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Dams and population displacement on China's Upper Mekong River: Implications for social capital and social–ecological resilience

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ABSTRACT

China is home to nearly half of the world's 50,000 large dams, which provide irrigation, flood protection, and hydroelectricity. Most of these projects involve substantial population displacement, which can disrupt social capital, the webs of interdependence and support that community members maintain with one another through relationships of trust and reciprocity. We use new empirical evidence to examine the association between dam-induced displacement and social capital in China and interpret our findings in the context of social–ecological resilience theory. Our focus is on agricultural households on the Upper Mekong River, where four large hydropower dams have been constructed over the past twenty years.

Our broad finding is that resettlement is associated with diminished social capital, as measured by two key indicators: inter-household exchange of financial resources, and inter-household exchange of agricultural labor. These effects differ across the four dam sites in the study based on local economic conditions and changes in resettlement policy. We find that population resettlement is associated with markedly lower levels of agricultural labor exchange. In an economically under-developed setting, this reduces the depth and breadth of social support that agricultural households rely on to produce crops for subsistence and income. This in turn diminishes social–ecological resilience because social capital is a key factor that helps agricultural or resource-dependent communities manage risk and adapt to changes and stressors.

We consider the policy implications of our findings in the context of scientific and industry efforts to minimize social harm, promote economic vitality, and improve the sustainability of hydropower as a form of renewable energy.

1. Introduction

The World Commission on Dams, an organization under the auspices of the World Bank and the World Conservation Union, published a landmark study in 2000 which concluded that, despite their significant contributions to human development over the years, dams have resulted in serious negative impacts on people and ecosystems. The WCD report estimated that approximately 50,000 large dams, which the International Commission on Large Dams defines as those greater than 15 m in height or having a storage capacity greater than 3 million cubic meters, exist worldwide (Scudder, 2005). Taken together, these dams have caused the displacement of 40–80 million people (WCD, 2000). China's role in this trend is startling: currently home to approximately half of the world's large dams, it adds dozens of new ones to its portfolio every year for irrigation, river navigation, flood control, and, most significantly, hydropower generation. Most of these dams involve large-scale population displacement, and China's Ministry of Water Resources acknowledges that at least 15 million people have been involuntarily resettled over the past several decades alone (Yao, 2004).

When dams are built and reservoirs fill behind them, they displace the people who live there, inundating farmland and changing people's lives and livelihoods. A growing body of evidence has shown that the social effects of displacement can last for generations as people cope with the consequences for their household income, their access to land and other resources, their community identities, and their physical and mental well-being. As the WCD concluded in its seminal report, these effects are "spatially significant, locally disruptive, lasting, and often irreversible" (WCD, 2000: 102), with the potential to undermine the long-term sustainability of the hydropower sector worldwide. Despite global assessments by the WCD and similar organizations, policymakers often make decisions without systematic

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information about the social impacts of dams, particularly those not readily measured in monetary terms.

In this paper, we use new empirical evidence from household surveys conducted in Yunnan, China to examine the association between dam-induced displacement and social capital, the relationships of interdependence that community members maintain with one another for cooperation and mutual economic support. Our focus is on agricultural households on China's Upper Mekong River, where four large hydropower dams have been constructed over the past twenty years. We develop two indicators of social capital that are crucial for farmers' economic viability: inter-household exchange of financial resources (loans), and inter-household exchange of agricultural labor. For each indicator, we develop a series of regression models in order to answer two research questions:

1) For all dam sites in the study, is resettlement associated with lower levels of social capital, as measured by financial exchange and agricultural labor exchange?
2) Given that our data set includes multiple resettlement projects spanning twenty years, does the relationship between resettlement and social capital differ by dam site based on local economic conditions and recent changes in resettlement policy?

We analyze our findings in light of recent advancements in social–ecological resilience theory (Berkes et al., 2003) and consider the implications for the sustainability of hydropower projects involving large-scale population displacement. To our knowledge, this research provides the first systematic, quantitative analysis of the impacts of hydropower development and population resettlement on social capital, building on previous studies focused primarily on resettlement's economic impacts.

1.1. Hydropower development in Yunnan, China

China's hydropower expansion is driven by remarkable growth in energy demand in the world's most populous nation and by policy decisions in the central government that promote new sources of energy. In a U.S.–China joint statement on climate change released in late 2014, Chinese leaders announced their intention to cap CO_2 emissions and reduce overall carbon emissions in the coming decades (White House, 2014). This will require dramatically scaling back dependence on fossil fuels, especially coal, which currently accounts for three-quarters of China's electricity generation (Economy, 2007; Liu, 2012). Hydropower dams have become a centerpiece of the policy discussion on renewable energy. In addition to high-profile projects like the Three Gorges Dam, hydropower facilities have already been built on nearly all of China's major river systems. Hydropower output accounts for more than 16% of China's total electricity portfolio and is growing at an annual rate of 12.9%, faster than any other electricity-generation source (Chinese State Council, 2013).

The southwestern province of Yunnan has been designated as one of thirteen key "hydropower bases" for the nation, and the Mekong River, which rises on the Qinghai-Tibet Plateau at an elevation of 5224 m, figures prominently in the region's hydropower development plans. The Upper Mekong, the segment of the river in China (known as the *Lancang* in Chinese), flows from north to south through Yunnan Province for 2200 km (see Fig. 1). Its watershed encompasses an area of remarkable biological diversity, from glacial scree at the headwaters to subtropical rice terraces and rubber plantations on China's southern border. It is also home to more than 20 of China's officially recognized "minority nationalities," ethnic groups who often endure economic and cultural marginalization and whose standard of living lags behind much of the rest of China (UNDP, 2008). The middle and lower segments of the Mekong, along with an extensive network of tributaries, support fishing and floodplain agriculture for tens of millions of people in five downstream riparian countries in Southeast Asia including Myanmar, Laos, Thailand, Cambodia, and Vietnam (Grumbine et al., 2012).

