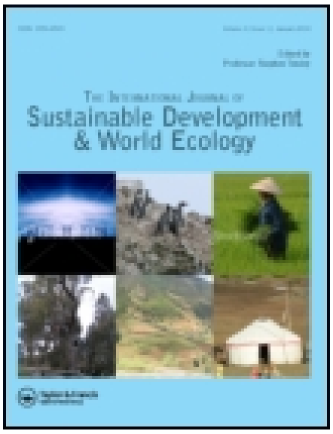

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Wood charcoal is generally viewed as a rudimentary form of energy. It is often understood in terms of its role of providing rural poor populations with basic energy needs, and/or the contribution its production makes to local forest degradation. More recently, the potentially much larger impact of urban demands on natural resources is attracting attention. Rural/urban supply chains are becoming an important research focus as nations try to start aligning with international environmental agreements by providing more honest environmental data regarding deforestation and associated emissions. This paper presents results from quantitative and qualitative research investigating the commercial charcoal supply chain servicing the metropolitan area of Lima, the capital of Peru. Long-term conservation initiatives protecting the species *algarrobo* (*Prosopis* spp.) were found to have caused a leakage effect in which the species *shihuahuaco* (*Dipteryx* spp.) from the Amazon region of Ucayali is compensating for the reduced production of *algarrobo* charcoal. Charcoal production in the urban area of Pucallpa, Ucayali is estimated to be more than eighty times the official figures, the vast majority of which goes to service the thousands of chicken brasseries in Lima. Commercial Amazonian charcoal is produced predominantly from sawmill by-product, and thus not found to be a direct threat to the rainforest. However, reduced availability of the by-product of the preferred species *shihuahuaco* to charcoal producers raises concern that this species is being heavily overexploited in the region.

Keywords: Peruvian Amazon; charcoal; supply chains; leakage; conservation

Introduction

Woodfuel[1] energy types are often understood to represent the most rudimentary of energy sources, harnessed mainly by rural or poor populations without the means to access more efficient fuels. However, in light of the increasing demand for wood charcoal by urban and industrial users, the traditional focus on the impact of energy requirements of rural populations on forest degradation and loss may be diverting attention away from the foremost global woodfuel users: urban consumers (Ribot 1993 in Lipschutz & Conca eds.; Ribot 1998; Arnold et al. 2003; Arnold et al. 2006). The potential environmental damage caused by large-scale pressures of urban users, both in terms of implications for forest degradation and associated greenhouse gas emissions is attracting interest as deforestation and climate change issues gain increasing attention within international policy dialogues such as the United Nations Conference on Climate Change and REDD+.

Servicing an urban charcoal market often involves complex supply chains, which provide crucial livelihoods on which many rural and urban actors depend (Schure 2012). Understanding how this supply chain is expressed in real life, its formal and informal activities, processes and institutions is key to informing environmental policy and conservation intervention plans related to charcoal production for commercial markets. Because of the complex nature of human dependence on forest resources, there is some concern that the net conservation benefits gained through mitigative policies and projects are negated through the displacement or 'leakage'[2] of the problem to other forests, as key actors may respond to mitigation projects by shifting their 'problem' activities elsewhere. Because such projects, as well as the concept of leakage itself, are relatively new, there exists a lack of meaningful experience in leakage effect as a consequence of project-level intervention (Aukland et al. 2003; Atmaja & Verchot 2012). However, long-term restrictions[3] on natural resource extraction have been in place at national and regional levels in many nations for some time. Although these controls exist at a different scale and maintain different methodologies and approaches to nested projects, analysis of their effects and outcomes could help with the challenge of understanding and managing leakage events. This could facilitate the development of strategies to prevent or account for such leakage events at the design phase of conservation projects.

In this paper, we examine the urban charcoal supply chain between the Amazonian zone in Ucayali and Peru's capital city of Lima. Woodfuels are a major source of rural and urban household and industrial energy in Peru.

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Twenty-two per cent of Peruvian citizens are thought to depend on fuelwood for domestic energy (MINAG 2011). Estimates are based on extrapolations of population data of the rural poor and per capita fuelwood allowance. However, obtaining accurate data on fuelwood and charcoal use is a challenge as charcoal supply chains feature intricate links between formal and informal actors and production activities (Schure 2012). National fuelwood and charcoal production output estimates (7,028,067 m^3 and 51, 543, 647 kg, respectively, for the year 2010) (MINAG 2011) do not correspond with the FAO's 103 million kg charcoal production approximation, (Food and Agricultural Organization of the United Nations Statistics Division 2010), and methods for deriving such statistics are not always seen as dependable (Arnold et al. 2005; La Torre-Cuadros 2012). Furthermore, as international policies, agreements and frameworks such as REDD+ proceed towards implementation at ground level through methods such as the nested approach (Pedroni 2009), accurate regional and local data are all the more valuable. Without understanding the particulars of the supply chain, it is difficult to predict whether or not targeting a specific link in the chain would result in its collapse, thereby reducing associated negative environmental effects, or whether the activity would simply be displaced.

The objective of this case study was to examine the commercial charcoal supply chain servicing the urban hub of Lima, Peru. The study endeavours to determine whether or not a link exists between trends in trade and state-led conservation measures. It explores how the dynamics of this relationship has influenced the commercial charcoal market, including changing prices and sources of supply and analysis the effects of such changes on local livelihoods. It reports production processes and quantities of charcoal being produced at the wood source, in order to establish the accuracy of official statistics available on charcoal production in Ucayali, Peru. Production processes are also investigated from the perspective of understanding the extent to which this industry poses a threat to natural forests in Ucayali.

Study regions and study sites

This paper presents data from a research project investigating the commercial charcoal market in Peru. This market is primarily concentrated in the capital city of Lima, home to one-third of the population (7.6 million people) of Peru. However, as charcoal is a natural resource derived from forests – of which there are none in Lima – Ucayali was selected as a source region and is the main focus of the study. Ucayali was highlighted in a recent CIFOR (Centre for International forestry Research) report as a key source region for charcoal supply to the capital. The report implied that it was unlikely that national statistics about charcoal production were accurate, and raised questions about quantities and methods of production which were unconfirmed (La Torre-Cuadros 2012). This CIFOR report, along with Ucayali's physical position in the Amazon rainforest motivated the selection of this region for the study.

