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Hydropower, Social Capital, Community Impacts, and Self-Rated Health in the Amazon*

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Abstract Nations in the global South have developed hydropower projects at a rapid pace in recent decades, most notably Brazil and China. These projects have long-documented impacts on social and ecological systems, yet the implications of hydropower for human well-being and health are not fully understood. In this paper, we examine eight Brazilian Amazon communities in the Madeira river basin, near the Jirau and Santo Antônio dams (sample size: 536 households). We evaluate how impacts on community resources, social capital, and the experience of resettlement influence self-rated health in these communities. Results suggest that the dams strained community resources and social capital, which were associated with reductions in self-rated health. In particular, cognitive social capital (i.e., trust) is lower after the dams' construction. The effect of resettlement and compensation is more nuanced and qualified. This work suggests that hydropower projects have broad deleterious impacts on well-being and health of human populations in hosting regions and that better directed efforts are required on the part of dam developers to reduce these negative outcomes.

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Introduction

Nations in the global South have increasingly turned to hydropower to power their economies and to guarantee energy demands, even as hydropower facilities have been dismantled in developed nations due to their socio-ecological impacts (O'Connor, Duda, and Grant 2015; Siciliano et al. 2018; Winemiller et al. 2016). In 2015, an estimated 3,700 large hydropower dams were in the planning stages or actively under construction, almost exclusively in the global South (Zarfl et al. 2015). Nations typically build dams in the hope that they will provide a secure, reliable source of power to support economic development. Brazil is at the forefront of dam construction (da Silva Soito, Leonardo, and Freitas 2011; Prado et al. 2016; Westin, dos Santos, and Martins 2014) second only to China in the growth of installed capacity.

In Brazil, installed capacity is over 157 GW, of an estimated potential of 260 GW (EIA 2019; EPE 2018). Brazil is the ninth largest consumer of energy in the world (da Silva, de Marchi Neto, and Seifert 2016) and relies on hydropower perhaps more than any other nation. Hydropower represents 67 percent of domestic energy consumption in Brazil, compared with a global average of 16 percent, with hydropower deployment continually growing (IHA 2018). Hydropower provides Brazil with many benefits, such as reduced reliance on imported fossil fuels and reliable energy services for some parts of the country—the latter has undoubtedly driven Brazil's economic growth because the nation has historically struggled with fuel shortages and intermittency (Atkins 2019). However, as da Silva, de Marchi Neto, and Seifert (2016) show, dependence on hydroelectricity can also compromise energy security, especially in the context of severe droughts, as happened in 2015, and is again happening in 2021. The specter of black-outs is ever present but diversification of energy sourcing has been slow.

Although hydropower is commonly seen as renewable and sustainable compared with other energy sources (coal, nuclear, etc.), hydro generates many negative socio-ecological consequences (Athayde et al. 2019; Kahn, Freitas, and Petrere 2014; Kircherr and Pohlner 2016; Rudd et al. 1993). These include disruption of river ecologies, causing subsequent changes to the livelihoods of communities that are dependent upon these ecosystems (Fearnside 2015; Moran et al. 2018; Stevenson and Buffavand 2018; Wiejaczka et al. 2018). Perhaps the single largest social impact is the displacement of significant numbers of people to make way for dams and associated reservoirs (Cernea 1997; Égré and Senécal 2003; Mayer, Olson Hazboun, and Malin 2020; Randell 2016). Estimates of the size of displacement vary. Scudder and Gay (2001) estimate that between

40 and 80 million people were displaced due to dams in the past century. Indeed, an estimated 12 million people have been resettled in China alone due to dam construction since 1949 (Webber and McDonald 2004). Cernea and Maldonado (2018) report that, between 2001 and 2010, some 15 million people per year were displaced due to infrastructure projects (not just hydropower) and between 2011 and 2020 that figure is believed to be more than 20 million per year. Historically, displaced populations received little to no compensation and some nations, like China, displaced thousands in the past presenting them with the argument that they were serving the national interest (Wang et al. 2013). In the last few decades, most nations now provide some type of compensation program for resettled communities, but these programs fail to fully compensate for all losses experienced by these populations (Cernea 2008; Hanna et al. 2016; Vanclay 2017).

However, resettlement is not the only social impact. In fact, the World Commission of Dams (2000) mentions that some 472 million people living downstream from the dams have been negatively affected by dam construction and never been compensated. Disrupted ecological systems also complicate livelihoods that are tethered to those system—perhaps the most obvious examples are fisherfolk, who find that fish stocks are depleted after damming of rivers (Arantes et al. 2019; Castro-Diaz, Lopez, and Moran 2018; Santos et al. 2020; Ziv et al. 2012).

Further, hydropower projects engender the types of impacts described in the classic "boomtown" and natural resource dependency literature from rural sociology (Bacigalupi and Fruedenberg 1983; Cortese and Jones 1977; England and Albrecht 1984). This literature, often focused on small mining communities in the western portions of the United States and Canada, described how resource booms create rapid population increases due to direct jobs provided by the mining companies and indirect jobs in other sectors (restaurants, hotels, etc.). This population increase in turn strains local infrastructure such as roads and public services and is associated with reductions in social capital (O'Connor 2015). Ultimately, a bust period follows, leaving communities worse off in the long run. Dams in the global South have similar deleterious consequences, as the influx of young, mostly male workers seeking construction employment can often overwhelm host regions (Cernea 2004). These regions are rarely prepared for rapid population growth at this scale and all that it entails in terms of public services. As noted by Gauthier and Moran (2018) for the city of Altamira, the host community of the Belo Monte dam in Brazil, sanitation services were overwhelmed by the amounts of garbage produced by the additional 50,000 people that came because of the dam construction.

Our work complements prior studies suggesting that dams have deleterious consequences on the health of populations in the host region (Camasmie Abe and Miraglia 2018; Del Bene, Scheidel, and Daniela 2018; Gauthier et al. 2019; Hacon et al. 2014; Phung et al. 2021; Veronez and Abe 2018; Yewhalaw et al. 2009a; 2009b). We examine two potential mechanisms related to boomtown effects that might reduce subjective well-being: a loss of social capital and the strain on important community resources. Subjective well-being or self-reported well-being "refers to how people *experience* and *evaluate* their lives and specific domains and activities in their lives" (Stone and Mackie 2013:15). Measures of self-reported well-being often include different aspects of life such as health, life in the community, networks, etc. Among these, many studies use self-rated health as an outcome. The association between self-rated health and social capital is robust across both high-income and low-income nations (Kim and Harris 2013; Sun, Rehnberg, and Meng 2009; Tampubolon, Subramanian and Kawachi 2013; Yip et al. 2007; Younsi and Chakroun 2014).

