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Burning biodiversity: Fuelwood harvesting causes forest degradation in human-dominated tropical landscapes

Maria Joana Specht[a], Severino Rodrigo Ribeiro Pinto[a], Ulysses Paulino Albuqueque[b], Marcelo Tabarelli[c], Felipe P.L. Melo[c,*]

[a] Centro de Pesquisas Ambientais do Nordeste (CEPAN), Rua Dom Pedro Henrique 167, Santo Amaro, 50050-150, Recife, PE, Brazil
[b] Universidade Federal Rural de Pernambuco, Departamento de Biologia, Laboratório de Etnobiologia Aplicada e Teórica (LEA), Rua Dom Manuel de Medeiros s/n. Dois Irmãos, 52171-900, Recife, PE, Brazil
[c] Departamento de Botânica, Universidade Federal de Pernambuco (UFPE), Av. Prof Moraes Rego s/n, 50670-901, Recife, PE, Brazil

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ABSTRACT

This study provides an approximation of the potential impact of fuelwood harvesting in one of the most threatened tropical biodiversity conservation hotspots, the northern portion of the Brazilian Atlantic Forest. We test the relationship between fuelwood consumption and per capita income for 270 households distributed over 7 rural settlements. In general 76% of the households use fuelwood regularly and consume on average 686 kg/person/year of tree biomass, poorer people, however, consume 961 kg/person/year. Harvesting is concentrated to a few early successional species. Yet, annual rural population demand from 210 municipalities may reach 303,793 tons, equivalent to 1.2 to 2.1 thousand hectares of tropical forest. Fuelwood harvesting cannot be ignored as a major and chronic source of forest degradation in highly fragmented and densely populated landscapes and conciliating biodiversity conservation with poverty amelioration is an urgent task.

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1. Introduction

Currently, up to 2 billion people depend on forest goods such as fruits, game meat, fibers and fuelwood to meet their basic needs (FAO, 2011; May-Tobin, 2011). Fuelwood harvesting in developing countries is so important that it rivals other sources of industrial energy such as electricity, principally among poor people in rural areas (FAO, 2011; Mead, 2005). In Africa, 58% of the energy supply comes from fuelwood and charcoal and this percentage in Latin America and Asia, though lower, is 15% and 11% respectively, and cannot be neglected as a potential source of ecosystem disturbance (Salim and Ullsten, 1999). Environmental damage from fuelwood harvesting can be significant if too many people depend on too few forested areas and the ecosystem services they deliver. Many tropical biodiversity hotspots (Bouget et al., 2012; Myers et al., 2000) represent such a scenario where numerous human populations rely on vanishing, reduced and fragmented forests to meet their demand for fuelwood, land for agriculture and ingestion of animal protein (Peres et al., 2010; Ruger et al., 2008). However, the environmental impacts of fuelwood consumption are somewhat neglected by both authorities and conservationists, probably because this activity constitutes a cryptic and chronic disturbance thought to be of less concern in the face of other major causes of biodiversity loss such as deforestation due to land use shifts (Bensel, 2008; Puyravaud et al., 2010).

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* Corresponding author. Tel.: +55 81 2126 8944.
E-mail address: felipe.plmelo@ufpe.br (F.P.L. Melo).

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The synergism between fuelwood consumption and biodiversity maintenance is actually poorly understood but negative feedbacks have been reported elsewhere in the literature (Bensel, 2008; Bouget et al., 2012; Brito, 1997; Mahiri and Howorth, 2001; Ravindranath and Sukumar, 1998; Tole, 1998). In Africa, some protected areas have been encroached by illegal charcoal traders, negatively affecting biodiversity and specifically threatening highly endangered species such as mountain gorillas (Ferraro et al., 2011; Sodhi et al., 2011). Most of the 34 biodiversity hotspots are totally, or principally, located in populous developing countries where a significant portion of the human population depends on biomass for cooking and heating their homes (Barrett et al., 2011; Myers et al., 2000). This can cause significant forest degradation not detected by satellite images and large-scale monitoring of forest cover (Peres et al., 2006; Puyravaud et al., 2010). Therefore, even sustainable and productive socioecological systems may experience pervasive and severe levels of small-scale chronic disturbance.

There is a significant amount of evidence on the major large-scale threats to tropical biodiversity such as habitat loss and forest fragmentation (Busa, 2013; Tscharntke et al., 2012), however, there is a lack of knowledge regarding the impact of several sources of small-scale disturbance, such as fuelwood harvesting (du Plessis and Maennig, 2011). Most reports on the potential impacts of fuelwood harvesting on tropical forests are anecdotal or come from studies aiming to assess poverty and/or energy issues that do not assess the biodiversity status of the forests that provide this ecosystem service (May-Tobin, 2011). On the other hand, at smaller spatial scales the dynamics of fuelwood harvesting can be described through the socioeconomic drivers that may help to feed broader scenarios (du Plessis and Maennig, 2011; Ramos and de Albuquerque, 2012; Top et al., 2004). In Brazil, unfortunately, even these community-based studies are extremely rare but the few that do exist suggest that poverty is positively correlated with fuelwood consumption (Ramos and de Albuquerque, 2012; Ramos et al., 2008a,b).

