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Frontier spaces of vulnerability: Regional change, urbanization, drought and fire hazard in Santarém, Pará, Brazil

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Abstract. Fire hazard is a mounting concern in tropical rainforests of the Brazilian Amazon and has raised awareness within the science community of the links between agricultural fire use, drought and accidental fire. As a result, fire is being addressed as a crisis event with mitigation focused on those who light fires, particularly smallholder agriculturalists. Little attention is paid to the historical and ongoing ways in which Amazon landscapes and peoples have been made more susceptible to fire. Frontier regions of the Brazilian Amazon serve a variety of functions within the larger Brazilian society, including as extractive reserves for economic development, as social safety valves to reduce population pressures, and as areas to support urban regional integration. Each of these functions has impacted frontier environments in ways that create more flammable landscapes and/or shape the vulnerability of people to fire hazard. This paper uses a case study in the Brazilian Lower Amazon to understand how vulnerability to fire hazard develops. It argues that if fire mitigation remains centered on fire as a crisis event, an understanding of what constitutes frontier spaces of vulnerability, both in landscape and in populations, will be limited.

Keywords: fire hazard, drought, Brazilian Amazon, vulnerability, regional change, frontiers

Introduction

Frontier landscapes are often presented as creating unique circumstances that not only shape everyday life but impact greater society. They leave long lasting imprints on national identity and national institutions (Turner, 1994); act as a social safety valve to alleviate population pressures in non frontier areas (Sewastynowicz, 1994; Smolensky *et al*., 1996); provide a means of social mobility (Sewastynowicz, 1994); serve as extractive reserves that unequally benefit the core economy (Bunker, 1984; Becker, 1990); and more recently, have become focus of intense battles over environmental degradation (Becker, 1996). The frontier experience also implies local hardship often in the face of environmental challenges, and as such, local settler populations are vulnerable in ways that other members of society are not. Yet, there has been little consideration of how frontiers, as manifestations of larger socioeconomic processes, create spaces of vulnerability. Nor, of how these processes may differentially impact vulnerability on frontiers. While clearly frontiers fulfill distinct purposes within greater society, the implications of these purposes for the everyday existence of local frontier residents needs further consideration.

In addition, the dimensions of frontiers are shifting as land settlement persists, particularly so in Latin America. Contemporary frontiers are increasingly seen as urbanizing, characterized either by growing albeit disarticulated networks of urban hierarchies (Sawyer, 1997; Browder and Godfrey, 1998; Brown *et al.*, 1996) or by a transformation of frontier spaces from uniquely rural to a peri-urban or rural-urban fringe. In the Brazilian Amazon, these shifts to a more urbanized frontier did not at first seem to result from a strictly 'urban bias' in regional development strategies, but emphasis on industrialization and linking large-scale economic projects has persisted, planting an urban face onto the far reaches of frontiers. Not only have substantial cities continued to grow, but regional towns now dot the landscape, altering dynamics between urban and rural spheres. Coupling these circumstances has been a chronic lack of adequate attention to rural development at the local level, further fomenting an orientation towards and reliance upon urban areas. Of importance in this work is how urbanizing frontiers in impacting environments, shape vulnerability either by exacerbating the overall experience of vulnerability in frontier areas or by facilitating a differential impact of vulnerability in remaining rural frontier portions.

This paper opens a discussion on vulnerability in frontier spaces by addressing vulnerability to environmental hazards, in particular drought and fire hazard within the Brazilian Lower Amazon.[1] It does so by considering how hazards are positioned in frontier landscapes and then by looking at how the presence of urbanizing frontiers may exacerbate the impact of fire. While fire events are overtly caused by human decisions to light fire, the conditions that make forests and people vulnerable to fire are often established prior to fire events. These conditions become masked by the magnitude and crisis of the fire event with little hindsight into understanding how landscapes and the people living in them become vulnerable. In fact, vulnerability is rarely discussed when the scale of drought and fire hazard remains local in frontier areas. It is not until hazard is magnified and brought to national or international awareness, that these frontier risks are considered.

Vulnerability to fire hazard is not merely a direct outcome of fire events at crisis stage. It is a facet of ongoing frontier evolution, which given the positions of frontiers within larger economic development processes, is constructed in an ongoing manner. To draw more attention to frontier spaces of vulnerability, this paper first considers conceptualizations of vulnerability within natural disaster/hazards research and their application within frontier regions. It argues that although longstanding research treats hazards as chance events occurring in discrete material spaces, more systematic analyses are critical to understanding vulnerability on frontiers. In particular, an understanding of the biophysical and social implications of frontier urbanization and industrialization is needed. The paper then presents how drought and fire hazard have been studied in tropical forest ecosystems in the Brazilian Amazon, with particular focus on the positioning of fire as a crisis event, its relation to drought within material space, federal responses to wildland fires, and the creation of flammable landscapes. In this section, the paper implies that the conventional positioning of drought and fire hazard is aligned heavily with the longstanding approaches to hazards as crisis events. In doing so, the impacts of frontier urbanization on rural peripheries are overlooked, and thus, scant attention is paid to understanding frontier vulnerability in depth. Only an integrative look at urban-rural linkages will highlight more fully frontier spaces of vulnerability. The paper then posits the ongoing forces indicative of Brazilian

frontier regional development, which can hasten both social and biophysical vulnerability to drought and fire hazard, highlighting the necessity to envision frontiers as an urban-rural nexus. Here the paper considers the impacts of regional change and urbanization along the frontier edges of Santarém, Pará, Brazil's fourth largest Amazon city in the last decades of the 20th century. It argues that a combination of urban and rural industrial based initiatives not only creates a more vulnerable physical environment, but encourages the settlement of populations which are differentially vulnerable to environmental hazard. The paper then takes a closer look at the more marginalized populations, with discussion of how drought and fire hazard impact local smallholder households. Here, I use qualitative field notes taken from in depth interviews in the Santarém frontier region of Pará, August–April 1996–1997, July 2000 and July 2001. Lastly, the paper concludes with a call for further investigation into the links between frontier urbanization, landscape change, and vulnerability.

The case study used in this paper is the urban-rural frontier extending south and southwest from the city of Santarém, Pará, Brazil, in the municipality with the same name. The city is Brazil's fourth largest Amazon city and is located at the confluence of the Tapajós and the Amazon River. Research on fire hazard has typically been conducted along the 'arc' of deforestation that runs westerly along the southern flank of the Legal Amazon then up the eastern side. As such, older frontiers, which are characterized by urbanizing and peri-urban frontier edges have not been as carefully considered. The study region is one such area, situated central and north of this arc. Frontier expansion into upland regions south and southwest of the city have been significant in the 1970s period onward. The native vegetation consists of upland forest cover that is typically characterized as terra firme and situated on well-drained plateaus. Accompanying ongoing frontier expansion, vegetation is more varied now, with swaths of crops, pastures, and secondary succession dominant in areas closer to the city, and logged forests with patches of primary forest existing in more remote areas. Annual rainfall averages over 2000 mm with a distinct dry season of 2–3 months and mean annual temperatures of 25°C (Olegário, 1992). Throughout the Brazilian Amazon, drought year rainfall can drop at least 40% and in some instances to even 70% below normal year measurements (Nobre and Renno, 1985). Santarém is no exception to this trend, and has thus been impacted by drought during dry years.

