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Social Vulnerability to Climatic Shocks Is Shaped by Urban Accessibility

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Despite growing interest in urban vulnerability to climatic change, there is no systematic understanding of why some urban centers have greater social vulnerability than others. In this article, we ask whether the social vulnerability of Amazonian cities to floods and droughts is linked to differences in their spatial accessibility. To assess the accessibility of 310 urban centers, we developed a travel network and derived measures of connectivity and geographical remoteness. We found that 914,654 people live in roadless urban centers ($n = 68$) located up to 2,820 km from their state capital. We then tested whether accessibility measures explained interurban differences in quantitative measures of social sensitivity, adaptive capacity, and an overlooked risk area, food system sensitivity. Accessibility explained marked variation in indicators of each of these dimensions and, hence, for the first time, we show an underlying spatial basis for social vulnerability. For instance, floods pose a greater disease risk in less accessible urban centers because inadequate sanitation in these places exposes inhabitants to environmental pollution and contaminated water, exacerbated by poverty and governance failures. Exploring the root causes of these spatial inequalities, we show how remote and roadless cities in Amazonia have been historically marginalized and their citizens exposed to structural violence and economic disadvantage. Paradoxically, we found that places with the highest social vulnerability have the greatest natural and cultural assets (rainforest, indigenous peoples, and protected areas). We conclude that increasing accessibility through road building would be maladaptive, exposing marginalized people to further harm and exacerbating climatic change by driving deforestation. **Key Words:** Brazil, cities, extreme events, remoteness, spatial inequalities.

尽管对城市之于气候变迁的脆弱性之兴趣日益增加，但对于为何若干城市中心较其他具有更高的社会脆弱性之问题，却未有系统性的理解。我们于本文中，质问亚马逊城市之于洪泛与旱灾的社会脆弱性，是否与其空间可及性之差异有关。为了评估三百一十座城市中心的可及性，我们发展了一个旅行网络，并衍生连结性与地理偏僻性的衡量方法。我们发现，离国家首都两千八百二十公里的距离之内，有九十一万四千人居住在没有道路的城市中心（样本数为六十八）。我们接着检验可及性测量是否解释了社会敏感度、调适能力，以及一个被忽略的风险领域——粮食系统敏感度的量化测量中的城际差异。可及性解释了上述面向个别指标的显著差异，我们从而初次展现社会脆弱性的根本空间基础。例如洪泛在可及性较差的市中心产生更大的疾病风险，因为这些地方的卫生条件并不充分，将居住者暴露在环境污染与污水之下，并因贫穷与政府失能而恶化。我们探讨这些空间不均的根本肇因，展现亚马逊偏远且无路的城市，如何在历史上受到边缘化，而其市民暴露在结构性暴力与经济劣势之下。矛盾的是，我们发现，社会脆弱性最高的地方，拥有最为丰沛的自然与文化资产（雨林、原住民族和保护地）。我们于结论中主张，透过道路建设逐渐增加可及性，将可能会适应不良，让边缘化的人们暴露在进一步的伤害中，并因驱动去森林化而使得气候变迁更为恶化。关键词：巴西，城市，极端事件，偏远，空间不均。

Pese al creciente interés sobre la vulnerabilidad urbana al cambio climático, no hay un entendimiento sistemático del porqué algunos centros urbanos tienen una vulnerabilidad social más alta que otros. En este artículo nos preguntamos si la vulnerabilidad social de las ciudades amazónicas a las inundaciones y a la sequía está relacionada con las diferencias en su accesibilidad espacial. Para evaluar la accesibilidad de 310 centros urbanos, desarrollamos una red de viajes y derivamos medidas de conectividad y de lejanía geográfica. Hallamos

que 914.000 personas viven en centros urbanos sin carreteras (n D 68) que se localizan a 2.820 km de su capital estatal. Luego examinamos si las medidas de accesibilidad explicaban las diferencias interurbanas en medidas cuantitativas de sensibilidad social, capacidad de adaptación, y un área de riesgo ignorada, la sensibilidad al sistema alimentario. La accesibilidad explicó la marcada variación en los indicadores de cada una de estas dimensiones y, por lo tanto, por primera vez, mostramos una subyacente base espacial de la vulnerabilidad social. Por ejemplo, las inundaciones representan un riesgo más grande de enfermedad en los centros urbanos menos accesibles debido a que las políticas de salubridad inadecuadas en estos lugares exponen los habitantes a contaminación ambiental y agua contaminada, exposiciones exacerbadas por la pobreza y fallas de gobernanza. Explorando las causas raíz de estas desigualdades espaciales, mostramos cómo las ciudades de la Amazonia alejadas y sin carreteras han estado históricamente marginadas y sus habitantes expuestos a violencia estructural y desventaja económica. Paradójicamente, encontramos que los lugares que registran la más alta vulnerabilidad social tienen los más grandes activos naturales y culturales (selva pluvial, pueblos indígenas y áreas protegidas). Concluimos que incrementar la accesibilidad por medio de la construcción de carreteras resultaría ser una mala adaptación, al exponer a gente marginada a mayores males y exacerbar el cambio climático facilitando la deforestación. *Palabras clave:* Brasil, ciudades, eventos extremos, lejanía, desigualdades espaciales.

In this article, we explore the role of two measures of spatial accessibility—geographical remoteness and road connectivity—in determining variation in the social vulnerability of urban centers. This piece therefore advances current understanding by first elucidating the relative accessibility of hundreds of cities in the Brazilian Amazon and then exploring how this shapes social vulnerability to climatic shocks. We assess interurban differences in social vulnerability using quantitative measures of social sensitivity, adaptive capacity, and an overlooked risk area, food system sensitivity. Finally, we engage with ongoing debates about the contentious roles of roads as either “ecologically disastrous” or pathways to development (Ibisch et al. 2016).

Social Vulnerability to Climatic Shocks

Worldwide, cities are facing climatic shocks of increasing frequency and severity, with myriad consequences for human welfare (Field 2012). This contributes to growing interest in urban vulnerability to global environmental change (Gasper, Blohm, and Ruth 2011; Pelling 2012; Tate 2013; Revi et al. 2014; Sherly et al. 2015). Consequently, understanding and reducing vulnerability to climatic shocks has advanced from academic debate to become a “political necessity” (Hinkel 2011). Understanding why some cities are more socially vulnerable than others is crucial for designing appropriate policy interventions. This is vital in the Global South, where many cities are highly vulnerable to shocks due to development and governance failures (Parnell, Simon, and Vogel 2007), compounded by overcrowding arising from rapid urbanization (Hardoy and Pandiella 2009).

Two decades of research have demonstrated that vulnerability to shocks—defined as the propensity or

predisposition of people or places to be adversely affected—is multidimensional (Blaikie et al. 1994), and impacts vary according to levels of development and preexisting vulnerabilities (Birkmann 2013). Thus, hazards are not just physical events but are socially constructed situations (Cutter, Mitchell, and Scott 2000). Hence, vulnerability is generally taken as the outcome of hazard exposure and the two conventional dimensions of social vulnerability (sensitivity and adaptive capacity; Adger 2006). Extreme climatic events therefore act as threat multipliers when hazard exposure combines with social vulnerability (i.e., economic, social, and political weaknesses and stresses; Wilbanks and Kates 2010). Hazard exposure is the extent to which a place or community experiences undesirable change due to system perturbations (Turner et al. 2003).

Where societies are sensitive to shocks and lack sufficient adaptive capacity, exposure to extreme climatic events causes harm through loss of assets, reduced access to services or employment (Gasper, Blohm, and Ruth 2011), and physical and mental health impacts (Wickrama and Kaspar 2007). Sensitivity is the susceptibility to harm following exposure to a shock and adaptive capacity reflects the ability of individuals or a system to anticipate, respond to, and recover from stresses (Adger and Vincent 2005). Sensitivity reflects development stage, such as demographic transitions in fertility, population structure, and levels of education (Stephenson, Newman, and Mayhew 2010). It is affected by the impacts of previous shocks, manifested through health, nutrition, and housing conditions. Adaptive capacity is likewise strongly related to development and can be analyzed at the institutional or individual level (or aggregates thereof). This capacity represents governance, rights, and literacy (Brooks,

Adger, and Kelly 2005) and is often low in developing world contexts. Deficiencies can be related to either specific (e.g., related to climate risks and agriculture) or generic capacities (e.g., limited income or political power; Lemos et al. 2016).

