	3.387 (1.496)
Change in laborers	Change in the number of laborers from 2009 to 2014.	−0.183 (1.718)
Laborers' education	The average schoolyears of laborers. (Year)	5.979 (3.037)
Change in laborers' education	Change in laborers' average schoolyears from 2009 to 2014.	1.164 (4.21)
Respondent's gender	The gender of the respondent in our survey (0, female; 1, male)	0.602 (0.491)
Respondent's education	The schoolyears of the respondent. (Year)	5.688 (3.560)

[a] 1 mu = 1/15 ha.
[b] 1 Yuan = 0.16 USD as of June 2014.

and indirect impacts of the earthquake. We observed that the proportion of households having laborer(s) with temporary or permanent off-farm jobs inside Wolong maintained a high level after the earthquake (Fig. 3(a)): 75.6% in 2009 and 65.2% in 2014, as compared to 75.4% in 2007. However, the main source of local off-farm jobs changed after the earthquake. Before the earthquake, about 90% of the off-farm job opportunities were related to tourism development directly (e.g., employment in a hotel) or indirectly (e.g., labor work for construction of tourism facilities). But the tourism industry collapsed because of earthquake damage to the main road and tourism facilities. Post-disaster reconstruction projects supported by the Chinese government became the main source of local off-farm income opportunities for households in Wolong. Our survey data show that 74% in 2009 and 63% in 2014 of local off-farm income activities were related to the post-disaster reconstruction projects (e.g., reconstructing roads, schools, hospitals and residential houses). The decline in the local off-farm opportunities between 2009 (75.6%) and 2014 (65.2%) might be explained by the completion of many reconstruction projects in recent years (China News, 2012).

In Wolong, crop production plays an important role in local economy. After the earthquake, however, crop production in Wolong decreased due to the impacts of landslides caused by the earthquake and post-disaster reconstruction. The average amount of cropland owned by households in Wolong decreased from 4.7 mu (1 mu = 0.067 ha) in 2007, to 3.4 mu in 2009, and to 2.9 mu in 2014 (Fig. 3(b)). Of the cropland loss from 2007 to 2014, about 39% was attributable to the direct damage by the earthquake and the associated landslides, while the rest (about 61%) was due to government appropriation of land for the post-disaster reconstruction. Concomitant with the loss of land, the percentage of average household income from selling crop products to outside markets declined by 32% between 2007 and 2014.

The other two major types of livelihood activities, labor migration and livestock husbandry, increased after the earthquake and may represent a shift in portfolios to compensate for the decline in farming and tourist industry employment. The proportion of households with member(s) temporarily out-migrating to work in cities rapidly increased from 2.6% in 2007, to 26.8% in 2009, and to 48.2% in 2014 (Fig. 3(c)). Although the proportion of households that raised livestock after the earthquake maintained at a level similar to what it was before (around 30%), pastoral households (households that raise livestock) had expanded their livestock population after the earthquake. The average equivalent amount of sheep raised by each pastoral household increased from 70.8 in 2007, to 80.2 in 2009, and to 107.8 in 2014 (Fig. 3(d)).

3.2. Human Well-being Changes After the Earthquake

Human well-being indices indicate that households' well-being in Wolong has been recovering after the earthquake (Fig. 4). The average