Hazards research, material space, and vulnerability in frontier spaces

Hazards research has traditionally approached natural hazards by envisioning them from a distinctly temporal and material perspective: natural hazards are devastating but *unintentional chance events* caused by uncontrollable natural phenomena (Coburn and Spence, 1992; Clayton, 1994; Cutter, 1996). They interfere into everyday life and often cause great crisis because of their uncontrollable nature. Within this context, vulnerability is perceived as a material risk based on direct exposure to the natural phenomena, frequency and magnitude of the event, and rapidity of onset (White, 1974; Heyman *et al.*, 1991). Mitigation of risk and thus, elimination of vulnerability is often sought through technological interventions—engineered flood control embankments, complex storm prediction/detection units, elaborate warning/evacuation systems, or establishment of safety regulations/codes.

This conventional perception of hazards and risk mitigation becomes problematic when considering frontier regions because it oversimplifies the causal mechanism of the hazard and thus, limits our ability to understand what constitutes vulnerability. The impact on local people when environmental disturbances occur is not restricted to discrete temporal or material spaces, but is often multilayered, and contingent on historical and ongoing frontier dynamics. All of these processes get overlooked when attention is exclusively focused on hazards as chance events. First, the treatment of hazard within discrete spaces limits the possibility of envisioning various forms of environmental phenomena as multiplying overall impact. In frontier regions, the sequence of events can very well combine to exacerbate vulnerability, both in terms of environments and livelihoods. For example, the two natural phenomena considered in this paper, drought and fire are rarely considered in tandem. Yet, a few years of subtle drought may dry a forested area and prime it for a fire event. These same drought years may diminish crop yields and place rural households in such a position that they are less capable of being resilient to losses incurred by an accidental fire. In frontier areas where livelihood strategies are often closer to subsistence levels, ongoing subtle environmental changes may be all that is necessary to dramatically influence vulnerability when a crisis event occurs. Approaching vulnerability from the perspective of mitigating risk from hazards that result exclusively from chance natural phenomena reduces our ability to perceive the multiple facets that interact to create vulnerability in frontier landscapes.

Second, when hazards are positioned as chance events, causal explanations and assessment of vulnerability are tied to the natural parameters of those events. This leaves little room to consider social systematic processes, which often underlie and can explain the differential impacts of natural phenomena. For example, it is quite apparent that natural events of equal magnitude can have very different impacts on human populations residing in different geographic locations, depending on a variety of socio-economic factors (Apteker, 1994; Blaikie *et al.*, 1994). It is also apparent that different social groups do not necessarily suffer equally from hazard, even if they are equally exposed to the exact same hazardous event (Schroeder, 1988; Khondker, 1996). These factors point to the differential effects of natural phenomena that are mediated by ongoing social processes influencing the hazard area, but which were initiated outside of the discrete material space in which the natural phenomena occurred. Societal structures, some of which may not be easily measurable in material space, often have causal links to discrete material events and thus contain mechanisms that lead to these events (Sayer, 1992). Yet, any social factor that may contribute to vulnerability becomes masked when the causes of hazard have only been attributed to nature's capricious actions at a specific point in time.

To enhance this longstanding perception of hazards, research has more recently taken structural and pluralistic approaches to understanding vulnerability, employing historical, political, and broadly social analyses (Hewitt, 1983; Watts, 1983; Bogard, 1989; Downing, 1991; Blaikie *et al.*, 1994). In such research, hazards are no longer envisioned as irregular events but are symptomatic of systematic failure (Mustafa, 1998). This allows vulnerability to be conceptualized as a gradual or ongoing formation based on a nexus of societal, political, and historical conditions. It also allows for more integrated scenarios of environmental hazards, such as the combination of drought and fire. To this extent research has evaluated differential vulnerability to natural hazards based on explicit political constraints on

individuals (Emel and Peet, 1989), urban-biased and uneven development policies (Mustafa, 1998), gender and ethnicity (Schroeder, 1988; Cutter, 1995; Khondker, 1996), and a complex web of entitlement, enfranchisement, and political economy (Watts and Bohle, 1993). Teasing out the differential vulnerabilities as well as multiple layers to creating vulnerability is important when considering frontier regions, precisely because frontiers are positioned within the larger national society in very specific ways.

While such approaches expand conceptualizations of vulnerability to consider how social structures and processes mediate the impact of natural phenomena, the unique capacity of frontiers to reflect biophysical and social processes together should not be overlooked. Frontier populations are often placed in remote and relatively undeveloped areas where the interface of human environment interactions is more pronounced. Livelihood needs are more likely to be directly met by the immediate physical environment and thus, more responsive or volatile to landscape changes. As frontier urbanization persists and influences landscape change, these human environment relationships will shift. They will be linked to urban dynamics and the position of those dynamics in larger society. They will also reflect the links between urban and rural areas, between frontiers and nations. The following section begins to consider these links by looking more specifically at the national positioning of fire hazard as a crisis event in the Brazilian Amazon and the implications of such positioning for understanding vulnerability in frontier regions.

Crisis events: The positioning of drought and fire hazard in the Brazilian Amazon

Fire in tropical forests, scientific inquiry and the federal PROARCO program

Drought has historically drawn little attention within the context of tropical moist forest ecosystems. By necessity, these forest systems have to receive regular amounts of rainfall to support their relatively large biomass structures. Thus, prolonged dry spells were not perceived of as drought and their impacts not sufficiently studied (Salafsky, 1994). This lack of attention to connections between drought and tropical moist forests changed when the 1982–1983 ENSO event induced drought in South East Asia and an estimated 4.5 million ha. of land burned uncontrollably in its aftermath. The dramatic impacts of the Borneo fires, brought to international attention the potential of drought in tropical forests in a way that no single event had done before (Malingreau, 1985; Goldhammer and Seibert, 1990). In South American tropical forests, fire frequency was thought to be extremely low, with major fires occurring once every 100 years or perhaps 1000 years (Saldarriaga *et al.*, 1988; Turq *et al.*, 1998). The strong ENSO events of the 1980s and 1990s changed these perceptions as large fires continued to occur during ENSO years and South American countries experienced them as well. For Brazil, the most dramatic situation occurred in the Amazon state of Roraima when fires burned uncontrollably for three months in early 1998. Approximately, 20% of the state burned, with 9,254 km^2 of it tropical forests. While subtle droughts occurred with minor ENSOs as well as major ones, it is the dramatic impact of fire on tropical forests that has called attention to links between drought and forest cover change.