Vulnerability analysis tends to ignore food security (e.g., Cutter and Finch 2008; Mansur et al. 2016) even though climatic shocks can strongly affect food systems (Sherman et al. 2015). Climatic shocks can compromise food security by disrupting food access or affecting the natural resource base for local livelihoods (Maru et al. 2014). Moreover, floods and droughts can exacerbate chronic food insecurity and malnutrition in developing world contexts, especially among marginalized groups such as the urban poor (Ericksen 2008). The climate–food security literature is largely focused on food production (Ericksen 2008), yet a shock might instead disrupt the poor’s access (Devereux and Berge 2000) to safe, affordable, and nutritious food by affecting income (O’Brien 2006) or transportation networks, food storage, or market dynamics (Maru et al. 2014). We therefore attempt to advance social vulnerability analysis by adding an extra dimension to Adger’s (2006) framework: food system sensitivity.

Disregard of Spatial Inequalities

Studies have identified place-based differences in the level of social vulnerability to disasters with high intraregion variability (Cutter, Boruff, and Shirley 2003; Cutter and Finch 2008), including in Latin America (Hummell, Cutter, and Emrich 2016). Mapping and rankings are also widely used to describe spatial differences in vulnerability (e.g., Antwi-Agyei et al. 2012). To our knowledge, though, no study has adopted a quantitative approach to test for an underlying spatial explanation for interurban differences in social vulnerability. Overall, vulnerability science offers only limited insights into how urban vulnerability might vary spatially (see Cutter, Ash, and Emrich 2016) and even fewer as to why. This is an important shortcoming because, for example, marginalized remote rural communities are highly vulnerable to climate change (Maru et al. 2014) and this might also be true for remote urban centers. The unclear spatial basis of urban vulnerability to climatic shocks is also important because understanding difference is vital for enabling local-level climate change adaptation (Satterthwaite, Dodman, and Bicknell 2009) and humanitarian intervention during disasters. This knowledge

gap is surprising given long-term recognition of spatially uneven development (i.e., inter- and intraregional disparities; N. Smith 1984; World Bank 2009). Indeed, there is widespread evidence of spatial inequalities in many of the factors that constitute sensitivity to shocks and adaptive capacity. Urban vulnerability research is dominated by case studies, though, biased toward metropolitan areas, using conflicting theoretical lenses and methodologies (Romero Lankao and Qin 2011).

Differences in accessibility to other cities could shape interurban variation in social vulnerability. Accessibility is defined as the ease with which goods and services in one location can be accessed by people living in another location (Castree, Rogers, and Kitchin 2013). Within our study context of the Brazilian Amazon, we conceptualize urban accessibility as the outcome of geographical remoteness (transport distances to other cities) and road connectivity (or not). The latter is important in contexts such as Amazonia, where urban accessibility can depend largely on fluvial transport (Salonen et al. 2012). The relationship between roads and development is contentious (Rigg 2002), and it is unclear whether roadless urban centers in Amazonia and elsewhere are more or less vulnerable to shocks than road-connected urban centers, when controlling for remoteness. Roads are also polemic because they have widespread negative impacts on ecosystems yet are mentioned in the Sustainable Development Goals for contributing to economic growth, despite the social and environmental costs (Ibisch et al. 2016).

Irrespective of whether less accessible cities are more vulnerable, spatial analysis of vulnerability should also recognize the ways in which space and spatial relations are produced (Lefebvre 1991). Ribot (2011) argued that vulnerability research must address the social and political–economic processes that have caused marginalization and vulnerability because this is a prerequisite for climate risk reduction. Accordingly, we highlight two theoretical framings of spatial inequalities that can provide insights into potential spatial variation in social vulnerability. The first engages with the work of early twentieth-century geographers and, later, geographical economists. Both groups emphasize how distance to markets determines transport costs and suggest that economic growth is lower in less accessible locations due to competitive disadvantage (Krugman 2011). The World Bank’s (2009) view of spatial inequality is, not surprisingly, derived from geographical economics; less accessible cities are “lagging” in development because high transport costs and small

size incur less economic growth and investment and impaired flows of finance, goods, and services. They contend that these constraints contribute to poverty and poor access to basic services such as electricity and sanitation. Yet, these arguments generally ignore the political and historical factors that strongly influence “uneven development” (N. Smith 1984).

The second framing draws on political economy, going beyond spatial patterns to examine how differences emerge and are perpetuated. Political economic geographers have analyzed the spatial nature of inequalities in well-being (e.g., N. Smith 1984; Harvey and Braun 1996; Goodchild et al. 2000) using the lenses of place-specific histories and cultures, institutions and politics, power relations, and justice (e.g., Massey 1979). Hence, this scholarship has examined spatial inequalities in development albeit not using a vulnerability framework or pursuing generalizable spatial explanations.

Study Aim and Research Questions

Here we ask whether the spatial accessibility of cities is an underlying driver of social vulnerability to extreme climatic events in the Brazilian Amazon. The vulnerability of urban Amazonians to climate change has received very little research attention (Mansur et al. 2016) and there is an urgent need for more research on the human dimensions of climatic change in this region (Brondízio et al. 2016). We address our main objective by asking four specific research questions. First, to what extent do remoteness and connectivity determine the social dimensions (social sensitivity, adaptive capacity, and food system sensitivity) of urban vulnerability to climatic shocks? Second, how are these spatial inequalities produced and perpetuated? Third, what are the relative merits of potential adaptation pathways for redressing spatial inequalities and reducing social vulnerability in less accessible urban centers? Fourth, related to the previous question, what might be the environmental and societal costs of increasing urban accessibility? We answer these questions using empirical data analysis (Q1 and Q2, see Results) and through the interpretation of our findings in relation to the literature and public policy (Q3 and Q4, see Discussion). Although explanations differ, geographical economics and political economy perspectives would agree that less accessible urban centers might suffer disadvantages that limit the capacity of individuals and institutions to thrive.

Hence, we predict greater social vulnerability in less accessible urban centers due to high levels of sensitivity and low levels of adaptive capacity.

Materials and Methods

Study Region

The Brazilian Amazon is well suited to answering our research questions because many of this vast region’s urban centers are located in places where accessibility is precarious (Guedes, Costa, and Brondízio 2009), dependent on a transport infrastructure highly susceptible to floods (inhibiting road transport) and droughts (inhibiting river transport; Szlafsztein 2015). These issues create challenges for municipal, state, and federal governments, tasked with reducing vulnerability and protecting citizens from harm. Moreover, Amazonian urban centers face multiple vulnerability threats: rapid urbanization (Browder and Godfrey 1997); increasing exposure to extreme floods and drought events (Marengo et al. 2013); and underdevelopment, including income poverty and low levels of education (Instituto Brasileiro de Geografia e Estatística [IBGE] 2010) and food insecurity (IBGE 2009).

Experimental Design

Our study is based mainly on analysis of secondary socioeconomic data (for dependent variables employed as indicators of social sensitivity and adaptive capacity) and spatial analysis (for independent variables) from 310 cities in the six states entirely within the Legal Amazon (Figure 1). These data sets are supplemented by primary data on food prices collected from a subset of urban centers. Our study region had 14.48 million inhabitants, 10.58 million (or 73 percent) of whom are urban, distributed in 2.70 million households (IBGE 2010). All data sources and their spatiotemporal references are described in the Supplemental Material.