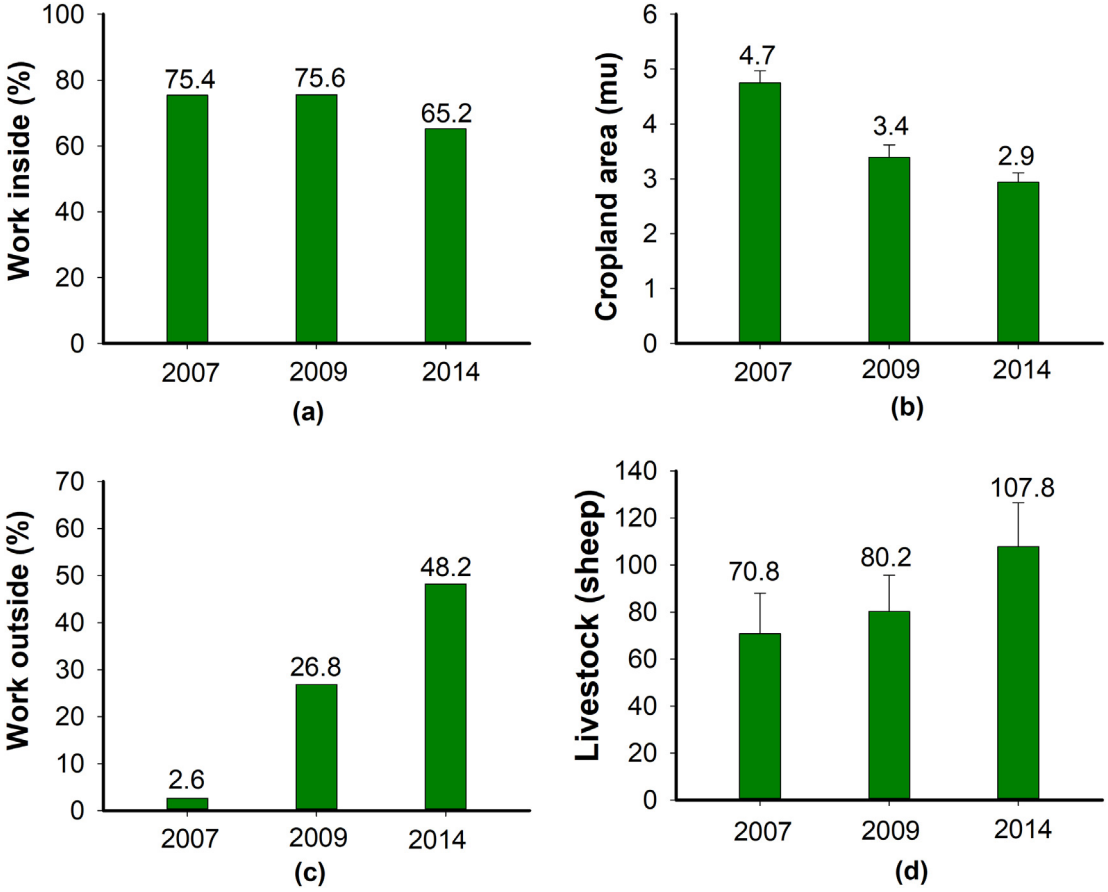

Fig. 3. Livelihood changes across years in Wolong. (a) The percentage of households with member(s) working in off-farm sectors inside Wolong; (b) The average cropland area each household had in Wolong (no cropland sat fallow); (c) The percentage of households with member(s) working outside Wolong; (d) The average number of livestock (as measured by equivalent number of sheep) raised by pastoral households in Wolong.

value of overall human well-being index increased by 68% between 2009 and 2014 (from 0.37 in 2009 to 0.62 in 2014), reaching a level similar to that before the earthquake (0.63 in 2007). The five dimensions of human well-being experienced different levels of recovery. The value of the sub-index representing basic materials for good life increased from 0.37 in 2009 to 0.61 in 2014, a level only slightly lower than that in 2007 (0.69). The value of the sub-index representing security was almost tripled from 0.22 in 2009 to 0.63 in 2014 and became