Although there are indications that large-scale hydropower projects reduce social capital in impacted communities (e.g., Nguyen, Pham, and De Bruyn 2017; Tilt and Gerkey 2016, Mayer et al. forthcoming), the *implications* of this loss of social capital are not well understood. That is, we do not know what the loss of social capital means for the well-being of communities impacted by hydropower infrastructure. Further, it has long been well-established that energy projects, such as hydropower, can put excessive strain on public services and infrastructure (Cernea 2004; Siciliano and Urban 2017). Yet, few studies have asked how this loss of services and stress on infrastructure impact health or individual or community well-being (e.g., health outcomes, subjective well-being, etc.). Scudder (2012) mentions that for individuals who were resettled, it is common to see multidimensional stress (physiological, psychological, and sociocultural) associated with the displacement. In Brazil, studies have covered a wide range of dam-associated health impacts, focusing on outcomes such as malaria (Barcellos et al. 2018), syphilis, homicides and suicides (da Silva Marques et al. 2018; Gristotti 2016); leishmaniasis (Ferreira et al. 2011); stress, hypertension, undernourishment, respiratory problems, and alcoholism (Giongo and Mendes 2015; Rosa et al. 2018). Yet, to our knowledge, this is the first analysis of the association between self-rated health, community resources, and social capital loss in the context of large hydropower dam construction. In this paper, we consider the case of two dams constructed in the Madeira river basin region of the Brazilian Amazon and their impacts in five upstream and three downstream communities in the area.

Background

Energy Boomtowns and Hydropower Impacts

Classic "boomtown" and natural resource dependency research has identified several social disruptions that plagued communities that hosted large energy infrastructure projects. This work, primarily focused on the Western United States and Canada, can be traced to Kohrs (1974) who identified a "Gillette syndrome," named after the town of Gillette, WY. This syndrome was a combination of social ills ranging from prostitution, domestic violence, and a more generalized feeling of loss that was caused when young, male workers flooded the town during a mining boom. Other work from this era qualified and extended the nature of boomtowns (Bacigalupi and Fruedenberg 1983; Cortese and Jones 1977; England and Albrecht 1984), with most research arguing that sudden population increases in rural places due to resource booms engendered a host of social problems, as well as strains on community resources (i.e., sanitation and education systems, and transportation infrastructure). This early work came to be criticized because of its rather simplistic assumptions about the nature of energy workers and questionable methodological choices (Summers and Branch 1984; Wilkinson et al. 1982). After a deluge of papers in the 1980s, interest in the boomtown phenomenon largely faded, with a few notable exceptions from time to time (Brown, Dorins, and Krannich 2005; Brown, Geertsen, and Krannich 1989; Luthra et al. 2007; Smith and Krannich 2001). Importantly, later research described how some communities eventually recover from a resource boom as time progresses (Brown, Dorins, and Krannich 2005). The sudden increase in oil and gas production in places like the U.S. and Canada has also created new interest in the boomtown model, with several studies extending and qualifying the original work (e.g., Jacquet and Kay 2014; Ruddell et al. 2014; Mayer, Olson-Hazboun, and Malin 2018; Mayer et al. 2020).

Although researchers studying hydropower projects may not engage with the boomtown literature directly, there are clear parallels in this literature in terms of the types of impacts that dam researchers describe (Cernea 1997; 2004). Scudder (2012) created a Four Stage Framework to outline how resettlers may respond when a successful and well implemented resettlement plan is implemented, a process that Scudder suggests may well take two generations. The author explains that Stage 1 occurs before the displacement during the planning process, Stage 2 may last around two years, and communities should see first a decline in their living standards, and some of them will face multiple stresses. Stage 3 happens after a successful resettlement process occurs, thus living standards get better because of community development. In this stage, individuals invest in crops, livestock, education, and form community organizations. Lastly, Stage 4 occurs when the community transitions to a second generation. This framework is unique because it takes into consideration a temporal scale to study resettlement caused by dams, however, the framework focuses strictly on people who must be resettled and leaves behind all the other communities that are also impacted but not taken into consideration for resettlement or compensations. Kirchherr, Pohlner and Charles (2016) stress that often dams are studied during the construction phase, yet it is necessary to study them during the operational phase because both dams and their impacts last for a long time. The authors also note that communities such as downstream communities are understudied.

Hydropower projects often have negative consequences for host communities, leaving some of them worse off in the long-run. For instance, in 2016 Brazil completed Belo Monte, the world's third largest dam at the time. Proximate communities experienced impacts such as loss of livelihoods, especially related to fishing and farming (Calvi et al. 2020; Castro-Diaz, Lopez, and Moran 2018). The negative effects on subsistence livelihoods are widely reported in the literature on hydropower (Chandy et al. 2012; Obour et al. 2016; Urban et al. 2015). Host communities often lack the capacity to provide basic sanitation services for the large number of in-migrants. In the case of Belo Monte, Altamira, the host city that received the newcomers, relied heavily upon septic systems for human waste disposal and the growth of these systems in a dense, urban environment led to ground water contamination (Gauthier and Moran 2018). In line with the boomtown literature, Marin and Oliveira (2016) report significant increases in violence due to the construction of the Belo Monte dam.

Dams have been linked to health through a variety of other mechanisms. Reservoirs can create ideal breeding conditions for mosquitos that can in turn spread vector-borne diseases such as malaria (Kibret et al. 2015; 2017; Yewhalaw et al. 2009a; 2009b; 2013), a challenge that will likely be exacerbated by climate change (Kibret et al. 2015). Ong et al. (2016) find evidence for increased fish-borne diseases in dam reservoirs. Hydropower also erodes health by disrupting ecosystem services that provide food and other services that are essential for the food security of many households (Baran and Myschowoda 2009). Crooks, Cligget, and Gillet-Netting (2008) studied children displaced from a dam project in Zambia, reporting that they experienced stunted growth and other markers that pointed to malnutrition. The authors argue that this likely occurred because the displaced population was relocated to a region with less arable land, resulting in food insecurity. Studying Belo Monte, Castro-Diaz et al. (2018) find that women living in a community downstream from the dam are seeing a decrease in the fishing catch, leading to concerns about the food security of their families. For the Amazon's Madeira river, Doria et al. (2021) used the Fishery Performance Indicators (FPIs) to measure before and after the Santo Antônio and Jirau dams were built. The authors find a decline in the ecological health of the fishery, and in the catch and revenue that fisherfolk get from fishing that could also affect what these households eat. Thus, dam projects appear to strain local infrastructure and resources. Following this literature, we evaluate the following hypothesis in this manuscript:

> **Hypothesis 1** Loss or strain of the infrastructure (e.g., education, transportation) and shared resources of communities will be associated with lower self-rated health.