Vulnerability Indicators

Accessibility Measures

We assessed urban accessibility using measures of inter-urban connectivity and geographical remoteness within an urban hierarchy. Our focus was place-based accessibility rather than travel time or considering individual mobility (see Kwan 2013). To assess connectivity, we developed a travel network for the study area in a

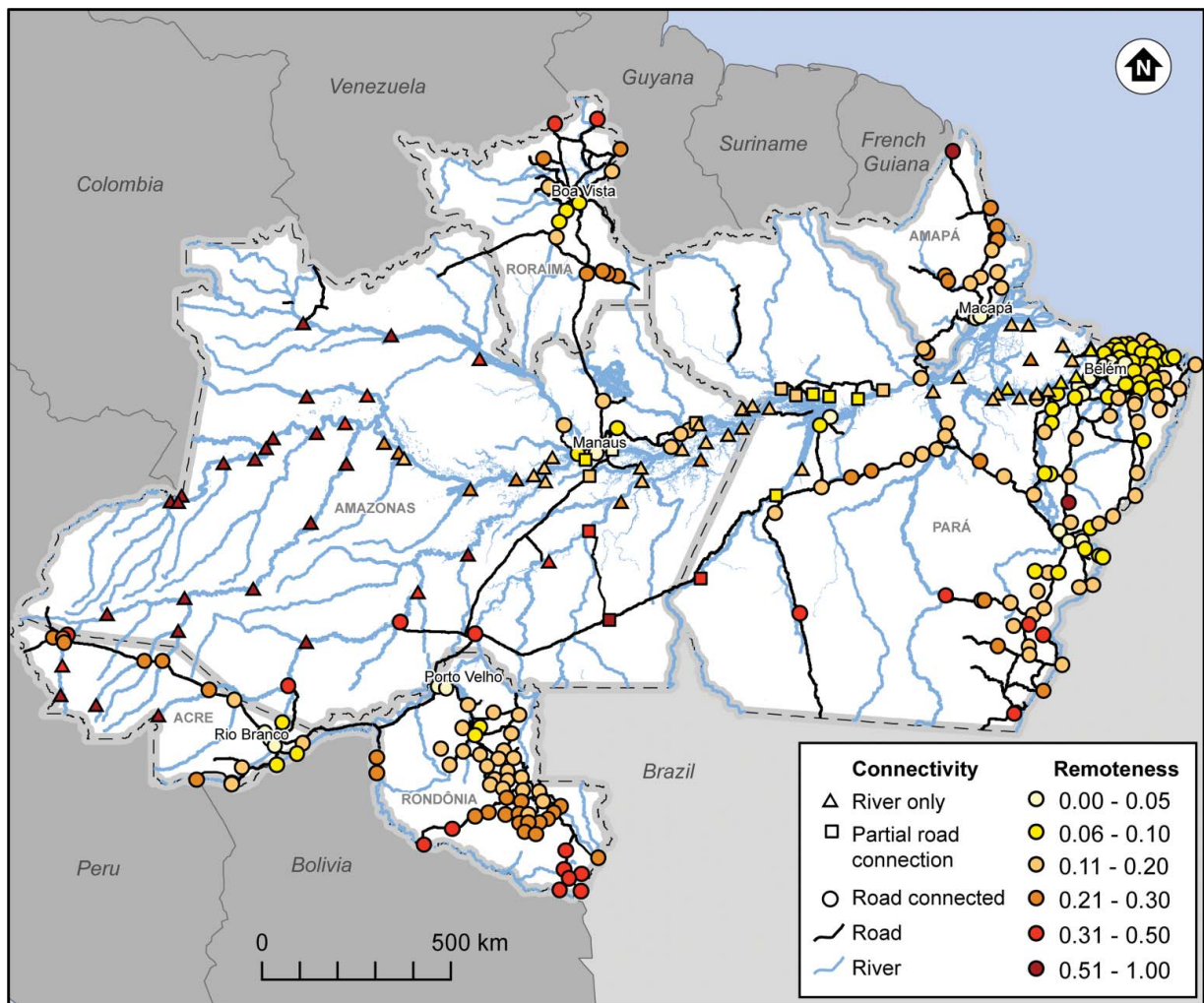


Figure 1. Map illustrating the Brazilian Amazon, road connectivity, and remoteness scores of the 310 urban centers included in this study. Also shown is the road network (official and unofficial) and river network. Shapes indicate connectivity and colors indicate the level of remoteness for each urban center. (Color figure available online.)

geographic information system (GIS), combining information on roads, river networks, and urban locations (see Supplemental Materials). We categorized each center as either (1) having no connection to the road network (roadless), (2) having access to the road network but with a route requiring partial use of rivers (ferry boats or barges to cross rivers), or (3) fully connected to the road network. We calculated a remoteness score ($0.0 > 1.0$) for each center, based on minimum travel distances to centers of different levels in the IBGE urban network (see Supplemental Material). Minimum travel distances between all cities were calculated by identifying routes across our network based on the likely travel potential (0/1) of an arbitrary cargo load. Distances were standardized and weighted by level (Figure 1, Figure 2, Supplemental Material; IBGE 2007), with greater weighting for remoteness from higher order cities (Supplemental Material).

Estimating Sensitivity and Adaptive Capacity

Vulnerability indicators are a well-established (and scrutinized) method for identifying vulnerable people, communities, or regions. We used a deductive approach for selecting indicators of social vulnerability to climatic shocks, drawing on theoretical links between indicators and vulnerability dimensions (Cutter, Boruff, and Shirley 2003; Tate 2012; see also Supplemental Materials). Based on consideration of theoretical linkages, our conceptualization of extreme event impacts in our study system, and data availability, we considered six elements of social sensitivity (Supplemental Material): (1) demography (Cutter, Boruff, and Shirley 2003; Revi et al. 2014; measure = young dependency ratio); (2) sanitation (Brooks, Adger, and Kelly 2005; lacking tapped water, private toilet access); (3) ethnicity (Cutter, Boruff, and

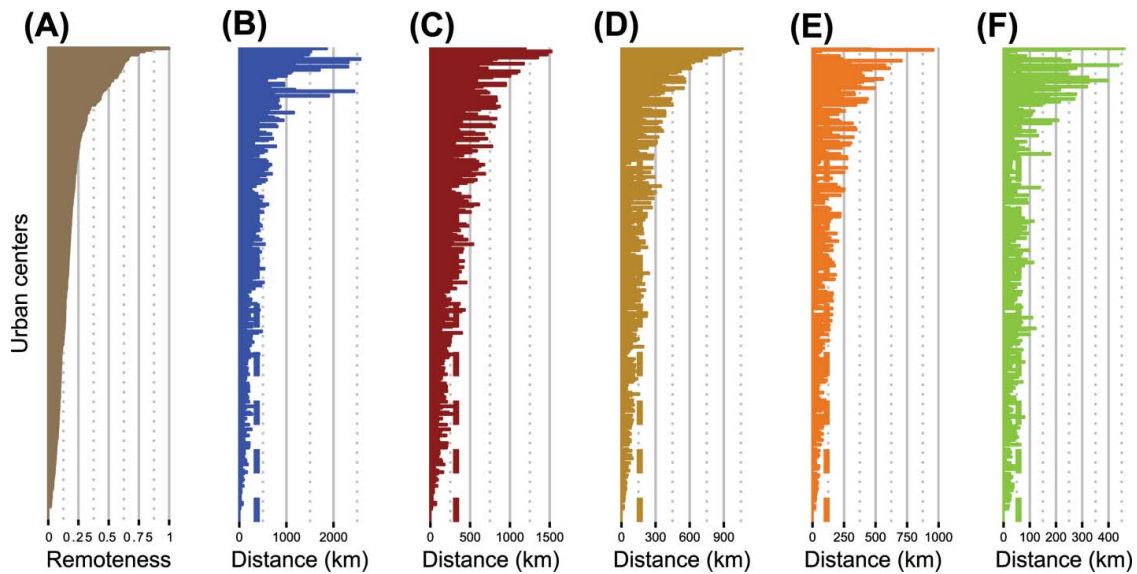


Figure 2. Travel distances from Amazonian urban centers to the nearest centers of different levels in a hierarchical urban network. Urban centers are ranked in decreasing order of overall remoteness score: (A) (gray) Based on a weighted composite of distances to (B) own regional center (blue); (C) any regional center (dark red); (D) subregional center (light brown); (E) zonal center (orange); and (F) local center (green). Journeys could be made by river or road and mean distances are displayed by colored dashed lines for each journey type. (Color figure available online.)