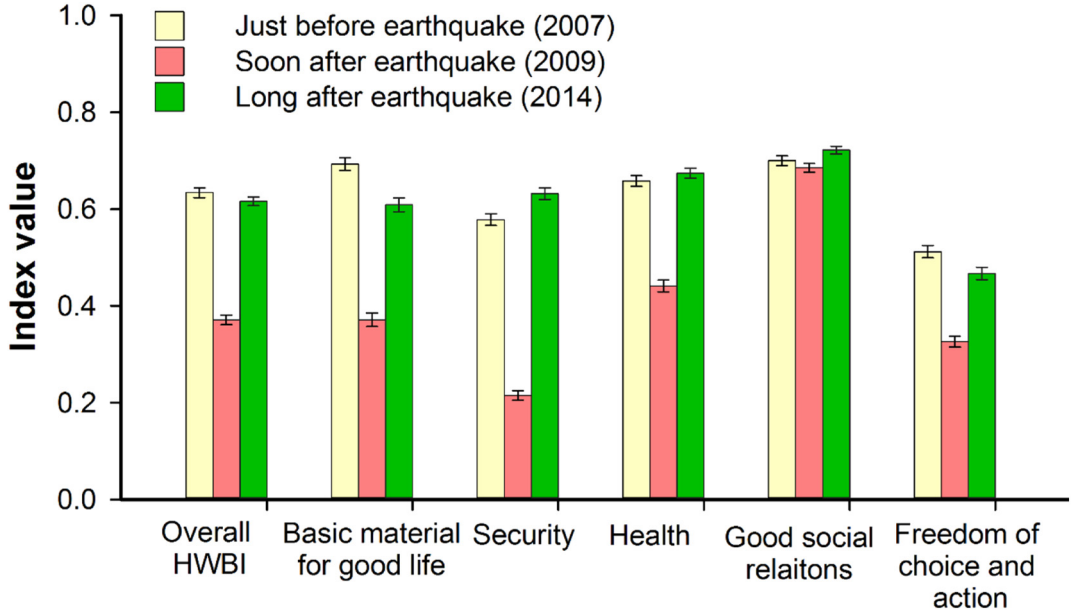

Fig. 4. Average values of human well-being indices in Wolong before and after the earthquake. A larger index value represents a better state of well-being. All changes in overall human well-being index and its sub-indices between 2007 and 2009, and between 2009 and 2014 are statistically significant ($p < 0.05$).

Table 2
Results of the linear regression model on human well-being recovery after the earthquake (sample size = 186). R^2 of the ordinary least square regression is 0.517. The model passed all diagnostics of regression assumptions. Variance inflation factors were all tested to be < 10.

Variables	Coefficients	Robust standard error
Livelihood activities and their changes		
Labor work inside 09	0.0620**	0.0201
Change in labor work inside	0.0333*	0.0132
Cropland production 09	0.0064†	0.0036
Change in crop production	0.0074†	0.0044
Labor work outside 09	0.0256	0.0230
Change in labor work outside	−0.0150	0.0138
Livestock husbandry 09	−0.0001	0.0001
Change in livestock husbandry	−0.0003*	0.0002
Socioeconomic and demographic characteristics		
Human well-being 09	−0.6121***	0.0874
Change in well-being 07–09	−0.1517†	0.0913
Total income 09	−0.0124	0.0081
Household size 09	−0.0378*	0.0147
Change in household size	−0.0255*	0.0114
Laborers 09	0.0374†	0.0191
Change in laborers	0.0385**	0.0134
Laborers' education	0.0025	0.0062
Change in laborers' education	−0.0008	0.0050
Respondent's gender	0.0005	0.0226
Respondent's education	0.0063†	0.0034
Constant	0.4973***	0.1006

† $p \le 0.1$.
* $p \le 0.05$.
** $p \le 0.01$.
*** $p \le 0.001$; two-tailed tests.

higher than the level before the earthquake (0.59 in 2007). The value of the sub-index representing health increased from 0.44 in 2009 to 0.67 in 2014, a level that was slightly higher than before the earthquake (0.66). The sub-index representing good social relationship did not change much throughout our study period (decreased slightly from 0.70 in 2007 to 0.69 in 2009 and bounced back to 0.72 in 2014). The sub-index representing freedom of choice and action increased from 0.33 in 2009 to 0.47 in 2014 but was still lower than the level before the earthquake (0.51 in 2007). All value changes in the overall human well-being index and the sub-indices, from 2007 to 2009 and from 2009 to 2014, are statistically significant ($p < 0.05$ based on *t*-tests).