Resettled populations often receive some type of compensation, although they may have little say in what type of compensation they receive and where they will be resettled (Green and Baird 2016; Scudder 2005). Compensation programs rarely cover the full value of what people leave behind, with social and cultural losses being especially difficult to quantify (Cernea 1997; Vanclay 2017). A few studies have considered the subjective well-being (e.g., mental health, life satisfaction, self-rated health) implications of the compensation, displacement, and resettlement process, generally finding that displacement is associated with reductions in various indicators of subjective well-being. By studying the Three Gorges Dam in China, Hwang et al. (2007) report that depressive symptoms were higher in a community that was anticipating resettlement than a community in the same region that was not going to be resettled. A related study found similar impacts on depressive symptoms using multiple waves of data (Xi and Hwang 2011). Displaced Chinese farmers report lower life satisfaction, due largely to disrupted agrarian livelihoods (Tong, Zhu, and Lo 2019). A notable exception is described in Randell (2016), who finds that one compensated population in the Belo Monte dam region reported increased subjective well-being, at least in the short run, in part because their household wealth improved via compensation. Thus, the literature paints a mixed picture. Accordingly, we test the following hypothesis in this manuscript:

> **Hypothesis 2** Displaced and resettled populations will report lower-self rated health than those who were not displaced.

Social Capital

Above we identified two distinct but conceptually related bodies of literature—the boomtown literature and the broad literature on hydropower impacts. Both point to social disruptions caused by rapid population growth in mostly rural communities that host energy projects. In the case of hydropower, these disruptions could be even more severe given that significant population displacement often occurs, likely engendering a loss of social capital.

There is no singular definition of social capital that has been broadly accepted by social scientists, but conceptualizations of social capital emphasize factors like social connections, trust within or across groups, and related considerations (Bourdieu and Wacquant 1992; Putnam 2001). As the theoretical understanding of social capital began to be more precise, scholars differentiated between "cognitive" social capital and "structural" social capital (Ferlander 2007; Forsman et al. 2012; Jones et al. 2014; Yip et al. 2007).

Cognitive social capital typically refers to shared understandings of social norms, reciprocity, and trust within a social group, or perhaps between social groups. Trust has emerged as an especially important variable for a range of desirable outcomes. Trust facilitates the diffusion of knowledge through social groups, sometimes leading to changing social norms, such as the spread of more health-conscious behaviors (Dean et al. 2014; 2015; Yip et al. 2007). Individuals with more trust tend to be more altruistic and more likely to engage in pro-social actions (Uslaner 2002). Social groups with more trust tend to be able to engage in collective action to address complex problems more effectively (Adger 2003; Mayer 2018) and trust also enhances the resilience of groups and individuals (Habibov and Afandi 2011). Trust can also be important for economic development because it reduces transaction costs (Fafchamps 2001; 2006; Nootebloom 2007).

Structural social capital encompasses connections within a social network and the strength of networked ties. Connections among family, community, membership organizations, and the like are all typically construed as structural social capital. Structural social capital is thought to be important because social capital can provide resources (e.g., access to employment) and a sense of belonging that improves well-being (Curley 2010; De Silva and Harpham 2007; Franzen and Hangartner 2006; Yip et al. 2007). Densely connected social networks may be more resilient against external shocks (Aldricht and Meyer 2015; Nakagawa and Shaw 2004). A long line of research links social capital to health via several mechanisms (Kawachi and Berkman 2000; Kim, Subramanian, and Kawachi 2006). Individuals leverage their social capital during times of hardship, using their social networks to provide important resources ranging from employment opportunities to information about health problems (Franzen and Hangartner 2006; Lancee 2016; Nieminen et al. 2010).

More specific to subjective well-being, De Silva and Harpham (2007) used data from four developing nations—Peru, Ethiopia, Vietnam and India—and found that new mothers with less cognitive and structural social capital were more likely to suffer from anxiety and depression. Hamano et al. (2010) employ data from nearly 6,000 individuals across 199 neighborhoods in Japan and report that trust (i.e., cognitive social capital) and membership in organizations (i.e., structural social capital) are both associated with improved mental health. Cognitive and/or structural social capital have a positive relationship with self-rated health in Colombia (Hurtado, Kawachi, and Sudarsky 2011), Finland (Nieminen et al. 2010), Argentina (Ronconi, Brown, and Scheffler 2012), Europe (Mayer 2018; Mayer and Foster 2015), and many other regions. Most of the research on self-rated health and social capital uses cross-sectional designs that do not necessarily provide evidence of causality but only of association. This is due, in part, to the nature of social capital—it cannot simply be manipulated by researchers in an experiment because it emerges via long-run social processes (Grootaert and Bastelar 2002; Murayama, Fujiwara, and Kawachi 2012). The size and nature of the relationship between social capital and health varies within and across countries, but social capital remains a salient predictor of health in nearly every social context where it has been studied.

Although researchers studying the impacts of dams do not always invoke the term "social capital"[1] notions of lost social connections, social isolation, and subsequent maladjustment are common in the hydropower literature (Cernea 1997, Hwang et al. 2007; Nguyen, Phan, and De Bruyn 2017; Tilt and Gerkey 2016). A smaller group of studies have linked social capital to indicators of subjective well-being in the context of hydropower projects, typically focusing on displacement as a primary cause of the loss of social capital.

Xi and Hwang (2011) found that rural communities displaced by China's Three Gorges Dam had lower rates of social integration than displaced and resettled urban communities—the authors argue that this loss of social capital caused depressive symptoms among resettled rural people. Four

[1]It is important to note that some authors study social capital, together with other capitals (i.e., human, financial, natural, physical) when they apply the *Sustainable Livelihood Framework* to study the impacts caused by dams. See Bui and Schreinemachers (2011).

other studies have used proxies for social capital and report deleterious effects of displacement and resettlement. Nguyen, Pham, and De Bruyn (2017) found that a large majority of a displaced and resettled population in rural Vietnam had less bonding social capital than before displacement and resettlement. In their study of a dam on the Upper Mekong River in China, Tilt and Gerkey (2016) relied upon indicators of inter-household exchange of financial resources and agricultural labor as a proxy for the strength of social networks. The authors compare a resettled group with a group that was not resettled, and they found that the resettled households were less likely to give out loans—arguing that this is indicative of lost social capital. Wang et al. (2020) developed a sophisticated framework connecting various dimensions of social capital (e.g., cognitive vs. structural) and social integration in six resettled communities in China, finding that resettlement significantly reduced social integration. Mayer et al. (in press) studied social capital by comparing a resettled and a host community in the context of Brazil's Belo Monte dam. The authors found that individuals in the resettled community have lower levels of structural social capital, whereas individuals in the host community have lower cognitive social capital. Thus, the prior literature indicates that hydropower projects likely reduce social capital, but the consequences for this loss of social capital for self-rated health are not fully understood. We evaluate the following hypothesis in this manuscript:

Hypothesis 3 We expect that the loss of social capital will be associated with reduced self-rated health.