China Huaneng Group, a large shareholder corporation in which China's central government is the principal investor, holds a monopoly on the right to develop dam projects on the Upper Mekong (Magee and McDonald, 2009). Four large hydropower dams have been constructed on the Upper Mekong over the past 20 years and are the basis of this study: Manwan (132 m tall, 1500 MW installed capacity, completed in 1996); Dachaoshan (121 m tall, 1350 MW installed capacity, completed in 2003); Xiaowan (292 m tall, 4200 MW installed capacity, completed in 2010); and Nuozhadu (260 m tall, 5850 MW installed capacity, completed in 2014). These dams represent nearly 30% of the Upper Mekong's estimated hydropower potential, and have thus far displaced approximately 50,000 people (He et al., 2007). Under a policy known as "Send Western Electricity East," most of Yunnan's hydroelectricity is transported more than 1500 km away to coastal cities in Guangdong Province, where electricity demand in the manufacturing and commercial sectors is high (Magee 2006). Our study does not include all dams, current and planned, on the Upper Mekong, but focuses on the four dams that were completed and operational as of 2010. The Jinghong Dam, in southern Yunnan Province, was completed as data collection commenced for this study. In addition, the northernmost segment of the Upper Mekong, in Yunnan and the Tibet Autonomous Region, is targeted for an "upper cascade" of dams, ranging in number from five to eleven. A series of dams is also under construction on the middle and lower reaches of the Mekong, including the Xayaburi Dam in the Don Sahong Dam, both in Laos (Grumbine et al., 2012).

1.2. Population displacement, social capital, and social–ecological resilience

Understanding the social and economic impacts of dam-induced displacement has become a major focus of research and advocacy for academic institutions, government agencies, international financial institutions, and NGOs around the world (Cernea, 2000; Scudder, 2005; Richter et al., 2010). In China specifically, a series of recent studies has shown that population resettlement is associated with a wide range of negative impacts on communities, including reduced land holdings (Chen, 2008); reduced access to natural resources and ecological services (Kittinger et al., 2009; Wilmsen et al., 2011); declining household incomes (Tilt et al., 2009); widening inter-household and inter-community economic disparities (Wang et al., 2013); and diminished mental health and well-being (Xi and Huang, 2011). Many of these effects fall disproportionately on vulnerable social groups, including ethnic minorities and low-income communities, who lack the power to participate in political decision-making (Tilt, 2012).

At present, however, researchers know comparatively little about how resettlement projects affect social capital, the networks of interdependence that community members maintain with one another through relationships of trust and reciprocity (Field, 2003). Social scientists have long recognized that these networks provide a means to distribute resources, disseminate information, and provide economic support in good times and bad (Van Deth, 2003). But despite widespread agreement about the importance of social capital for economic development and community resilience, particularly in less-developed countries (Lin, 2002; Grootaert and van Bastelaer, 2002), there is little consensus about how to precisely define and measure the concept (Adger, 2003),

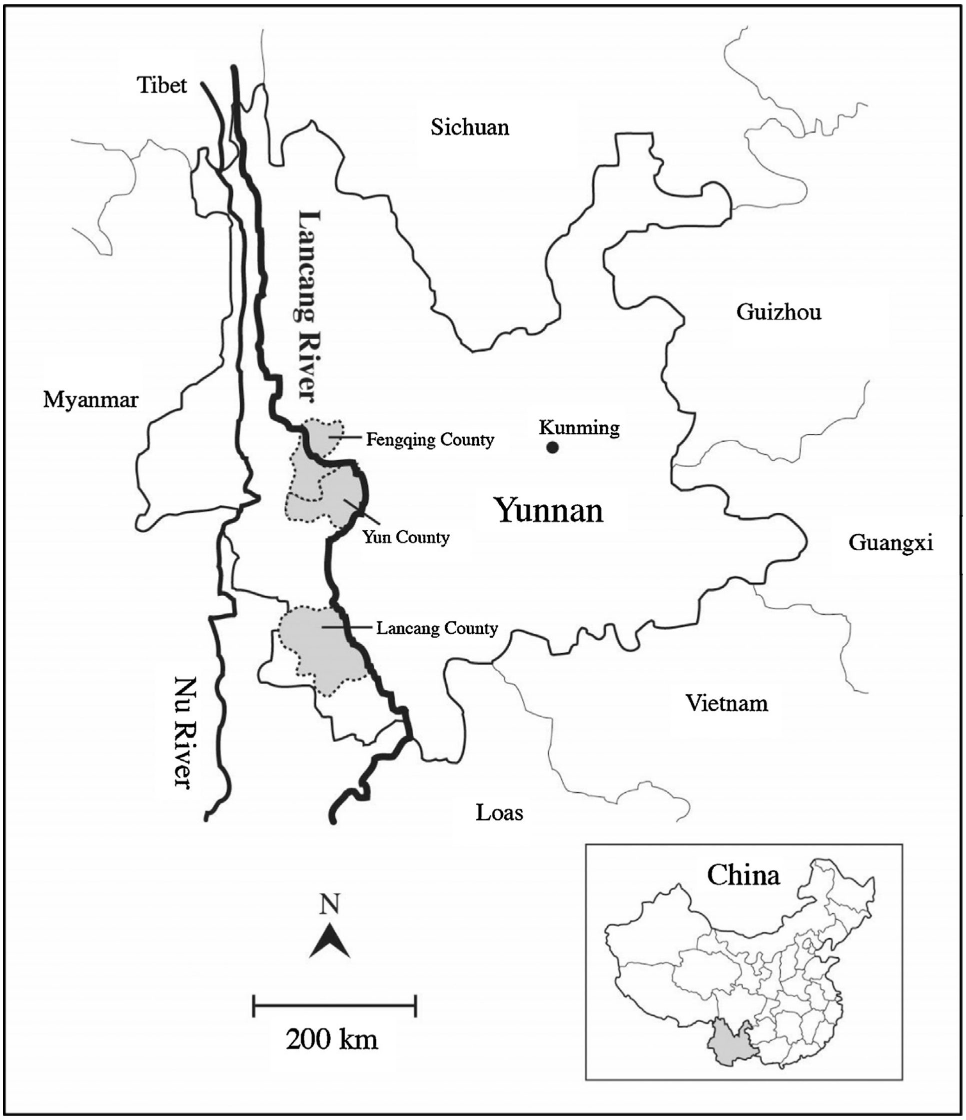

Fig. 1. Map of Yunnan Province showing the Upper Mekong River study sites.

and researchers must often use proxies or indicators that are valid within the local cultural and economic context.