The department of Ucayali is an inland region of Peru situated in the central Oriental zone of the Peruvian territory and the Amazon rainforest (Figure 1). The economy is based on agriculture and extraction of natural resources such as metals and timber (INEI 2008). The processing industry provides 45% of the employment in Ucayali, a large portion of which is based on forest products (Guevera-Salas 2009). Most of the present study took place in the urban area of Pucallpa, the department capital, and its rural surroundings. It is a tropical region with a warm, humid climate, average temperature range of 22–31°C and precipitation of 1567 mm per annum (Fujisaka et al. 1999). The general landscape outside the central urban hub is a mix of forest vegetation and heterogeneous agricultural landscapes, including expanding oil palm plantations. Pucallpa is an Amazonian city, located on the Ucayali river, a major tributary of the Amazon river. It is the heart of Ucayali's timber industry and represents Peru's largest timber milling centre, hosting large sawmills of both extractive and transformative remit. An 846 km highway links Pucallpa to Lima, making it the most well-connected Amazonian city to the country's capital.

A great number of Pucallpino households are multi-sited or follow 'circular migration' patterns, meaning that they maintain homes in the city to access amenities such as schools whilst also owning and utilising small agricultural landholdings (*chacras*) outside the city zone (Padoch et al. 2008). There is a strong history of slash and burn land clearing activity in the area, coupled with short-term *chacra* tenancy periods and boom and bust economic cycles (Pinedo-Vasquez et al. 1992; Coomes 1995; Labarta et al. 2008).

Within the urban area of Pucallpa, four main 'sites' were selected; Puerto Luz Abensur (LA), Puerto JK (JK), Manantay and Kilómetro 8-10 (KM 8-10). These areas are recognised by government administrators and charcoal producers (*carboneros*) alike as the main charcoal-producing nuclei in the city. A three-day survey of the city confirmed this to be true. All sites were characterised by concentrations of numerous *carboneros* in one area, apart from the KM 8–10 sites, which were more dispersed across roads leading off of the highway junctions (junctions 8, 9 and 10). The LA and JK sites were located near the river and city centre, whilst the Manantay and KM 8–10 sites are situated in the urban areas to the south and east of the city centre.

The remaining Pucallpa area sites were a series of five rural hamlets, which remain anonymous in order to protect the identity of any participants engaging in quasi-legal charcoal production. Hamlets were accessed by river and/or roads, and are mainly populated by small-scale agriculturalists that maintain *chacra* plots on an average of 1-hour walk from the hamlet nucleus. Agricultural goods are reasonably consistent across all hamlets with crops of cassava, banana, maize, rice and cacao. Almost all *chacras*

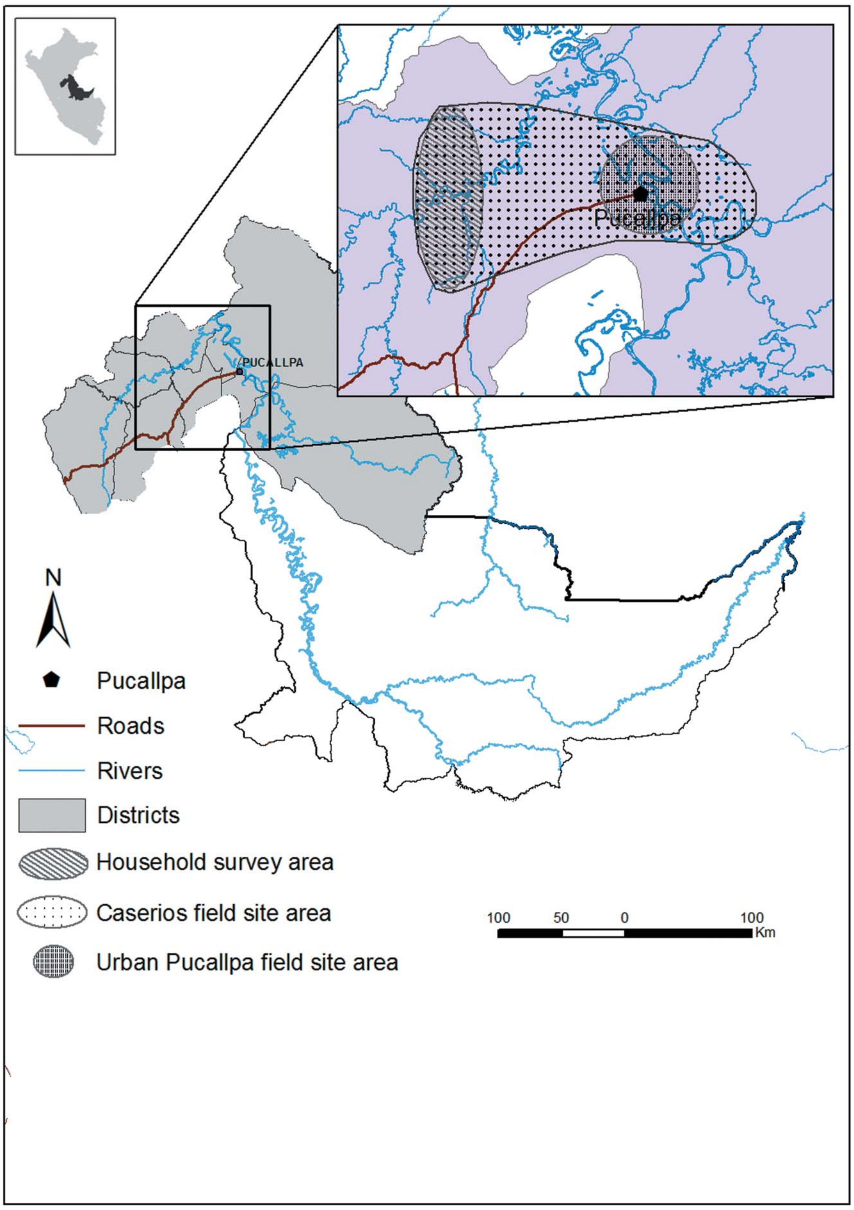

Figure 1. Study areas around Pucallpa situated in the Peruvian Amazon basin Ucayali, Peru.

maintain primary or old growth forest on parts of the farm not yet cleared for sowing crops.