Conservation programs must consider the "human matrix" in which forest remnants are embedded, by quantifying the magnitude of the chronic small-scale disturbances as a key component of landscape quality (Melo et al., 2013). In Brazil, the Atlantic coastal forest – probably the "hottest of the hotspots" (Laurance, 2009) – was drastically reduced by the expansion of sugar-cane monocultures during the 1970s, but its remnants are currently the main source of fuelwood and game meat for millions of people (Brito, 1997; Medeiros et al., 2012). In the northern portion of the Brazilian Atlantic Forest, the average per capita income is amongst the lowest in Brazil (IBGE, 2011) and millions of people live in this region, where only 11% of the original forest expanse still remains, albeit in a highly fragmented landscape where more than 90% of the forest fragments are smaller than 50 ha (Ribeiro et al., 2009). In this scenario is reasonable to expect that the demand for fuelwood has the potential to be an important source of forest degradation.

Official data on fuelwood consumption is often focused on industrial demands and neglects domestic consumption (Ministério de Minas e Energia, 2011). An alternative for assessing domestic demand is to indirectly estimate fuelwood consumption through its relationships with socioeconomic variables that are officially available through periodic population censuses. This allows reliable estimations that, although rough, are useful as an initial approach and have potential for practical applications and for the design of public policies. In Brazil, fuelwood for cooking and heating is often consumed by poor people that cannot access industrial sources of energy such as gas and electricity due to economic and/or infrastructural constraints (Brito, 1997). We therefore, tested whether household income is negatively related to both the likelihood of consuming fuelwood and the amount of this resource consumed in rural villages of Northeastern Brazil.

In this study we first describe the patterns of fuelwood consumption of 270 families in seven localities that represent the main socioeconomic and infrastructural conditions of rural populations across a $>$50,000 km^2 region. We then assess the nature of the relationship between per capita income and both the likelihood of fuelwood consumption and the biomass of fuelwood consumed by rural populations. Finally, based on the relationships found locally, we estimate: (1) the likelihood of rural populations relying on fuelwood as a function of the per capita income; (2) whether there is any synergism between fuelwood harvesting and shifts in tree species composition due to land use changes; and (3) the magnitude of tree biomass extraction from the forest remnants of the region as a whole. We then discuss our results in the face of the impacts of this cryptic source of forest degradation and its potential consequences for the conservation of a highly threatened and biologically diverse tropical forest.

2. Material and methods

2.1. Study area

The study took place in seven localities in the northern Brazilian Atlantic Forest (Fig. 1; Table 1).This is a distinctive region of the Brazilian Atlantic Forest (hereafter BAF) considered to be a center of endemism for several biological groups such as birds, frogs and vascular plants. It comprises approximately a 56,000 km^2 landscape, highly deforested and fragmented and constitutes one of the most threatened portions of the BAF with less than 11% of its original area still remaining in the form of thousands of forest fragments, most of them $<$50 ha and embedded in a biologically-inhospitable matrix of sugar-cane fields (Ribeiro et al., 2009). The region is also culturally and economically distinctive in Brazil as it harbors the most dense population along the Brazilian coast, combined with one of the lowest rural per capita incomes in Brazil (IBGE, 2011). Such a scenario of poor people living around degraded and fragmented tropical forests in a matrix of sugar-cane plantations belonging to big landowners led poor people to rely on natural resources, such as wood, for several purposes including fuelwood for cooking (Medeiros et al., 2012). The seven localities were chosen because they were representative of the main sociopolitical conditions of the region and were located near important forest remnants (Tabarelli et al., 2005). The localities surveyed were either: (a) small rural villages (less than 50 households) embedded within very large private lands