Methods

Study context. This study is part of a larger research project that examines hydropower projects in three river basins of the Amazon Basin, the Xingu, Tapajos, and Madeira Rivers and the experience of communities near dams in those regions. As of 2014, there were 74 dams in operation and 94 planned in the Brazilian Amazon (Tundisi et al. 2014).

The study area for this paper are communities along the Madeira Basin (Figure 1 and Table 1) where two large hydropower dams were built between 2008 and 2013, Santo Antônio and Jirau, each one having an installed capacity of approximately 3,000 MW. Like other dam projects in Brazil, planning began before environmental impact assessments had been completed (Fearnside 2014). The two dams were built by different construction consortia that won public bids for the projects and were initiated and completed within months of each other. These are "run-of-the-river dams," which require a smaller reservoir than traditional

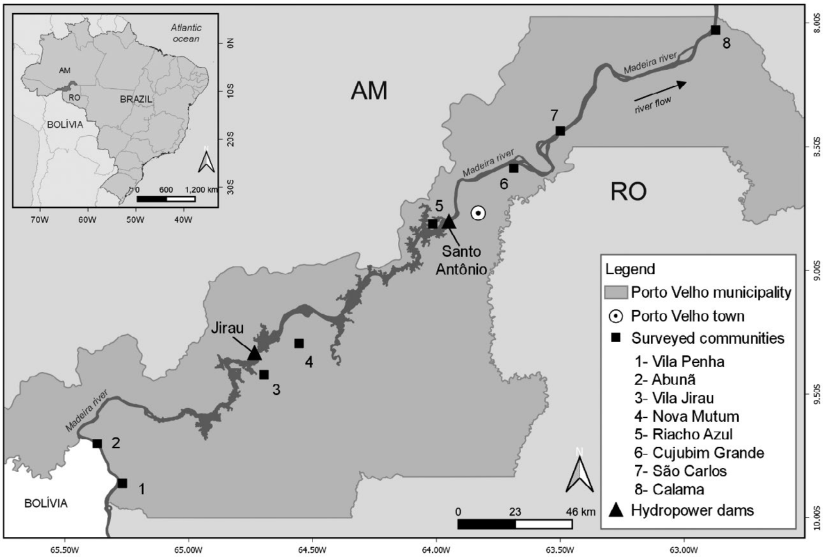

Figure 1. Study Area, Map of the Surveyed Communities.

dams. Nevertheless, because two dams were built within 120 km of each other, a very substantial reservoir was created between the two. The Santo Antônio dam is close to the capital city of the state of Rondônia at Porto Velho, a mere 7 km upstream from Porto Velho city with approximately 400,000 people. The second one, Jirau, is some 125 km upstream and flooded one small town, Mutum Parana, with its citizens resettled in other communities (mostly Nova Mutum and Vila Jirau). The dam builders held a few meetings with the impacted populations, and authors such as Gugliano and Luiz (2019) find that the company invited some leaders rather than doing an open invitation to join the meetings. In addition, these meetings were more to provide information than to allow the communities a say in the design or management of the dams—the construction of the dams was a foregone conclusion (Gugliano and Luiz 2019; Novoa Garzon 2008).

The population of this region near the Madeira River includes fishers, but there are some communities with substantial agricultural activities, logging, artisanal gold mining, and cattle ranching. We used a survey instrument that included questions to contextualize each community and its citizens, their experience with compensation and resettlement, and how the dams impacted their community, among other issues.

Table 1. Communities Included in Sample.

Community	Location relative to Santo Antônio Dam	Number of Houses	Houses Surveyed	Percentage of Houses Surveyed
Vila Penha	Upstream	148	33	22.3
Abunã	Upstream	212	100	47.2
Vila Jirau	Upstream	240	70	29.2
Nova Mutum	Upstream	267	79	29.6
Riacho Azul	Upstream	82	51	62.2
Cujubim Grande[a]	Downstream	220	79	35.9
São Carlos[b]	Downstream	282	109	38.7
Calama[b]	Downstream	440	151	34.3
Total		1,891	672	35.5

[a]Cujubim Grande is a pair of communities (Cujubim and Cujubinzinho) 40 km downstream from Santo Antônio dam.

[b]Sao Carlos, Calama, and Cujubim communities received as compensation a fruit processing industrial plant but none of the three facilities ever functioned and fell into disrepair. So, in a way, none were compensated, as they never benefitted from this action by the Santo Antônio Energy Company.

Data Collection

The research team collected survey data in the Madeira basin region of the Amazon between August 2019 and March 2020 in eight different communities, thus more than 6 years after the dams were built. Two communities upstream were compensated and resettled by the dam builders (Nova Mutum and Riacho Azul), two were downstream from the dams and were neither compensated nor resettled (Calama and Sao Carlos); another upstream community is made up of people who accepted the compensation arrangements but decided not to live in the community where they were told to resettle by the dam builder and auto-resettled in an already existing community (Vila Jirau), another downstream community was harmed by the floods of 2014, and they had to auto-resettle on higher ground after that (Cujubim), and the final two communities—Abunã and Vila Penha—were not slated to be resettled but expected to be resettled after all because the flooding from the dam has been larger than anticipated.

Data were collected in a geographically stratified fashion. First, we acquired satellite images that showed each community and observed their buildings' roofs. This was complemented by visits to the communities to verify the buildings and identify the houses. Each of these buildings was numbered in our maps and from this we drew a proportional random sample of each community. Enumerators were provided with these numbered maps as a guide to whom to interview, and a list of alternates to visit if after five tries they were unable to locate the residents. It is not uncommon in the Amazon in these types of small communities for families to close their homes and travel for an undetermined period.

The research team was trained for a week and was given a detailed set of procedures for conducting the interview following standard ethical guidelines. Before going to the field, different pilots were held with communities with similar characteristics of the ones in our sample. Each interview team consisted of two enumerators. At the time of the survey, they arrived at each house, introduced themselves, explained their academic affiliation and the objectives of the study, and asked if they could proceed, following their expressed consent and guaranteeing confidentiality of the information. One enumerator asked the questions from the household head, and the other took ancillary notes and ensured that other members of the household (especially small children) did not disturb the interview. Upon arriving at a house, interviewers asked to talk to the male or female head of household, and which one wished to answer if both were present. Usually, the respondent was the male head of household, when men were out, the female head answered. Interviewers used tablets to administer the survey using the Qualtrics platform. The tablets allowed automatic geolocation and facilitated the identification of sampled households.

At the end of the interview, the team gave a card to the interviewee with the contact information of a local university faculty member and collaborator in this project who was willing to answer any questions. Interviews lasted an average of 90 minutes and only between 3 percent and 5 percent of the households refused to participate. Table 1 describes the communities, number of households, and number of completed surveys. Below, we describe the variables that we use in our analysis.