In contrast to forest fires in temperate or boreal forests, which are commonly started through arson or through natural causes, most tropical fires are associated to a combination of

events: (1) the decisions to intentionally set fires, often made by smallholder farmers to clear their land for agricultural purposes; and (2) the unintentional spread of fire to extraordinary proportions fomented by unusually dry "natural" conditions that leave forest cover easily flammable. Once fires spread uncontrollably, they are characterized as 'accidental fire' by the scientific community (Nepstad *et al*., 1999) or as 'escaped fire' by the policy community (World Bank, 1998), both of which soften any notion of human intentionality or causality in relation to damage caused by fire. Thus, these fires are intentionally lit, but their magnitude and damage rendered are unintentional.

The recent dramatic fire events in Brazil and South East Asia have lead one leading research group to state in reference to the Brazilian Amazon:

> "Fire is the single greatest threat to biological integrity of the largest, richest tropical forests on the planet" (Nepstad *et al.*, 1999).

Further research supports this assertion. Recurrent fires within formerly burnt areas can destroy up to 80% of living biomass (Cochrane and Schultz, 1998). Such fires may increase overall forest cover loss by 129% (Cochrane *et al.*, 1999). In heavily logged eastern Pará, forest cover affected by fire is estimated to be three times greater than areas affected by deforestation (Alencar *et al.*, 1997). Environmental apprehension at the international level echoes this concern. Carbon emissions from forest conversion, shifting agriculture, and clearing of secondary vegetation in the tropics has been of concern for over 20 years. At latest estimates, 29% of total anthropogenic emissions from fossil fuels and land use change, are associated to biomass burning and related carbon loss (Fearnside, 2000). Thus, reputable scientists imply that fire is a great threat to tropical forests and to the viability of the global environment.

These valid apprehensions within the science community are expanding the focus of environmental threat in the Brazilian Amazon from deforestation towards forest flammability. The significance of this shift is that environmental threat becomes positioned as a crisis event. Response to crisis easily falls into the over simplification that occurred within hazards research and vulnerability to fire hazard is understood in a limited form. When fire emerges as the "single greatest threat", it becomes positioned within discrete temporal and material space–under drought conditions, fires that are intentionally lit, grow out of control. From such a perspective, it becomes very difficult to tease out any systematic failures that exacerbate fire hazard and create spaces of vulnerability, both societal and biophysical. The danger in associating environmental change in such a manner is that development strategies, regulations, and policies which deal with environmental change become re-oriented toward the hazardous event in its crisis state, rather than towards the systematic conditions that may foment the overall impact of this event.

The case of Brazil's fire policy exemplifies this. Brazil developed and submitted an emergency proposal to the World Bank for $15 Million dollars entitled PROARCO (Programa de Prevenção e Controle ás Queimadas e aos Incêndios Florestais no Arco do Desflorestamento—Emergency Fire Prevention and Control in the Amazon) to combat fire hazard in the Amazon region (World Bank, 1998). The proposal was submitted by the Brazilian Institute for the Environment and Renewable Resources (IBAMA), and was designed to prevent large scale wildfires in the 'arc of deforestation' where cattle ranching,

logging, and smallholder agricultural activities are common. The submission in August 1998 dovetailed a prolonged 1997–1998 dry season, and the uncontrolled burning in the state of Roraima.

PROARCO was designed through a series of components: (1) risk assessment and fire monitoring in critical areas, through integrating spatial information on soil moistures, vegetation cover, and human activity maps; (2) forest fire prevention, largely through heightened public awareness, increased local education campaigns about fire use, and establishment of well equipped and trained personnel to conduct prescribed burns; (3) forest fire suppression, through development of inter-agency[2] fire contingency plans to combat fire spread in the face of large scale wildland fires; and (4) coordination, monitoring and evaluation over day to day implementation of the project. No where in this proposal was there energy or resources allocated in understanding how frontier evolution shapes vulnerability in the first place, nor in evaluating if vulnerability is differentially affected. Rather, the proposal aimed at measuring and mitigating risk, developing early detection systems and beefing up emergency fire response systems to ameliorate exposure of forests and local populations to accidental fire. While certainly efforts by the federal government to prevent massive wildland fires are commendable, landscapes and populations living within frontier areas are vulnerable as a result of ongoing frontier dynamics. Their varying vulnerabilities and abilities to recuperate get less attention if drought and fire hazard remain positioned merely as crisis events within discrete material spaces.

Nowhere is this better exemplified than at local level implementation. The project allots approximately 35% of requested funds to the Forest Fire Prevention component, which implements community based programs to inform local people about the risks and consequences of uncontrolled burning. This component includes community mobilization and training of approximately 120,000 local community leaders and ranchers in techniques of controlled burns, as well as public awareness and education campaigns. In addition, the project states that it will rely on social capital by seeking "to strengthen and build on existing systems of social control at the community level to prevent irresponsible burning and consequent fire escapes during the . . . dry season" (World Bank, Summary Project Analysis, p. 3). Lastly, the proposal also states that it plans to incorporate local knowledge that already exists on burning within the Amazon ecosystems. All of these measures focus on the immediate antecedents to fire events, those who actually light fires. The questions of causality beyond the discrete material space where crisis occurs, or of if frontier conditions facilitate more vulnerable landscapes and populations are side stepped.

In addition, there is the potential for these immediate antecedents to fire events to be criminalized. In 1998, the Environmental Crimes Act was decreed making acts against the environment a crime. Intentionally setting fires that lead to large-scale wildland fires burning precious tropical forest resources could conceivably fall under the definitions of this act. The PROARCO proposal refers to eliminating what it considers illegal fire activity. IBAMA in coordination with Forestry Police and State Environmental Agencies, claims it will "conduct intensive enforcement operations and compliance to regulations would be increased . . . as part of an integral system that would prevent and regulate illegal burning activities" (World Bank, 1998, Annex 2, p. 1). Since the 1998 fires, IBAMA has begun requiring that landowners obtain permission to light fires. It remains to be seen whether and

to what extent this act and increased regulation on fire activity will be enforced because of the enormity of territory where fire activity exists in comparison to paucity of policing resources. But certainly since the 1998 fires, the pressure to deal with the fire issue has been stepped up and focus reamins exclusively on those who set fires. In the last few years, it seems that landowners closer to IBAMA branch offices and operations, particularly those intending to burn relatively large areas of land, such as, cattle ranchers are the ones required to seek permits to burn (personal observation, 2001, 2002). However, if such policy implementation persists and is more regularly enforced, then anyone setting fires without permission could be penalized. In the most extreme scenario, attention to fire hazard is exclusively focused on those who light fires, rather than upon the larger more ongoing factors that may lead to a landscape vulnerable to fire.