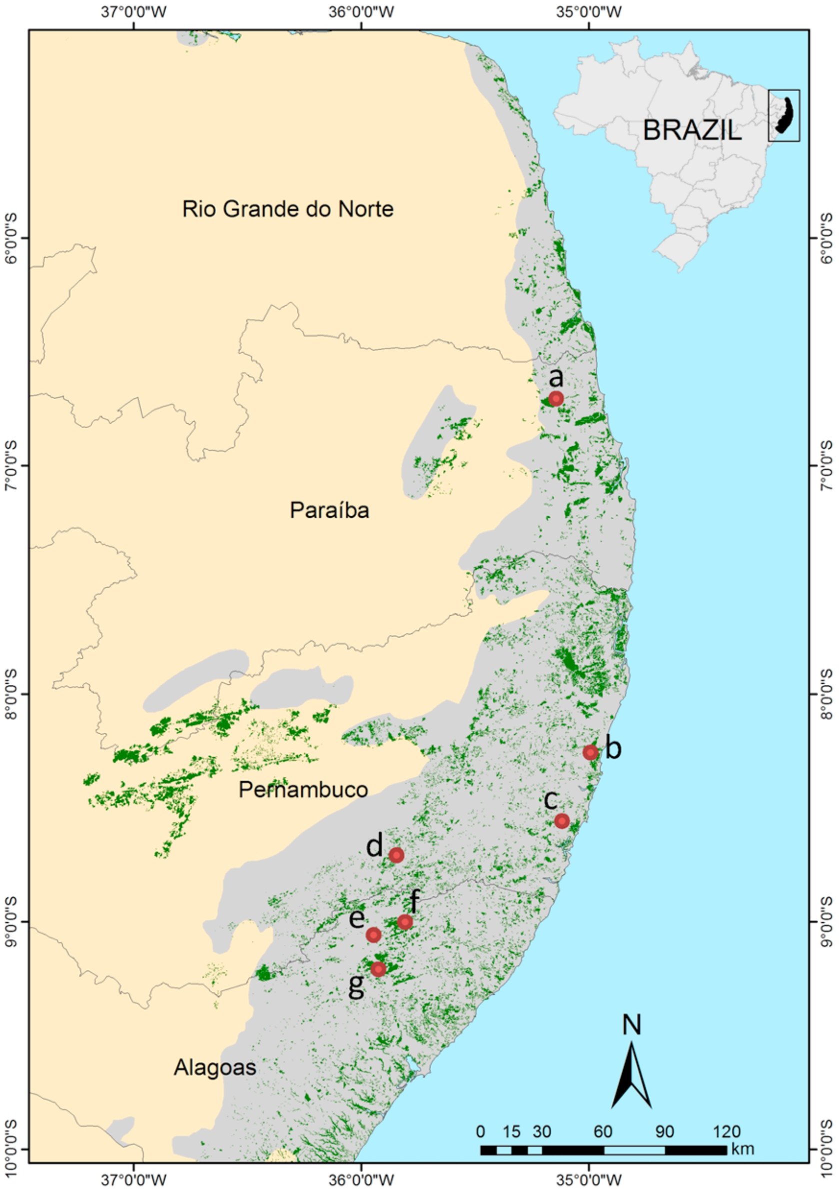

Fig. 1. Original limits of the northeastern portion of the Brazilian Atlantic Forest (gray) covering ca. 56,000 km^2, now reduced to 11% of its original extent (green). Red dots show surveyed human populations in rural areas of seven municipalities: Santa Rita (a), Cabo de Santo Agostinho (b), Rio Formoso (c), Lagoa do Gatos (d), São José da Laje (e), Ibateguara (f), Murici (g). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(often thousands of hectares) where sugar-cane plantation is the main economic activity; or (b) settlements of governmental agrarian reform established on former sugar-cane plantations that were confiscated by Brazil's government after being bankrupted and where the main economic activity is now small-scale subsistence agriculture. In both types of situation people's access to forest remnants were allowed for fuelwood harvesting. Obviously, the number of households interviewed is only a small subset of the rural population of the region but we are confident that it represents very well the average socioeconomic profile of the people in the region.

2.2. *Describing local fuelwood consumption*

In each locality we randomly selected and surveyed at least 20 households through questionnaires. For the smallest villages this represents more than half of the total number of households. For the largest, we selected more households in order to reach at least half the total number found in the village. The questionnaires/surveys aimed to collect two types of information. First we assessed the following socioeconomic variables in each household: (i) number of inhabitants and,

Table 1
Parameters related to socioeconomic status and fuelwood consumption of the 270 households interviewed in seven rural communities in the domains of the Northeastern Brazilian Atlantic forest. Values in parentheses refer to standard deviation and US$ 1.00 equals R$ 1.72 in 2010 values.

Municipalities where rural communities were surveyed (state abbreviation)	Number of households interviewed	Mean number of people per household	Average monthly per capita income in US$	Mean biomass (kg) of fuelwood consumed yearly per capita	Proportion of households using fuelwood
Cabo de Santo Agostinho (PE)	23	5.7 (3.5)	106 (92)	938 (1169)	0.91
Ibateguara (AL)	20	4.9 (2.6)	74 (32)	666 (458)	0.95
Lagoa dos Gatos (PE)	20	4.2 (2.4)	125 (128)	702 (507)	0.90
Murici (AL)	38	5.1 (2.5)	87 (49)	835 (799)	1.00
Rio Formoso (PE)	20	5.1 (1.9)	118 (44)	384 (411)	0.89
Santa Rita (PB)	20	4.5 (3.1)	127 (90)	656 (755)	0.90
São José da Laje (AL)	129	5.1 (2.1)	127 (137)	316 (381)	0.58

(ii) total family income. Second, we assessed characteristics related to the habits of fuelwood consumption, specifically: (i) main types of fuel used for cooking (fuelwood, gas or mixed); (ii) for those that did, the number of days per week each household used fuelwood; (iii) the duration of a standard 13 kg bottle of butane gas (when used) and; (iv) the origin of fuelwood consumed (whether self-harvested or bought). To quantify the fuelwood consumption we applied a standard method suggested by the Food and Agriculture Organization (FAO), the "average day" (FAO, 2003). This method consists of asking the main user of fuelwood in the household to set apart the amount of biomass usually consumed for cooking in an ordinary day. This load was then weighed and the biomass (in kilograms) multiplied by the number of days per week housekeepers report using fuelwood and then by 52 weeks to reach a yearly estimation per household. All weighed wood was "air dry" biomass whose moisture account for a maximum of 12% of the weight (FAO, 2003). Such a method is not as accurate as following stocks but is sufficient to estimate consumption at larger spatial scales when logistic limitations make impossible following stocks of hundreds of households (Jones et al., 2008). Finally, we were also interested in which tree species are preferably harvested as fuelwood. For that, we asked the interviewee that most frequently harvested fuelwood in the household to name three preferred tree species. We then compared the proportion of citations of each species with the number of herbaria records of those species divided into two time periods: before 1980 and after 1980. These time frames were chosen because 1980 marks the end of the last and most severe cycle of deforestation in the region, pushed by a governmental program to expand sugar-cane plantation to face the oil crisis in the 1970s. Today's landscape configuration is mostly the result of this deforestation wave and has been shown to be linked to the proliferation of some tree species in the landscape as a whole (Lobo et al., 2011). This meant we could establish whether there is any synergism between fuelwood harvesting and shifts already detected for the regional flora (Lobo et al., 2011).