3.3. Linkages Between Changes in Livelihoods and Human Well-being

Local off-farm labor work has significant positive effects on human well-being recovery. The change in the number of laborers with off-farm jobs inside the reserve during the recovery period (2009 to 2014) are positively related with post-disaster human well-being change ($p < 0.05$) (Table 2). The changes in sub-indices of basic materials ($p < 0.05$), health ($p < 0.05$) and freedom of choice ($p < 0.05$) are all positively related to the change in the number of laborers involved in local off-farm income activities (Table 3). Therefore, the high participation in local off-farm income activities (> 65%) after the earthquake seems to have promoted the human well-being recovery.

Crop production also has the potential to contribute to human well-being recovery. Cropland change is positively related to overall human well-being recovery ($p < 0.1$) (Table 2). Change in the sub-index of security between 2009 and 2014 shows significant positive relation with cropland change ($p < 0.05$) (Table 3). Therefore, the conspicuous cropland loss due to the direct impact of the earthquake (e.g., landslides) and post-earthquake reconstruction may have negatively affected the recovery of human well-being.

The coefficient for the relationship between change in labor migration and change in overall human well-being is negative, though not statistically significant ($p > 0.1$) (Table 2). Of the five sub-indices of human well-being, only change in sub-index of basic materials shows a positive relationship with labor migration and it is not statistically significant. The other four sub-indices are all negatively related to labor migration changes and two of these are significant: the dimension of health ($p < 0.05$) and freedom of choice and action ($p < 0.05$) (Table 3). Therefore, the rapid increase in the number of households with laborers that out-migrated to work in cities after the earthquake may have contributed little, or even impeded, the recovery of human well-being.

Livestock husbandry change is negatively associated with human well-being change ($p < 0.05$) (Table 2). The changes in indices representing dimensions of security and freedom of choice are both negatively related with the change of livestock number raised by local households ($p < 0.1$ and 0.01 respectively) (Table 3). These results indicate that the livestock expansion occurred in Wolong after the earthquake may have impeded the human well-being recovery.

Some demographic and socioeconomic characteristics of the households also show significant effects on human well-being recovery. Specifically, the number of laborers in a household is positively related to human well-being recovery. Both the number of laborers in 2009 and its change from 2009 to 2014 show significant positive effects ($p < 0.1$ and 0.01 respectively) on human well-being change (Table 2). Household size showed significant negative effects on human well-being. Households with a larger size in 2009 or increases in the recovering period (e.g., new birth during 2009 to 2014) tend to have a lower level of recovery ($p < 0.05$) (Table 2). The significant negative coefficients of the human well-being index value in 2009 ($p < 0.001$) and its change between 2007 and 2009 ($p < 0.1$) (Table 2) indicate households with higher well-being status in 2009 or whose well-being suffered little during the earthquake tend to have a smaller increase in human well-being during the recovering period from 2009 to 2014.

4. Discussion

Although human well-being after the earthquake has been recovering, we found many of the livelihood changes that resulted from the earthquake negatively affected well-being. Some of these negative linkages may be due to the limitations the local context places on the feasible portfolio of livelihood activities. For example, previous studies (e.g., Wong et al., 2007; Zhong et al., 2016) show that migrant workers in cities usually find it hard to adapt to urban environment, bear high living expenses, confront an unfair education system for their children, and lack a sense of belonging in cities. Therefore, labor migrants often suffer from high stresses and financial hardships that can harm their mental health and sense of freedom of choice. This is probably the reason for labor migration's negative effects on indices of health and freedom of choice and actions shown in Table 3. Another example is livestock husbandry. The extensive livestock husbandry practices in Wolong (e.g., livestock are set free to roam in the wild most of the time) may make the productivity of this work and its return on investment relatively low. Meanwhile, the initial investment for livestock (e.g., buying calves) is often high. Therefore, livestock expansion after the earthquake may have created heavy financial burdens on households and compromised their financial security and sense of freedom of choices and actions. This may be especially true for those who had experienced greatest loss in the earthquake and had to borrow money to expand their livestock holdings.