We focus our analysis on two indicators of social capital that provide crucial support for China's agrarian households: inter-household exchange of financial resources (loans), and inter-household exchange of agricultural labor. These can be thought of as instrumental networks, "embedded resources" (Zhao, 2002) that people can call upon in order to adapt to external stressors or to gain mutual economic advantage. Social capital is a salient feature of life throughout China, where interpersonal ties colloquially known as *guanxi* are an important means of securing a job, navigating the political system (Wellman et al., 2002), and coping with uncertain property rights and changes in agricultural policy (Rozelle et al., 2005). This is particularly true in Yunnan, where land plots are small and farmers produce rice as a staple crop for their own consumption and for market sale, plus a variety of commodity crops such as walnuts, tea, tobacco, sugar cane, mangos, melons, chestnuts and rubber (Tilt, 2015). Inter-household borrowing and lending are important means of support because many rural families operate just above the subsistence level and lack access to formal financial institutions such as banks, which makes it difficult to invest in improvements on their land, such as terracing or irrigation. Inter-household exchange of labor is also crucial because the region's rugged topography and terraced farming methods make mechanization impractical; as a result, almost all farm production relies on heavy human and animal labor inputs for cultivation, irrigation, harvesting, and land maintenance (Tilt, 2008; Day, 2013).

In agricultural or resource-dependent communities, social capital supports resilience (Ostrom and Ahn, 2003). Grounded in the ecological sciences, the concept of resilience refers to the ability of a system to adapt to change or perturbation and remain functioning within certain parameters (Holling, 1973; Holling and Gunderson, 2002). A growing body of research on "social–ecological resilience" has shown that social and ecological systems are intricately linked (Berkes et al., 2003), and that "patterns of abrupt change" in one can force unforeseen changes in the other (Gunderson, 2003). Much of this work remains conceptual and theoretical, consisting of a set of propositions and research questions rather than direct empirical observations (Walker et al., 2006). By contrast, our study contributes original data and analysis, allowing us to directly examine the relationship between population displacement and social capital, something that has not been undertaken to date in research on the human impacts of hydropower development. Specifically, we explore the effects of dam-induced resettlement on financial and labor exchanges that are key sources of resilience for agricultural households in rural China.

2. Materials and methods

Understanding the effects of dam-induced resettlement poses some unique methodological challenges. An ideal approach would be to collect longitudinal data from communities before and after resettlement, documenting how social and economic conditions vary from a known baseline. But the effects of resettlement typically unfold over a long time horizon, often many decades, making this approach impractical. Very few longitudinal studies of displacement have been undertaken. Two notable exceptions in China involve projects conducted in the Three Gorges area using a pre- and post-survey approach to analyze changes in economic assets (Wilmsen et al., 2011) and mental health outcomes (Xi and Huang, 2011). A common alternative is to conduct a retrospective study asking a cohort of displaced people to compare socioeconomic conditions pre- and post-resettlement (Webber and McDonald, 2004), but this introduces obvious recall bias. We used a cross-sectional study approach that compared resettled communities at the four dam sites with nearby communities that had similar demographic and economic characteristics but had not undergone resettlement. This approach does not allow us to directly measure diachronic change in socioeconomic conditions and social capital for any given household, but it does allow for a systematic examination of differences between households based on resettlement status. Given the practical constraints of research on resettlement, our study stands out for its systematic approach and fairly robust survey sample.

2.1. Household survey and sample

In 2010, in collaboration with Chinese researchers at Yunnan Normal University in Kunming, we administered a household survey questionnaire to 729 households in more than 30 villages across Fengqing, Yun, and Lancang counties in Yunnan Province, using township and village household registration records to obtain a random sample. All survey enumerators participated in a one-week training workshop on survey sampling and administration, and the survey instrument itself underwent rigorous pretesting. The research team performed regular quality-control checks to ensure data were recorded correctly.

Because of our specific interest in agriculture, we analyzed a restricted sample that includes only those households who reported participating in farming activities during the previous 12 months, removing 56 households. We also removed an additional 201 households who had not participated in at least some labor exchange during the previous 12 months, in order to ensure that agricultural labor exchange was a relevant indicator of social capital for all households in the dataset. Our final sample thus consisted of 472 households at four dam sites (Manwan = 143, Dachaoshan = 106, Xiaowan = 150, Nuozhadu = 73), including both resettled and non-resettled households. Basic demographic and economic information about the study sample is shown in Table 1. Because of the cultural diversity of the study area, survey participants represented ten ethnic groups, including Han (the Chinese majority group) and ethnic minority groups such as Yi, Lahu, and Bulang. All resettled households in the sample had received reallocation of farmland. The questionnaire included modules on household demographics, education, health, agricultural and non-agricultural economic activities, and social capital. The dataset used in our analysis is publicly accessible via Scholar's Archive (https://ir.library.oregonstate.edu/xmlui/handle/1957/56277) and is licensed and referenced via Creative Commons.

2.2. Dependent variables

Each indicator of social capital was used as a dependent variable in the models and was measured in two ways: the number of exchange partners, and the amount of money or labor exchanged, as follows.

- Indicator 1: Exchange of Financial Resources. In the 12 months prior to the survey, money lent (number of households and total amount); money borrowed (number of households and total amount).
- Indicator 2: Exchange of Agricultural Labor. In the 12 months prior to the survey, labor provided (number of households and total person-days provided); labor received (number of households and total person-days received).

From a social capital perspective, the number of exchange partners gives us an estimation of the breadth of a household's social network, while the total amount of exchange gives us an estimation of the depth of resources that flow through this network.

2.3. Independent variable

- Resettlement Status: Dichotomous variable indicating whether the household was resettled (=1) or not (=0) due to the dam project. Households that were scheduled to be resettled but had not done so by the time of survey administration were coded = 0.

2.4. Control variables

- Ethnic Group: Dichotomous variable indicating whether the household head belongs to the majority Han ethnic group (=1) or a minority ethnic group (=0).
- Land Allotment: Three variables, representing the amount of land allotted to a household for (a) paddy rice agriculture, (b) dry land agriculture, (c) forest production, measured in Chinese *mu* (1 *mu* is equal to 0.066 ha or 0.165 acres).

Table 1
Basic characteristics of the Upper Mekong River study sample.