2.3. Estimating regional fuelwood consumption

In order to estimate fuelwood consumption for the Atlantic forest of Northeastern Brazil, we first tested for a relationship between categories of per capita income and the likelihood of households using fuelwood among the 270 interviewees (i.e. households). We then recorded the average consumption of each economic class using the same categories of per capita income for rural populations used by the Brazilian Institute for Geography and Statistics (IBGE in Portuguese). For those economic classes that were statistically more prone to consume fuelwood we multiplied their average consumption by the rural population recorded in the last official national census (2010) by the IBGE (2011). We considered only rural population as potential consumers of fuelwood for cooking purposes (Brito, 1997). IBGE divides rural populations into categories of per capita income of one 1/4 the Brazilian minimum wage. In 2010, when the study was performed, the Brazilian minimum wage was of R$ 510.00 (Brazilian currency, Real) or equivalent to US$ 296.51 in 2010 values (IBGE, 2011). We then divided rural populations following the same categorization in order to test our hypotheses.

To put in context the pressure of fuelwood harvesting, we also describe municipalities in terms of remaining forest cover using the best updated estimation of forest cover for the region provided by the non-governmental organization SOS Mata Atlântica and the National Institute for Space Research, (INPE in Portuguese) (SOS Mata Atlântica/INPE, 2008). We also used previous studies from our research group that estimate the average aboveground tree biomass per hectare of the northeastern Brazilian Atlantic forest (see Dantas et al., 2011). Biomass data were used to project the potential impact of fuelwood harvesting on forests in terms of impacted hectares. According to Dantas et al. (2011) the interior of a typical forest fragment of the region harbors on average 245.63 ± 131.1 tons/ha (mean ± SE) but edge-affected portions of the same forests have only 138.9 ± 50.1 tons/ha (measured for trees >10 cm DBH) and this is the predominant type of forest habitat of the region (Ranta et al., 1998; Ribeiro et al., 2009).

2.4. Data analyses

We first described the patterns of fuelwood consumption of the populations in the seven localities studied through descriptive statistics. We then found that all socioeconomic variables were correlated with fuelwood consumption and decided to use per capita income for the analyses because it can be used in broader comparisons and at larger scales. Still

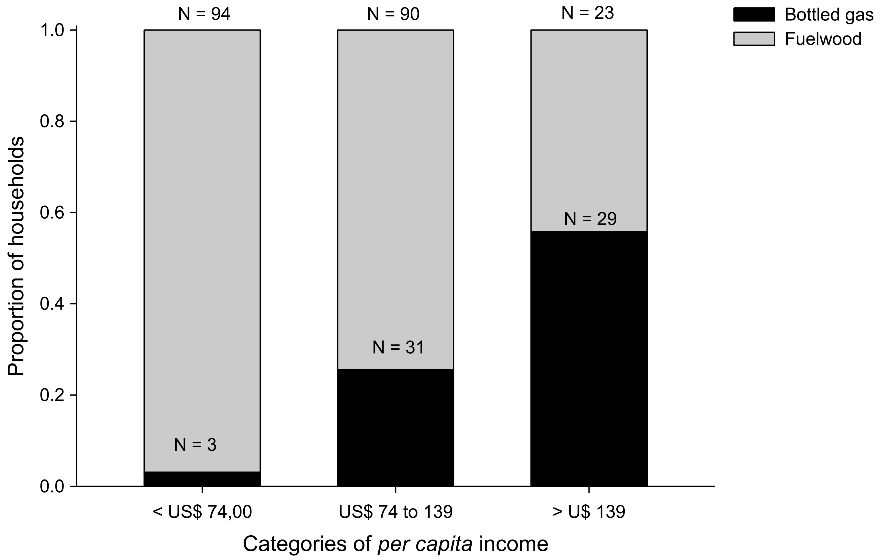

Fig. 2. Relationship between categories of per capita income and proportion of households using fuelwood (both fuelwood exclusively or mixed use with gas) and bottled gas only. Categories of per capita income follow the categorization used by the Brazilian government, i.e. quarters of the Brazilian minimum wage. At the time of the study, the Brazilian minimum wage was R$ 510 or equivalent to US$ 296 in 2010 values.

within the surveyed population, we tested for relationships between per capita income and the likelihood of fuelwood consumption using contingency table analyses through G tests. To test whether preferred species reported by households are the same as those currently dominating the altered human-dominated landscape we used Pearson's correlation on the proportion of citations of a species by households that depend on fuelwood against the proportion of herbaria registers pre- and post-1980. Then, to estimate the potential biomass of fuelwood consumption over the entire region of the northeastern Brazilian Atlantic forest we used the average biomass of fuelwood consumed per category of per capita income (including those people that reported no fuelwood consumption as to represent the economic class) following the subdivision used by the IBGE into quartiles of the Brazilian minimum wage and multiplied the total number of people within each category reported in the last official population census (2010) through the following formula: $F = \Sigma(N_i * C_i)$, where F is the total biomass of fuelwood consumed as a result of the sum of the number of people 'N' in the income category 'i' according to the 2010 official census, multiplied by the average consumption 'C' of this category estimated with field data from the 270 households interviewed.