Creating flammable landscapes and social vulnerability

Despite reaction to crisis events, there are substantial strands of evidence that formulate links between frontier evolution and vulnerability to fire hazard. Both social and physical scientific inquiry present critical arguments that provide a picture of how fire hazard is constructed given the position of the Amazon frontier in Brazilian society and its urbanizing character. The construction of fire hazard results from both the physical creation of a more flammable landscape, and the placement of populations within the landscape with varying social vulnerabilities, capacities to respond to drought and fire conditions. While one process alone can not be exclusively attributed to fires in tropical forests, the layering of all these activities demonstrates the urban rural links that create circumstances ripe for fire hazards to emerge. As populations and landscapes continue to interact, creation of a fire hazardous environment occurs.

The function of the frontier as an extractive reserve highlights connections in these arguments. Timber extraction has historically occurred in small scale operations on floodplains where rivers are used to transport logs for processing in industrial areas or to markets (Rankin, 1985; Barros and Uhl, 1995). Since the 1970s, the drive to take advantage of Amazon resources has encouraged logging efforts into upland areas (Browder, 1989), which has had an impact on forest flammability in a not so subtle way. Selective logging opens up canopy cover creating drier micro environments while leaving highly flammable fuel loads in the form of dead residual debris on the forest floor (Uhl and Buschbacher, 1985; Fearnside, 1990; Uhl and Kauffman, 1990). These forest gaps experience re-growth in the following years, but it takes many years for them to structurally develop the more closed canopies characteristic of mature forests that trap moisture and are less susceptible to fire. Forest gaps take years to develop the extensive root systems that tap into underground moisture and become drier during drought years dropping more leaves that produce a light fuel load at ground level.[3] Whereas in 1976, Amazonian production of industrial roundwood accounted for only 14.3% of national production, by 1987 it had climbed to 54% (Browder, 1989). An estimated 10,000–15,000 km^2/yr of forest cover is currently affected by logging operations (Instituto do Homen e Meio Ambiente da Amazônia, cited in Holdsworth and Uhl, 1997; Nepstad *et al.*, 1999). Compounded yearly this creates a sizeable landscape in which forest dryness and potential flammability exists.

While timber extraction occurs within forested areas, the logging industry reflects economic interests at state and national levels. Again this demonstrates the function of the frontier within the Brazilian state both in its extractive and industrializing capacity. Federal export led growth strategies in the 1980s invigorated small boom town logging industry operations (Browder, 1987, 1989). These regional towns form the bulk of new urbanization throughout the Amazon. In some towns logging operations have progressed so much as to be vertically integrated. A federal ban on the export of round wood was designed to encourage wood processing industries, most of which have emerged in larger cities with transport capabilities that extend beyond the immediate region. Sawmills, wood processing and manufacturing industries which utilize wood all require energy, labor, and transport facilities that both attract jobless rural residents into urban areas and are also fostered by the infrastructure of the urban presence. The promotion of economic growth through extraction and processing of frontier resources plays a role in the creation of a flammable landscape.

Indirect outcomes of logging also contribute to fire hazard. Logging roads allow access to landless populations who arrive and use fire to clear land for agricultural production (Detwiller and Hall, 1988; Stone, 1998). As these areas are relatively remote, the ability to enforce any sort of environmental monitoring is minimal. The precariousness of land tenure for those who invade land also leads to situations that make reduction of fire use less viable. When land tenure is uncertain, smallholders have minimal incentive to invest in long term land use strategies such as perennials or agroforestry. Instead they rely on slash and burn agricultural strategies that require fire use. Lastly, the livestock industry also has links with timber extraction. Cattle ranchers often sell logging rights to forested areas of their properties in an effort to accrue funds to subsidize pasture maintenance and livestock operations (Uhl and Buschbacher, 1985). This has particularly persisted since government subsidies for large scale ranching operations ceased in the 1980s. Frontier extraction of timber interacts with a variety of social processes to create more flammable conditions within the physical environment.

Another important function of the Amazon frontier within larger Brazilian society was as a safety valve to alleviate population pressure in other parts of the country. This function also contributed to landscape flammability and social vulnerability. Federal colonization projects were designed to distribute land to the landless by shifting populations from the land scarce south and northeast to the land abundant Amazon region (Moran, 1981; Smith, 1982). These colonization projects brought a wave of smallholder farmers into the Amazon who relied on fire use to clear land for agricultural fields. Their agricultural practices further introduced a patchwork of secondary succession that is more vulnerable to drought and fire hazard, than its predecessor tropical forests. Thus, not only were more fire users living in frontier areas, but these users were working in an ever more flammable landscape of crops and vegetation at various stages of secondary succession. While the financial support for federal colonization projects has since waned, spontaneous land invasion continues. This pool of people remains the most vulnerable to environmental hazards, such as fire. They have the fewest economic alternatives to practicing slash and burn agricultural techniques. They also are the least resilient if fires go out of control.

Federal incentives for livestock practices, further peppered the frontier with flammable landscapes and fire users, with varying levels of social vulnerability. These ranches were part

of corporatist strategies to economically develop the Amazon (Browder and Godfrey, 1999). They required the opening and burning of large tracts of forested areas. And once created, a more frequent fire dynamic was inserted onto the landscape. Ranchers intentionally burn pasture areas as a maintenance strategy to control weedy growth and reinvigorate grass development. These fires occur annually over the same areas of land, chronically exposing bordering forest cover to fire. Repeated burning then gradually deteriorates forest edges, making them more susceptible to fire hazard. Grassland cover dries quickly during the dry season, and is quite susceptible to fire. As a social group, ranchers are in a different position than are smallholders. They often have economic strategies within nearby urban areas, and thus do not exclusively rely on rural landholdings for their livelihoods.

These arguments demonstrate the impacts of social frontier processes, which shape frontier environments, create flammable landscapes, and shape social vulnerability. They are initiated months to years before crisis fire events occur, yet may affect forest flammability, magnify repercussions of fires set by local residents, and exacerbate vulnerability of local populations. They also connect rural environments to urban regional development and national interests, thus reflecting the position of frontiers in larger society. Yet, these more systematic understandings of landscape change are masked when fire hazard is positioned within discrete temporal spaces to be predicted, measured, and prevented. Subtle underlying causes that began prior to a fire event are often overlooked while understanding vulnerability is limited to the parameters of the specific fire. In order to better understand what creates vulnerable people and places, the following section considers frontier urbanization trends and their impacts on rural environments in a specific case study, the agricultural frontier of Santarém, Pará.