Shirley 2003; proportion of people who are indigenous Amerindians); (4) health (Tol and Yohe 2007; prevalence of low birth weight); (5) education (Brooks, Adger, and Kelly 2005; adults without completed elementary school); and (6) rurality (rural population).

We identified four key elements indicative of adaptive capacity: (1) health care provision (Gasper, Blohm, and Ruth 2011; our measure = prevalence of low antenatal care); (2) education provision (Cutter, Boruff, and Shirley 2003; educational delays among school-age children); (3) urban population growth (Stephenson, Newman, and Mayhew 2010); and (4) poverty (Posey 2009), including income poverty prevalence and income inequality. We normalized our indicators using minimum and maximum values and combined these into two unitless aggregate indexes ($0.0 > 1.0$): a social sensitivity score and an adaptive capacity deficit score.

Estimating Food System Sensitivity

Food access is strongly influenced by affordability, so we used food prices as a proxy. We collected prices for two categories of foodstuffs: those nearly always imported to Amazonian urban centers from outside the region, via major trading centers (i.e., state capitals), and foods that are generally sourced locally, through small-scale agriculture or artisanal fishing. We assessed the price of imported foods and local staples by conducting a telephone survey of hundreds of food

shops across 100 urban centers in Amazonas, Pará, and Acre. Using a structured questionnaire, we recorded the cheapest price available of five imported foods (frozen chicken, tinned meat, dried spaghetti, cracker biscuits, rice) and two locally sourced foods (toasted manioc flour and the cheapest fish species available; see Supplemental Material). These foodstuffs were surveyed because of their importance within Amazonian diets (Davies, Frausin, and Parry 2017). Per capita manioc production was calculated by dividing municipal production for 2010 by the total municipal population in 2010 (see Supplemental Materials).

Statistical Analysis

Our sample size allowed us to separate the effects of urban remoteness and connectivity (which are correlated; correlation = 0.46, $p < 0.05$) and also account for unexplained spatial effects across our study region (e.g., in colonization history, climate, proximity to the rest of Brazil) using state as a fixed-effect control variable. All analyses were conducted in the R platform version 3.2.3 (R Core Development Team, Vienna, Austria). We specified generalized linear models with quasibinomial error structures for proportional outcome variables and for continuous variables with a normal distribution, linear models with Gaussian errors (see Supplemental Materials). All dependent variables

Table 1. The number of urban centers and their inhabitants related to accessibility and social vulnerability

SocVu	Rem	Road-connected			Partial			Roadless			Grand total		
		N	%	Population (1,000s)	N	%	Population (1,000s)	N	%	Population (1,000s)	N	%	Population (1,000s)
Low	Low	98	43	7,693	4	29	161	7	10	151	109	35	8,005
Low	High	42	18	575	1	7	11	2	3	70	45	15	656
High	Low	65	29	857	7	50	66	25	37	274	97	31	1,198
High	High	23	10	283	2	14	19	34	50	419	59	19	721
Total		228	100	9,408	14	100	256	68	100	915	310	100	10,579

Note: Low and high are defined as above or below the overall mean score for social vulnerability and remoteness. Also shown is the total number of urban inhabitants in each category. SocVu = social vulnerability; Rem = remoteness.

were specified in their undesirable form (e.g., proportion of households without a private toilet).

Results

Accessibility Measures

Around three quarters (228/310) of the urban centers in our study region are connected through a road network (Figure 1). These centers are home to 89 percent (9.41 million people) of the region’s urban population (Table 1). We identified sixty-eight centers as having no road connection, inhabited by 9 percent (0.91 million people) of the urban population. Around half ($n = 33$) of the roadless urban centers were in Amazonas state, twenty-one in Pará, and four in Acre. Fourteen urban centers had partial connections to the road network. The most remote urban center was Itamariti, located in Amazonas state, 1,856 km travel distance from its own state capital (Supplemental Material). Roadless urban centers were significantly more remote than road-connected centers (Supplemental Material).

High Levels of Social Vulnerability in Amazonian Urban Centers

Overall, the social sensitivity and adaptive capacity deficit indicators showed that the inhabitants of urban centers in Amazonia contend with challenging development conditions that are likely to increase their risk of harm following exposure to extreme climatic events (Supplemental Material). For instance, on average over one third (36 percent) of urban households lacked access to tap water, nearly a quarter (23 percent) lacked a toilet, and nearly two thirds (64 percent) of adults lacked full elementary education.

Linkages among Social Sensitivity, Adaptive Capacity, and Accessibility

A main finding was that remote urban centers have higher levels of social vulnerability (Figure 3) because they are significantly more sensitive to shocks and have greater adaptive capacity deficits. Remoteness, connectivity, and the spatial control variable explained a relatively high amount of the variation in social vulnerability to shocks, as represented by our indexes of social sensitivity ($R^2 = 0.33$) and adaptive capacity deficit ($R^2 = 0.57$; see Table 2). Results indicate an increase of 0.50 in remoteness score is associated with a 0.07 increase in social sensitivity ($p < 0.01$; Figure 4A), and 0.12 decrease in adaptive capacity, $p < 0.001$; Figure 4C). Five social sensitivity indicators were significantly higher in remote urban

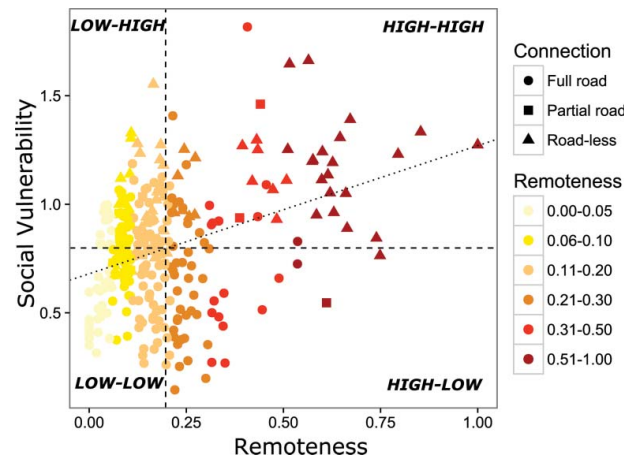


Figure 3. Relationship between remoteness and social vulnerability of urban centers in Amazonia. Social vulnerability is defined here as the sum of two dimensions of social vulnerability to shocks (social sensitivity and adaptive capacity deficit) and is illustrated in relation to two accessibility measures: connectivity (by shape) and remoteness from other cities in a hierarchical urban network (by color). (Color figure available online.)

Table 2. Results of statistical models assessing the relationships between urban accessibility and indicators of social sensitivity, adaptive capacity deficit, food system sensitivity, and environmental measures