The estimates reported in this study must be taken with caution as they are likely to be conservative. We may have underestimated the real impact of fuelwood consumption if the data collected through interviews, which are volunteered by interviewees, regarding the amount of fuelwood used in an average day is lower than actually used. Also, we may have underestimated the impacts of fuelwood consumption if the income values reported by interviewees are greater than they actually are. On the other hand, overestimations are less likely to have affected our data since other uses of tree biomass were not assessed such as charcoal, construction and fencing. Moreover, overestimations may have occurred if we had considered metropolitan regions of the four capitals within the studied region (nearly 7.5 million people), however, they were excluded from the analyses because the infrastructure of these regions makes industrial sources of energy more easily available even to rural people. All analyses were conducted in the statistical program JMP version 8.0.

3. Results

3.1. Fuelwood consumption

From the 270 households assessed, 76% ($N = 205$) reported using tree biomass as the main source of fuel for cooking. These included both households that depend on fuelwood exclusively ($N = 33$) and those that reported mixed use of fuelwood and gas ($N = 174$). Within those households that practiced mixed use, the duration of a standard 13 kg bottle of gas was 53% longer than those using only gas and averaged 63 ± 39 days (range = 15–240 days) compared with 40 ± 18 days (range = 15–105 days) ($t = 4.45$; $df = 217$; $p < 0.0001$). Altogether, the biomass consumed yearly by those 205 households that used fuelwood regularly averaged 686 ± 644 kg/year/person, but those that reported mixed use consumed on average one third less biomass (634 ± 615 kg/person/year) than those that depended exclusively on fuelwood for cooking (961 ± 773 kg/person/year). Dependency on fuelwood was inversely correlated to per capita income categories (Fig. 2). Poorer people, that earned less than US$ 74 monthly, tended to rely more than expected by chance on fuelwood ($X^2 = 47.3$; $df = 2$; $p < 0.0001$), while the probability of people with per capita income between US$ 74 and US$ 139

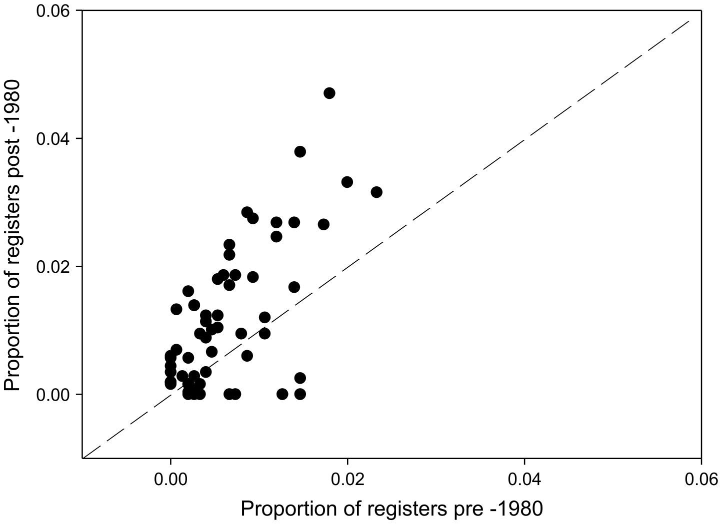

Fig. 3. Relationship between proportion of herbaria registers of the 60 native plants reported as main sources of fuelwood before and after 1980 (the end of the most recent major deforestation wave in the region). Points above dashed diagonal ($N = 43$) show increases in herbaria registers and suggest proliferation whereas points under the dashed line ($N = 17$) show species whose registers in herbaria became rarer after 1980.

relying on fuelwood did not differ from that expected by chance and those with higher living standards (earning more than US$ 139) were less likely to expected by chance to use fuelwood.

3.2. Synergisms with ecosystem disturbance

The majority of households (88%) reported harvesting fuelwood from nearby forest remnants and regenerating forest stands. The rest reported buying fuelwood from local vendors. The source of fuelwood is likely to be nearby forest remnants as exotic species that could be harvested in backyards accounted for only 11% of the 67 tree species cited by interviewees and were amongst the least cited species (Table A.1). Harvesting tended to be concentrated within early successional native tree species (80% of cited tree species) and appear to be concentrated within a small subset of these species that were repeatedly cited by households (Table A.1). This may be linked to the long-term human-driven changes in the studied landscape expressed by the positive correlation between the proportion of household citations of the 60 native tree species and their proportions in the herbaria database of the region after 1980 (Pearson's $r = 0.48$, $N = 60$; $P < 0.0001$), while no relationship was found for the period before 1980 (Pearson's $r = 0.12$, $N = 60$; $P = 0.34$). The average increment of herbaria registers for these 43 tree species reported to be used as fuelwood was 136% between pre- and post-1980 and only 17 species showed decreases (Fig. 3).