In evaluating livelihood changes and their effects on human well-being, we found post-disaster reconstruction led by the government generated unintended effects on human well-being through appropriating cropland. This cropland loss may be partly caused by the lack of local households' input in the planning and implementation of the reconstruction. In addition to reduced income from cropping, cropland loss due to post-disaster reconstruction may increase households' expenditures to buy agricultural products that they could grow on their own land before the earthquake. These negative impacts on the well-

Table 3
Results of the linear regression models on changes of sub-indices of human well-being recovery after the earthquake (sample size = 186). The five columns represent results for sub-indices corresponding to basic material for good life, security, health, good social relations, freedom of choice and action, respectively. The models passed all diagnostics of the regression assumptions. Variance inflation factors were all tested to be < 10.

Variables	Coefficients (Robust standard error)				
	Basic materials	Security	Health	Social relations	Freedom
Livelihood activities and their changes					
Labor work inside 09	0.0800** (0.0291)	0.0146 (0.0224)	0.0548** (0.021)	0.0113 (0.0105)	0.0607** (0.0232)
Change in labor work inside	0.0484* (0.0189)	−0.0022 (0.0157)	0.0322* (0.0132)	0.0082 (0.0071)	0.0313* (0.0152)
Crop production 09	0.0084† (0.0049)	0.0065 (0.0044)	0.0045 (0.0039)	−0.0044† (0.0022)	0.0051 (0.0048)
Change in crop production	0.0057 (0.0055)	0.0122* (0.0049)	0.005 (0.0051)	0.0007 (0.0034)	0.0072 (0.0049)
Labor work outside 09	0.0741* (0.0320)	−0.0116 (0.0270)	−0.0005 (0.0244)	−0.0124 (0.0129)	0.0281 (0.0258)
Change in labor work outside	0.0276 (0.0196)	−0.0084 (0.0175)	−0.0314* (0.0145)	−0.0035 (0.008)	−0.0329* (0.0164)
Livestock husbandry 09	−0.00002 (0.00009)	−0.0003** (0.0001)	0.00005 (0.0001)	−0.0001 (0.0001)	−0.0001 (0.0001)
Change in livestock husbandry	−0.0003 (0.0002)	−0.0005† (0.0002)	−0.0002 (0.0002)	0.0001 (0.0001)	−0.0004** (0.0002)
Socioeconomic and demographic characteristics					
Index value 09[a]	−0.8031*** (0.0776)	−0.5046*** (0.0971)	−0.4387*** (0.0812)	−0.0066 (0.0548)	−0.5261*** (0.0751)
Index value change 07–09[b]	−0.0839 (0.0745)	−0.1916** (0.07)	−0.2584** (0.0917)	−0.273** (0.1003)	−0.0335 (0.1096)
Total income 09	−0.0197 (0.0132)	−0.0158† (0.0086)	−0.0133 (0.0087)	−0.0053 (0.0043)	−0.0009 (0.009)
Household size 09	−0.0365† (0.0199)	−0.0413* (0.0179)	−0.0391* (0.0163)	−0.0217* (0.0106)	−0.0353* (0.0165)
Change in household size	−0.0262 (0.017)	−0.0348* (0.0139)	−0.0297* (0.0115)	−0.0127† (0.0068)	−0.0148 (0.0128)
Laborers 09	0.0201 (0.0273)	0.045* (0.0216)	0.0447* (0.0213)	0.0146 (0.0135)	0.035† (0.0201)
Change in laborers	0.0247 (0.0189)	0.0351* (0.0164)	0.0437** (0.014)	0.0016 (0.0075)	0.0376** (0.0143)
Laborers' education	0.0034 (0.0104)	−0.0089 (0.0071)	0.0057 (0.0061)	0.0034 (0.0028)	0.0041 (0.0073)
Change in laborers' education	−0.0020 (0.0086)	−0.0075 (0.0061)	0.0025 (0.0048)	0.0022 (0.0027)	0.000003 (0.0058)
Respondent's gender	−0.0101 (0.0336)	0.0249 (0.0271)	−0.0024 (0.0228)	0.0109 (0.0129)	−0.0028 (0.0255)
Respondent's education	0.0067 (0.0057)	0.0047 (0.0045)	0.0029 (0.0035)	−0.0023 (0.002)	0.0102* (0.004)
Constant	0.7038*** (0.1501)	0.6002*** (0.1205)	0.4131*** (0.1117)	0.1094 (0.0672)	0.2648* (0.1032)
R^2	0.565	0.350	0.503	0.253	0.401