Dam site	Household count (sample%)	County and year completed	Han ethnicity (%)	Median income (100s of Yuan)[a]	Mean paddy land holdings (Mu)[b]	Mean dry land holdings (Mu)	Mean forest land holdings (Mu)	Households displaced (% of sample)
Manwan	143 (29.7%)	Yun, 1996	64	163	1.2	11.2	7	36
Dachaoshan	106 (19.5%)	Yun, 2003	94	289	1.5	11.8	9	50
Xiaowan	150 (27.3%)	Fengqing, 2010	82	273	1.1	4.6	8.2	33
Nuozhadu	73 (23.5%)	Lancang, 2014	12	154	1.6	17.9	21.4	22
Total sample	472		69	228	1.3	10.3	10	36

[a] 1 yuan = approximately 0.16 USD.
[b] 1 mu = 0.066 ha or 0.165 acres.

- Income: Total household income, calculated as the sum of net agricultural sales, wage income, and self-employment income. Income is reported in hundreds of yuan.

3. Results

Based on household survey data collected from resettled and non-resettled households at the four dam sites in this study, for each indicator (DV) we estimated a series of OLS regression models that allow us to examine the association between resettlement and social capital across the four dam projects (with socioeconomic variables such as ethnicity, land holdings and income as controls). We also estimated OLS regression models with interactions between resettlement status and dam site. These interaction models allow us to investigate the unique association between resettlement and social capital for each dam project. Regression model results are shown in Tables 2 and 3.

3.1. Association between resettlement and social capital for all dam sites

Compared with labor exchanges, loans were relatively infrequent in our sample, with 12.3% of households giving and 15.3% receiving a loan in the previous year. On average, households in the study reported lending money to 0.2 households and borrowing money from 0.27 households during the previous year. The average amount loaned was 1249 Yuan, and the average amount borrowed was 1051 Yuan. There are no statistically significant differences in the number of households lent to (Table 2, Model 1, $b = -0.109$) or borrowed from (Table 2, Model 2, $b = -0.054$) based on resettlement status. However, in terms of the total amount of inter-household exchange, resettlement is associated with increased borrowing (Table 2, Model 4, $b = 1254$, $p < 0.05$), and this effect remains when controlling for differences between Han and other ethnic groups; differences in paddy, dry, and forest land allocation; and differences in household income.

On average, households reported giving 10.4 person-days of farm labor to 2.5 households and receiving 11.3 person-days of farm labor from 2.7 households during the previous year. As Table 3 shows, resettlement is associated with significant differences in labor exchange. Specifically, our models predict that resettled households give labor to about one fewer household (Table 3, Model 1, $b = -1.133$, $p < 0.01$) and give nearly four fewer person-days of labor (Table 3, Model 3, $b = -3.610$, $p < 0.001$). Moreover, our models predict that resettled households receive labor from about one fewer household (Table 3, Model 2, $b = -0.857$, $p < 0.05$) and receive about two fewer person-days of labor (Table 3, Model 4, $b = -2.268$, $p < 0.05$). These associations remain significant when controlling for differences between Han and other ethnic groups; differences in paddy, dry, and forest land allocation; and differences in household income.

Table 2
Regression model results for inter-household exchange of financial resources.

Loan	Number of households		Amount (Yuan)	
Variable	Given Model 1	Received Model 2	Given Model 3	Received Model 4
Settlement status (1 = resettled)	−0.109 (0.072)	−0.054 (0.102)	−132.818 (647.003)	1254.416** (547.160)
Ethnic group (Han = 1)	−0.001 (0.069)	−0.185* (0.098)	−878.788 (619.583)	29.015 (523.971)
Paddy land (Mu)	0.014 (0.023)	0.011 (0.033)	648.558*** (211.847)	589.551*** (179.155)
Dry land (Mu)	−0.002 (0.002)	−0.005* (0.003)	31.544** (15.952)	2.875 (13.491)
Forest land (Mu)	0.002 (0.003)	−0.005 (0.004)	131.754**** (22.812)	4.420 (19.292)
Income (in 100s of Yuan)	0.000** (0.000)	−0.000** (0.000)	−0.739 (0.720)	−1.254** (0.609)
Manwan	Omitted	Omitted	Omitted	Omitted
Dachaoshan	−0.054 (0.075)	−0.163 (0.106)	−135.138 (673.100)	−522.600 (569.230)
Xiaowan	−0.118* (0.068)	−0.070 (0.096)	311.895 (610.117)	2265.318**** (515.966)
Nuozhadu	0.458**** (0.095)	−0.200 (0.135)	4450.571**** (854.675)	−360.023 (722.785)
Constant	0.146** (0.074)	0.665**** (0.106)	−1119.525* (669.125)	−427.046 (565.868)
R^2	0.14	0.05	0.29	0.13
N	468	468	468	468

Values represent unstandardized coefficients with standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

Table 3
Regression model results for inter-household exchange of agricultural labor.

Labor	Number of households		Amount (person days)	
Variable	Given Model 1	Received Model 2	Given Model 3	Received Model 4
Settlement status (1 = resettled)	−1.133*** (0.344)	−0.857** (0.340)	−3.610**** (0.952)	−2.268** (0.936)
Ethnic group (Han = 1)	−1.093**** (0.329)	−1.036*** (0.326)	−0.771 (0.912)	0.075 (0.897)
Paddy land (Mu)	0.287** (0.113)	0.263** (0.111)	1.617**** (0.312)	1.419**** (0.307)
Dry land (Mu)	−0.028**** (0.008)	−0.026*** (0.008)	−0.084**** (0.023)	−0.058** (0.023)
Forest land (Mu)	−0.012 (0.012)	−0.004 (0.012)	0.125**** (0.034)	0.195**** (0.033)
Income (in 100s of Yuan)	0.001 (0.000)	0.001** (0.000)	0.000 (0.001)	0.001 (0.001)
Manwan	Omitted	Omitted	Omitted	Omitted
Dachaoshan	−1.408**** (0.358)	−1.091*** (0.354)	−2.963*** (0.990)	−1.147 (0.974)
Xiaowan	−1.261**** (0.324)	−1.022*** (0.321)	−0.706 (0.898)	0.447 (0.883)
Nuozhadu	−2.089**** (0.454)	−1.722**** (0.449)	−3.224** (1.258)	−1.058 (1.237)
Constant	4.563**** (0.356)	4.205**** (0.352)	10.991**** (0.985)	8.854**** (0.968)
R^2	0.14	0.10	0.15	0.15
N	468	468	468	468

