Available online at www.sciencedirect.com
SCIENCE DIRECT®

Forest Ecology and Management 205 (2005) 299–309

Forest Ecology and Management

www.elsevier.com/locate/foreco

Species, sources, seasonality, and sustainability of fuelwood commercialization in Masaya, Nicaragua

Jeffrey K. McCrary[a,b,*], Byron Walsh[c], A.L. Hammett[a]

[a]College of Natural Resources, Virginia Tech, Blacksburg, VA 24061, USA
[b]University of Central America, Managua, Nicaragua
[c]Asociación Gaia, ACS 091, Ciudad Sandino, Managua, Nicaragua

Received 23 June 2004; received in revised form 13 October 2004; accepted 14 October 2004

Abstract

The structure of the fuelwood supply chain and the impacts of urban residential fuelwood consumption on forests in Nicaragua are little known. To characterize the nature of fuelwood movements toward residential centers, we examined the fuelwood inventories and movements in the largest fuelwood market, in Masaya, during the peak of the rainy season, in October 1999, and again at the peak of the dry season, in May 2000. We found a stressed fuelwood supply that depended greatly upon natural forests. There was a diverse (64 tree taxa from 28 families) and strongly seasonally variable taxonomic composition of the supply of fuelwood. Greater volumes concentrated in fewer taxa (63,648 kg per 5-day period, with 58.9% in three species) were sold to vendors in the dry season than in the rainy season (12,921 kg per 5-day period with 24.6% among the same three species). The proportion of fuelwood derived from natural forests increased from one-third of the market sales during the rainy season to one-half in the dry season; virtually none of the fuelwood was derived from plantation forestry. We recommend a fuelwood supply management strategy based on incentives to farm owners for supplying managed fuelwood and increased vigilance to limit forest destruction for fuelwood production.

Keywords: Fuelwood; Forest products; Tropical dry forest; Natural resource management; Plantation forestry; Agroforestry; Nicaragua

1. Introduction

Resource management for fuelwood, being a de facto open access forest resource, is often difficult to achieve effectively where land tenure is limited or distorted and opportunity costs for many individuals are low (Ostrom, 1999). Although research interests in forest management in the tropics is often centered upon timber economics (Ozzane and Smith, 1993), most wood felled is dedicated to the fuelwood trade throughout the tropics (FAO, 1985). In communities where fuelwood is used for residential cooking, it is replaced by other technologies reluctantly, driven by cost differentials (Hadikusumah et al., 1991). In Nicaragua, fuelwood preference remains high, even

* Corresponding author. Tel.: +505 882 3992.
E-mail address: jmccrary2@yahoo.com (J.K. McCrary).

0378-1127/$ – see front matter
doi:10.1016/j.foreco.2004.10.012

among those who could afford propane–butane gas or other cooking technologies: more than half the energy need of Nicaragua is supplied by fuelwood (FAO, 2002). A broad perception exists among Nicaraguans that fuelwood extraction is occurring in unsustainable manners and quantities, but little information is available with which to interpret the sustainability of fuelwood extraction. Fuelwood was previously found to originate principally as a byproduct from forest conversion to agriculture (see van Buren, 1990); natural forests near Masaya are stressed by potentially unsustainable levels of fuelwood removal (McCrary et al., 2004).

It is widely considered that plantation forestry is not economically feasible, in part due to the perception of abundant natural forest woods available for timber and fuelwood. However, the potential and realized quantities of fuelwood from natural forests and agroforestry systems in this region are not known. We make here a first attempt at characterizing the sources and quantities of fuelwood commercialized in the Masaya market by analyzing the volumes and species of wood during wet and dry seasons. We hypothesize that the Masaya fuelwood market activities are dominated by wood from natural forests and agroforestry systems. To estimate the proportions of fuelwood arriving from each potential source type, we assigned likely origins of natural forest, agroforestry system, and plantation forestry to each taxon found in the market. We compared the volumes and taxonomic compositions and hence the sources of fuelwood in the market by season, and we also compared native and exotic species in the fuelwood supply.