As people earning more than US$ 139 were unlikely to use fuelwood, except occasionally, and those with per capita income between US$ 74 and 139 did not differ from chance in the likelihood of depending on fuelwood for cooking, they were excluded from the following analyses. Therefore, considering only people earning less than US$ 74 (1/4 of the BMW) in 2010, there were 521,791 people living in the rural areas of 210 municipalities within the domains of the Brazilian Atlantic forest that are prone to regularly consume fuelwood for cooking; i.e. 46% of the whole rural population. This summed up to 303,793 tons of tree biomass consumed yearly for cooking purposes only and most municipalities may burn more than a thousand tons of fuelwood yearly (Fig. 4(a)). However, for the 210 rural municipalities from which data on forest cover is available, there are only 449,692 ha of Brazilian Atlantic forest left in 2010 and many municipalities ($N = 88$) harbor less than 1000 ha of forest (Fig. 4(b)). This means that there is only 0.86 ha of forest available per person that is socioeconomically susceptible to fuelwood consumption in the study region as a whole and 62% of the municipalities present values below 1 ha per person earning less than US$74.

4. Discussion

Our results suggest that fuelwood harvesting cannot be ignored as an important source of forest degradation in highly fragmented and densely populated landscapes such as the Brazilian Atlantic forest, one of the hottest of the biodiversity conservation hotspots. In this region, a considerable fraction of the rural population still relies on fuelwood for meeting its basic cooking needs, consuming over ½ ton of tree biomass per capita per year. These findings reveal the extent to which rural populations are dependent on fuelwood and highlight its socioeconomic drivers. In synthesis, one of the world's most biologically diverse and threatened tropical forests experiences chronic disturbances imposed by over 500 thousand rural inhabitants; i.e. spatially scattered but tangible amounts of biomass removal from small remnants of forests.

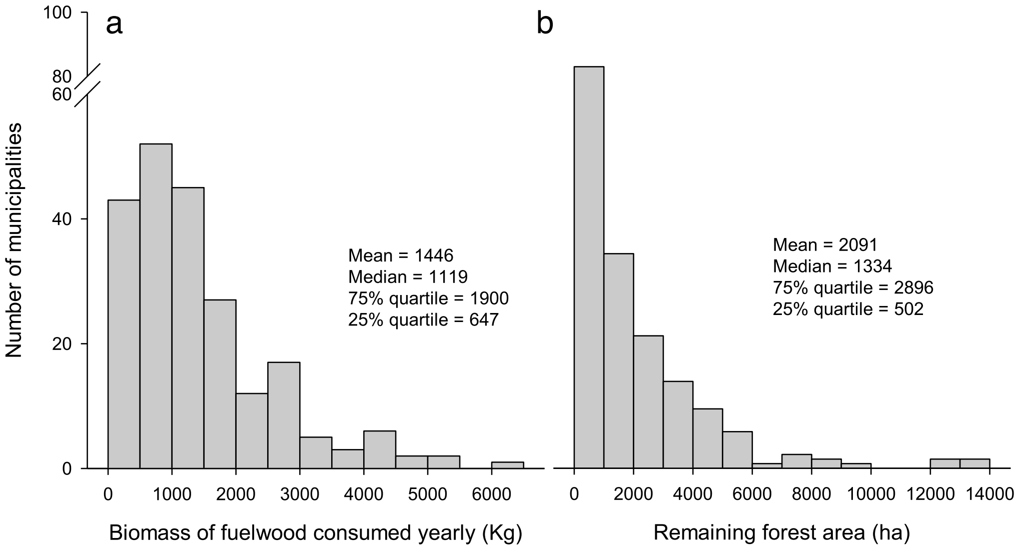

Fig. 4. Distribution of: (a) estimated forest biomass consumed yearly as fuelwood for cooking by people earning less than a quarter of the 2010 Brazilian minimum wage of R$ 510,00 (equivalent to US$ 296) and (b) municipalities according to remaining tropical forest area in hectares in 2008.

In the Atlantic forest region, people consume self-harvested fuelwood from remnant native forests (Medeiros et al., 2012), harvesting is adopted without management techniques and biomass is burned on inefficient improvised stoves (Heltberg et al., 2000). The relationship between poverty and fuelwood dependency has also been documented in Brazil and in other countries around the world at local scales (Hiemstra-van der Horst and Hovorka, 2009; Matsika et al., 2013; Top et al., 2006). For example Medeiros et al. (2012) have found that socioeconomic characteristics of rural communities in the same region explains up to 31% of the consumption of fuelwood and monthly income was the most important variable. However, poverty is not the only, and sometimes neither is it the main determining factor for fuelwood dependency. Other factors such as proximity to source (forest remnants), access to private lands, availability of manpower for harvesting and access to other sources of energy may help to explain the amount of fuelwood consumed by families in the region studied (Medeiros et al., 2012; Ramos et al., 2008a). Most of these socioeconomic variables are hard to access but we could detect that mixed use with bottled gas reduced significantly the biomass consumed.