Model	Remoteness					Connectivity (Roadless)				Compared to Acre	
	R ²	Coeff	SE	t	p	Coeff	SE	t	p	Better	Worse
Sensitivity models											
Sensitivity score	0.33	0.14	0.05	2.91	0.0038	0.13	0.02	6.38	0.0000	RO	RR
Dependency ratio	0.58	0.18	0.05	3.30	0.0011	0.17	0.02	7.12	0.0000	PA; RO	AP
No tap water	0.21	2.35	0.56	4.19	0.0000	-0.69	0.24	-2.86	0.0045	RR	PA; RO
No toilet	0.46	1.46	0.28	5.12	0.0000	0.31	0.12	2.57	0.0107	All	
Indigenous people	0.56	4.88	0.65	7.50	0.0000	0.98	0.50	1.98	0.0487		RR
Low birth weight	0.08	0.09	0.15	0.60	0.5504	0.15	0.06	2.41	0.0164	RO	(RR)
Low education	0.24	0.37	0.06	6.40	0.0000	0.06	0.02	2.41	0.0164	AM; AP; RR	
Rurality	0.07	0.21	0.34	0.62	0.5365	0.37	0.14	2.54	0.0116	AP; (AM)	
Adaptive capacity deficit models											
Adap cap deficit	0.57	0.24	0.05	4.81	0.0000	0.13	0.02	5.76	0.0000	RO; AM	
Low antenatal	0.41	0.17	0.05	3.12	0.0020	0.10	0.02	4.50	0.0000	AM; PA; RO	
Education delay	0.44	0.17	0.06	2.84	0.0048	0.09	0.14	3.68	0.0003	RO	PA
Urban growth	0.06	50.7	21.4	2.36	0.0187	6.27	9.21	0.68	0.4964	AM; PA; RO; RR	
Poverty	0.62	0.08	0.13	0.60	0.5464	0.34	0.05	6.36	0.0000	RO	PA
Inequality	0.38	0.11	0.02	5.18	0.0000	0.02	0.01	2.12	0.0346	PA; RO	RR
Food system models											
Imported food prices	0.29	0.35	0.12	2.89	0.0050	0.13	0.06	2.34	0.0216	AM; PA	
Farinha price	0.24	1.32	0.74	1.80	0.0758	-0.17	0.35	-0.49	0.6235		(PA)
Fish price	0.35	2.76	1.76	1.57	0.1214	-1.12	0.83	-1.36	0.1803	(AM)	(PA)
Manioc production	0.21	-0.22	0.62	-0.35	0.7249	-0.29	0.25	-1.16	0.2461		All
Natural capital models											
Forest remaining	0.58	3.15	0.72	4.37	0.0000	2.06	0.26	8.00	0.0000	AP; RR	PA; RO
Protected areas	0.26	2.70	0.89	3.02	0.0027	-0.50	0.53	-0.95	0.3454		AM; PA; (RR)
Indigenous reserves	0.37	5.04	0.69	7.28	0.0000	-0.17	0.36	-0.46	0.6440	RR	

Note: Roadless coefficients are compared to being road-connected. Significant state effects in relation to Acre (control group) are shown without brackets ($p < 0.05$) and with brackets ($p < 0.10$). RO = Rondonia; RR = Roraima; PA = Pará; AP = Amapá; AM = Amazonas.

centers, whereas rurality and low birth weight were not significantly different (Supplemental Material). Considering adaptive capacity deficits, four indicators were significantly higher in remote urban centers, whereas poverty prevalence was not significantly different (Supplemental Material).

Another major finding was that roadless urban centers are more sensitive to shocks (Figure 4B) and have greater adaptive capacity deficits than road-connected cities (Figure 4D). When controlling for remoteness, in roadless urban centers, social sensitivity scores are 0.13 higher ($p < 0.001$) and deficits in adaptive capacity are 0.13 higher ($p < 0.001$). All social sensitivity indicators were significantly better in road-connected urban centers (Table 2, see also Supplemental Material). Roadless urban centers were significantly worse for adaptive capacity measures, with the exception of urban population growth, which was not significantly different (Supplemental Material). For instance, in

roadless urban centers, income poverty is 40 percent more likely, when controlling for other variables. State was also a significant predictor in statistical models even when controlling for accessibility measures.

The majority (61 percent) of road-connected urban centers had lower than average social vulnerability, including ninety-eight (relatively) nonremote (total population 7.7 million) and forty-two remote centers (0.57 million population; Table 1, Figure 3). Thirty-nine percent of road-connected centers had high social vulnerability, including twenty-nine nonremote (population 0.86 million) and ten remote urban centers (0.28 million population). In contrast, the majority (87 percent) of roadless urban centers had high levels of vulnerability, including twenty-five nonremote (population 0.27 million) and thirty-four remote centers (0.42 million population). Hence, only 13 percent of roadless cities had low vulnerability, including seven nonremote and two remote

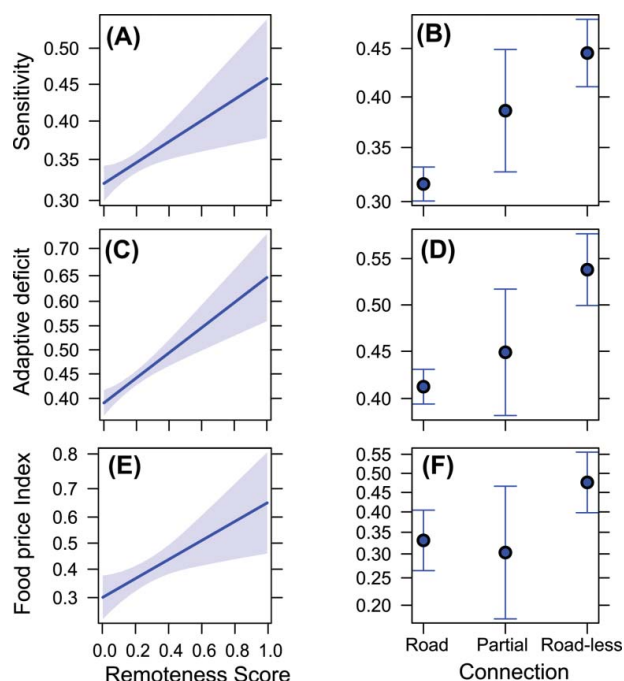


Figure 4. Relationship between urban accessibility and social vulnerability indicators. (A) Social sensitivity scores are related to remoteness from other cities ($p < 0.01$) and (B) connectivity to roads ($p < 0.001$). Adaptive capacity deficits are higher in (C) more remote cities ($p < 0.001$) and in (D) roadless cities ($p < 0.001$). A price index of five key imported foodstuffs (frozen chicken, tinned meat, spaghetti, rice, and biscuits) was significantly higher in (E) more remote cities ($p < 0.01$) and (F) in cities unconnected to the road network or dependent on crossing river(s) ($p < 0.05$). (Color figure available online.)

centers. Variation in the relationship between remoteness and social vulnerability (Figure 3), however, demonstrates that other contextual factors are also important determinants of vulnerability.

Linkages between Urban Accessibility and Food System Sensitivity

Our telephone survey revealed that imported food prices vary hugely among urban centers. For example, the per kilogram price of frozen chicken ranged from R\$2.96 to R\$8.00. Spatial predictors together explained 29 percent of the variation in imported food prices (Table 2). Imported food prices were significantly higher in remote urban centers—the score increased by 0.17 for a 0.50 increase in relative remoteness ($p < 0.01$; Figure 4E). Controlling for remoteness, the food price index was 0.13 higher in roadless urban centers ($p < 0.05$), compared to fully road-connected ones (Figure 4F). Road connections were not significantly related to toasted manioc flour prices. Toasted

manioc flour, however, was more expensive in remote urban centers ($p < 0.10$). Fish prices and per capita manioc production were not associated with remoteness or connectivity but varied by state.

Forest Cover and Reserve Presence around Urban Centers

We found a negative relationship between urban accessibility and natural capital; there has been less deforestation around remote and roadless urban centers. Together, accessibility and the spatial control variable explained 58 percent of the variance in cumulative proportional forest loss at the municipal scale. Remaining forest cover increases significantly with remoteness, to nearly 100 percent around remote urban centers (i.e., in the surrounding rural areas of the same municipality; Table 2). Remaining forest cover is significantly lower ($p < 0.0001$) around road-connected than roadless urban centers (Figures 5A and 5B). Strictly protected areas cover a significantly higher ($p < 0.01$) proportion of remote municipalities and are more prevalent around urban centers with partial road connections than either full- or roadless urban centers (Figures 5C and 5D). Coverage of indigenous reserves was not significantly related to road connectivity but was strongly related to the remoteness of urban centers. Indigenous reserves coverage was very low around nonremote urban centers and very high (in many cases over 50 percent of land area) around highly remote urban centers (Figure 5E and 5F).