The focal trees for the study are species of the genus *Dipteryx* spp, locally known as *shihuahuaco*. *Dipteryx* spp. is discussed at the genus level, as there are several species of *Diperyx* present in the study region, locally known as red, yellow and black *shihuahuaco*. *Shihuahuaco* is a widespread, slow growing neotropical tropical rainforest canopy species (Ektvedt 2011; Putzel et al. 2011). Brightsmith (2005) referred to *shihuahuaco* as a 'keystone tree' as there are several bird and bat species that rely on it as a nesting site and source of food. Macaws and several species of tree canopy bats use natural holes in the trunk to build their nests, and toucans, nuthatches and woodpeckers are also frequent residents of this unique tree (Infosur, http://mail.cmtdelsur.com/shihuahuaco.htm). *Algarrobo* (*Prosopis* spp) or carob in English, a species that thrives in the northern dry forest ecosystem, is discussed in this paper from a lesson-learned perspective as an additional species that has been overexploited. *Shihuahuaco* is primarily extracted from Peruvian forests for construction and flooring for the international hardwood markets. *Algarrobo* continues to be an important source of wood for local and national woodfuel needs, as well as non-timber products such as those derived from the algarroba fruit (López et al. 2006; Putzel et al. 2011; Dürbeck 2012).

Methods

Sources and methods for data collection and analysis

In order to address the central enquiries of the study, information was used from both secondary and primary sources. A mixed methods research strategy was employed to gather the primary data, which included methods of both qualitative and quantitative nature. The merit of such a strategy from the viewpoint of a 'triangulation' approach (Webb et al. 1966) is that the weaknesses of one will be supported by the strengths of the other. Primary quantitative and qualitative data were gathered through interviews, using both structured and semi-structured questionnaire procedures. Empirical data were acquired through the measurement of sizes, weighs and quantities of charcoal and fuelwood, as well as counting and plotting participating *carbonero* populations. Secondary sources were academic and grey literature sourced through library databases and institutional contacts.

Participant characteristics; selection methodology and rationale

The target populations were a range of key actors involved in the commercial charcoal production and supply chain between the metropolitan area of Lima and urban and rural sites in Ucayali. Charcoal wholesale depository owners in Lima ($n = 10$) were located through visits to markets and industrial estates and selected for the study based on established links with the charcoal source. *Carboneros* in urban Pucallpa ($n = 41$) qualified for selection based on status as proprietor or spouse of proprietor of a charcoal kiln. Interviews with Pucallpa sawmills managers ($n = 5$) were mainly solicited through written request. The location of the charcoal production sites belonged to rural *carboneros* participating in the commercial market ($n = 5$) were identified through the interviews with urban *carboneros,* which solicited information regarding rural land holdings of *carboneros*. Representatives of various national and regional governmental and non-governmental offices were interviewed in Lima, Pucallpa and Piura for the purpose of understanding official perspectives on the current charcoal market in Peru. This mainly focused on the legal parameters and bureaucratic paper trail system involved in producing, transporting and selling wood-based charcoal, and any perceived difficulties in monitoring and administering these processes. Information was also requested about interventions historically and/or currently in place to redeem the population of a*lgarrobo*. Finally, the rural household sample was selected opportunistically *en route* to or from rural charcoal sites. Homes were selected where the household head or spouse was present. Household surveys were incorporated into the study to provide a comparison between urban and rural, commercial and domestic charcoal consumption. Rural charcoal production was a minor but important aspect of research for addressing the question about whether the charcoal production poses a threat to the forest or not.

Questionnaires and preference ranking

Structured and semi-structured questionnaires were conducted at all sites. The design of questionnaires was modified for each participant group. The structure and layout of the questionnaires draw on designs of the CIFOR questionnaire for the 2010 *Global Comparative Study on REDD* (Component 2 on REDD Project Sites) (Sunderlin et al. 2010), which was acquired through the CIFOR office that funded this study. Specifically, this questionnaire was used to guide the coding of the structured questionnaires, however, the questions created for this study were unique.

Structured questionnaires were ground-tested by two native and experienced field technicians. The pilot phases of questionnaires informed the final draft, specifically the coding configuration, which was built on commonality of answers given during the pilot phase. Data derived from questionnaires conducted during the pilot phase were only used in cases where questionnaires were not modified after the pilot phase. Participants in the charcoal business for less than 1 year were excluded from questions pertaining to historical price changes and/or changes in availability of wood species; these are signposted in section four as 'not in business long enough'.

Preference ranking is a simple analytical tool, which is part of the Participatory Rural Appraisal (PRA) approach to data collection (Chambers 1981; Chambers 1994; Martin 2004; Breitbart 2010). Ranking exercises are participatory and often practical in nature, and are frequently used to support rural ethnobotanical research of natural resource knowledge and use (Mukherjee & Chambers 2004; Gupta & Köln 2006). In the case of the present study, the main criterion was charcoal quality. Attributes constituting 'quality' were established during pilot phases and are elaborated in the results section.

Preference ranking was conducted with Lima wholesale owners and urban Pucallpa *carboneros*. As many wholesalers were unable to identify charcoal types, the question of preference was simply inserted into the questionnaire in order to establish at least a theoretical preference. The preference ranking in urban Pucallpa comprised one basic activity; to select the five best wood types from the piles of wood beside the kilns and arrange them in order of preference. Where *caboneros* lacked time, this activity was conducted orally, asking them to list the species in order of preference. Each rank was given an integer value between 1 and 5, the most preferred wood was assigned the highest value. The order of preference indicated during these activities was cross-checked with answers obtained from interviews for consistency.

Empirical measurements: motivation and methods

As regional government offices had no master list of charcoal producers in the area, it was necessary to count and plot the informal *carbonero* population using a Global Positioning System (GPS). Since the quantitative field data was intended to form the basis of annual extrapolations, populations were recorded conservatively. For example, 20 *carboneros* in a 'pop up' charcoal zone were excluded from the total population figure ($n = 122$), and the final results because of an apparently significant and regular fluctuation in population size and because a large majority (76%) of *carboneros* had been active for less than 6 months.

Units of measurements cited by participants were not uniform. Furthermore, many of these were informal ways of measuring quantities of fuelwood and charcoal such as 'small' and 'large' van cargos and 'sacks' (industrial size bags of charcoal). The question of quantities of charcoal being produced and sold was of central importance to the study, and in particular, for addressing questions about accuracy of national statistics. In order to standardise all measurements, informal units were measured and converted into scientific units.