Creation of a fire hazardous landscape in Santarém Municipality: Urbanization, industrial development and frontier change

Frontier expansion and industrialization in Santarém

Contemporary frontier expansion in Santarém Municipality resulted from a combination of regional development initiatives designed to enhance industrialization and secure Santarém's economic position within the Amazon, along with spontaneous settlement that

Table 1. Landholdings in Santarém municipality, 1980–1995 by size

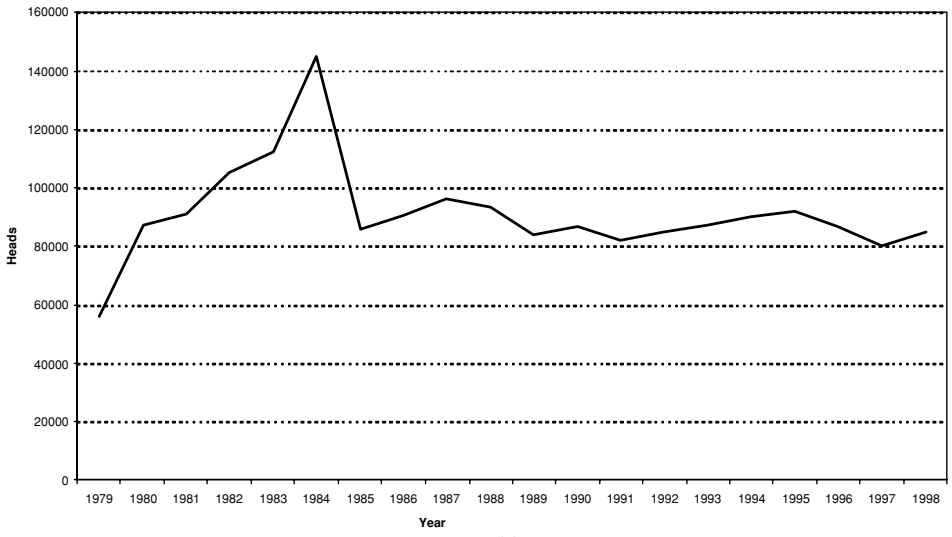
	Establishments less than 100 ha		Establishments 100 ha to less than 200 ha		Establishments 200 ha to less than 500 ha		Establishments 500 ha and above	
	Establishments	% of total est.	Establishments	% of total	Establishments	% of total	Establishments	% of total
1970	10,434	94.4	523	4.7	76	.7	25	.2
1980	11,482	87.6	1,525	11.6	57	0.4	39	0.3
1995	13,201	78.5	2,936	17.5	500	3.0	174	1.0

Instituto Brasileiro de Geografia e Estatisticas (IBGE). 1970–1995. Agricultural census for the state of Pará. IBGE, Rio de Janeiro, Brazil.

emerged in tandem with these initiatives. Historically, Santarém's economy was characterized by extractive boom and bust cycles, particularly that of rubber (late 1800s, 1930s–1940s) and Juta[4] (late 1930s–1980s), and rural population remained higher than urban (McGrath *et al.*, 1993; WinklerPrins, 2001). In 1960, only 26.6% of the population of Santarém Municipality resided in urban areas, predominantly in the city of Santarém. By the year 2000 that percent had grown to 71% with total urban population reaching 186,567 (IBGE, 1960–2000; Prefeitura Municipal de Santarém, 2000). Throughout this time period, some urban growth was associated with population increases in smaller towns in the municipality, including Alter do Chão, Belterra,[5] Mojuí dos Campos, and Jabutí. However, by far the preponderance of urban growth occurred in the city of Santarém proper with 95% of the urban population in Santarém Municipality living within the 31.6 km^2 of the city urban area by the year 2000. As in other parts of the Brazilian Amazon, this trend towards frontier urbanization created specific urban-rural linkages that took a toll on rural landscapes by exacerbating both social and biophysical vulnerability. These linkages brought fire activity to frontier regions, while biophysically creating flammable landscapes and allowing socially vulnerable populations to reside in them.

Santarém's south western frontier edge was largely opened with construction of an intrastate road, PA 370, which extends southwesterly from Santarém to the Curuá-Una River. This road and subsequent frontier expansion was planned to enhance economic potential in the city of Santarém, but with limited success, while consistent attention to local rural populations and landscapes has been modest. Of most importance was to tap into hydroelectric resources on the Curuá-Una River through construction of the Curuá-Una Dam, which was filled with water in 1977. While projected energy capacity was 100 mw (Fearnside, 1995), only 30 mw was transported directly to the city of Santarém via power lines that bypassed many rural households. While in the 1960s this energy may have been sufficient for the city, lack of industrial development in the last few decades has often been blamed on poor energy access limited by the dam (IDESP, 1992; Prefeitura Municipal de Santarém, 1998). Meanwhile, the opened road spawned spontaneous settlement particularly at the outskirts of the urban area, bringing smallholder farming operations that used fire to clear land.

A second characteristic of this frontier edge became important to Santarém's economic interests as well as having implications for fire activity and hazard. Year round water sources were more readily available, making livestock practices viable. As such, federally subsidized large-scale cattle ranching projects were initiated in the 1980s and attracted corporate interests from the south of Brazil as well as Santarém's local elite population. Between 1980 and 1985 the Superintendency for Development of the Amazon (SUDAM—Superintendencia de Desenvolvimento Amazonica) oversaw public land transfer for the creation of ranches. Number of livestock heads, both beef and milk cattle, in Santarém Municipality peaked in this early 1980s period then dramatically dropped in 1985 and has yet to recover to its earlier 1980s capacity (figure 1). These ranches also introduced a population with business interests onto the landscape and created a more affluent social group that could more powerfully vie for its interests in the municipality. These business interests bridged urban and rural areas in a unique manner, maintaining business strategies that included urban operations and rural ones. As a population they straddled urban and rural areas, some being absentee or weekend rural residents and residing in urban areas during the week to



(a)

(b)

Figure 1. Livestock production in Santarem municipality. (a) Beef cattle production, 1979–1998. (b) Milk cattle production, 1981–1998 (Data is taken from Prefeitura de Santarem, 2000).

conduct business. Between 1970 and 1995, medium and large scale landholdings (200 ha or more), which largely represent livestock operations, increased. In comparison, smallholder landholdings less than 100 ha steadily decreased, though represented significantly larger number of establishments (78.5% of all establishments by 1995).