Variables

Outcome Variable

We use self-rated health as our outcome. The use of self-rated health has several advantages, perhaps the most obvious of which is the efficiency and speed at which self-reported data can be collected. Subjective indicators of health have a high degree of validity and are predictive of health status measured by more objective measures such as obesity or mortality (Benyamini 2011; Cislaghi and Cislaghi 2019; Lundberg and Manderbacka 1996; Schnittker and Bacak 2014). Further, individuals will adapt their subjective impressions of their health to changes in their actual health status—for instance, Okosun et al. (2001) find that people report improved health after a significant weight loss. For our purposes, respondents were asked if their health improved, stayed the same, or had gotten worse due to the construction of the dam. Forty-one percent of respondents indicated that their health had "gotten worse," while 50 percent stated that their health had stayed the same (Table 2), and 9 percent indicated that their health status improved since the construction of the dams.

Predictors

Infrastructure strain. Hydropower projects often place immense strain on local infrastructure and resources including, but not limited to, education, transportation, healthcare, electricity, and job opportunities. To understand how these factors predict self-rated health, we use a series of questions that asked respondents if these areas had improved, stayed the same, or gotten worse. We also included two variables to capture experiences with resettlement and compensation. The first asked if respondents were resettled due to the dams and the second assessed if respondents had been given any

Table 2. Descriptive Statistics

	%	Mean	SD	Min	Max
Outcome Variable					
Self-Rated Health					
Gotten Worse	41.1				
Remained the Same	50.2				
Better	8.7				
Predictors					
Impact Factor Score		1.4	0.6	−0.0	1.9
Structural Social Capital Factor Score		0.9	0.4	0.1	1.6
Cognitive Social Capital Factor Score		1.4	0.5	-0.1	2.0
Resettlement					
No	78.2				
Yes	21.8				
Compensated					
No	85.0				
Yes	15.0				
Controls					
Education					
No formal education	11.9				
Primary	53.5				
Secondary	26.8				
Technical/ Vocational	1.9				
University Studies	5.9				
Sex					
Male	47.8				
Female	52.2				
Age		48.1	15.2	18	87

compensation. As given in Table 2, 22 percent of the sample was resettled and 15 percent were given compensation.[2] Figure 2 shows the results of questions related to impacts on infrastructure and changes to community resources. We found that more than half of the total population interviewed stated that access to education and job opportunities had "gotten worse," 54 percent and 62 percent, respectively. Interestingly, while a slight majority of the resettled population stated that their access to electricity had improved

[2]Some fifteen percent of respondents received compensation for resettlement, but the type of compensation differed. Among those compensated, only five percent reported having a choice as to the specific compensation that they received. Seventy-three percent of the compensated respondents reported receiving only cash. The reminder received a mix of access to new fishing spots, boat motors, boats or canoes, agricultural inputs, and credit. Fourteen percent of the sample reported that they had participated in a lawsuit to receive compensation, with a small proportion of those still involved in litigation. Among the resettled, only one percent indicated that they had been offered a choice of location.

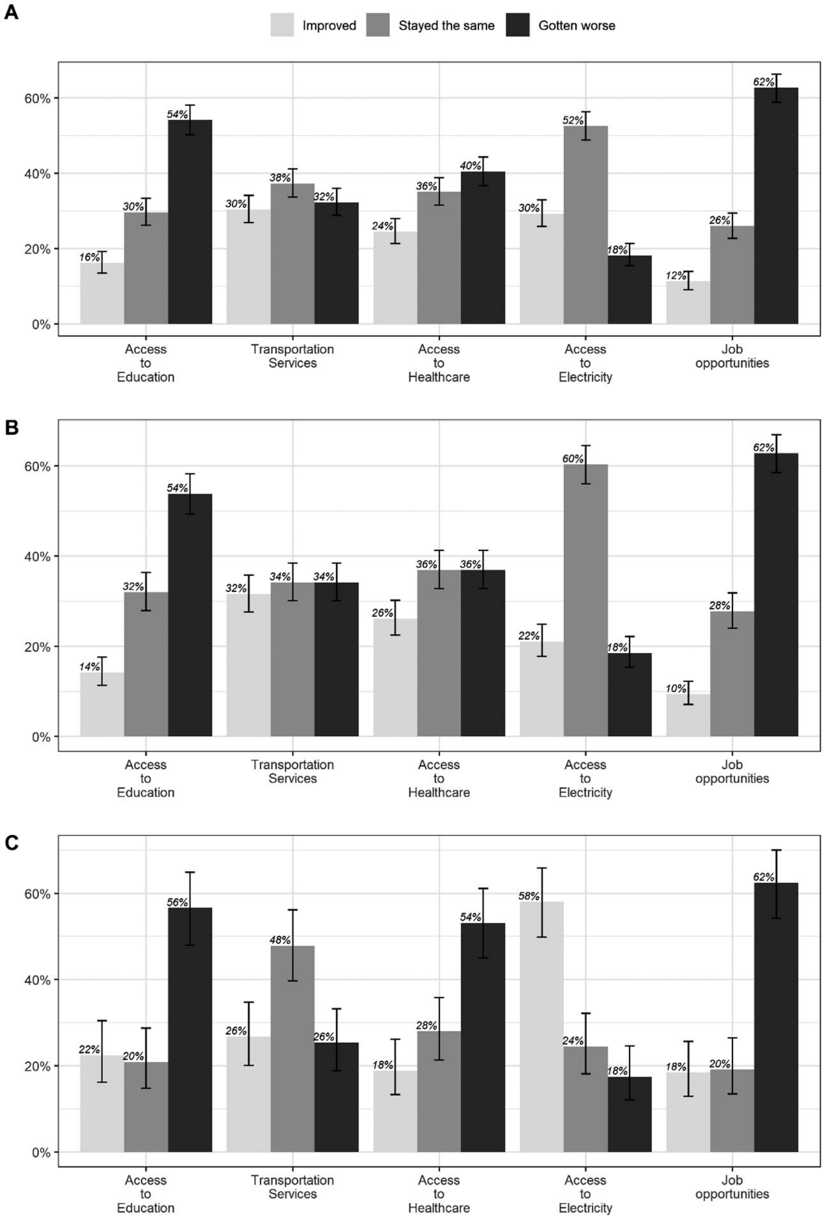

Figure 2. Infrastructure and Resource Changes from the Dams for Total Population Interviewed (A), Not Resettled (B) and Resettled (C).

Table 3. Factor Analysis for Community Impacts.