Natural forests in the Pacific region of Nicaragua have been given little attention by policymakers, although the conservation status of the region is designated as critical (Biodiversity Support Program, 1995). The disastrous landslides and floods of Hurricane Mitch in 1998 demonstrated that environmental services provided by forests in the region had become dramatically compromised (Sáenz, 1999). Land clearing for agriculture is coupled with a clandestine, chaotic set of events including fuelwood harvesting, dry season fires, grazing, and uncontrolled pesticide use which affect the character and sizes of primary and secondary forest patches in the region (van Buren, 1990). Even the most casual observer can note that in the Pacific region of Nicaragua today, fuelwood cutting is a localized organized, commercial enterprise distributed throughout the region and is an important component of rural livelihoods. Where this wood goes, how it is consumed, and whether this activity is sustainable are still little known in Nicaragua, as this activity pertains to the little-studied informal economy which is an important component of livelihoods of the great majority of peasants in the highly populated Pacific region of Nicaragua.

Analysis of the fuelwood movements in Nicaragua has been elusive largely because of the large number of small and largely undocumented members of the market chain and a harshly criticized permitting process that does not guarantee tracking of fuelwood through the different levels of the market chain. Although the environmental sustainability of fuelwood use in Nicaragua is frequently questioned, little is known about the fuelwood commercialization patterns in the country upon which to base management plans for fuelwood and the farms, fields, plantations, and forests from which it is harvested. Initiatives such as the Madeleña Project (Cannon and Galloway, 1995) have promoted integrated sustainable fuelwood promotion in the area, although the impacts of these programs on other scales have not been evaluated.

Some studies of fuelwood dynamics focus on the domestic end-user (Shankar et al., 1998), while others measure fuelwood extraction rates from specific forests or areas (McCrary et al., 2004) or analyze the nature of the fuelwood supply chain (van Buren, 1990; Hadikusumah et al., 1991). Focus on the aspects of diversity of fuelwood species marketed as an indicator of quality of natural forest fuelwood supplies, however, has not been attempted, except in our recent study of fuelwood extraction (McCrary et al., 2004).

Subsector analysis, which focuses on specific links in market chains rather than specific enterprises, is particularly applicable to the analysis of such a market chain. By focusing on the input and output linkages of the enterprises in a specific level of the market chain, this has proven particularly facile in the analysis of market dynamics where small enterprises dominate (Boomgard et al., 1992). We conducted a subsector analysis of fuelwood commercialization in the Masaya fuelwood market, a central retail center on the edge of the municipal market, to determine fuelwood species, source types, transport distances, and seasonality of the fuelwood trade, in order to estimate the sustainability of the fuelwood trade in Nicaragua and to make specific recommendations to maintain a stable and inexpensive fuelwood supply.

2. Site description and methods

Masaya is the capital of the smallest and most densely populated department in Nicaragua. The city is the second largest in population in the country (pop. 124,000 in 1995 census). It is traditionally known as the hub of bread and candy production in Nicaragua. The municipal market in Masaya, Nicaragua, contains the largest fuelwood market in the country (Walsh and Castillo, 1999). Most of the bakeries, candy producers, and restaurants, as well as the homes of poor and middle-class residents in Masaya, depend at least partly on fuelwood. In addition, Masaya is a sawmill hub, center of furniture production and an important center of production of forest-based artisan products (Hammett et al., 1999). Although municipal services such as water, roads, and electricity reach virtually all of its residents, the non-wood options for household cooking as well as in many small industries are limited, and fuelwood use continues to be an important cultural element (Walsh and Castillo, 1999). The fuelwood market is located on the edge of the centrally located municipal market, although the size of the city makes walking to the market for some of its residents not feasible.

We analyzed the movement of fuelwood and charcoal in the Masaya municipal market during 4–8 October 1999 and 1–5 May 2000. Our first period of study of the market was at the height of the rainy season, when wood is wettest and transport in rural areas is most difficult. The second study period corresponded to the hottest and driest period of the dry season, when fuelwood would be of best quality for use and just before the first rains close or destroy seasonal rural roads.

In October 1999, we measured the volumes of fuelwood according to taxon by subsampling the inventories in three of the 11 market stalls, and we estimated the volumes of all fuelwood entering the market by taxon during this period and determined the precedence of each load. Our analysis of inventory volumes and taxonomic composition was limited to three stalls because of the reluctance of stall proprietors to permit inspection of their inventories during the rainy season; we were permitted to enter all market stalls during May 2000, when we repeated the entire protocol including inventory of all 13 market stalls operating then. Arrivals of fuelwood and charcoal for direct sale to the public at the entrance gate to the fuelwood market were also recorded. Wood taxa were determined by first by achieving a consensus among the fuelwood vendors and our technicians, and then confirming doubtful cases by seeking field specimens and comparing with records in the National Herbarium in the University of Central America. We used nomenclature consistent with Salas (1993).