The Santarém frontier was also opened through construction of the Santarém-Cuiabá Highway (BR 163) which began in 1972 and extends due south of the city. The reasons for road construction also pertained largely to regional development interests rather than local rural needs. The road was conceived as a regional transport corridor and became the first terrestrial link from Santarém to Brazil's more urban and industrialized south (Santos, 1996). Upon completion of this terrestrial link, manufactured goods assembled in Manaus' export processing zone could be shipped via the Amazon River to the port of Santarém, then distributed southward by road onto the more populated and affluent portions of the country. This would conceivably secure Santarém a strong economic position in the Amazon.[6] In conjunction with road construction, the National Institute of Colonization and Agrarian Reform (INCRA—*Instituto Nacional de Colonização e Reforma*) proceeded to open up forested areas though an Integrated Colonization Project (PIC—*Projetos Integrados de Colonização*) along side the road. The project consisted of 750 lots, typically 100 ha in size, as were established in other colonization projects in the Brazilian Amazon (Miranda *et al.*, 1996; Prefeitura Municipal de Santarém, 2000). The potential of secure land tenure rights on these lots encouraged many smallholder families to settle in this area, but minimal agricultural extension and other infrastructure to support successful transitioning onto the lots was offered (Miranda *et al.*, 1996). Smallholder farming persisted in a largely subsistence semi commercial form with limited large scale mechanized farming or livestock operations until the mid 1990s. Fire was used on an annual basis at the end of the dry season to clear land for agricultural fields or pastures. Since the 1970s, colonization has created a patchwork of secondary succession (fallowed areas) running parallel to the Santarém-Cuiabá Road (Sorrensen, 1998).

Timber extraction has also steadily developed in the region, with the city of Santarém benefiting from industrial development. The *Primeiro Polo Agroflorestal-Industrial* plan was initiated in western Pará with the intention of harvesting 613 million m^3 of commercial timber and developing industrial complexes to facilitate wood processing operations (Movimento Pró-Oeste, 1995). Logging ranks second in Santarém's exporting activities with the most commercially viable species being Jarana, Itaúba, Tauari, and Massanranduba. There were 31 industrial establishments associated to logging in 1980, by 1995 that number had increased to 140 including sawmills, wood processing, and wood manufacturing establishments (IBGE, 1980 and 1995). The number of establishments located along the Santarém-Cuiabá Road heading south from the city alone is estimated at 120, with new establishments coming in every month (McGrath *et al.*, 2001). A Brazilian ban on log exports, designed to stimulate wood processing industries, has also supported industrial growth in the Santarém Municipality (Barros and Uhl, 1995). Yet, while logging extraction has steadily grown, capacity to develop other wood industry was somewhat stalled by the restricted energy capacity to process logs. Thus, attention soon focused on measures that would enhance energy to Santarém and facilitate its industrial growth.

In 1998, power lines linking the city of Santarém to the Tucuruí Dam, over 900 km southwest of the city, were completed. The dam has capacity to supply 148 mw to Santarém with the explicit hope of stimulating industrial growth within the city. Power lines now run parallel to the Santarém-Cuiabá Road and can even be deciphered from satellite imagery.

With these in place, increased industrialization is occurring in the city and log processing operations are developing which will continue to encourage logging and the fire susceptible forest spaces that it creates.

The increased electrical and industrial capacity of Santarém also made it an attractive hub for further economic integration with Brazil's newly developing central and west breadbasket region. In the mid 1980s mechanized production of soybeans and rice became viable along the southern savanna edge of the Amazon Basin, extending through the state of Mato Grosso and into the southern rim of Pará. The search of a viable transport route to international markets pointed towards improving the Santarém-Cuiabá road and port facilities in Santarém. The geographic location of Santarém port made it particularly well suited to link the central west of Brazil to markets in North America, Asia, and Europe. Produce would be carried north up the Santarém-Cuiabá Highway, then shipped down the Amazon River from Santarém's upgraded port facility to the Atlantic Ocean out onto other countries. Conversely, the port and road combination could become a major importing player to the more affluent Brazilian central south. The first major road improvements began in 1998 on the swath of road extending south from Santarém when 90 km were paved. The paved road passed directly alongside many of the INCRA colonization plots established in the 1970s, facilitating transportation between rural and urban areas. Both the states of Pará and Mato Grosso promoted the road as a "corridor of integration" to ameliorate regional economic inequality (IDESP, 1992; Santos, 1996; Prefeitura Municipal de Santarém, 1998).

Lastly, the most recent set of dynamics emerging from regional strategies to improve Santarém's economic integration with the Amazon and beyond, is mechanized farming. With improvement in transport and energy now underway, mechanized farmers are buying up smallholder properties and consolidating land in anticipation of large-scale soybean and rice export operations through the port of Santarém. These dynamics are further linking rural spaces to the urban center and influencing frontier vulnerability, by implanting a set of social actors onto the frontier that is wealthier and has access to many more resources on and outside of the frontier. Once mechanized agriculture is in full swing, smallholder farmers will have a harder time competing and many will sell out to mechanized operations, if they have not done so thus far. Those who are pushed off their lands may join others as part of urban poor, swelling the urban-rural fringe population, or they may search for more remote frontier areas to homestead. In the later case, they become more vulnerable as they are essentially beginning the settlement process again, with limited resources. For those who are able to stay on their land, land speculation and consolidation places them in a more vulnerable position because it is more difficult to maintain their livelihoods and therefore, maintain a resiliency if environmental hazards occur.

These transformations of the Santarém frontier region into a space that supports more industrialized and urbanized processes continue to have a many fold impact on smallholder vulnerability, of which four aspects are argued here. First, overall regional economic strategies have historically and continue to pay scant attention to local rural development. This signifies that a vulnerable population, which was initially encouraged into rural areas, has fewer possibilities to develop strategies that keep them resilient in times of crisis. Second, through logging processes and road improvements, the urban/industrial focus of the frontier

continues to perpetuate a more hazard vulnerable environment for the smallholders that are able to stay on their properties. All the direct and indirect outcomes of logging indicate that it is an activity that produces a drier landscape, one more susceptible to fire hazard. Third, industrialization in the Santarém region is fomenting a land consolidation process, which will further marginalize already poor smallholder households. Again, this reduces their ongoing potential to be resilient in times of crisis. Lastly, once a large scale fire has occurred, the repositioning of drought and fire hazard into a crisis event would likely invoke pressures to prevent fire use which will adversely stress those most reliant on it. These pressures are already appearing on the Santarém frontier, despite the fact that as yet there has not been a devastating fire of the proportions that occurred in Roraima in 1998. Because these pressures are focused on direct perpetrators of fire, predominately local rural households, they focus on one of the most vulnerable populations without fully considering what constitutes vulnerabilities on the frontier.

Impacts of drought and fire hazard on rural smallholder agriculture

Against the backdrop of frontier expansion and differentiation, smallholder settlement has persisted, expanding the rural population whose livelihoods rely directly on their immediate environments. Smallholders continue to be vulnerable to drought and fire hazard, while less likely benefiting from regional initiatives oriented towards the city. They are vulnerable not only because of regional changes that are influencing frontier landscapes, but because their land use strategies are immediately affected by drought and fire. Rural smallholders utilize a diversity of farming strategies, including some combination of annuals, perennials, agroforestry, and livestock practices, all of which are impacted when drought occurs. With a shortened rainy season the ability of annual crops to mature is limited and perennial crops can be damaged or die altogether. Reductions in overall crop production make for meager years on smallholder farms and can place rural households at an extra disadvantage if environmental conditions change.