	Factor 1	Factor 2	Factor 3
Access to Education	–	0.345	–
Transportation Services	0.396	–	–
Access to Healthcare	0.708	–	–
Access to Electricity	–	0.539	–
Job Opportunities	0.446	–	–

Note: Factors extracted from a polychoric correlation matrix with a varimax rotation. Kmo = 0.71. The eigenvalues were 1.27 and 0.23. The first factor accounts for 84% of the interitem variance and has an eigenvalue proportion of 0.78

(58 percent), 18 percent stated that access to electricity got worse. With regards to healthcare, 54 percent of resettled population claims that access to healthcare had "gotten worse." Overall, these variables suggest that there were no substantial improvements in community resources after the dams' construction, independently of resettlement status.

We conducted factor analysis to understand the dimensionality of these items. We first estimated a polychoric correlation matrix and extracted factors using the iterated principal factors method and a varimax rotation (Holgado–Tello et al. 2010). Table 3 provides the results of this factor analysis. The first factor had an eigenvalue of 1.27 and explained 84 percent of the inter-item variance, strongly suggesting a single factor solution. We then estimated a factor score for these items with higher scores corresponding to greater perceptions of impacts.

Social Capital

As noted above, social capital has long been associated with health outcomes, including self-rated health and other subjective indicators of health status. To capture cognitive social capital, we use variables for community trust and trust in leaders. For structural social capital, we use indicators for frequency of seeing friends, frequency of community meetings, membership in organizations, and religious attendance. As Figure 3 shows, all of these variables are scored "improved," "stayed the same," or "gotten worse." For the population interviewed, community trust and trust in leaders appear to have declined since the completion of the dams, with a slight majority indicating "gotten worse." Roughly half stated that visits with friends had stayed the same, while 45 percent stated these visits had "gotten worse" (i.e., became less frequent). Community meetings declined, while memberships in organizations and

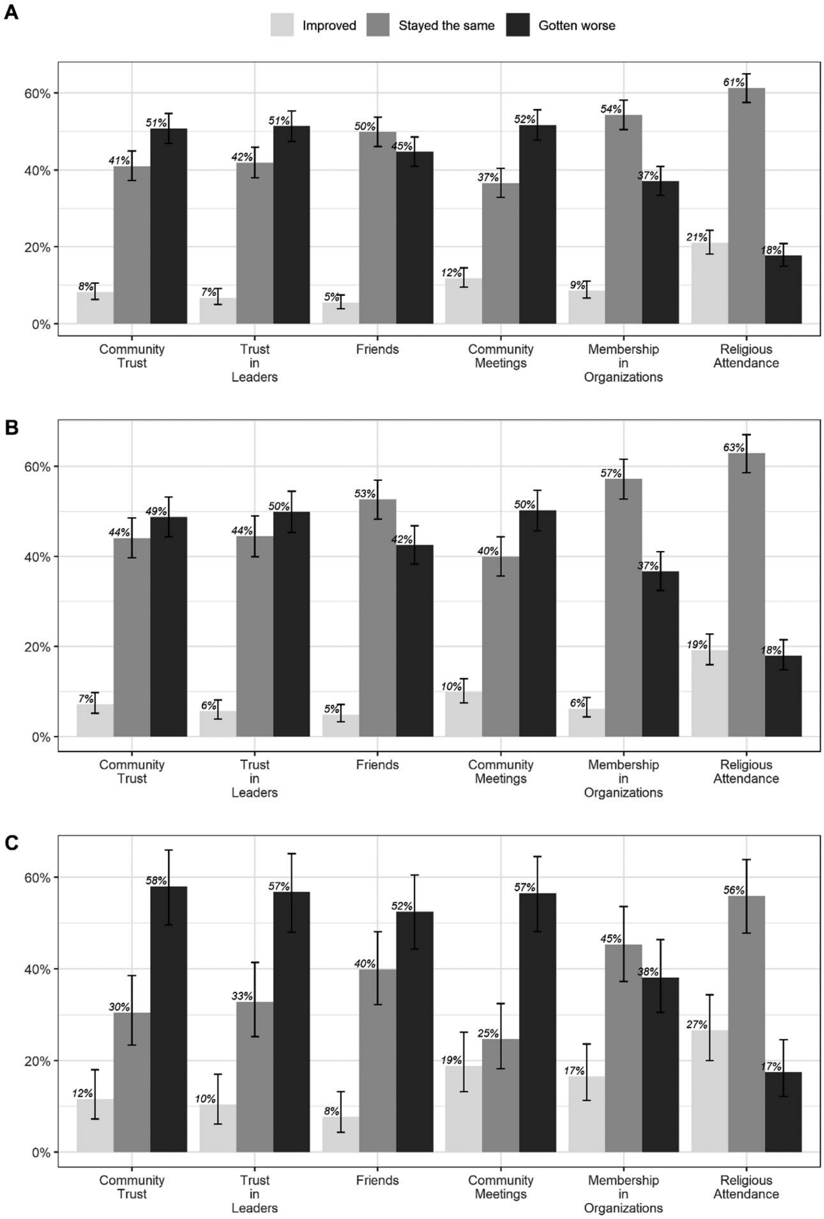

Figure 3. Social Capital Variables for Total Population Interviewed (A), Not Resettled (B), and Resettled (C).

Table 4. Factor Analysis for Social Capital.

	Factor 1	Factor 2	Factor 3
Community Trust	0.803	–	–
Trust in Leaders	0.739	–	–
Meeting with Friends	–	–	–
Community Meetings	0.300	0.502	–
Membership in Organizations	–	0.451	–
Religious Attendance	–	–	–

Note: Factors extracted from a polychoric correlation matrix with a varimax rotation. Kmo = 0.64. The eigenvalues were 1.32 and 0.47. The first eigenvalue has an eigenvalue proportion of 0.821. Factor 1 accounts for 71.4% of the interitem variance, while factor 2 accounts for 28.6%.

religious attendance stayed the same for most respondents. By comparing resettled and not resettled population, the variables with a highest disparity are community trust and trust in leaders, which had "gotten worse," respectively, for 58 percent and 57 percent of the resettled population. Notably, across all variables very few respondents indicated that social capital had improved.

To explore the dimensionality of these items, we conducted an exploratory factor analysis and computed factor scores. From there, we extracted factors using the iterated principal factors method with a varimax rotation. Table 4 provides eigenvalues and factor loadings for this factor analysis—to facilitate more straightforward interpretation, we omit factor loadings below the standard criterion of 0.3. Table 4 implies that meetings with friends and religious attendance do not load on any factors. However, community trust and trust in leaders load strongly on the first factor, while community meetings and memberships in organizations load strongly on the second—these loadings align with the distinction between cognitive and social capital we described above. The eigenvalue for the first factor was 1.32, while the same score for the second factor was 0.47, below the standard cut-off of 1.0. However, given the theoretical importance of both cognitive and structural social capital, we calculated factor scores for the first two factors. We call these factors "cognitive social capital" and "structural social capital," respectively. Both are scored such that higher values indicated a greater loss of that type of social capital.