In many African nations, an established fuelwood trade in the form of charcoal is controlled by macroeconomic factors such as the cost of extraction and demand–supply chain as industrial sources of energy are scarce (Ahrends et al., 2010; Madubansi and Shackleton, 2007). However, the general pattern of fuelwood consumption recorded in this study is similar to those registered for other developing tropical countries such as México, Vietnam and Cambodia (Garcia-Barrios et al., 2009; Masera et al., 2006; Top et al., 2006) where fuelwood consumption is not controlled by market forces because it is a subsistence practice. But even in this context, our results reveal that fuelwood consumption is affected by socioeconomic drivers, responds to resource availability and represents a source of chronic disturbance (collection is a weekly occurrence) with potential impacts on forest habitat. As an important source of energy, especially for poor human populations, domestic harvesting has a strong potential to cause forest degradation, particularly in those areas where forest/people ratio is small such as in the region addressed here (Hosier, 1993; Mahiri and Howorth, 2001).

Only recently has fuelwood consumption caught the attention of conservationists and conservation practitioners as an important source of habitat degradation and carbon emission worldwide (May-Tobin, 2011). In many African countries with little access to industrialized sources of fuel, wood for fuel is consumed not only in rural areas but also in big cities, supporting immense and diffuse markets, which promote waves of forest degradation moving constantly beyond urban and degraded zones towards natural areas in remote locations (Ahrends et al., 2010). In contrast, the patterns documented in this study suggest that fuelwood harvesting is generally practiced by people that collect their own supply of biomass from nearby forest remnants and therefore might not be subject to supply–demand dynamics but should be correlated to population density and per capita income (Garcia-Barrios et al., 2009). This makes estimations of forest degradation resulting from domestic consumption difficult to either document or estimate at larger scales. Obviously, biomass removal represents a potential source of habitat degradation, particularly when it exceeds forest net primary productivity. Additionally, fuelwood harvesting may be correlated with other sources of disturbance such as hunting. Hunting pressure has been so pervasive in the Brazilian Atlantic Forest that, in synergism with habitat loss, it has driven to regional extinction most medium- to large-bodied mammals and birds (Canale et al., 2012; Silva and Pontes, 2008). Small-scale slash-and-burn agriculture is still a common practice across the region mainly by the same economically vulnerable human populations that also depends on fuelwood for cooking (Tabarelli and Gascon, 2005). As a working hypothesis we state that, collectively, fuelwood harvesting, hunting and slash-and-burn agriculture are likely to cause severe forest degradation across human-dominated landscapes,

Table A.1
Tree species cited as preferred for fuelwood by 205 interviewees that use fuelwood regularly in seven localities in the northeastern Brazilian Atlantic forests. Regeneration strategies are: early successional (ES); shade-tolerant (ST) and exotic species (EX).

Tree species	Family	Regeneration strategy	Percentage of household citation
Byrsonima sericea DC.	Malpighiaceae	ES	69.96
Tapirira guianensis Aubl	Anacardiaceae	ES	35.87
Cupania oblongifolia Mart.	Sapindaceae	ES	21.52
Mimosa caesalpiniaefolia Benth	Fabaceae	EX	16.14
Bowdichia virgilioides Kunth	Fabaceae	ES	15.70
Eschweilera ovata (Cambess.) Miers	Lecythidaceae	ES	15.25
Thyrsodium spruceanum Benth.	Anacardiaceae	ES	15.25
Schefflera morototoni (Aubl.) Maguire, Steyerm. & Frodin	Araliaceae	ES	14.35
Vockysia oblongifolia Warm.	Vochysiaceae	ES	14.35
Psidium guajava L.	Myrtaceae	EX	11.21
Vismia guianensis (Aubl.) Choisy	Hypericaceae	ES	11.21
Myrcia silvatica (G.Mey.) DC.	Myrtaceae	ES	10.76
Syzygium cumini (L.) Skeels	Myrtaceae	EX	10.31
Stryphnodendron pulcherrimum (Willd.) Hochr.	Fabaceae	ES	8.97
Miconia hypoleuca (Benth.)Triana	Melastomataceae	ES	8.52
Cecropia pachystachya Trécul	Urticaceae	ES	8.07
Plathymenia reticulata Benth.	Fabaceae	ES	8.07
Anacardium occidentale L.	Anacardiaceae	ES	6.73
Mangifera indica L.	Anacardiaceae	EX	6.28
Miconia prasina (Sw.) DC.	Melastomataceae	ES	4.93
Artocarpus heterophyllus Lam.	Moraceae	EX	3.59
Pera glabrata (Schott) Poepp. ex Baill.	Euphorbiaceae	ES	3.59
Guazuma ulmifolia Lam.	Malvaceae	ES	2.69
Protium heptaphyllum (Aubl.) Marchand	Burseraceae	ES	2.69
Apuleia leiocarpa (Vogel) J.F.Macbr.	Fabaceae	ES	2.24
Banara guianensis Aubl.	Salicaceae	ES	2.24
Brosimum guianense (Aubl.) Huber	Moraceae	ES	2.24
Croton floribundus Spreng.	Euphorbiaceae	ES	2.24
Mabea occidentalis Benth	Euphorbiaceae	ES	2.24
Miconia calvescens D.C	Melastomataceae	ES	2.24
Simarouba amara Aubl.	Simaroubaceae	ES	2.24
Casearia javitensis Kunth	Salicaceae	ES	1.79
Citharexylum myrianthum Cham.	Verbenaceae	ES	1.79
Henrietta succosa (Aubl.) DC.	Melastomataceae	ES	1.79
Pogonophora schomburgkiana Miers ex Benth	Euphorbiaceae	ST	1.79
Psidium guineense Sw.	Myrtaceae	ES	1.79
Talisia esculenta	Sapindaceae	ES	1.79
Xylopia frutescens Aubl.	Annonaceae	ES	1.79
Aegiphila pernambucensis Moldenke	Lamiaceae	ES	1.35
Campomanesia dichotoma (O. Berg) Mattos	Myrtaceae	ES	1.35
Clusia nemorosa G.Mey.	Clusiaceae	ES	1.35
Himatanthus bracteatus (A. DC.) Woodson	Apocynaceae	ES	1.35
Dialium guianense (Aubl.) Sandwith	Fabaceae	ES	0.90
Guapira opposita (Vell.) Reitz	Nyctaginaceae	ES	0.90
Hancornia speciosa Gomes	Apocynaceae	ES	0.90
Machaerium hirtum (Vell.) Stellfeld	Fabaceae	ES	0.90
Pourouma guianensis Aubl.	Urticaceae	ES	0.90
Schinus terebinthifolius Raddi	Anacardiaceae	ES	0.90
Syzygium malaccense (L.) Merr. & L.M. Perry	Myrtaceae	EX	0.90
Tovomita mangle G. Mariz	Clusiaceae	ES	0.90
Acrocomia intumescens Drude	Arecaceae	ES	0.45
Aspidosperma discolor A. DC.	Apocynaceae	ES	0.45
Astronium fraxinifolium Schott	Anacardiaceae	ES	0.45
Brosimum rubescens Taub.	Moraceae	ES	0.45
Caraipa densifolia Mart	Clusiaceae	ES	0.45
Casearia luetzelburgii Sleumer	Salicaceae	ST	0.45
Garcinia macrophylla Mart.	Clusiaceae	ES	0.45
Inga thibaudiana DC.	Fabaceae	ST	0.45
Inga vera Willd.	Fabaceae	ES	0.45
Luetzelburgia auriculata Duck	Fabaceae	ES	0.45
Miconia minutiflora (Bonpl.) DC.	Melastomataceae	ES	0.45
Parkia pendula (Willd.) Benth. ex Walp.	Fabaceae	ES	0.45
Pouteria bangii (Rusby) T.D. Penn.	Sapotaceae	ST	0.45
Protium giganteum Engl.	Burseraceae	ST	0.45
Tachigali densiflora (Benth.)	Fabaceae	ES	0.45