We estimated wood inventories in the market stalls as per the first day of each study period, and the total weight of fuelwood that entered the market by date and hour for the entirety of each study period. To accomplish the latter, we observed and documented by taxon all movements of wood into the market from 4 a.m. when the market opened until 5:30 p.m. At the beginning and end of each day, we canvassed the surrounding areas of the market to attempt to document for clandestine nocturnal deliveries of fuelwood into the market by spotting fuelwood cargos awaiting the evening departure of authorities. We estimated "volumes" actually as weight estimates, based on our sight estimates and use of weighed bundles of wood to calibrate our estimates, a technique we previously developed (McCrary et al., 2004).

3. Results

The market chain we encountered for this product began with the collection of fuelwood through individuals who collect wood from farms and forests, and sell their products daily along roadsides to regular purchasers (Fig. 1). The purchasers served as wholesalers and transporters, usually stopping regularly to make individual purchases at each home, en route to their sales point. The wholesalers in turn sold their products to the vendors in stalls in Masaya. Entrance into the fuelwood market by the vendors requires the presentation of permits from the Ministry of Agriculture. The fuelwood vendors sold principally to end-

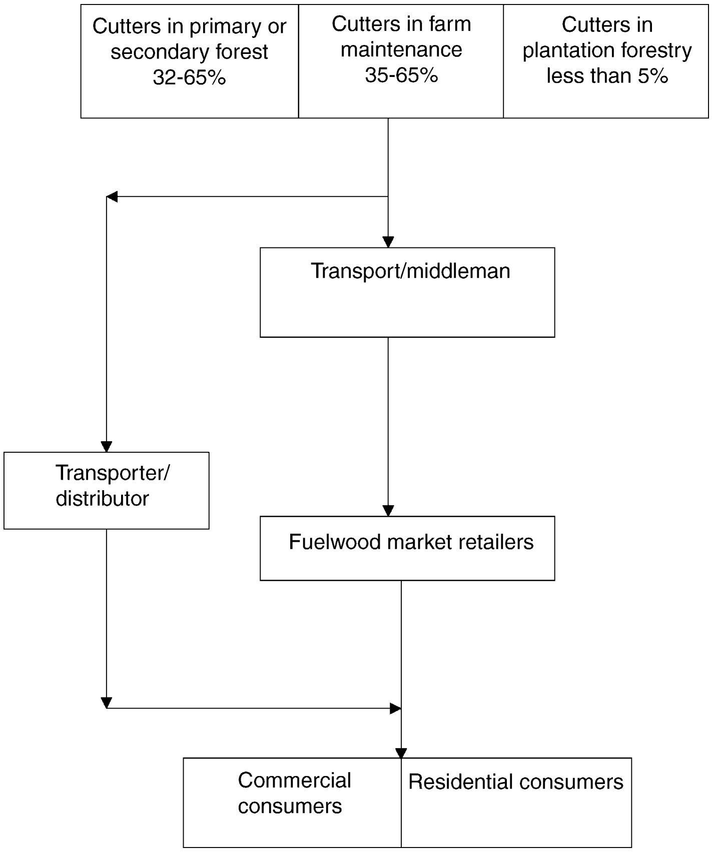

Fig. 1. Market chain flow diagram for fuelwood sold in Masaya Fuelwood Market.

use consumers for residential cooking, and to some restaurants and businesses. Fuelwood delivery from woodcutters directly to homes and small businesses was seen occurring through several neighborhoods in Masaya, in oxcarts. We did not survey sales outside the Masaya fuelwood market area.

We sought to determine origin of the fuelwood sold to vendors in the market during the dry season 2000 (Fig. 2). It was not clear to us how much of the fuelwood arriving on each truck had been harvested at the permitted site and how much had been received from other locations. We estimated that 17% of the marketed fuelwood during the dry season 2000 entered the market clandestinely, presumably because the transporters did not have permits to harvest and sell the fuelwood. Fifty-five percent of the fuelwood came from the Pacific coastal region, approximately 70 km by road from Masaya, where there are still substantial quantities of tropical dry forest. Twenty percent of the sales came from El Crucero, highland areas directly south of Managua, some 50 km by road from Masaya. The remaining 25% of sales were from forests and farmland within 25 km of Masaya.