† $p \leq 0.1$.
* $p \leq 0.05$.
** $p \leq 0.01$.
*** $p \leq 0.001$; two-tailed tests.
[a] The sub-index value of the corresponding dimension of human well-being in 2009.
[b] Change in the sub-index value of the corresponding dimension of human well-being between 2007 and 2009.

being of local households might be exacerbated as the market demand for and price of agricultural products have been increasing (Fukase and Martin, 2016). Furthermore, as cropland is essential for farming livelihoods, cropland appropriation for post-disaster reconstruction may have severely constrained households' choices of those livelihoods. This constraint on livelihood choices may have been exacerbated by the decrease of local off-farm job opportunities after the earthquake because local tourism industry had collapsed and a growing portion of reconstruction projects were completed (China News, 2012).

However, the post-disaster reconstruction in Wolong may have promoted human well-being recovery through pathways in addition to bringing off-farm income opportunities to local households. These are particularly important because most of these off-farm income opportunities are temporary. With the massive investment from the Chinese government, almost all households in Wolong were resettled to areas with flat terrain and close to the main road (Fig. 1). These features of the new settlements would make local households less susceptible to possible future disasters and may have contributed to the observed increase in the sub-index of security after the earthquake (from 0.22 in 2009 to 0.63 in 2014). In addition, with support from government, these newly constructed residential houses were designed and constructed with higher quality than had been typical of the previous housing stock (Yang, 2013). The improved housing conditions (e.g., larger dwelling area and closer to the main road) may have helped to address households' needs for basic materials for a good life after the earthquake and enhance their sense of freedom of choice and action. The housing improvement may also allow local households to develop their own off-farm business (e.g., operating restaurants or tourist farmhouses) and enhance their well-being in the future. Furthermore, the resettlement increased the distance of local households from core panda habitats (Fig. 1), which may reduce negative human impacts on ecosystems and enhance the ecosystem services (e.g., tourism) that can be essential for the well-being of local communities in the future.

An enriched understanding of the linkages between livelihood changes and human well-being has important implications for post-disaster management. A major lesson learned from our study is that post-disaster reconstruction plans should pay special attention to conserving or enhancing household capitals that are essential for livelihood activities that can improve human well-being. For example, our results show that cropland is an important capital for the well-being of local households but was compromised due to the post-earthquake reconstruction activities led by the government, which had larger impacts on cropland than did the earthquake itself. In Wolong, crop production has small direct ecological impacts because local cropland parcels are distributed within in a small area (about 0.05% of the whole reserve) and most of them are far from wildlife habitat (Liu et al., 2016). We thus suggest post-disaster reconstruction and other possible future infrastructure development (e.g., construction of tourism facilities) should avoid appropriation of productive cropland to reduce associated stress on the well-being of local households. Furthermore, productive cropland previously enrolled into payment for ecosystem services programs (Yang, 2013) and distant from wildlife habitat might be allowed to be converted back to cropland after the end of these programs. In other areas where cropping can generate substantial negative impacts on local ecosystems, management agencies may take the opportunity of post-disaster reconstruction to enhance capitals that can promote the shift from on-farm to off-farm activities as in Wolong. For example, the post-disaster reconstruction might relocate affected households to areas close to the main road and tourism sites. The enhanced housing conditions may afford local households to participate in local off-farm activities (e.g., operating a tourist farmhouse) and discourage them from crop production near core wildlife habitat, which ultimately may

reduce the negative ecological impacts by local communities while improving their well-being.