(*continued on next page*)

Table A.1 (*continued*)

Tree species	Family	Regeneration strategy	Percentage of household citation
Terminalia catappa L.	Combretaceae	EX	0.45
Zollernia paraensis Huber	Fabaceae	ST	0.45

contributing to the ongoing process of "secondarization" already reported for some Brazilian Atlantic forest landscapes (Melo et al., 2013; Tabarelli, 2010).

Permanently human-modified landscapes are expected to represent the main habitat configuration across most tropical countries in coming decades (Karp et al., 2012; Melo et al., 2013). This implies that remaining natural habitat will continue to suffer from direct human use of natural resources such as hunting (Arroyo-Rodriguez and Dias, 2010; Brashares et al., 2011; Parry et al., 2009) and fuelwood harvesting (Bensel, 2008; Puyravaud et al., 2010) in the long term. These chronic sources of disturbance have been neglected by wildlife managers, public sector and academia as important sources of forest degradation because such a fuzzy pattern of consumption is difficult to assess but quantifying locally the types and intensity of use of each natural resource (FAO, 2011). However, the whole set of small-scale chronic disturbances potentially plays an important role in the arrested forest succession and biotic homogenization already documented for the northeastern Brazilian Atlantic Forest (Lobo et al., 2011; Tabarelli, 2010). Not coincidently, the set of species reported by Lobo et al. (2011) to be proliferating in the same region where this study was conducted are those most cited by families as preferred for fuelwood. We cannot affirm that harvesting for fuelwood is the cause of the hyper-proliferation of these species or a response of consumers to increased availability of those species. However, the synergism found suggests that both the tree communities and human uses of these resources have shifted in response to habitat degradation (Melo et al., 2013).

5. Conclusions

Unlike major sources of habitat loss and degradation, such as land-use shifts, that can be confidently measured by governments and conservationists, the cryptic sources of disturbances that usually follow habitat loss are driven by more complex socioeconomic factors (Angelsen and Kaimowitz, 1999; Brashares et al., 2011; Mahiri and Howorth, 2001). Therefore, it is time to seriously consider that, in an overpopulated world, every use of natural resources may have consequences for the long-term persistence of biodiversity in human-modified landscapes (Melo et al., 2013). Yet, most of these cryptic disturbances are related to poverty traps that push human populations into poverty and make them more dependent on natural resources while natural capital is depleted (Barrett et al., 2011; Coomes et al., 2011). Such chronic disturbances surely add more complexity to the response of biodiversity in face of ecosystem alterations, therefore, including the "human matrix" in the framework will clearly help to move conservation approaches towards a broader solution to conservation problems linked to people's socioeconomic vulnerability (Ellis, 2013). Therefore, conciliating biodiversity conservation in biologically diverse tropical forests with the poverty amelioration of a huge contingent of the human population that still depends directly on forest goods is a hard but crucial task (Kareiva et al., 2011).

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Appendix

See Table A.1.

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