We detected a number of clandestine movements of wood into the fuelwood market without permits. One residence near the market stocked up to a few metric tons of fuelwood and purchased from trucks that did not have permits. Some of this wood was later sold into the market at night, when vigilance was absent. Some trucks waited outside the gates until police vigilance disappeared nightly to enter and sell fuelwood illegally to the vendors. In addition, the charcoal and fuelwood vendors situated just outside the gates did not have permits to sell in the market nor did they have permits from the Ministry of Agriculture to sell their products.

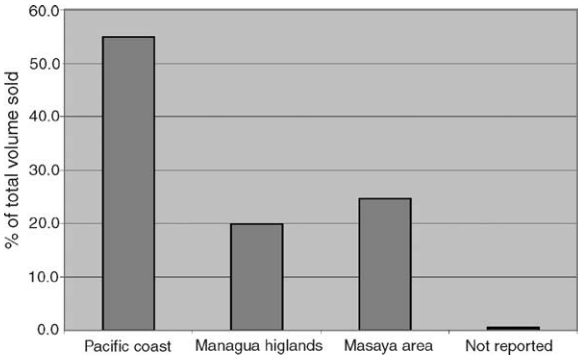

Fig. 2. Origin of fuelwood by location, May 2000.

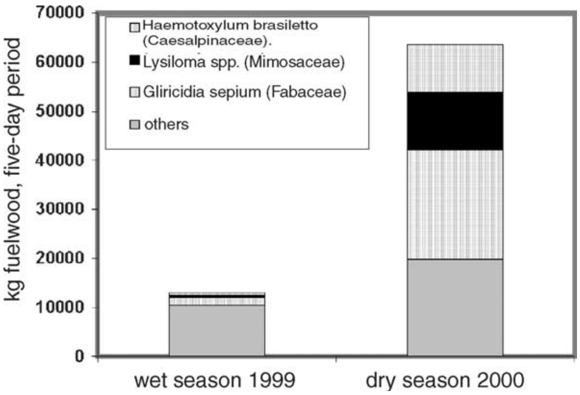

Fig. 3. Fuelwood sales to vendors, Masaya fuelwood market.

There were clear preferences for types of fuelwood among consumers and vendors. Many of the vendors used a strategy of combination of ‘‘dark’’ and ‘‘light’’ woods in the individual sale package. The vendors reported this strategy as a means to move the less preferred, lighter species. All fuelwood sold to vendors and in the inventory in the market was produced from pieces of a diameter of at least 10 cm. There was no evidence of small branches or industrial scrap. Three small pieces of wood were tied with plastic cord into each ‘‘manojo’’ or bundle, the most typical purchase unit. The retail price averaged 1 córdoba (US $0.075) for a ‘‘manojo’’ which averaged 0.7 kg in the rainy season 1999 and increased in weight to 0.9 kg in the dry season 2000, although wood was occasionally sold by ‘‘raja’’ which was quartered but not split into ‘‘manojos’’. Although the great majority of retail purchases were for only a few ‘‘manojos’’, the mean purchase size was estimated at 17 kg per person.

There was a dramatic difference in the movements of fuelwood into the market between seasons. More than four times the volume entered during the dry season 2000 study period (63,648 kg per five-day period) as in the wet season 1999 (12,921 kg; Fig. 3). Likewise, dependence upon source types for fuelwood varied by season. We determined 64 taxa (all at least to level of genus) among 28 families in the inventories and sales. In the dry season, when roads into remote areas for forest woods are more easily traveled, three species dominated the fuelwood sales to vendors, constituting 58.9% of total sales (Table 1). However, the same three species accounted for only 24.6% of the sales in the rainy season. An important component of the fuelwood market during the rainy season 1999 was charcoal, which constituted 20.3% of the sales during this period. All the charcoal that entered the market was sold by 9:00 a.m. each day, leaving none in inventory. Very little charcoal was found in the market during the dry season 2000.

Exotic species constituted a higher proportion of the fuelwood wholesale purchases and fuelwood market inventory during the rainy season than in the dry season (Fig. 4), whereas species which are not typically cultivated and are therefore representative of forest extraction (Cannon and Galloway, 1995; Pérez and McCrary, 2003) constituted a lower percentage of total volumes of sales and inventories during the rainy season than during the dry season (Fig. 5).