In Pucallpa, commercial charcoal is sold in two forms, industrial sized bags of the tropical hardwood species *shihuahuaco* only, and as bags of mixed charcoal types of the same size. Average bag weights were established through the weighing of bags of *shihuahuaco* and mixed species in Lima and Pucallpa. To ascertain fuelwood to charcoal ratios, information about the number of bags of charcoal derived from small and large vans (the principal method of wood delivery) was solicited in questionnaires. This information was cross-checked by measuring van cargo volumes, and weighing contents of these vans using a spring scale. This method provided a per m^3 wood weight, allowing for the substantial air volume created by the wood's processed state on delivery to the kilns (i.e. in small pieces and stacked loosely). Dimensions and weights of pieces of woods were measured to verify consistency in wood weights. *Carboneros* were asked how many bags of charcoal would be produced from their current kiln(s), and furthermore whether these kilns represented a 'normal' cycle. The kiln dimensions were measured and paired with claimed yield to verify consistency in number of bags of charcoal yielded per m^3 of kiln.

In order to extrapolate the 'normal cycle' numbers into a reasonable annual estimate, care was taken to evaluate the likelihood of impediments to production caused by weather in the winter wet-season. Structured questionnaires asked *carboneros* to indicate whether they worked during winter. Furthermore, through analysis of local maps, it was decided that the production for two of the sites (Puerto JK and Luz Abensur) should be discounted during these months due to proximity to the river and/or altitude. Forty-nine of the 122 plotted *carboneros*, or 40% of them were in these areas. Therefore, 40% of the set were analysed from the perspective of only working 8 out of 12 months.

Since there was no way of confirming the number of *shihuahuaco* kilns *carboneros* would produce in a year, all translations of sack weight into kilos for extrapolations were made based on the lighter sack weight average (mixed woods).

Results

The commercial charcoal market in Lima

Charcoal wholesale outlets in industrial estates around Lima were found to be buying and selling large quantities of charcoal on a weekly basis. An average week's sale inclusive of all 10 wholesalers was calculated as 1,686,912 kg. Wholesalers buy *algarrobo* and *shihuahuaco* as superior product, and mixed wood charcoal as inferior, but saleable merchandise. The latter is mostly distributed amongst central marketplaces destined for domestic use and small-scale food enterprises such as street vendors. All participating wholesalers identified urban chicken brasseries as their principal clients, and the largest consumers of quality charcoal product. In addition to being recognised as the main consumers of *algarrobo* and *shihuahuaco*, brasserie chains were described as being relatively fixed on buying *only* these high quality wood charcoal types. Characteristics of quality charcoal fall in line with those identified in previous charcoal studies (Labarta et al. 2008; Mekuria et al. 2012) and include; longer burn time, low levels of ash produced and its ability to be transported without pulverising. However, this case study found that great importance was placed on the agreeable flavour derived from *algarrobo* and *shihuahuaco* charcoal. The taste produced from the smoke of these woods is considered to have high marketability and low replaceability. Other buyers include industrial businesses such as brick makers and metal workers for automobile parts.

Conservation policy and primary leakage effect

Policy measures working against unsustainable harvest of wood from the northern dry forests had been in place for some time. Firstly, law no. 26258 decreed in 1993 prohibited the felling of trees from natural forests in the Northern departments of Tumbes and Piura in the Grau Region, and the north-eastern Region of Lambayeque for a period of 15 years. In addition, the government initiative 'Project Algarrobo' administered by INRENA (National Institute for Natural Resources), had invested 13 years of research and intervention measures into protecting this species from overharvest. Research included: inventories of the composition and health of dry forest plant species and the mapping of findings thereof, the development of technologies to produce products from *algarrobo* that did not require felling the tree, and a compilation of LANDSAT satellite images since 1972. Complimentary action included: community projects such as sustainable use and alternative livelihood education programmes, capacity building for community forest watch, reforestation initiatives, opening of applications for private reforestation enterprises and clamp downs on transport and sale of clandestine wood products such as logs and charcoal. This project ended in 2003, though its benefits are understood by the government representatives to continue to be effective to some extent, as villages residing on communal land become more confident in monitoring and regulating sustainable use of their forest-lands. However, many key informants viewed these interventions as having a relatively minor impact on the changing charcoal market in Lima. Rather, they attributed the lack of *algarrobo* charcoal to the physical absence of a*lgarrobo* trees in the north of Peru, as a result of the overexploitation for charcoal, fuel and roundwood on local and commercial levels.

The official perspective of the decline in *algarrobo* charcoal in the urban commercial market was not echoed by Lima wholesalers. Exhausted natural resources and government prohibitions were identified as almost equally responsible for the decline in the availability of *algarrobo* for charcoal (50% and 56%, respectively), and therefore the increase in the use of *shihuahuaco* and other Amazonian tree species. Although 100% of the wholesalers identified *algarrobo* as the preferred species, 67% of the wholesalers indicated that *shihuahuaco* was the quality charcoal type, of which they had bought the highest quantity at the time. Although principal charcoal sources varied amongst informants, sources averaged at 48% northern dry forest (Piura, Lambayeque and Tumbes), 49% Amazon forest and 3% other regions. The per-kilo price of Amazonian *shihuahuaco* charcoal has increased in value from an average of 0.59PEN (0.22USD) to 1.10PEN (0.43USD) in the past 2 years. This is due to the recent difficulty in obtaining supplies of *shihuahuaco*-only bags of charcoal. Information conveyed by actors at source locations about the increasingly longer distances being covered to source *shihuahuaco* trees in the Peruvian Amazon further explained the rising prices.

Charcoal production processes and wood sources

Charcoal production processes in Ucayali vary both between and within rural and urban regions, differentiated by available human and material resources such as expertise, manual labour support, other work commitments, availability of wood (and other materials), distance to travel to acquire materials and level of finance required and/or available. Rural kilns are generally round earth mounds, except where charcoal production sites are located along a river in which case sand (considered a superior material) is used instead of earth. However, some rural *carboneros* involved in the commercial charcoal market are transporting several tonnes of sawdust from the city to their rural terrains at distances of up to 50 kilometres (Figure 2b). Previous publications have described the rural earth mound kiln production process in the area well (Figure 2a) (Coomes & Burt 2001), therefore this paper focuses on urban processes. Permanent ‘beehive’ stone kilns were present at some sites, however, they had not been in use for quite some time. All urban kilns had a similar structure (Figure 2c and d) and production process, and the average production cycle was 15 days (Figure 3). Almost all of the wood used by urban *carboneros* was derived from local sawmills and constituted by-product of processed wood. Sawmill wood derivatives are bought from sawmills by a middleman, who then drives around the four main charcoal sites to sell it.