Discussion

Our findings provide clear evidence that less accessible urban centers in Amazonia have greater social vulnerability, indicating higher potential impacts of extreme climatic events. Striking interurban differences in social sensitivity to shocks, adaptive capacity, and food system sensitivity were partly explained by two spatial factors: remoteness from other urban centers and road connectivity. This study therefore demonstrates an underlying spatial dimension of the vulnerability framework (Adger 2006), with significant application for refining vulnerability assessment. Our results show that marginalization affects not just subgroups of people (Young 2009) but also less accessible places. We scrutinize whether urban accessibility is a root cause of vulnerability (Blaikie et al. 1994) using two framings for explaining spatial

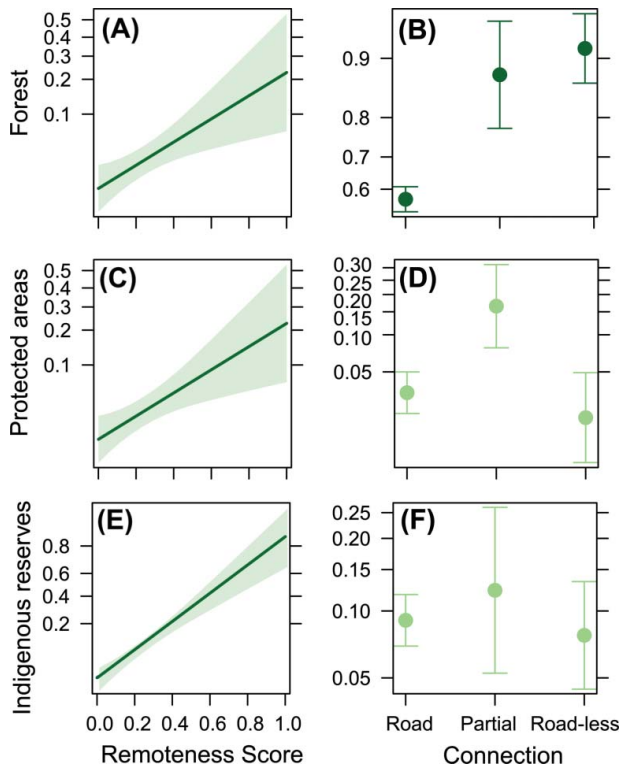


Figure 5. High natural capital and reserve coverage around less accessible cities. The proportion of original forest remaining (i.e., inverse of deforestation extent) is higher around cities that are (A) remote ($p < 0.001$) and (B) unconnected to the Amazonian road network ($p < 0.001$). Remoteness is associated with higher proportional coverage of (C) protected areas ($p < 0.01$) and (E) indigenous reserves ($p < 0.001$). The coverage of (D) protected areas and (F) indigenous reserves is not significantly different around roadless and road-connected urban centers. (Color figure available online.)

inequalities (Rigg et al. 2009): geographical economics and political economy. As we attempt to illustrate, higher social vulnerability to climatic shocks is related to economic and political history (Ribot 2011). We also reflect on the context-specific relationship between accessibility and urban vulnerability and explore adaptation pathways for reducing spatial inequalities.

This article builds on research showing high vulnerability to climate change in remote rural communities (Maru et al. 2014) and shows that this also applies to remote urban centers. Our study also contributes to a small but growing literature on the human dimensions of climatic change in Amazonia (Pinho, Marengo, and Smith 2015; Sherman et al. 2015; Brondízio et al. 2016; Mansur et al. 2016). It is significant that following decades of deforestation, road building, and colonization in Amazonia, four fifths of urban centers are at least partly connected to the road network, and these

urban centers are home to nine out of ten city dwellers. In this urbanized forest “wilderness” (Parry, Barlow, and Pereira 2014) it is paradoxical (to environmentalists; Raudsepp-Hearne et al. 2010) that we found places with the greatest natural capital to have the greatest social vulnerability. We highlight the social and environmental risks posed by road building (Ibisch et al. 2016) and consider the relevance of our findings for other systems.

Less Accessible Cities Are More Sensitive to Climatic Shocks

Our study shows that inhabitants of remote and roadless urban centers are more susceptible to harm following exposure to climate shocks, reflective of an earlier stage of development and demographic transition (Stephenson, Newman, and Mayhew 2010). In other words, a given flood or drought would be more harmful to the inhabitants of less accessible cities, even if exposure was uniform. We show how spatially unequal vulnerability to climatic shocks is partly the outcome of variable access to sanitation among urban centers. Poor sanitation reflects inadequate public infrastructure and poor housing conditions related to poverty and deprivation (Perz 2000). It also exposes people to health risks from environmental pollution and contaminated water supplies (Brooks, Adger, and Kelly 2005). The health impacts of extreme events in Amazonia are poorly understood, but reports suggest outbreaks of diseases during floods (e.g., hepatitis and rotaviruses) and restricted access to safe drinking water, food, and energy during droughts (Supplemental Material). The “racial” aspect of vulnerability relates to lack of access to resources, cultural differences, and marginalization (Cutter, Boruff, and Shirley 2003). Consistent with case studies of remote, vulnerable communities (Maru et al. 2014), indigenous people made up a greater proportion of the urban population in less accessible urban centers.

Strikingly, low birth weight was significantly more likely in roadless municipalities, even when controlling for remoteness. This indicates lower levels of maternal health and nutrition (Christian 2010) and food insecurity (Rose-Jacobs et al. 2008) in these places and supports a posited link between “roadlessness” and malnutrition (Ibisch et al. 2016). Chronic food insecurity and malnutrition in roadless urban centers in the Global South might arise from a combination of stressors, including dietary intake, unemployment and housing conditions (Borders et al. 2007), the burden

of insect-borne and parasitic diseases (Steketee 2003), and perhaps impacts of previous climatic shocks. We found evidence of limited education among adults in less accessible urban centers, further supporting Ibisch et al.'s (2016) predictions. Low education suggests the populations of less accessible urban centers are more susceptible to harm when exposed to shocks (Brooks, Adger, and Kelly 2005), due to increased likelihood of low salaries, informal employment, access to information, and limited power. Limited education in these Amazonian centers might reflect either relatively recent waves of rural–urban migration and poor rural education provision (Parry et al. 2010) or shortcomings in urban education provision. Many aspects of the potential harm experienced by the inhabitants of less accessible urban centers are evidence of societal marginalization (cf. Ribot 2011).

Less Accessible Urban Centers Have Lower Adaptive Capacity

Adaptive capacity was lower in less accessible centers, meaning that the ability of their residents and institutions to anticipate, respond, and recover from stresses is limited (Adger and Vincent 2005). Good antenatal care is vital for reducing maternal mortality and was worse in these places. This implies that local health services would be unable to effectively respond to extraordinary demands, such as disease outbreaks during extreme climatic events (Hales, Edwards, and Kovats 2003). Low uptake of antenatal care in developing world contexts is linked to low availability of clinics and perceived low quality of care (Say and Raine 2007) and consistent with evidence of spatial inequalities in health care (Gatrell and Elliot 2014). Significant educational-stage delays among teenagers in less accessible municipalities might reflect weak school provision, with teacher absence or school closures, for example. Educational delays also illustrate the “blurred” distinction (Hinkel 2011) between adaptive capacity and sensitivity because household deprivation also influences school attendance and attainment (Engle and Black 2008).

Population growth was faster in remote towns yet not significantly different in roadless towns, even though both forms of (relative) inaccessibility were associated with high dependency ratios. Perhaps poor roadless towns experience relatively high rates of out-migration to larger urban centers (Garcia, Soares-Filho, and Sawyer 2007) and thus the linkage between fertility and population growth is partially broken.

Rapid population growth compromises adaptive capacity by overloading public services such as water, sanitation, and health systems and causes unemployment (Stephenson, Newman, and Mayhew 2010; Gasper, Blohm, and Ruth 2011). There is a two-way interaction between poor public service provision and underdevelopment in Amazonia because limited local economic activity limits local investments in services and infrastructure, which reduces employment opportunities (Brondízio 2011). Moreover, embezzlement of public funds by mayors and associates is rife in remote Amazonian towns, partly due to limited state capacity for financial scrutiny in these places (Jardim 2016).

Our findings suggest that weak public administration combines with inequality and deprivation in remote and roadless urban centers to confer intergenerational disadvantages and high social vulnerability to shocks. This mirrors research in Australia showing that people living in remote rural communities encounter economic and social disadvantages throughout their life course (Tanton, Gong, and Harding 2012). Accessibility explained considerable variation in vulnerability, yet significant deviations from this trend highlight a tension in the utility of identifying generalizable determinants of vulnerability. It is clear that it is also important to understand contextual place-specific differences (Romero Lankao and Qin 2011) as well as develop measures of social vulnerability that are meaningful to local people (Oulahen et al. 2015).