A better understanding of the effects of livelihood changes on human well-being can also support adaptive management after earthquakes and other disasters and help to avoid unintended consequences of recovery efforts. For example, an important factor driving the rapid livestock expansion in Wolong is the incentive policy of the local government, which provides interest-free loans to households to raise more livestock (Zhang et al., 2017). Despite the policy's good intention to facilitate the human well-being recovery after the earthquake, our findings show that the resulting livestock expansion actually did the opposite. To make matters worse, several studies in Wolong show that livestock had encroached into core wildlife habitat because the available pasture land is not sufficient to support the rapidly growing number of livestock (Hull et al., 2014; Zhou et al., 2016). The livestock compete with wild animals, such as giant pandas, for food, water, and space, and thus degrade wildlife habitats (Zhang et al., 2017). To avoid the continuance of this unexpected "lose-lose" outcome, we suggest that livestock expansion should be discouraged instead of encouraged in Wolong.

As rural livelihoods are increasingly affected by telecouplings (socioeconomic and environmental interactions over distances, such as labor migration from rural to urban areas) (Liu et al., 2013a; Liu et al., 2015), factors distant from the local system can have important influences on recovery outcomes in disaster-affected areas. For example, as demonstrated in our study, labor migration can negatively affect certain aspects of household well-being because labor migrants in cities often confront many hardships (e.g., poor education resources for their children). However, besides contributing to household income, labor migration can also generate beneficial effects on local ecosystem through reducing human disturbances. In Wolong, for example, Chen et al. (2012a) found that as compared to households without labor migrants working in cities, households with labor migrant(s) collected 1,827 kg less fuelwood from local forest. So, including labor migration in a household's livelihood strategy has an indirect benefit by mitigating human impact on ecosystems. Therefore, policies in cities (e.g., investing more to provide quality education to children of labor migrants) that help to overcome the hardships confronting labor migrants may generate beneficial effects not only on human well-being recovery but also ecosystem conservation in disaster-affected areas distant from cities.

5. Conclusions

Using long-term household survey data on household well-being and livelihood strategies from Wolong, we found that livelihood portfolios after the earthquake experienced conspicuous changes. However, not all livelihood changes generated desirable effects on the recovery of human well-being, indicating evidence-informed policy interventions are essential for the sustainable development after natural disasters. Of course, in different political, geographic, and temporal settings, the specific linkages between livelihood changes and human well-being recovery might be different. For example, the reconstruction of the main road connecting Wolong and the outside was completed in October 2016 and is expected to generate substantial impact on the telecouplings linking Wolong and other places, in large part because of Wolong's status as a highly biodiverse protected area. The completion of road reconstruction will help to attract more tourist visitations and thus change local livelihoods and human well-being. Although not all the specific changes in human well-being and livelihoods might occur in other post-disaster recovery areas, some of the concerns such as declines in tourism revenues due to road destruction may have many parallels in the effects of and recovery from disaster in other biodiversity hotspots and protected areas. More interdisciplinary research is needed in the future to construct a database of evidence on how disasters change livelihood activities that in turn affect human well-being. Such a cumulative set of evidence should also incorporate information on other outcomes (e.g., ecosystem health) across different spatial and temporal contexts. We believe that the methods presented in this paper can be easily adapted to other contexts to construct such an evidence base and help design effective management strategies to achieve Sustainable Development Goals amid natural disasters around the world.

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Appendix A. Supplementary Materials

Supplementary materials to this article can be found online at https://doi.org/10.1016/j.ecolecon.2018.05.008.

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