Control Variables

Self-rated health is known to be influenced by a range of sociodemographic characteristics. Accordingly, we include variables for sex (0 = male, 1 = female), a five-category indicator for education, and age in years.

Models

Our dependent variable is a three-category indicator for self-rated health status, wherein respondents were asked if their health had improved, stayed the same, or gotten worse due to the construction of the dams. Given the ordinal nature of this variable, we employ ordinal logistic regression. We also tested the proportional odds assumption, also known as the parallel lines assumption, that if violated for multiple predictors would imply that our models are inappropriate and a more complex modeling strategy should be used (Brant 1990; Williams 2006). The proportional odds assumption was only violated for control variables, particularly the variable for upstream versus downstream status, and not in a way that would significantly change the conclusions we derive from our models.

We estimate a model for each of our theoretically relevant groups of predictors—the social capital variables, the factor score for infrastructure impacts, and the resettlement and compensation variables. We also present the results of a model considering all predictors. All models include the control variables described above.[3] Given the well-documented problems with interpreting logistic regression coefficients directly (Mood 2010; Williams 2012), we rely on average marginal effects to understand how a one-unit change in our predictors alters the probability of a given category of our outcome variable.[4] We also turn to Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) to understand improvements in model fit with the addition of new variables. AIC and BIC are both calculated from the log likelihood of each model, wherein lower scores indicate improved model fit. However, BIC also penalizes for the number of predictors included in the models (Kuha 2004).

Ordinal Logistic Regression Results

Table 5 provides the results of the ordinal logistic regression models where "gotten worse" is the highest category on self-rated health's ordinal scale. In model 1, we include our factor score for perceived impacts and the control variables, which generally do not approach statistical significance at conventional thresholds (e.g., alpha = 0.05). The lone exception is living in an upstream community, wherein

[3]As a robustness check, we also estimated models that include our variables for meeting with friends and religious attendance as standalone predictors. Neither of these variables was statistically significant and did not improve the model fit statistics.

[4]We also checked our models for multicollinearity using variance inflation factors, none of which exceeded 2.0, indicated that our models were not impacted by multicollinearity.

Table 5. Results of Ordinal Logistic Regression Models for Self-Rated Health.

	Model 1	Model 2	Model 3	Model 4
	Perceived Impacts	Resettlement and Compensation	Social Capital	Full Model
	b/se	b/se	b/se	b/se
Community Impacts				
Impacts	−0.097 (0.14)			−0.128 (0.16)
Resettlement and Compensation				
Resettled		−0.101 (0.25)		−0.134 (0.28)
Compensated		−0.113 (0.28)		−0.332 (0.31)
Social Capital				
Cognitive Social Capital			0.861*** (0.17)	0.839*** (0.17)
Structural Social Capital			0.149 (0.20)	0.194 (0.20)
Controls				
Education (ref. no formal education)				
Primary	−0.288 (0.26)	−0.274 (0.26)	−0.514 (0.32)	−0.525 (0.33)
Secondary	−0.211 (0.30)	−0.207 (0.31)	−0.207 (0.36)	−0.250 (0.37)
Technical/Vocational	0.365 (0.60)	0.350 (0.60)	0.033 (0.65)	−0.082 (0.66)
University Studies	−0.528 (0.41)	−0.515 (0.41)	−0.667 (0.47)	−0.735 (0.47)
Female	0.044 (0.16)	0.041 (0.16)	0.066 (0.18)	0.036 (0.18)
Age	0.011 (0.01)	0.010 (0.01)	0.017* (0.01)	0.018** (0.01)
Upstream	0.374* (0.16)	0.416* (0.18)	0.377* (0.17)	0.560** (0.21)
AIC	1,205.597	1,193.823	986.319	975.667
BIC	1,250.382	1,242.967	1,033.607	1,035.645

Note: $N = 536$.
***$p < .001$
**$p < .01$
*$p < .05$.

respondents who live upstream are more likely to state that their health had "gotten worse." Model 2 adds in the resettlement and compensation variables. Although the sign for both variables is negative, neither is statistically significant, but the AIC and BIC imply improved model fit. In Model 3, we include the factor scores for cognitive and structural social capital, with only cognitive social capital emerging as statistically significant—here, lower cognitive social capital is associated with a greater likelihood of stating that health had "gotten worse." Yet, again, both the AIC and BIC have improved. Finally, Model 4 includes all predictors. Cognitive social capital has retained its statistical significance, as has our "upstream" variable. Age is also associated with a greater likelihood to state that health had "gotten worse." In model 4, the AIC has been reduced, but the BIC has increased, providing a mixed picture of improved model fit.

Average Marginal Effects

We provide average marginal effects (AMEs) in Figure 4 for each set of theoretically salient predictors in model 4. Average marginal effects can be interpreted as the average change in probability (in our case, the probability of health getting worse for a one unit increase in each predictor). We chose the "Gotten Worse" category because prior research on self-rated health typically models low or worsening self-rated health, as opposed to excellent or improved health (Blakely, Lochner, and Kawachi 2002; Kim, Subramanian, and Kawachi 2006; Veenstra 2005). Our predictors are all scored on different scales, so the AMEs cannot be directly compared. Recall that our indicators for compensation and resettlement are binary. The AMEs largely underscore the null effects of many predictors that we reported in Table 5. Notably, one-unit increase in the cognitive social capital scale (i.e., a loss of cognitive social capital) is associated with nearly a 0.2 increase in the probability of "Gotten Worse" self-rated health, implying that cognitive social capital may be a uniquely important predictor of self-rated health in Amazonian communities that host hydropower.

Discussion and Conclusion

The purpose of this paper was to understand how dam projects along the Madeira river impacted self-rated health across eight different communities a few years after the construction of the dam. We argued that a combination of factors including resettlement and compensation, the loss of social capital, and negative impacts to community infrastructure would reduce self-rated health in this context. Our work is informed by the energy boomtown perspective and the literature on hydropower

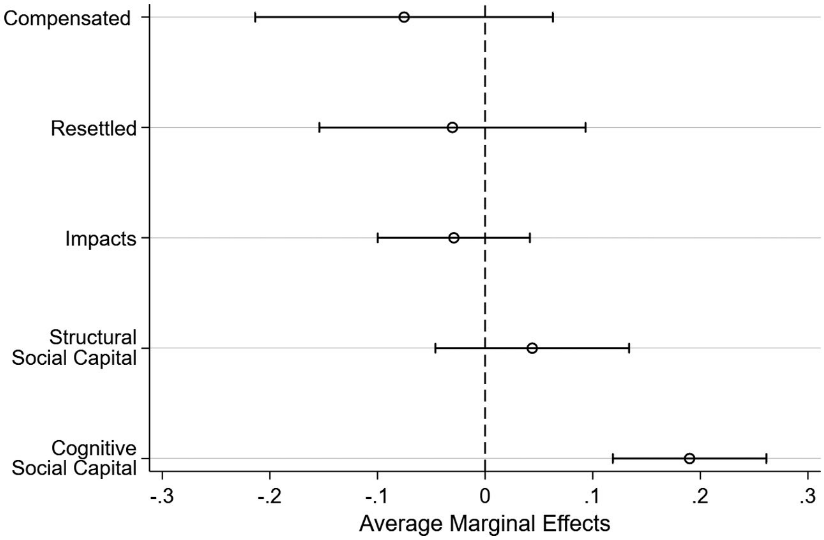

Figure 4. Average Marginal Effects of Predictors. Estimates Derived from Table 5, Model 4.

impacts. In this section, we discuss these findings in the context of our hypotheses and current debates in the literature on hydropower.