Many urban sawmills hold legal permits for wood extraction from Ucayali forest concessions, which are generally located in old growth forest lands, at a considerable distance from the city. Concession holders cited overly bureaucratic sustainable forestry clauses attached to newly extended concession allowances as the reason for their preference to work with communities with land title rather than extract from their own concessions. Native communities in particular have access to a variety of logging permits that sanction extraction from community lands based on annual quotas. By buying from communities, sawmills can avoid a large element of responsibility for how the wood is extracted. Seventy-five per cent of the communities cited as sources of *shihuahuaco* supply were located in the Ucayali Amazon region.

Figure 2. (a) Rural earth mound kiln. (b) Rural sawdust covered artisanal kiln. Sawdust is derived from nearby sawmills or transported down rivers from the city. (c) Urban kiln in construction. (d) Urban kiln in carbonisation.

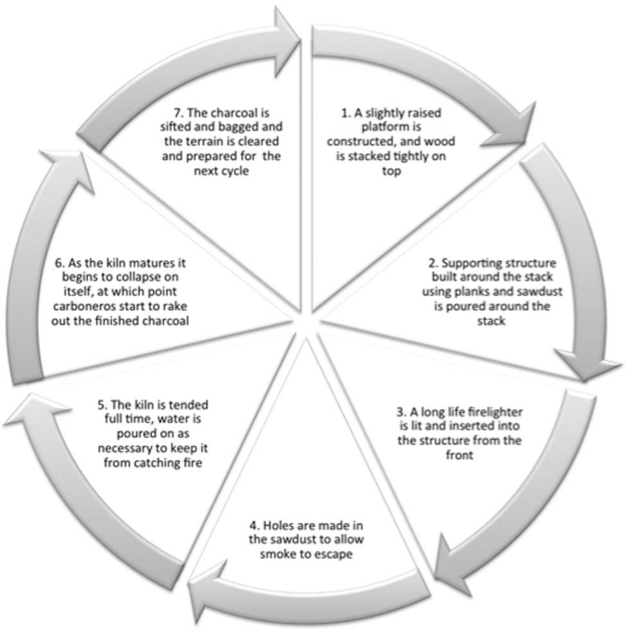

Figure 3. Charcoal production process in Pucallpa city.

Fuelwood ratios, kiln yields and quantities of charcoal being produced

Woods measured and weighed had a significant correlation for both *shihuahuaco* and mixed categories ($R^2 = 0.95$ and $R^2 = 0.97$, respectively) (Figure 4). There is also a significant positive correlation between kiln size (measured by the researcher) and charcoal output (stipulated by the *carboneros*) (Figure 5), with kiln size as the independent variable for quantity of charcoal produced.

Bags of *shihuahuaco* and mixed charcoal had a mean mass of 102.4 ± 14.4 kg (standard deviation) and 71 ± 4.0 kg, respectively. Table 1 shows the estimated annual output for the area is 30,727,801 kg (approximately, 30.7 tonnes year^{-1}), based on extrapolations of the lighter wood weights and primary data gathered in the field, and adjusted for seasonal impediments to production. A total of 97.6% of the charcoal surveyed in Pucallpa was destined for the Lima market, 1.42% designated to local needs and only 0.92% directed elsewhere. According to the measurements made during our study, 3.6 kg of *shihuahuaco* wood is needed to make one kilo of charcoal and a similar figure of 3.5:1 was found for the mixed woods measured as shown in the study. However, 'mix' by nature means that the weight and output of this category will vary with each van load, as the contents changes.

Winter weather (rain and flooding) was not found to be a definitive constraining factor for urban charcoal production. Thirty-one per cent of the total sample set stopped charcoal production during the rainy season (January to April). Even erring on the safe side, and theoretically excluding all *carboneros* located in Luz Avensur, Puerto JK and the river bank from winter production, a likely maximum of 40% of the urban *carboneros* population stop production in the winter months (30% of the year).

Preferred tree species and perceptions on their decline

Fifteen principle tree species were used for urban charcoal production. Results from preference ranking exercises show that 100% of the urban *carboneros* identified *shihuahuaco* as the preferred species for quality charcoal production, illustrated by its maximum integer value of 102^4. Preference ranking results showed significant incongruence between preferred wood for charcoal production and actual wood being used (Figure 6). *Carboneros* attribute this discrepancy mainly to a decline in the availability of *shihuahuaco* wood because of the degeneration of the species abundance, and local competition with the new breed of super *carboneros* (Table 2).

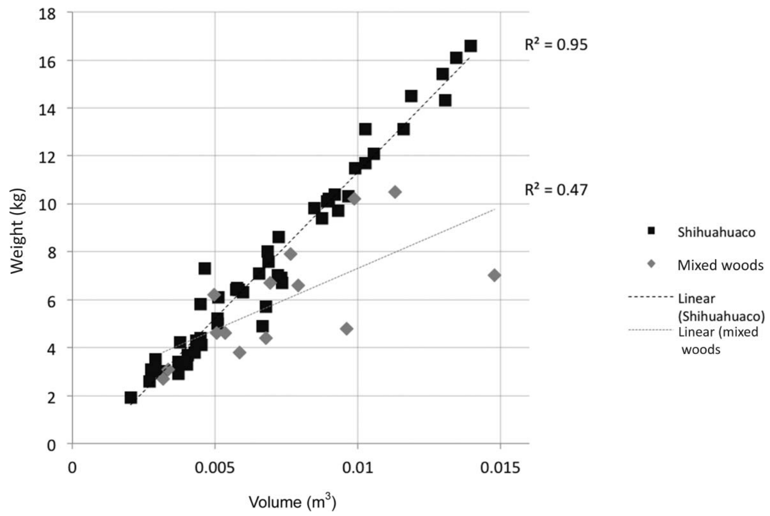

Figure 4. Relationship between sizes and weight of pieces of wood measured.