Values represent unstandardized coefficients with standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

3.2. Association between resettlement and social capital across dam sites

We observed significant differences in financial and labor exchange across the four dam sites. Relative to households in Manwan, households in Xiaowan borrowed significantly larger amounts of money (Table 2, Model 4, $b = 2265$, $p < 0.001$) and lent money to fewer households (Table 2, Model 1, $b = -0.118$, $p < 0.10$), although the latter difference is small and only marginally significant. Households in Nuozhadu lent money to more households (Table 2, Model 1, $b = 0.458$, $p < 0.001$) and lent significantly larger amounts of money (Table 2, Model 3, $b = 4{,}451$, $p < 0.001$). Moreover, households in Manwan engaged in more days of labor exchange (Table 3, Models 3 and 4) with more households (Table 3, Models 1 and 2) than households in any of the other dam sites.

Although the regression models presented in Tables 2 and 3 control for these differences in financial and labor exchange across dam sites, the estimated effect of resettlement status on social capital is constant across dam sites. To investigate the unique associations between resettlement status and social capital for each dam site, we added interaction terms to a second series of models. The key results are visualized in Fig. 2, with full results reported in Appendix A (Tables A1–A4).

Results from the interaction models and contrast tests suggest significant differences in the association between resettlement status and indicators of social capital for each dam site. The effects of resettlement appear to be greatest at the Manwan dam site, the earliest dam in the study, completed in 1996. Resettled households in Manwan gave labor to and received labor from fewer households and gave fewer person-days of labor than non-resettled households. Similarly, resettled households gave loans to and received loans from fewer households and received smaller loans than non-resettled households. Similar differences in labor exchange are found at the three other dam sites. Resettled households generally exchanged fewer days of labor with a smaller number of households than non-resettled households. However, these differences are only statistically significant for Dachaoshan (households given) and Xiaowan (amounts given and received).

Associations between resettlement status and financial exchange exhibit more variation across dam sites. Whereas resettled households were involved in smaller loans with fewer households in Manwan, this pattern only partly holds for Dachaoshan (amounts received) and Nuozhadu (households and amounts given). Surprisingly, the opposite association arose in Xiaowan, where resettled households received larger loans from more exchange partners.

4. Discussion

Our study provides credible evidence for an association between population resettlement and diminished social capital in China's hydropower sector. However, the effects of resettlement are not uniform across the four dam sites in the study. The effects of resettlement appear to be greatest in the context of labor exchange, where the depth (amount) and breadth (households) of social capital is lower for resettled households across all dam sites except Nuozhadu (the most recent dam in the study, completed in 2014). The most striking pattern is for Manwan, the earliest dam site in this study (completed in 1996), where resettled households reported significantly fewer labor-exchange partners (approximately two households, compared to four for non-resettled households), even twenty years after being displaced. These persistent differences may be due to endogenous conditions in the community (e.g., crop types or market conditions). But social impact studies conducted by Chinese researchers have revealed systemic problems in resettlement at Manwan: the actual number of displaced villagers was double the prediction of project managers; villagers endured temporary food shortages due to lost farmland; and the cost of building materials rose sharply in the 1990s, making it difficult for villagers to construct replacement housing (Guo, 2008). Two decades of community dissolution following resettlement have undoubtedly hampered recovery at Manwan.

This represents a dramatic reduction in the breadth and robustness of the networks that farmers rely upon for the labor-intensive tasks involved in producing rice and other crops for subsistence and market sale. Households in this study are among the poorest in China (Chinese Statistical Bureau, 2010); even a slight reduction in available labor can mean the loss of a subsistence crop. This risk is compounded by significant policy reforms in China's agrarian economy since the 1980s. Under the Household Responsibility System, farmers sell commodity crops on the market and are required meet their own economic needs as the government provides fewer services such as education and health care. Any unexpected change in socioeconomic conditions can mean the difference between economic viability and insolvency. Monetary compensation, despite recent improvements in Chinese law and policy (Wang et al., 2013; Tilt, 2015), may not be sufficient to offset non-monetary losses, such as social capital, that constitute an important part of agrarian livelihoods.

In terms of inter-household financial exchange, resettled households in the study borrowed larger amounts of money, a trend that appears to be driven largely by study participants at the Xiaowan dam site (completed in 2010). The effect size may appear

Fig. 2. Predicted financial and labor exchange by resettlement status for each dam project. Margins and 95% confidence intervals based on interaction models in Tables A1 and A3, with p-values from corresponding contrasts in Tables A2 and A4 (see Appendix A).

small (several thousand yuan), but in this context it represents more than 10% of an average household's annual income. Increased borrowing, on the one hand, may be viewed as evidence of intact social networks, since households have retained sufficient social ties to obtain the capital needed to invest in their agricultural land plots. However, related research in this region shows that borrowing may be part of a pattern of indebtedness as resettled households attempt to offset lost income or to invest in making improvements in irrigation or other infrastructure on their newly acquired agricultural land (Galipeau et al., 2013). The long-term consequences of increased debt for resettled households are difficult to predict. Unexpectedly, households at the Nuozhadu dam site, particularly those in the non-resettled category, reported lending significant sums to other households. In some cases, it appears that households scheduled to be resettled in the near future, but not yet resettled at the time our survey was administered, had already received government compensation payments and were lending a portion of this money to their networks.

Interpreting the temporal trends observed in our data requires a basic understanding of changes in compensation policy in China's hydropower sector in recent years, the most significant of which is an ordinance called *Regulations on Land-Acquisition Compensation and Resettlement of Migrants for Construction of Large- and Medium-Scale Water Conservancy and Hydropower Projects*, which was passed in 1991 and revised by China's State Council in 2006. The 2006 revision greatly increased compensation levels to 16 times a household's average annual income and also increased compensation for lost homes and other structures. The ordinance also emphasized that resettled people have a right to know in advance about development plans affecting them and to participate in public hearings, which may give affected people more time to prepare for the effects of resettlement (Tilt, 2015). Recognizing the inadequacy of resettlement planning and compensation for earlier dam projects, China's central government has retroactively increased compensation levels for villagers at Manwan and other sites (Wang et al., 2013).