Higher Food Prices in Less Accessible Urban Centers

Urban accessibility is linked to the sensitivity of food systems because chronic high food prices in remote and roadless places make lower income groups more vulnerable to price shocks. The prices of staple foodstuffs normally imported to Amazonia via regional centers are more than twice as expensive in the most remote centers compared to the least remote and significantly more expensive in roadless urban centers. Hence, even during nondrought periods the affordability of these staple foods is lower in less accessible places. Consequently, if price increases occurred in remote and roadless centers due to droughts, the poor would face greater risks of disrupted food access (Devereux and Berge 2000; Maru et al. 2014). Indeed, if adjusting incomes by food prices (Shorrocks and Wan 2005), income poverty would also be higher in remote and roadless urban centers. Our results

tentatively support the hitherto untested assumptions that distance from markets is indicative of vulnerability to food insecurity (Haan, Farmer, and Wheeler 2001). Our findings are also consistent with research in the Solomon Islands that found that overall remoteness contributed to national vulnerability because high transport costs between urban centers drove up the prices of imported foodstuffs (Schwarz et al. 2011). Linkages between accessibility and the price of locally produced foods were less apparent. In summary, our results of food prices and birth weight support findings that the impacts of climate shocks on food insecurity and malnutrition are unequally distributed (Grace, Brown, and McNally 2014).

Urban Vulnerability in Amazonia

Research into climatic change in Amazonia is dominated by environmental concerns (e.g., Davidson et al. 2012), and understanding of local health and social impacts is sorely lacking (Brondízio et al. 2016). This bias does an injustice to the ~25 million inhabitants of Amazonia, who are increasingly exposed to extreme hydroclimatic events (Marengo et al. 2013; Filizola et al. 2014). Our study therefore makes an important contribution to current knowledge, especially in relation to cities. Overall, we found high levels of social vulnerability for Amazonian urban centers. This is congruent with a recent Brazil-wide vulnerability assessment (Hummell, Cutter, and Emrich 2016), although our analysis controls for the potential biases of using only municipal-scale aggregate data that homogenize differences in rural and urban social vulnerability (Cutter, Ash, and Emrich 2016). This is important because the ways in which urban Amazonians cope (or not) with flood and drought events are likely to be qualitatively different from the strategies and capacities of rural communities (Pinho, Marengo, and Smith 2015; Sherman et al. 2015). Our central findings are also supported by a case study of Eirunepé, a town with poor public service provision, rendered “invisible” to outsiders by its remoteness (Schor 2013). Other smaller scale urban studies in the Brazilian Amazon have also found ongoing deficiencies in infrastructure, public services, and employment opportunities (Costa and Brondízio 2011). Moreover, Mansur et al. (2016) found that within urban centers, the marginalized poor tend to live in the areas most prone to flooding, combined with low levels of sanitation. Spatial inequalities with richer regions in Brazil are persistent because two decades ago Browder and Godfrey (1997) observed that

rapid population growth in Brazil’s “rainforest cities” had not been accompanied by sufficient economic growth or local development, resulting in “overurbanization” (see Supplemental Materials). Urban expansion in the 1980s entailed rapid shantytown growth, pollution, poor access to social and medical services, and inadequate provision of basic services such as water and sanitation (Perz 2000; Guedes, Costa, and Brondízio 2009).

Underlying Drivers of Spatial Inequalities

Our quantitative findings provide insights into the consequences of accessibility for social vulnerability to climatic shocks but they cannot explain why remote and roadless urban centers are underdeveloped. We interpret our results using the positivist explanations posited by geographical economists versus the more critical, Marxist-influenced arguments of political economy. The importance of transport costs in economic geography (Hoover 1948) could partially explain high food prices in remote Amazonian urban centers. “New” geographical economists argued that proximity to major centers also promotes higher economic growth due to greater flows (of information, ideas, and technology; Krugman 1999) and agglomeration economies in which larger markets grow faster (Krugman 2011). Using this lens, southern Brazil is a more attractive place to produce than the north because of concentrated purchasing power and intermediate input availability (Krugman 1999). These factors have sustained market and supplier concentration and might also partly explain relatively low social vulnerability to hazards in southern Brazil (Hummell, Cutter, and Emrich 2016). The World Bank (2009) certainly follows a core–periphery doctrine and regards spatial inequalities in economic growth between well-connected “leading” areas and less accessible “lagging” areas as inevitable. Gallup, Sachs, and Mellinger (1999) suggested that “hinterland regions” are geographically disadvantaged and exhibit inhibited development due to high transport costs. Applied to our results, high social vulnerability in less accessible urban centers is related to underdevelopment, a consequence of high transport costs impeding flows of goods (ranging from imported food items to exported natural resources or agricultural produce), information, and ideas. Critical and radical geographers, however, have long criticized the reduction of space to an economic variable (Bunker 1989). Using absolute notions of space, they argue, ignores the role of politics, power,

and history in producing space and spatial relations (following Lefebvre 1991). Hence, assumptions that spatial inequalities are inevitable or even desirable (Hirschman 1958) are rejected.

Understanding the underlying causes of marginalization and vulnerability is an important prerequisite of any climate risk reduction approach (Ribot 2011). Vulnerability and resilience research, however, can offer little guidance on how spatial inequalities emerge and has been criticized for ignoring, power, history, and social relations (Brown 2016; but see Romero Lancao and Qin 2011). In contrast, political economists have explored the role of history and power structures in producing unequal regional development (Massey 1979; N. Smith 1984; Martin 1999), and their insights provide useful heuristic tools for interpreting spatially uneven social vulnerability. Political economic explanations for spatial inequalities in development rest on Lefebvre's (1968) contention that space is always political, reflects social facts, and influences social relations. Moreover, political economists argue that, left unchecked, capitalism inevitably leads to uneven regional development. In that sense, spatial inequality in Amazonia is unsurprising because urbanization in developing countries has been characterized by inequality between rural and urban, between urban centers and within urban centers (D. A. Smith 1996). We argue that the underlying explanation for higher social vulnerability in less accessible urban centers is that politics and history—both inextricable from capitalist penetration of Amazonia (Browder and Godfrey 1997)—have shaped the urban hierarchy and created “spatially uneven institutional geographies” (Amin and Thrift 1995). For example, highways in Amazonia have been strategically placed to facilitate resource extraction, agricultural expansion, and international trade. The Amazonian urban hierarchy has also been profoundly influenced by the politics of migration, colonization, state creation, and regional identities (Browder and Godfrey 1997).

To understand the causal mechanisms leading to underdevelopment in less accessible urban centers, we point to Young (2009). She reasoned that structural inequalities are unjust and result from five forms of oppression; exploitation, marginalization, powerlessness, cultural domination, and violence. Young addressed inequalities among social groups, and we extend this to explore how oppression might have created spatial inequalities in social vulnerability. Clearly, the economic history of Amazonia has been defined by the exploitation of natural resources

and labor to meet global demand for commodities. The rubber boom led to the diffusion of poor migrants across Amazonia and was characterized by exploitation of workers and direct or indirect violence against indigenous peoples (Dean 1987; Guzmán 2013). Notably, rubber wealth accumulated in large trading centers rather than in provincial outputs. Applying Massey's (1979) analysis to contemporary Amazonia, the labor demands of Manaus's industrial district could mean that underdevelopment in provincial cities suits the demands of capital interests because it promotes a flow of cheap labor. Marginalization of remote and roadless urban centers also reflects political centrism—the concentration of power and capital in capital cities (Massey, Amin, and Thrift 2003). Historical analysis shows that remote places become marginalized and underdeveloped due to distance from centers of power, which systematically exclude certain social and ethnic groups (Kanbur and Venables 2005; Rigg et al. 2009). Importantly, certain interests benefit from regional inequality and its perpetuation, and these interests are overrepresented in the political and economic institutions reproducing these inequalities (Rigg et al. 2009). Cultural domination of indigenous people arises from unequal power relations and colonial history (Richmond and Ross 2009), which is itself linked to capitalist penetration. Our results show that indigenous people are more populous in the marginalized, less accessible urban centers. We also show how social vulnerability predisposes the citizens of relatively inaccessible urban centers to harm from extreme events, through violence that is structural (Baker 2010) and “silent” (food insecurity and malnutrition; Watts 1983).