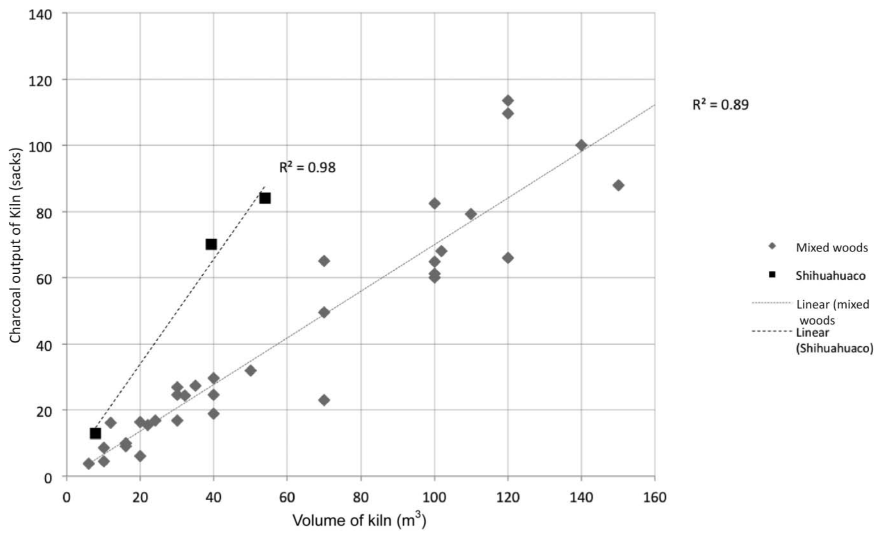

Figure 5. Relationship between kiln size and charcoal output.

Table 1. Estimated annual output of charcoal in Pucallpa city according to interviews as well as wood piece, transportation van and kiln measurements made during the study.

	Species	
Characteristics	Mix	*Shihuahuaco*
Average sample size (m^3)	0.00925	0.00689
Average sample weight (kg)	5	7.54
Wood density (kg/m^3)	567.9	1093.4
Average kiln wood volume (m^3)	43.55	33.7
Average kiln weight (kg)	24,732	36,848
Average kiln charcoal yield (kg)	4,540	5,700
Yield (kg/m^3)	104.2	169.1
Wood to charcoal conversion rate (kg)	5.44	6.46
Mean sack weight (kg)	71	102.4
Yield (sacks/m^3)	1.46	1.65
Van density (kg/m^3)	365.4	604.3
Implied air component	36%	45%
Air adjusted conversion rate	3.5	3.6

Note: Total p/a estimate 30,727,801 kg.

New trends in urban and rural livelihood and secondary leakage effects

Fifty per cent of Pucallpa city *carboneros* interviewed had started their charcoal initiative only in the past 3 years. All of these 'new' *carboneros* attributed this shift to increased demand, higher charcoal prices and a resultant increased income potential. Indeed, the sale price has almost doubled from 0.45 PEN (0.17 USD) per kilo of *shihuahuaco* charcoal 2 years ago to 0.89 PEN (0.34USD) today. Forty-one per cent of the *carboneros* interviewed said that they had other income streams, but charcoal still accounted for between 60–100% of their total income.

The principal drivers of the enhanced value of Amazonian *shihuahuaco* charcoal were identified by local *carboneros* as 1. The decline in the availability of *shihuahuaco* wood because of depletion of species abundance, and 2. The oppressed *algarrobo* market. *Carboneros* reported increasing difficulty in acquiring *shihuahuaco* and see the decline in availability as a serious threat to their livelihood. Although most *carboneros* claimed to have worked predominantly with *shihuahuaco* in the past, only 15% of the *carboneros* interviewed currently produce bags of *shihuahuaco* only charcoal.

The dramatic and rapid price increases in charcoal means a much higher price for the product, however this price increase is echoed in the growing costs of the wood used to make it. As little as 3 years ago, wood derivatives from wood processing activity in Pucallpa sawmills were either given away, or sold at a very low price. Now, however, selling by-product or making charcoal from their by-product accounts for 10–30% of their total revenue. In addition, sawmills also sell hundreds of tonnes of sawdust per week, which is used by *carboneros* to cover their kilns during the production process. Therefore, access to more capital is now needed in order to purchase *shihuahuaco* on a large enough scale to produce a kiln (or more) of *shihuahuaco* charcoal. As charcoal production is based on a system of credit (i.e. between the time the wood is bought and the time that charcoal is made and sold, the *carboneros* must be able to survive without the capital used to buy the wood), expensive wood pushes the smaller artisanal charcoal makers out of the *shihuahuaco* market. Elite charcoal enterprises that maintain larger terrains, multiple kilns and paid workers ('super *carboneros*') are stepping in to dominate the Pucallpa *shihuahuaco* market. Super *carboneros* often have agreements with sawmills so that they receive the best quality wood first.

Small-scale charcoal livelihoods may face the challenge of a proposed 'Clean Air' programme by a local authority that has revealed intentions to 'clean up' the charcoal industry in Pucallpa through measures such as *carboneros* relocation (further away from domestic populations), education (about negative health effects of the

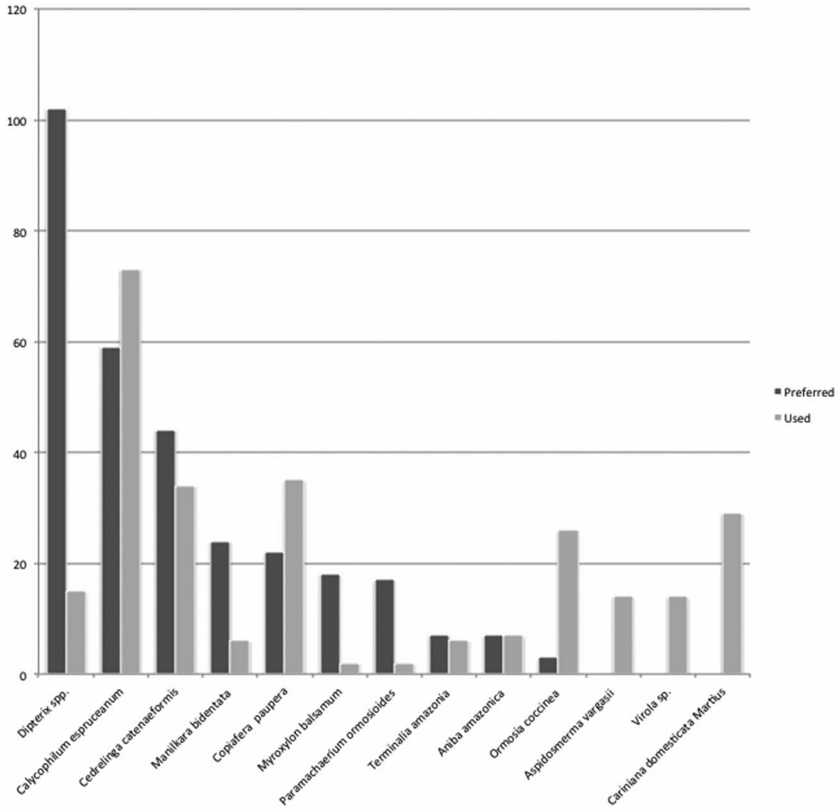

Figure 6. Relationship between preferred woods and woods used amongst urban Pucallpa charcoal makers according to integer values derived from preference ranking activities.