Viewing these results in light of social–ecological resilience theory, our analysis suggests that resettlement's effects on social capital can be lasting and significant. Rapid socioeconomic change in our study communities, driven by involuntary displacement, may be outpacing the communities' capacity to adapt, which may be indicative of a regime shift (Walker et al., 2006) from one socioeconomic state to another. A reduction in labor-exchange partners constrains the resources that individuals and households draw upon to manage risk and vulnerability and adapt to changes and stressors. This in turn diminishes community resilience because social capital is a key factor that helps agricultural or resource-dependent communities adapt to change (Ostrom and Ahn, 2003). Related research on China's agricultural economy suggests that rural households are increasingly pursuing off-farm labor opportunities in order to support their families with remittances, and even leaving the agricultural sector altogether in many cases (Webber and McDonald, 2004; Wilmsen et al., 2011; Galipeau et al., 2013; Tilt, 2015). This has important implications for the nation's food supply and for the viability of various government-sponsored rural development programs, including the New Socialist Countryside Program, which aims to better support poor, agrarian regions and households. As recent research has demonstrated, social capital plays a crucial role in promoting economic vitality, poverty reduction, and overall human development (Lin, 2002; Grootaert and van Bastelaer, 2002).

A key critique of the literature on social capital is that it implies directional causality, that a loss of social capital *causes* some adverse outcome (Adger, 2003). Our results should be carefully interpreted using the language of association, rather than causation, not only because of the cross-sectional nature of the study design, but also because issues of causality in a resilience framework are not well understood currently (Ostrom and Cox, 2010). This underscores the need for more rigorous social assessment procedures for large-scale development projects, such as hydropower dams, involving population resettlement. Longitudinal studies that include baseline data and strong controls would give scientists and policymakers a much better understanding of causality. We argue that locally valid indicators of social capital should be part of this analysis, because such relationships constitute a crucial means of economic support, particularly for agricultural or natural resource-dependent communities. Our study provides a model for how to develop such indicators and how to test their association with population resettlement. Ideally, a similar approach could be used prior to population resettlement, allowing scientists and policy makers to conduct vulnerability assessments (Adger, 2006) in order to understand a population's susceptibility to harm and capacity to adapt to the environmental and socioeconomic changes induced by resettlement.

5. Conclusion

Based on household surveys conducted in rural Yunnan, China at four large hydropower dams constructed over the past twenty years, we developed two indicators of social capital—inter-household exchange of financial resources, and inter-household exchange of farm labor—and tested their association with dam-induced displacement. Our results indicate that resettlement is associated with diminished social capital. In many cases, households resettled twenty years ago show poorer outcomes than those resettled for more recent projects, and this trend is likely due in part to improvements in China's resettlement and compensation policy framework over the years. The long-term consequences for these communities, which are among the most economically disadvantaged in China, may include reduced access to capital, increased debt, and less robust labor-sharing networks, all of which are indicative of diminished resilience.

Hydropower development will likely continue to contribute to China's energy security and its plans to scale back carbon emissions in the coming years. However, formulating policy that accounts for the full range of costs and benefits associated with dams will require a thorough understanding of the social impacts related to dam-induced resettlement. Our study has implications far beyond China. At the global scale, resettlement policies and practices in the hydropower sector are gradually beginning to address social impacts, social–ecological resilience, and sustainability. The World Bank, for example, has developed a framework for ensuring that displaced populations receive compensation and understand the risks involved in resettlement (Cernea, 2000). Similar research and policy formulation on China's hydropower sector will be crucial in the years to come. After a brief downturn in the 1990s due to declining support from the World Bank, global investment in hydropower is once again on the rise (Richter et al., 2010). Now, however, rather than international financial institutions it is Chinese banks, government agencies and shareholder corporations leading the industry. Chinese firms are currently involved in the planning and construction of more than 300 dam projects in 70 countries, from Southeast Asia to sub-Saharan Africa (International Rivers, 2012). As a result, Chinese standards for environmental and social review are becoming the world's standards. Hydropower development continues to gain momentum as an important source of renewable energy, and more comprehensive social impact analyses are needed in order to ensure that dam siting, design and operation are conducted in ways that minimize social harm. Our approach can thus contribute to scientific and industry attempts to improve the social, economic and environmental sustainability of hydropower production.

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Table A1
Interaction model results for inter-household exchange of financial resources.

Loan	Number of households		Amount (Yuan)	
Variable	Given Model 1	Received Model 2	Given Model 3	Received Model 4
Settlement status (1 = resettled)	−0.206* (0.108)	−0.482*** (0.156)	887.039 (993.332)	−1706.813** (801.063)
Ethnic group (Han = 1)	0.099 (0.070)	−0.059 (0.101)	−589.443 (642.242)	932.463* (517.929)
Paddy land (Mu)	−0.043 (0.027)	0.000 (0.038)	218.362 (244.358)	790.414**** (197.060)
Dry land (Mu)	−0.003 (0.002)	−0.007*** (0.003)	33.242** (16.160)	−19.842 (13.032)
Forest land (Mu)	0.000 (0.003)	−0.004 (0.004)	115.046**** (23.052)	17.095 (18.590)
Income (in 100s of Yuan)	0.000*** (0.000)	−0.000* (0.000)	−0.372 (0.721)	−0.909 (0.581)
Manwan	Omitted	Omitted	Omitted	Omitted
Dachaoshan	−0.167* (0.098)	−0.370*** (0.142)	−208.831 (899.199)	−348.921 (725.150)
Xiaowan	−0.308**** (0.086)	−0.406*** (0.124)	176.131 (785.449)	−461.577 (633.418)
Nuozhadu	0.679**** (0.111)	−0.263 (0.161)	6552.159**** (1,020.413)	−1220.403 (822.902)
Settlement status × Manwan	Omitted	Omitted	Omitted	Omitted
Settlement status × Dachaoshan	0.229 (0.145)	0.452** (0.209)	11.854 (1330.633)	−363.480 (1073.076)
Settlement status × Xiaowan	0.470**** (0.139)	0.847**** (0.201)	263.764 (1855.225)	3325.527** (1496.128)
Settlement status × Nuozhadu	−0.647*** (0.202)	0.292 (0.292)	−6609.092**** (1855.225)	3325.527** (1496.128)
Constant	0.190** (0.075)	0.761**** (0.108)	−1166.707* (687.945)	−64.221 (554.787)
R^2	0.20	0.09	0.32	0.23
N	468	468	468	468

Values represent unstandardized coefficients with standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

Table A2
Contrasts of marginal linear predictions for financial exchange from interaction models in Table A1.