Of the annual crops, rice is particularly affected by a shortened wet season because it needs a full 5 months of rainy weather to mature. Rice seeds do not deteriorate quickly when planted and can thus, be planted near the end of the dry season and will still produce after rains come. Thus, farmers who are unaware that their region is experiencing drought, may be likely to go ahead and plant rice, despite indications that the rainy season has not quite arrived. When rains do not come, or come for an insufficient time period, losses in rice crops can be great. Not only are overall crop yields lower, but losses in proportion to seeds planted also occur. Between 1980 and 1999, rice production per hectare dipped or merely stabilized during the peaks of drought periods (figure 2(a)).

The seeds of two other common annual crops, corn and beans, are more likely to deteriorate in dry weather so are not usually planted until rains have begun. Thus, in the scenario of a drought season farmers might postpone planting these crops or opt not to plant at all if sufficient rain does not eventually arrive. This cushions their losses in a potentially dry year. While corn is usually planted at the beginning of the rainy season, beans are planted half way through. Both have shorter growing cycles and are thus have a better chance of reaching maturity in a shortened wet season. Corn production per hectare of land for Santarém

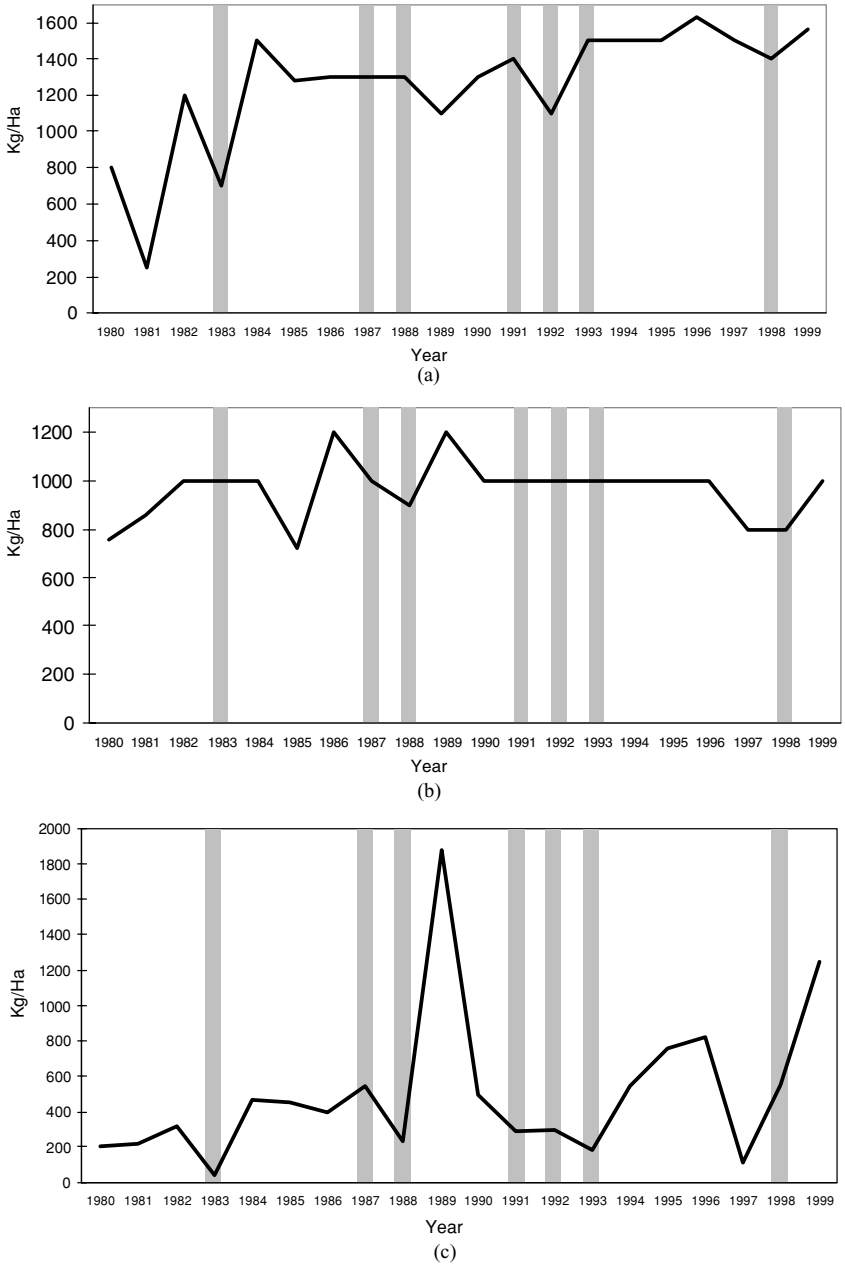


Figure 2. Agricultural production in Santarem municipality. (a) Rice production. (b) Corn production. (c) Bean production. (d) Manioc production (Grey bars indicate years in which sea surface anomalies were significantly positive January through March and thus, ENSO was occurring during the season that affects crop production most).

(*Continued on next page.*)

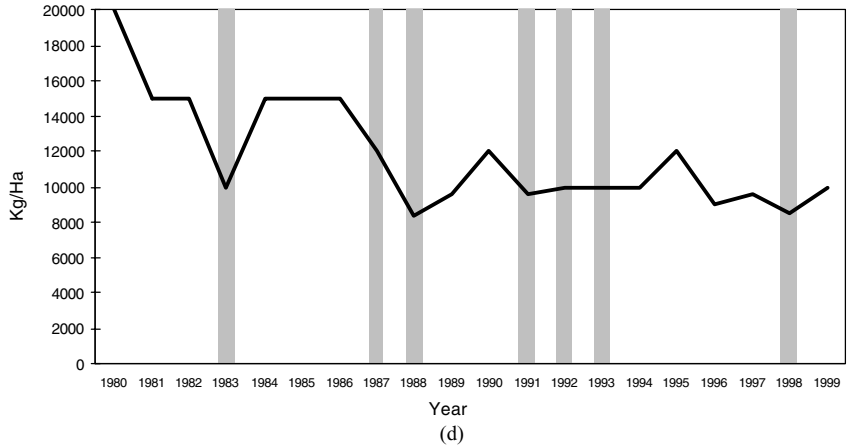


Figure 2. (*Continued*).

municipality either dipped or remained constant during drought years, while bean production dipped during many drought years, but showed more resiliency (figure 2(b) and (c)).

The last major annual staple, manioc is the most resistant to drought and becomes a fallback crop if other yields fall short. It is usually planted at the beginning of the wet season and remains in the ground one to two years before harvest occurs. Manioc is a very flexible crop in that once plants have sufficiently matured, harvesting can occur at any season of the year. Manioc is most commonly soaked, mashed and roasted into a gritty substance that can be sprinkled over foods at home or sold in Santarém city at weekly markets. Being able to sell manioc at any time allows farmers some flexibility in income generation.