Table 2. Perceptions of decline in the availability of *shihuahuaco* for charcoal production amongst urban *carboneros* in Pucallpa, Ucayali and the perceived causes of this decline (n = 41).

Perceived decline		Perceived reason for decline	
Increase	0%	Competition	5%
No change	0%	Exhausted natural resources	82%
Slight decline	3%	Other	5%
Significant decline	67%	Does not know	13%
Not in business long enough	31%	–	

smoke) and stricter regulations (not yet decided). This idea is perceived by *carboneros* as having a potentially devastating impact on their livelihood. Many *carboneros* sense that relocations are the first step in completely eliminating their rights to produce charcoal in the city.

Seventeen per cent of the urban sample own *chacras* and 100% of these plots contain primary or old growth forest of noteworthy size relative to the total landholding. Six per cent of the urban *carboneros* interviewed said that they occasionally extract wood for charcoal from their *chacra* land to supplement low availability of woods available in the city.

All *carboneros* in the rural sample fell into the 'new *carboneros*' category (0–3 years). Three of the five rural site owners were in the process of becoming full-time charcoal makers, choosing charcoal production over their traditional crop planting activities. *Carboneros* claimed that charcoal production was currently more profitable than harvesting crops. The emergence of a sort of 'charcoal cooperative' was apparent at rural sites, as *carboneros* with capital encouraged neighbours to produce charcoal for them, and labour was shared amongst those participating.

Rural domestic charcoal production and use

Forty per cent of the rural households ($n = 52$) said they used charcoal for domestic purposes, but 93% of these only use charcoal on Sundays or special occasions to cook '*parrillada*' (grilled chicken). One to two kilograms of charcoal per household is needed for this culinary activity. Ninety-five per cent of the hamlet households maintained an agricultural *chacra,* and most of these had significant relative proportions of old growth forest remaining on the land (with a mean of 53% forest cover) 41% had made charcoal in the past, but only opportunistically as *chacra* land is cleared to extend agricultural areas. Historically, as *chacra* land is cleared, valued tree species such as *shihuahuaco* and cedar are sold as roundwood to sawmills. However, all household heads are aware of the recent increases in prices of wood for charcoal, and most were able to name a local *carbonero* to whom they could sell their *shihuahuaco* wood in the form of roundwood or by-product, should they choose to do so.

Discussion

A World Bank Report published in 2012 highlights the need to look beyond small scale, poor forest dwelling loggers to large-scale enterprises in order to truly tackle the illegal logging problem in the Peruvian Amazon (Food and Agricultural Organization of the United Nations 2011). This sentiment can be extended to the charcoal industry where research has often focused on rural and domestic production and use (Coomes & Burt 2001; Cooke et al. 2008; Labarta et al. 2008; Medeiros et al. 2012; Mekuria et al. 2012), and little attention has been paid to the larger-scale commercial supply chains. More recently, this gap in our knowledge has begun to be addressed by some very compelling case studies and policy papers based in Africa and Asia (Zulu 2010; Msuya et al. 2011; Agyeman et al. 2012; Schure et al. 2013). The case study presented here contributes to this literature by describing a contrast between frugal rural domestic use and a booming urban commercial charcoal market in Peru's capital of Lima.

The most desirable characteristics of charcoal are commonly known as burn time, low levels of ash produced and ability to be transported without pulverising (Labarta et al. 2008; Agyeman 2012). However, one key and seemingly novel discovery of this research is that urban chicken brasseries often have a fixed preference for *algarrobo* (*Prosopis* spp) and *shihuahuaco* (*Dipteryx,* spp.) charcoal not only because of these characteristics but also because of the agreeable flavour it gives to the meat. The cultural preference for charcoal derived from slow-growth hardwood species presents a conservation conundrum. Reforestation project endeavours could be problematic because the time commitment needed to achieve even one reforestation cycle would not parallel the typical length of supporting funding and/or government administrations. Other commonly advocated interventions that are unlikely to work in this case include the replacement of slow-growth woods with alternative faster growing and/or softer woods, using more efficient stove apparatus or shifting to other fuels such as kerosene, generators or gas (Reddy & Reddy 1994; Mobarak et al. 2012). This highlights that understanding the characteristics of the various points of the supply chain is an important precursor to deciding on interventions to reduce the environmental impact of charcoal production, as leakage events are more likely in cases where populations are less flexible on alternative products.

Accounting for leakage at the design stage of such projects is a challenge, as developing nations are limited by a lack of experience in leakage events (Aukland et al. 2003). Looking to non-project level conservation interventions that exist at various levels from national and regional to sub regional initiatives might facilitate understanding of some of the characteristics of leakage events that apply also at the project level. Two long-term conservation policies had been in place to help the dry forests in northern Peru to recover from the crippling overexploitation they have experienced, and prohibitions on the felling of the valued species cedar and mahogany are in place nationally. All three injunctions have contributed to the leakage of source of supply of wood charcoal from the northern dry forests to the Amazon in Peru. They have also influenced changes in the commercial market and created knock-on effects on charcoal-based livelihoods. Law no. 26258 and *Proyecto Algarrobo* limited the legal extraction of *algarrobo* – the preferred wood species for the urban commercial market – but its leakage response increased the value of Amazonian (particularly *shihuahuaco*) charcoal, and consequently the quantity being produced in this area. Parallel laws prohibiting the logging of cedar and mahogany triggered a need to find new quality species for the international hardwood market, which also turned out to be *shihuahuaco* (Putzel et al. 2011). Furthermore, new laws promoting sustainability through longer concession titles were not perceived by concession holders as a positive move, rather they fear the prospect of the accountability of long tenures. Planning for leakage caused by these decrees could include closer supervision of forest areas titled to native peoples, and monitoring of deforestation in areas immediately outside of concession areas.