Policy Options for Reducing Social Vulnerability in Amazonia

Would transport infrastructure improvements benefit vulnerable people living in less accessible urban centers? According to the World Bank (2009), investing in transport infrastructure in the Global South can reduce distances between cities and encourages increased economic growth. Geographical economists have also argued that development in “hinterlands” is constrained by transport costs and recommended investment in related infrastructure (Henderson 1999). Although causality is unclear, improved transport infrastructure has been associated with economic growth (Calderón and Servén 2014) and might lead

to a decline in the primacy of large cities. Proponents believe that these investments stimulate growth and reduce poverty by lowering transport costs and boosting productivity, wages, information flows, and labor mobility (e.g., Reardon, Stamoulis, and Pingali 2007). However, urban agglomerations might continue to thrive even if initial locational advantages are eroded by new transport infrastructure (Venables 1999). Furthermore, a political economy lens suggests that making roadless urban centers connected would affect social groups unequally and reinforce existing vulnerabilities. In Southeast Asia, connecting remote communities with roads has been motivated by quelling insurgency and market integration, the latter having mixed economic effects (Rigg 2002).

The social risks posed by building roads in Amazonia are supported by evidence that they become focal points for violent social conflict (Dalakoglou and Harvey 2012), marginalization of vulnerable social groups, and disease outbreaks (Barcellos et al. 2010; Ibisch et al. 2016). Moreover, road building in Amazonia would be maladaptive because the inevitable deforestation and land use change would contribute to further climate change (Ibisch et al. 2016), outweighing the potential benefits to some inhabitants of a given city (Eriksen et al. 2011). Indeed, new roads could undermine the “resourcefulness” of remote places (Maru et al. 2014) if deforestation reduced access to diversified livelihoods and natural resource use and immigration compromised existing social relations. Nevertheless, the persistence of forest poverty to privilege a conservationist agenda and mitigate climate change is unjust (Brown 2016). River dependency is problematic for roadless urban centers in Amazonia during drought periods and warrants investment in adaptation (Maru et al. 2014). Alternative, more climate-friendly strategies for maintaining accessibility during droughts include hovercraft transport (Kubo, Akimoto, and Moriwake 2003) or improved air transport infrastructure (e.g., more hydroplanes). The impacts of transport problems could also be reduced by moving toward a more local food system (Sundkvist, Milestad, and Jansson 2005).

If resilience is the antonym of vulnerability, then building the former is critical to reducing the latter (United Nations Development Program 2014). Brown (2016) argued that building resilience can be radical—escaping assumptions of economic growth—through “positive transformations” that redress structural inequalities. After all, balanced economic growth is not the only means of redressing spatial inequalities and injustice. Accounting for historical wrongs is also a legitimate criterion for making spatially targeted

policy choices (Rigg et al. 2009). Yet, identifying suitable pathways is challenging because actions must address the root causes of spatial inequalities in welfare and facilitate adaptation to a changing climate. Resilient development requires communities, neighborhoods, and urban centers to enhance their adaptive capacity for absorbing change, plus diversity, adaptive governance, learning, and self-organization (Nelson, Adger, and Brown 2007; Hardoy and Pandiella 2009). Adaptations must achieve transparent government (Leichenko 2011) and give voice and representation to vulnerable populations (Fransen et al. 2013). Those from marginalized places and social groups must be involved in the decision-making processes that set policy agendas. This would enable interventions to account for local priorities for livelihoods (Bunce, Brown, and Rosendo 2010) and thus engage with the place-based nature of vulnerability (Cutter, Boruff, and Shirley 2003). The Brazilian government has invested in policies likely to assist the poor and vulnerable with adaptation, including health promotion and cash transfers (Lemos et al. 2016). Key services, however, such as education, sanitation, and health care, are worse in less accessible places, evidence of distributive injustice. Further challenges in the Brazilian Amazon include deficiencies in tax collection (Costa and Brondízio 2011), a lack of public early warning systems (Pinho, Marengo, and Smith 2015), and a poorly funded natural disasters agency that overlooks long-term adaptation (Szlafsztein 2015).

Study Limitations

Establishing linkages between indicators of social vulnerability and urban accessibility is an important first step in elucidating spatial inequalities in the potential impacts of climatic change, but important questions remain. Our indicators-based approach cannot account for how agency and subjective perceptions of shocks influence the capacity of individuals and groups to cope with environmental change (Romero Lankao and Qin 2011). Hence, we might overestimate vulnerability in less accessible urban centers by failing to account for structural adaptations to climate shocks—in transport, early warning systems, or livelihoods—that enhance coping capacity (Hardoy and Pandiella 2009). People living in remote places might have rich local ecological knowledge, cultures of reciprocity and sharing, a strong sense of place and belonging, and informal institutions that help them

deal with uncertainty (M. S. Smith and Huigen 2009; Maru et al. 2014; Sherman et al. 2015). In addition, we assess only place accessibility (assuming shorter travel distances mean greater accessibility) and ignore space–time constraints mediated through, for example, mobilities related to the effects of social difference (Kwan 2013). Finally, it is important to establish whether a relationship between accessibility and social vulnerability exists in other systems. Relatively inaccessible cities are found in the Congo Basin, Mekong Delta, Sahara, Himalayas, and Arctic, all of which are increasingly exposed to climatic change (Field 2012).

Conclusions

The unique contribution of this article is using novel empirical evidence to show an underlying spatial basis for the social vulnerability of cities to climatic shocks. This was achieved by evaluating the geographic remoteness and road connectivity of hundreds of urban centers in the Brazilian Amazon and testing the role of these accessibility measures as determinants of social sensitivity, adaptive capacity, and the novel component of food system sensitivity. Understanding vulnerability to extreme climatic events is essential for developing policies that protect vulnerable places and people from harm (Field 2012). Despite clear evidence of widespread spatial inequalities in development and growing interest in the vulnerability of urban populations to environmental change, until now we have lacked a systematic framework for understanding how and why some urban centers have greater social vulnerability than others. Our results show that higher sensitivity to floods and droughts in remote and roadless Amazonian urban centers is related to underdevelopment, including poor sanitation, which increases disease risk. Furthermore, limited adaptive capacity in less accessible urban centers reflects deficient public administration and deprivation, constraining the ability to respond to and recover from shocks. Hence, we demonstrate an underlying spatial basis for vulnerability, which advances Adger's (2006) framework and Cutter's (2003) place-based analysis. Vulnerability assessments of multiple places at a community scale (Cinner et al. 2013) or county scale (Cutter and Finch 2008) have not attempted to systematically explain spatial patterns of vulnerability.

We have explored how the underlying causes of high social vulnerability in less accessible urban centers are rooted in political and economic history

(N. Smith 1984; Ribot 2011), which has led to structural economic disadvantage through high transport costs (Krugman 1999) and underdevelopment. Adaptation pathways for reducing vulnerability in less accessible urban centers should build adaptive capacity through transparent and inclusive governance that accounts for historical injustices and context specificity. In contrast, even if building new roads brought certain advantages such as improved educational access, these might well be outweighed by the social costs borne by already marginalized people (Ibisch et al. 2016). New roads could also reinforce existing vulnerabilities by fueling conflict and disease and eroding social relations in less accessible urban centers. Moreover, the poorest of Amazonia's urban poor often depend on rural livelihoods (Parry, Barlow, and Pereira 2014), which could be undermined by the inevitable deforestation from new roads, which can be "ecologically disastrous" (Ibisch et al. 2016). Deforestation would also increase overall hazard exposure to climatic shocks by contributing to global climate change.

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Supplemental Materials

Supplemental materials for this article can be accessed on the publisher's Web site at <https://doi.org/10.1080/24694452.2017.1325726>.

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