Although 28 families of trees were represented in the inventory and purchases by vendors in the two study periods, the majority of the volume was

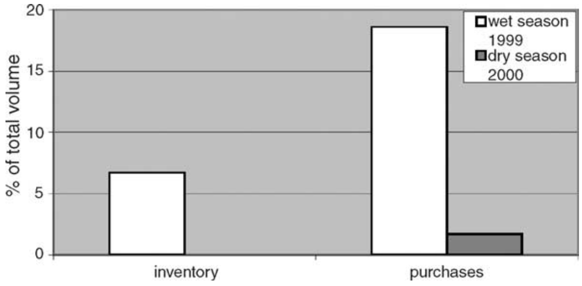

Fig. 4. Exotics as percentage of total volume in Masaya fuelwood market.

Table 1
Proportions of fuelwood inventory and sales to vendors by family and species in the Masaya fuelwood market

Family/species	Fuelwood market inventory				Sales to fuelwood market vendors			
	Rainy season 1999		Dry season 2000		Rainy season 1999		Dry season 2000	
	No. of species	Percent of total volume	No. of species	Percent of total volume	No. of species	Percent of total volume	No. of species	Percent of total volume
Anacardiaceae	0		1	<0.1	0		0	
Spondias mombin		NP[a]		<0.1		NP		NP
Annonaceae	0		1	<0.1	0		0	
Unonopsis pittieri[b]				<0.1				
Bignoniaceae	1	1.4	2	<0.1	0		2	<0.1
Tabebuia chrysantha[b]				<0.1				<0.1
T. stans		1.4		<0.1				<0.1
Boraginaceae	1	1.3	2	<0.1	1	1.3	3	1.5
C. alliodora		1.3		<0.1				0.3
C. bicolor[b]				<0.1		1.3		1.1
C. dentate								<0.1
Caesalpinaceae	3	1.5	5	14.8	1	4.0	5	21.7
C. exostemma[b]				0.3				3.7
C. violacea[b]				<0.1				1.1
Haemotoxylum brasiletto[b]		1.0		14.2		4.0		15.3
H. courbaril[b]		0.1		0.2				1.3
Senna atomaria[b]				<0.1				
S. reticulata[b]		0.3						
Schizolobium parahybum[b]								0.1
Clusiaceae	0		1	<0.1	0		1	1.0
Calophyllum brasiliense				<0.1				
Clusia spp.								1.0
Ebenaceae	0		1	<0.1	0		0	
Diospryos nicaraguensis[b]				<0.1				
Fabaceae	5	36.6	10	34.1	2	19.1	6	44.6
A. inermis[b]				0.2				1.7
Apoplanesia paniculata[b]				0.3				
D. retusa[b]		0.1		0.2				
D. robinioides[b]		2.7		1.2		3.0		3.2
Gliridia sepium		33.3		30.6		16.1		35.1
Lonchocarpus phlebifoius[b]				0.3				<0.1
Lonchocarpus spp.[b]				0.2				0.7
Myrospermum frutescens[b]	0.3			1.0				
P. pleitostachyum[b]		0.1		<0.1				
P. rohrii[b]				<0.1				3.4
Flacourtiaceae	1	0.3	0		0		0	
Zuelania guidonia[b]		0.3						
Lauraceae	0		0		0		1	<0.1
Phoebe mexicana[b]								<0.1
Lecythidaceae	1	0.3	1	<0.1	0		1	1.1
Couroupita nicaraguensis		0.3		<0.1				1.1
Malpighiaceae	1	2.3	0		1	8.3	1	0.3
Byrsonima crassifolia		2.3				8.3		0.3
Meliaceae	0		0		0		2	0.5
C. odorata								0.4
S. humilis[b]								0.1
Mimosaceae	4	23.1	5	44.2	4	11.9	5	20.8
Acacia farnesiana				<0.1				
A. hindsii[b]				<0.1				

Table 1 (*Continued*)