Perennials can also be affected by drought and their loss can have a greater impact than in a given year because they are a less flexible form of produce than are annuals. Coffee, cacao, pepper, and commercial fruits require periods of growth before maturity and production begins. They also have larger initial start up costs that include cost of seedlings and inputs such as, fertilizers or pesticides. Households often borrow money to initiate these sorts of projects in anticipation that eventual yields will be of higher commercial value than that of annual crops. When these crops dry up due to lack of rain, households lose a larger investment than would be in the loss of annual crops. In addition, when these crops are part of larger agroforestry systems that include very slow maturing tree crops such as mahogany and fruit trees or coffee, the loss due to drought or fire passing through the area can be substantial and virtually not recoverable in the immediate future.

Pasture areas that are necessary for livestock practices are also susceptible to drought. Often rural smallholders maintain pasture areas and small herds because livestock adds flexibility to the overall farming strategy. Pasture grasses dry up quickly in most years despite drought, but in prolonged dry spells, particularly in more exposed areas such as hilltops, they can dry such that cattle become undernourished and do not gain weight. To this end, certain grass types are more drought resistant than others, thus land use decisions on grasses planted has potential to influence severity of drought impact. Yet, drought resistant grasses

are not necessarily the best food sources to beef up cattle or to increase milk production. There is often a trade off between pasture maintenance and livestock production. Year round drinking water sources may also dry up during drought years, making it harder to insure the survival of the cattle or requiring that cattle be transferred to other areas such as Varzea (floodplains) areas, where water is more abundant. While large scale cattle ranching operations have resources to transport cattle to the Varzea, smallholder farmers more often are forced to sell off their cattle during prolonged dry spells, regardless of potentially below market values. They are also more likely to lose cattle if conditions persist.

Drought then increases the potential of accidental fire during the dry season when farmers and ranchers are using fires to clear land for agricultural use. While many farmers take some sort of precaution such as creating fire lanes, notifying and coordinating with neighbors, or burning after the first rains, the potential of accidental fires is greater in drought years. Fires can not only burn out of control on one household's property but can pass over into neighboring areas, causing damage to crops, pastures, or secondary succession there as well. If loss is great, it can cause friction between neighbors, with relatively little legal means for resolution. Dry pastures also spread fires rapidly and if logged forest cover borders these areas there is greater chance for larger uncontrollable forest fires to develop. In addition, since many rural households use fire to clear agricultural fields, multiple fires are often set and thus can enter forested areas from different sides, accumulating to create powerful wildland fire fronts. Once fires compound and have spread into forested areas, the nature of hazard shifts away from being merely a local risk that is a given characteristic of the frontier setting, to becoming an environmental issue that invokes federal concern and international attention.

Concluding thoughts

Populations often confront natural phenomena in frontier settings. Unfortunately, it is often not until those phenomena reach crisis situations or pose threats to national and/or international interests that much attention is paid to them. In the Brazilian Amazon, periodic drought, fire use practices and small-scale fire spread have been present for almost as long as humans have. Yet the opening of the Amazon to frontier development repositioned this human environment relationship, providing the conditions for small scale fire activity to transform into large-scale fire events. Once fire grew to become one of the greatest threats to "the biological integrity . . . of tropical forests", the historical dynamics of the frontier, which brought fire to the forefront in environmental issues, were overshadowed by the immediacy of impending fire threats. Fire hazard has become positioned within discrete temporal spaces which negate consideration of the ongoing processes that served to create more vulnerable populations and more flammable landscapes in the first place. In the Brazilian Amazon, federal policy and programs are now working to take precautions against large scale fire by focusing on immediate fire prevention strategies. These strategies respond to fire hazard as it is perceived of as a crisis event, while the undercurrents of frontier development, the urban-rural linkages within frontiers, and the historical function of the frontier within larger society is not addressed in fire policy implementation.

Along the frontier edges of Santarém Municipality, development strategies have gradually focused more intently on industrial capacity, and linking the urban area to Brazil's national and international economic interests. This has occurred through a variety of regional changes that transformed rural areas without fully considering the impacts upon those areas. These changes reflect the historical function of the frontier within the Amazon Basin and the larger Brazilian nation. Regional development strategies have placed different social actors onto frontier landscapes shifting not only the biophysical character of the frontier, but also the social character. As the landscape becomes more susceptible to fire, smallholders are increasingly more vulnerable. They have fewer resources to help them through drought periods or fire hazard; their livelihoods strategies are immediately impacted by drought; and they are least likely to benefit in other ways from the further interconnectedness of urban and rural areas.

Fire hazard and extensive tropical forest fires have occurred in other regions of the Brazilian Amazon and the world, and these events are now framing perceptions of potential fire activity in the Santarém area. Brazilian federal fire policy and programs are now working to take precautions against large scale fire by focusing on immediate fire prevention strategies. These strategies are important but, respond to fire hazard as it is perceived as a crisis event, while the undercurrents of frontier development, the urban-rural linkages within frontiers, and the historical function of the frontier within larger society is not addressed. As long as environmental hazards are positioned as crisis events, an understanding of what constitutes frontier spaces of vulnerability, both in landscape and in populations, will be limited.

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Notes

1. The Brazilian Lower Amazon is a mesoregion in Pará state, delineated by the Instituto Brasileiro de Geografia e Estatística (IBGE), the Brazilian census organization.
2. All governmental agencies with either fire fighting units/equipment, or regional or environmental jurisdictions, including IBAMA (The Brazilian Institute of Environment and Renewable Resources), the Ministry of the Air Force, the Ministry of the Army, the Military Fire Department, and the Ministry of Regional Policies.
3. To its credit, the PROARCO documents acknowledge that logging occurs on a large scale without comprehensive forest management, that logged areas are especially prone to fire, and that logging roads with debris create pathways for fires (World Bank, 1998). Yet, these dynamics and their potential contribution to a more flammable landscape have not found its way into fire policy design and implementation.
4. Jute is a fiber crop grown in the floodplains of Santarém Municipality used to make sacks for transporting agricultural products, particularly coffee. For more information on the history of Jute in the Santarém region, see McGrath *et al*. (1993) or WinklerPrins (2001).

5. Belterra became the seat of a new municipality in 1997. It is included here because until this time it was a district within municipality of Santarém.
6. Most of the 217 km segment of the Santarém-Cuiabá Highway from Santarém to the next sizeable town, Rurópolis, remained unpaved for the next 25 years, making limiting the initial vision of the road as a regional transport corridor. It was virtually impassable in the rainy season, making commercial transport unreliable and transport costs prohibitive. Since the mid 1990s, there has been a move to pave the full extent of the road and implementation is ongoing.

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