Whilst the Amazonian charcoal market has grown, so too has the number of families that depend on it as a primary source of livelihood. Fifty-one per cent of the *carboneros* interviewed had charcoal production as their only source of income, the other 49% said that charcoal accounted for 60% + of their total annual earnings. There has been rapid and dramatic price increase (almost double in 2 years) in a natural resource that is easily accessible to the vast majority of a population that is operating within a boom and bust economic climate. Therefore, charcoal production is likely to continue to be a popular and attractive livelihood option in the area, regardless of whether the source of the wood is sawmill by-product or not. This is worrying in light of the high percentage of remaining old growth forest on the *chacras* of circular migrants highlighted in this paper.

Higher income is derived from charcoal made of better quality woods. However, incongruence in preference ranking results between preferred wood and actual wood used highlights a discrepancy between the product that *carboneros* want to produce and what they were actually generating. This inconsistency is in large part explained by *carboneros* by a recent decline in the availability of *shihuahuaco* wood because of degeneration of species abundance. This decline may be attributable to the overexploitation of the species by loggers extracting for international markets, which is creating the need to cover increasingly larger distances to locate it. This raises some urgent questions about the conservation status of the species, which is currently not registered under any CITES (Convention on International Trade in Endangered Species of Wild Flora and Fauna) listing. Furthermore, although the head of the General Forestry and Wildlife Office in Piura – who was involved in Project *Algarrobo* for many years – said that the project contributed to a more abundant population, this was difficult to confirm as results from research on northern dry forest tree species done by INRENA in the name of Project *Algarrobo*, and those conducted by other research bodies do not always agree (La Torre Cuadros & Linares Palomino 2008). Based on satellite imagery between 1999 and 2001, Cruz et al. (2011) postulate that 38% of the area coverage of dry forest remained the same, 13% saw an improvement in forest condition and 23% reduced their coverage. Again, this is not specific to the *algarrobo* species, of which no up-to-date inventory exists.

Charcoal production is often associated with unsustainable use of natural resources and associated forest degradation, and there are case studies that highlight this as a very real conservation issue (French 1986; Stevenson 1989; Msuya et al. 2011). However, charcoal production is not necessarily synonymous with unsustainable extraction from natural forests. Wood can also be derived from a variety of sustainable sources such as the utilisation of farm clearance and wood processing by-product (Arnold et al. 2003; Lattimore et al. 2009). This paper described a large charcoal production system that is based almost entirely on utilisation of sawmill by-product. The question of wood source is central to determining the pressure on natural resources caused by this activity, and any subsequent need for reactive conservation measures. This is particularly relevant in the current political climate, as institutional elites strive to reconcile development and environmental goals. Decisions about who should bear the most responsibility for environmental damage caused by natural resource extraction ties in tightly with issues of equity and rights and are not always straightforward. In the case of the current study for example, accountability for environmental damage caused by the exploitation of this natural resource is in question with relation to the chicken brasseries in Lima.

An increasing global concern about ‘wrong data’ is emerging, as it is recognised that incorrect data leads to confused baselines and mislead mitigative action (Ghirardi & Steirer 2011). It is impossible to understand or predict the flows of this market based on assumptions about population demographics or registered trade, the standard methods used to derive national statistics on firewood and charcoal use in Peru (La Torre Cuadros 2012). This study was limited by the lack of availability of reliable baselines for charcoal production in the area. For example the quantitative aspect of this research suggests that official figures hugely underestimate charcoal production in Peru. The Ministry of Agriculture in Peru, the body responsible for producing data on forests products reported that 369, 599 kg of charcoal were produced by the state of Ucayali in 2010 (MINAG 2011). However, this field research indicated that over 80 times more wood charcoal was being produced in the urban area of Pucallpa alone. The discrepancy between official production estimates and those reported here are relevant beyond Pucallpa and Ucayali. If the production estimates for Ucayali deviate this far from reality then questions arise concerning the modesty of the formal numbers for other regions. This is particularly urgent in regions such as Grau and Lambayeque, where it is known that trees are felled directly for charcoal production (Vega Arambulo 2004; MINAG 2011).

Using the urban charcoal supply chain between Ucayali and Lima, Peru as a case study, this paper is an example of the sequence of events that can contribute to displaced pressures on natural resources over long periods of time. The paper has illustrated how primary and secondary level leakage overlaps, modelled by Atmadja and Verchot (2012), can look in real life. It highlights the need for qualitative research beyond modelling and quantitative analysis when it comes to mitigation of leakage events. Although it has been shown that charcoal production in Ucayali is not a culprit of forest degradation, policies in place to regulate this activity have caused changes in the market and had a knock-on effect. The regulatory policies in place to protect cedar, mahogany and *algarrobo* may have caused the overexploitation of *shihuahuaco*, which is evident in the diminishing availability of sawmill by-product to *carboneros* in Pucallpa compared to in the past. Further research is called for to assess the conservation status of this species, and to look at what other species might take its place as the favoured Amazonian hardwood export when all the *shihuahuaco* is too far away to profitably log. In light of the alarming discrepancy between the charcoal quantities published by the state and those estimated by us, a rethink is needed as to how national statistics on natural resources are derived in Peru. This is particularly relevant with the advent of REDD+ activity in Peruvian departments. Finally, although questions of equity and responsibility within the charcoal supply chain were a side-line theme in this paper, further research delving into this further and/or quantifying the charcoal consumption of the thousands of chicken brasseries in Lima might help to inform how legislation might be best organised to support the small-scale artisanal charcoal makers. This could involve maximising non-timber forest product revenue for communities at the source (Sutcliffe et al. 2012) whilst also identifying those that are profiting the most from environmental damage caused by the production and burning of wood charcoal in the urban metropolis.

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Notes

1. In line with Schure et al. (2012) Woodfuels are defined as ‘All types of biofuels originating directly or indirectly from woody biomass. This includes fuelwood and charcoal. Fuelwood is understood as woodfuel in which the original

composition of the wood is preserved. This category includes wood in its natural state and residues from wood-processing industries. Charcoal is defined as the solid residue derived from carbonisation, distillation, pyrolysis and torrefaction of wood' (p. 1).
2. Based on Atmaja and Verchot (2001) leakage is defined as 'The decrease or increase of GHG benefits outside of an intervention boundary that is either directly or indirectly attributable to the intervention implemented within those boundaries' (p. 313).
3. This paper intends 'long term' to mean more than 5 years.
4. Integer values were derived from preference ranking where *carboneros* ranked wood in order of preference with 5 as the highest possible value.

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