Family/species	Fuelwood market inventory				Sales to fuelwood market vendors			
	Rainy season 1999		Dry season 2000		Rainy season 1999		Dry season 2000	
	No. of species	Percent of total volume	No. of species	Percent of total volume	No. of species	Percent of total volume	No. of species	Percent of total volume
A. pennatula		3.7		0.3		6.0		0.8
A. caribea				0.3		0.7		1.0
Inga vera								<0.1
Lysiloma spp.[b]		16.7		43.6		4.5		18.5
Pithecellobium leucospermum[b]		0.3						
P. saman		2.4				0.7		0.3
Moraceae	2	2.4	2	0.3	1	6.0	1	0.2
Brosimum spp.[b]		1.1		0.2		6.0		0.2
C. tinctoria[b]		1.4		<0.1				
Myrtaceae	0		0		0		2	0.0
Eucalyptus spp.[c]								0.0
Eugenia salamensis[b]								0.0
Rhamnaceae	0		1	<0.1	0		1	0.2
Colubrina arborescens[b]								0.2
Karwinskia calderonii[b]				<0.1				
Rubiaceae	1	5.0	1	0.6	2	15.0	2	1.3
Calycophyllum candidissimum		5.0		0.6		4.2		0.4
Coffea spp.[c]						10.8		0.9
Rutaceae	1	1.0	1	0.8	0		1	0.6
Casimiroa edulis[b]		1.0		0.8				
C. sinensis[c]								0.6
Sapindaceae	1	6.7	0		1	7.9	1	0.1
M. bijugatus[c]		6.7				7.9		0.1
Sapotaceae	2	15.7	2	3.7	2	26.0	3	1.8
Chrysophyllum caimito								0.1
Manilkara spp.		10.0		2.3		6.6		0.6
M. capiri[b]		5.7		1.4		19.4		1.1
Simaroubaceae	0		0		1	0.6	1	0.2
S. glauca						0.6		0.2
Solanaceae	0		0		0		1	0.0
Solanum americanum[b]								0.0
Sterculiaceae	1	1.3	1	0.2	0		1	1.3
G. ulmifolia		1.3		0.2				1.3
Tiliaceae	0		1	0.7	0		2	2.6
Luehea candida								0.3
Leuhea sp.				0.7				2.3
Ulmaceae	1	1.0	1	0.3	0		2	0.2
Phyllostylon brasiliensis[b]		1.0		0.3				0.2
Trichospermum mexicanum[b]								<0.1
Vochysiaceae	0		1	<0.1	0		0	
Vochysia ferruginea[b]				<0.1				
Zygophyllaceae	0		0		0		1	<0.1
Guiacum sanctum[b]								<0.1
64 taxa/28 families		26 taxa/15 families		40 taxa/19 families	16 taxa/10 families		46 taxa/23 families	

Taxa not identified to species listed as spp.

[a] NP: not present.

[b] Noncultivated, forest species.

[c] Exotic species.

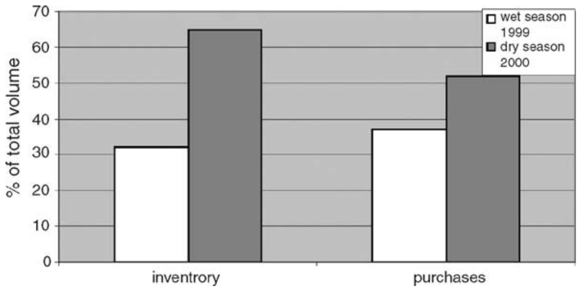

Fig. 5. Non-cultivated forest species in Masaya fuelwood market.

concentrated among relatively few families. Caesalpinaceae, Fabaceae, and Mimosaceae together constituted more than 80% of the inventory and more than 80% of the sales to vendors in the dry season 2000, whereas during the wet season 1999, five families, Fabaceae, Mimosaceae, Sapotaceae, Rubiaceae, and Sapindaceae, combined for more than 80% of the volumes in sales and inventory (Table 1).

4. Discussion

Although farms supply a large quantity of wood to the market, natural forests are important sources, particularly in the dry season when penetration into forests along logging roads is feasible. On the other hand, plantation-based fuelwood forestry products are essentially absent from the market.