In formulating hypothesis 1, we noted that much of the literature indicates that large-scale energy projects and boomtowns are associated with significant strains on the infrastructure (schools, hospitals, etc.) of host communities, and research suggests that this is especially true for hydropower projects in the global South, as seen in the work carried out on Brazil's Belo Monte dam (Grisotti 2016; Mayer et al. in press; Moran 2016), among many others (LeTurcq 2018; Stickler et al. 2013). Our results imply that a significant portion of respondents report a loss of key community resources ranging from education to health, this being even more prominent for the resettled population (Figure 2, panel C). These losses occur despite frequent promises that the dam projects would improve local infrastructure and engender broad-based benefits for the region. One exception is access to electricity, as a slight majority of the resettled respondents stated that it had improved. This result is striking since the surveys were done more than 6 years after construction had ended, and resettled communities do not seem to be beyond the stage 2 described by Scudder (2012) or entered the recovery phase described by Brown, Dorins, and Krannich

(2005)—on the contrary, living standards seem worse than before the resettlement process.

For hypothesis 2, we predicted that displacement and resettlement would be associated with deleterious impacts on self-rated health. Our analysis was informed by the large literature on resettlement and compensation due to hydropower. This literature implies that the resettlement process can have a range of long-run negative consequences for communities and that compensation programs often do not adequately compensate resettled populations for everything they have lost (Cernea 1997; Vanclay 2017). A loss of well-being (e.g., life satisfaction, self-rated health, or mental health) seems to be common (Hwang et al. 2007; Tong, Zhu, and Lo 2019; Xi and Hwang 2011). However, Randell (2016) finds that a generous compensation program led to more positive outcomes for the case of one rural resettled population in Belo Monte. Our results suggest that the process of resettlement and compensation does not always damage self-rated health but does not improve it either. Indeed, significant portions of the resettled and compensated said that their health remained the same.

For hypothesis 3, we drew upon the voluminous research that links social capital and health, noting that social capital is commonly measured as a multi-dimensional construct. Here again we find nuanced findings. We observed the erosion of cognitive social capital after the dam's construction, especially with regards to community trust and trust in leaders, and this was particularly pronounced for the resettled population (Figure 3, panel C). In terms of structural social capital—networked ties to friends, family, and community—community meetings had gotten worse compared with the period before the dam's installation, once again the impact was more striking for the population who had to resettle. However, analyzing the entire surveyed population, we found that structural social capital has a null effect in models 3 and 4. That is, respondents who report less frequent interactions since dam construction began are not apt to report worsening self-rated health as a result. We were surprised by this finding, but one possible explanation is that our respondents were able to rebuild or salvage parts of their social network after the dams were completed. Yet cognitive social capital appears to have a consistent and large effect. Individuals who report that the construction of the dams has eroded trust indicate lower self-rated health as a result. We speculate that trust may be associated with other variables that improve self-rated health, such as adherence to treatment programs, willingness to seek treatment or medical care, or stress levels. Evaluating these relationships is an important task for future work.

These results have several implications for the future of hydropower, displacement, and energy booms more broadly. Like work reported elsewhere (Mayer et al. in press), our analysis suggests that communities near large-scale energy projects often experience negative consequences. Further—as noted by others (e.g., Cernea 2004; Vanclay 2017)—the present analysis bolsters claims about the insufficiency of compensation programs, and difficult questions as to who deserves compensation. One key finding is that many types of community infrastructure and resources were damaged by the construction of the dams, with few respondents saying that conditions had improved. Another key finding is that many of our respondents who did not experience displacement still reported a loss of social capital and worsening community resources even years after the competition of the dams. This implies that the impacts of hydropower development are quite broad, with impacts occurring at a regional scale and in communities that were not displaced and receive no compensation. In that sense, this result confirms the work of Kirchherr and Charles (2016) showing the need to study dams taking into consideration additional dimensions related to space, time, and value in addition to the ones studied so far. Although in some instances compensation programs may mitigate some of the impacts of displacement (Randell 2016; 2017), our analysis suggests that many people continue to be impacted by dams even years after the completion of the dams and have not been compensated adequately or at all. Programs that enhance community resources—such as schools and healthcare facilities—may be needed just as much as efforts to compensate individual households. Further, resettlement programs could be planned to avoid some of the apparent destruction of social capital we have observed. The impacts from large-scale energy infrastructure projects unfold over time in stages (e.g., Brown, Dorins, and Krannich 2005; Scudder 2005). Our study was conducted 6 years after the dams were completed and results may have been different if we had gathered data right after the dams were constructed. Likewise, our findings would likely not be the same if we re-visit this location to gather additional data in the future. This process can help to understand some of the null effects observed here. We suggest that future research should study multiple communities over time with varying impacts from dam development, ideally tracking the same individuals as they experience changes in social capital and well-being (e.g., self-rated health). Such research, while ideal, is also fraught with many practical difficulties.

Earlier we noted that the origins of social capital are obscure. That is, we do not have a complete understanding of why some groups have more social capital than others, and very few studies have attempted to create social capital to better understand its origins. Our results imply that an erosion of cognitive social capital is a primary channel by which hydropower projects reduce self-rated health. This poses some significant implications in terms of justice and compensation—since cognitive social capital cannot easily be created, how can dam builders possibly ameliorate this impact? That is, what degree of monetary or equivalent compensation (e.g., land) is sufficient to repair a loss of trust in an impacted community? Or how can these impacts be avoided altogether? What can be done to salvage social capital in the context of hydropower megaprojects? How do the effects of infrastructure projects on social capital and self-rated health vary across time, space, and type of project? In short, are hydropower megaprojects worthwhile considering given their measurable and not measurable social impacts? These important questions remain unanswered. Further, it is possible that dams reduce health by other means, which could further reduce social capital. These questions, and many others, warrant future research.

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