Loan	Number of households		Amount (Yuan)	
Variable	Given F (p)	Received F (p)	Given F (p)	Received F (p)
Manwan	3.63 (0.06)*	9.51 (0.00)***	0.80 (0.37)	4.54 (0.03)**
Dachaoshan	0.03 (0.86)	0.03 (0.87)	0.58 (0.45)	4.75 (0.03)**
Xiaowan	6.41 (0.01)**	5.88 (0.02)**	1.45 (0.23)	45.01 (0.00)****
Nuozhadu	24.32 (0.00)****	0.58 (0.45)	12.97 (0.0004)****	1.60 (0.21)
Joint	8.71 (0.00)****	4.58 (0.00)***	3.72 (0.0054)***	16.91 (0.00)****

* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

Table A3
Interaction model results for inter-household exchange of agricultural labor.

Labor	Number of households		Amount (days)	
Variable	Given Model 1	Received Model 2	Given Model 3	Received Model 4
Settlement status (1 = resettled)	−2.228**** (0.532)	−2.185**** (0.524)	−3.371** (1.482)	−2.247 (1.457)
Ethnic group (Han = 1)	−0.934*** (0.344)	−0.838** (0.339)	−0.920 (0.958)	−0.091 (0.942)
Paddy land (Mu)	0.362*** (0.131)	0.359*** (0.129)	1.530**** (0.365)	1.379**** (0.358)
Dry land (Mu)	−0.032**** (0.009)	−0.031**** (0.009)	−0.078*** (0.024)	−0.052** (0.024)
Forest land (Mu)	−0.006 (0.012)	0.004 (0.012)	0.124**** (0.034)	0.195**** (0.034)
Income (in 100s of Yuan)	0.000 (0.000)	0.001* (0.000)	−0.000 (0.001)	0.001 (0.001)
Manwan	Omitted	Omitted	Omitted	Omitted
Dachaoshan	−1.911**** (0.482)	−1.661**** (0.474)	−3.616*** (1.342)	−1.880 (1.319)
Nuozhadu	−2.752**** (0.547)	−2.523**** (0.538)	−3.178** (1.523)	−1.297 (1.497)
Xiaowan	−1.829**** (0.421)	−1.731**** (0.414)	−0.208 (1.172)	0.915 (1.152)
Settlement status × Manwan	Omitted	Omitted	Omitted	Omitted
Settlement status × Dachaoshan	1.141 (0.713)	1.294* (0.701)	1.437 (1.986)	1.631 (1.952)
Settlement status × Nuozhadu	2.270** (0.994)	2.742*** (0.978)	−0.201 (2.768)	0.712 (2.721)
Settlement status × Xiaowan	1.456** (0.683)	1.815*** (0.672)	−1.245 (1.902)	−1.157 (1.869)
Constant	4.785**** (0.369)	4.468**** (0.363)	11.076**** (1.027)	8.974**** (1.009)

Table A3 (*Continued*)

Labor	Number of households		Amount (days)	
Variable	Given Model 1	Received Model 2	Given Model 3	Received Model 4
R^2	0.15	0.13	0.15	0.15
N	468	468	468	468

Values represent unstandardized coefficients with standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

Table A4
Contrasts of marginal linear predictions for labor exchange from interaction models in Table A3.

Labor	Number of households		Amount (person-days)	
Variable	Given *F* (*p*)	Received *F* (*p*)	Given *F* (*p*)	Received *F* (*p*)
Manwan	17.54 (0.00)****	17.42 (0.00)****	5.17 (0.02)**	2.38 (0.12)
Dachaoshan	2.97 (0.09)*	2.06 (0.15)	1.21 (0.27)	0.13 (0.72)
Xiaowan	2.27 (0.13)	0.54 (0.46)	10.47 (0.00)***	5.90 (0.02)**
Nuozhadu	0.00 (0.96)	0.44 (0.51)	2.27 (0.13)	0.43 (0.51)
Joint	4.65 (0.00)***	4.52 (0.00)***	4.05 (0.00)***	2.02 (0.09)*

Note: significance levels (*p*-values) reported in Fig. 2 and Tables A1–A4 have not been adjusted for multiple comparisons, which increases the risk of Type I error. We have chosen not to use a Bonferroni correction or related adjustment because this increases the risk of Type II error. Consistent with the precautionary principle, as applied to the potential negative impacts of dam displacement on the well-being of a vulnerable population, we have chosen to err on the side of the caution and minimize Type II error.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.
**** $p < 0.001$.

Appendix A.

See Tables A1–A4 .

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.gloenvcha.2015.11.008.