Although sugar mills cultivate the exotic *Eucalyptus camaldulensis* for co-generation of electric power (Carneiro de Miranda and van den Broek, 1996), and *Eucalyptus* is planted in windbreaks and in a variety of urban situations in Nicaragua, we find it notable that almost no *Eucalyptus* was found in the fuelwood market in either study period. *Eucalyptus* plantations for industrial energy generation in Nicaragua totaled some 12,000 ha in 1996, and aside from pine forestry in the north, plantations for construction wood, pulpwood, and energy other than in industrial co-generation do not exist in significant sizes in Nicaragua (Ladrach, 1996; Hammett et al., 1999). The absence of *Eucalyptus* in the Masaya Fuelwood Market was even more surprising, given that all the vendors with whom we spoke recognize the wood. *Eucalyptus* and other exotic species occupied a minor component of the fuelwood market. Coffee (*Coffea* spp.) and two fruit trees (*Melicoccus bijugatus* and *Citrus sinensis*) were found in the fuelwood market particularly in the rainy season, when pruning of cultivated trees is performed. Coffee plant cutting after harvesting produces large quantities of fuelwood as a byproduct of coffee production. Several species such as *Gliricidia sepium*, *Tecoma stans*, *Simarouba glauca*, *Albizia caribea*, *Enterolobium cyclocarpum*, and *Cordia alliodora* are native but commonly encountered as shrubs and trees in fencerows, shade trees in pastures, and components of multistory agroforestry production systems. Maintenance of these systems provided a substantial proportion of the fuelwood found in the market during this study.

Our finding that species which are rarely encountered in production systems, yards, and pastures, such as *Haemotoxylon brasilettum*, *Caesalpinia exostemma*, *Andira inermis*, *Diphysa robinioides*, *Pterocarpus rohrii*, and *Mastichodendron capiri*, constituted a significant proportion of the total fuelwood in the market, particularly in the dry season when rural roads are good and volumes brought to the market are highest. Forest species constitute at least one-third of the market volume in the rainy season and more than half of market volume in the dry season 2000. van Buren (1990) found similarly that fuelwood from forest cutting, as a byproduct from land conversion to pasture or agriculture, constitutes the most important component of the fuelwood marketed (van Buren, 1990). Thirty-six of the 64 taxa are present in a nearby forested nature reserve which is currently heavily exploited for fuelwood (McCrary et al., 2004).

Although some bark and odd-shaped pieces were sold at the market as byproducts, there was virtually no fuelwood of bark-free diameter smaller than 8 cm. The smaller parts of a felled tree simply do not make it to the Masaya fuelwood market, reflecting a continued strong supply to meet demand for high-quality fuelwood. A gap between the market forces and forest conservation needs as wildlife habitat and source of environmental services has already developed, requiring coercive intervention to prevent destruction of potentially ecologically important forests.

Three of the species promoted by a regional initiative to improve rural livelihoods through increased silviculture for fuelwood and other uses, the Madeleña Project (Cannon and Galloway, 1995), are abundant in the market: *C. alliodora*, *G. sepium*, and *Guazuma ulmifolia*. Most of the species promoted by this project, however, are not native to Nicaragua and do not reach the Masaya fuelwood market (Table 2). Seven of the species promoted by this project are found commonly in Nicaragua, but are absent or present in insignificant quantities in the Masaya fuelwood market. The three species present in appreciable quantities, however, point to the success of on-farm development projects to integrate multiuse species in silvicultural systems in the Pacific. As is shown by the results of this project, Nicaragua has high fuelwood potential with native species which can be integrated into farm systems.

Table 2
Promising species in the MADELENA project (Cannon and Galloway, 1995)

Species	Native to Nicaragua	Present in silvicultural systems in Nicaragua	Present in Masaya Fuelwood Market
A. mangium			
Alnus acuminata			
Azadirachta indica		X	
Bombacopsis quinatum	X	X	
C. velutina	X		
Calliandra calothyrsus			
Cassia siamea		X	
Casuarina cunninghamiana			
C. equisetifolia			
C. ferruginosa			
C. alliodora	X	X	X
Cupressus lusitanica			
E. camaldulensis		X	X
E. citriodora			
E. deglupta		X	
E. globules			
E. grandis			
E. saligna			
E. tereticornis			
G. sepium	X	X	X
Gmelina arborea		X	
Grevillea robusta		X	
G. ulmifolia	X	X	X
Leucaena diversifolia			
L. leucocephala		X	
Melia azedarach		X	
Mimosa scabrela			
Pinus caribaea	X		
Tectona grandis		X	

Fine woods with specialty uses constituted 5.3% of sales to vendors in the wet season 1999 and 16.1% during the dry season 2000. Turned and carved wood artisanry in Masaya utilizes principally *Hymenea courbaril*, *Dalbergia retusa*, *C. alliodora*, *Cedrela odorata*, and *Chlorophora tinctora*, and woven fiber products produced in nearby Masatepe depend on natural dye from *H. brasiletto*. Other species commonly used in turned wood handicrafts include *Swietenia humilis* and *Platymiscium pleitostachyum* (Raymunda Santana, unpublished data). Export pressure as timber and associated products is especially strong on *C. odorata* and *Swietenia* spp. (Hammett et al., 1999). All of these woods were present in the Masaya fuelwood market, although the most abundant in inventory and in sales in all periods among these was *H. brasiletto*, which represented 4.0% of sales to vendors in the rainy season 1999 and 15.3% of the sales to vendors in the dry season 2000 (Table 1).