References

Adger, N.W., 2003. Social and ecological resilience: are they related? Prog. Hum. Geogr. 24, 347–369.
Adger, N.W., 2006. Vulnerability. Glob. Environ. Change 16 (3), 268–281.
Berkes, F., Colding, J., Folke, C., 2003. Navigating Social–ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge.
Cernea, M., 2000. Risks, safeguards, and reconstruction: a model for population displacement and resettlement. In: Cernea, M., McDowell, C. (Eds.), Risks and Reconstruction: Experience of Resettlers and Refugees. World Bank, Washington, D.C, pp. 11–55.
Chen, L.H., 2008. Contradictions in dam building in Yunnan, China: cultural impacts versus economic growth. China Rep. 44 (2), 97–110.
Chinese State Council, 2013. Notice on Energy Production in the Twelfth Five-year Plan. State Council, Bejing.
Chinese Statistical Bureau, 2010. China Statistical Yearbook. Chinese Statistical Bureau, Beijing.
Day, A., 2013. A century of rural self-governance reforms: reimagining rural Chinese society in the post-taxation era. J. Peasant Stud. 40 (6), 929–954.
Economy, E.C., 2007. The great leap backward? The costs of China's environmental crisis. Foreign Aff. 86 (5), 38–59.
Field, J., 2003. Social Capital. Routledge, New York.
Galipeau, B.A., Ingman, M., Tilt, B., 2013. Dam-induced displacement and agricultural livelihoods in China's Mekong Basin. Hum. Ecol. 41 (3), 437–446.
Grootaert, C., van Bastelaer, T., 2002. The Role of Social Capital in Development: An Empirical Assessment. Cambridge University Press, Cambridge.
Grumbine, E.R., Dore, J., Xu, J.C., 2012. Mekong hydropower: drivers of change and governance challenges. Front. Ecol. Environ. 10 (12), 91–98.
Gunderson, L.H., 2003. Adaptive dancing: interactions between social resilience and ecological crises. In: Berkes, F., Colding, J., Folke, C. (Eds.), Navigating Social–ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge, pp. 33–52.
Guo, J.J., 2008. Fazhande fansi: Lancangjiang Liuyu shaoshu minzu bianqian de renleixue yanjiu (Rethinking Development: Anthropological Studies on the Development of Ethnic Groups in the Lancang-Mekong River Basin). Yunnan People's Press, Kunming.
He, D.M., Hu, J.M., Feng, Y., 2007. Zhongguo xinan guoji heliu shui ziyuan liyong yu shengtai baohu (Utilization of Water Resources and Environmental Conservation in the International Rivers of Southwest China). Science Press, Beijing.
Holling, C.S., 1973. Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4, 1–23.
Holling, C.S., Gunderson, L.H., 2002. Resilience and adaptive cycles. In: Gunderson, L. H., Holling, C.S. (Eds.), Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, D.C, pp. 25–62.
International Rivers, 2012. The new great walls: a guide to China's overseas dam industry, 2nd ed. International Rivers, Berkeley, CA.
Kittinger, J.N., Coontz, K.M., Yuan, Z.P., Han, D.J., Zhao, X.F., Wilcox, B.A., 2009. Toward holistic evaluation and assessment: linking ecosystems and human well-being for the Three Gorges Dam. EcoHealth 6, 601–613.
Lin, N., 2002. Social Capital: A Theory of Social Structure and Action. Cambridge University Press, Cambridge.
Liu, Z., 2012. Electric Power and Energy in China. China Electric Power Press, Beijing.
Magee, D., 2006. Powershed politics: hydropower and interprovincial relations under great western development. China Q. 185, 23–41.
Magee, D., McDonald, K., 2009. Beyond Three Gorges: Nu River hydropower and energy decision politics in China. Asian Geogr. 25 (1–2), 39–60.
Foundations of Social Capital. In: Ostrom, E., Ahn, T.K. (Eds.), Edward Elgar, Cheltenham, UK.
Ostrom, E., Cox, M., 2010. Moving beyond panaceas: a multi-tiered diagnostic approach for social–ecological analysis. Environ. Conserv. 37 (4), 451–463.
Richter, B.D., Postel, S., Revenga, C., Scudder, T., Lehner, B., Churchill, A., 2010. Lost in development's shadow: the downstream human consequences of dams. Water Altern. 3 (2), 14–42.
Rozelle, S., Brandt, L., Guo, L., Huang, J.K., 2005. Land tenure in China: facts, fictions, and issues. In: Ho, P. (Ed.), Developmental Dilemmas: Land Reform and Institutional Change in China. Routledge, New York, pp. 121–150.
Scudder, T., 2005. The Future of Large Dams: Dealing with Social, Environmental, Institutional and Political Costs. Earthscan, London.
Tilt, B., 2008. Smallholders and the household responsibility system: adapting to institutional change in Chinese agriculture. Hum. Ecol. 36 (2), 189–199.
Tilt, B., 2012. Damming China's angry river: vulnerability in a culturally and biologically diverse watershed. In: Johnston, B.R., Hiwasaki, I.J., Laver, A., Ramos Castillo, A., Strang, V. (Eds.), Water, Cultural Diversity, and Global Environmental Change: Emerging Trends, Sustainable Futures? UNESCO International Hydrological Program, New York, pp. 367–386.
Tilt, B., 2015. Dams and Development in China: The Moral Economy of Water and Power. Columbia University Press, New York.
Tilt, B., Braun, Y.A., He, D.M., 2009. Social impact assessment for large dam projects: a comparison of international projects and implications for best practice. J. Environ. Manag. 90 (S3), 249–257.
United Nations Development Program, 2008. Human Development Report: China. UNDP, Beijing.
Van Deth, J.W., 2003. Measuring social capital: orthodoxies and continuing controversies. Int. J. Soc. Res. Methodol. 6 (1), 79–92.
Walker, B., Gunderson, L.H., Kinzig, A., Folke, C., Carpenter, S., Schultz, L., 2006. A handful of heuristics and some propositions for understanding resilience in social–ecological systems. Ecol. Soc. 11 (1), 13–27.
Wang, P., Wolf, S.A., Lassoie, J.P., Dong, S.K., 2013. Compensation policy for displacement caused by dam construction in China: an institutional analysis. Geoforum 48, 1–9.
Webber, M., McDonald, B., 2004. Involuntary resettlement, production and income: evidence from Xiaolangdi, PRC. World Dev. 32 (4), 673–690.

Wellman, B., Chen, W.H., Dong, W.Z., 2002. Networking guanxi. In: Gold, T., Guthrie, D., Wank, D. (Eds.), Social Connections in China: Institutions, Culture, and the Changing Nature of Guanxi. Cambridge University Press, Cambridge, pp. 221–242.

White House, 2014. US–China Joint Statement on Climate Change. November 12. Full Text: http://www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change.

Wilmsen, B., Webber, M., Duan, Y.F., 2011. Involuntary rural resettlement: resources, strategies, and outcomes at the Three Gorges Dam, China. J. Environ. Dev. 20 (4), 355–380.

World Commission on Dams, 2000. Dams and Development: A New Framework for Decision-making. Earthscan, London.

Xi, J., Huang, S., 2011. Relocation stress, coping, and sense of control among resettlers resulting from China's Three Gorges Dam Project. Soc. Indic. Res. 104, 507–522.

Yao, R.F., 2004. Ministry of Water Resources: China's Dam-induced Migrants Total at Least 15 Million. Xinhua News, Beijing.

Zhao, Y.D., 2002. Measuring the social capital of laid-off Chinese workers. Curr. Sociol. 50, 555–571.