Our subsectorial analysis of the fuelwood industry at the level of the retail vendor has revealed clear tendencies regarding species utilization, seasonality, and land-use types involved in fuelwood consumption in Masaya. Fuelwood commercialization as is performed in Masaya presents a conflict between market and non-market valuation of natural resources. Our revealed market approach (Smith, 1993) to fuelwood commercialization in Masaya demonstrates that the extent of natural forest use for fuelwood is substantial, and is likely contributing to the advancement of the agriculture frontier in the Pacific slope of Nicaragua (van Buren, 1990). Forest-replacement schemes for continued supply of industrial fuelwood (Carneiro de Miranda, 1998) have not been applied for fuelwood destined for urban retail markets such as Masaya, and will require a number of actions that clearly have not occurred in Nicaragua.

The tendency toward diversification of utilized tree species in a stressed fuelwood market chain (Hadikusumah et al., 1991) is demonstrated here by the large number of taxa in the market and the increased number utilized during the rainy season. Whereas species harvested in farms are an important component of the fuelwood supply, they do not fill it completely, and wood from various directions may enter the market. Preferred woods from the most inaccessible forests enter when weather permits, and lesser species are increasingly marketed when access to these forests is limited.

Wood from more distant forests did not enter the Masaya market, presumably due to fuel and transportation costs. The woods of the North Central Highlands of Nicaragua did not reach the Masaya Fuelwood Market, as is demonstrated by the complete absence of Pinaceae, whose native range reaches the northern highlands and the north Atlantic coast of Nicaragua – Fagaceae, particularly *Quercus* spp., abundant in deciduous and mixed forests in the northern highlands – and the absence of many species of Lauraceae which are common to northern highland forests (Salas, 1993). Likewise, the mangroves of the Pacific coast do not provide wood for the market. We predict that exploitation of these forests to supply the Masaya area would occur before the conversion of fuelwood technologies to use industrial waste and small branches, in the absence of some management strategy which changes use patterns at the residential consumer level.

5. Management options

Tendencies toward residential fuelwood-use remain strong in Nicaragua. In fact, weaning Nicaraguans from fuelwood and toward imported fossil fuels may be unachievable and impractical in the foreseeable future, given the limited economic potential for the country to absorb additional importations. The economic conditions and natural resource base in Nicaragua suggest, furthermore, that the challenge to the country lies not in changing energy sources, but rather, in making the fuelwood supply economically and environmentally sustainable. The fuelwood market chain is still strongly connected to natural forests in Nicaragua, although much of the fuelwood in the markets already comes from agroforestry and silvicultural practices. We can point out four strategies in which residential fuelwood production can be more sustainable:

1. Greater inclusion of fuelwood production in farm management and certification of farms and plantations for sustainable fuelwood production. A demonstration of the economic feasibility of fuelwood production on farms could provide appropriate incentives to farmers to produce greater quantities and thereby reduce pressure on natural forests.
2. More effective control of fuelwood harvesting in protected areas and other natural forests and locations where it is otherwise not legally permitted. An effective, implementable policy on fuelwood harvesting and use in Nicaragua is lacking, largely due to the absence of adequate information on the character of the fuelwood market chain.
3. Greater inclusion of lower-grade products such as smaller branches and other wood industry by-products, utilization of more efficient fuelwood stoves, and the incorporation of the concept of fuelwood-use in a comprehensive policy analysis of alternative energy-use and potential in Nicaragua.
4. Development of clear understanding of the externalities (i.e. impacts on environmental services) and their increased incorporation in the structure of the fuelwood supply chain.

The tropical dry forest ecosystem which contributes fuelwood to Masaya also harbors key elements of the biodiversity of Nicaragua (Gillespie et al., 2001). Our examination of the fuelwood trade in this and a previous study (McCrary et al., 2004) provides a first approach to the identification and resolution of problems related to the conservation of natural forests and individual species in this forest type. Unfortunately, the high proportion of forest taxa in the fuelwood market chain and the presence of highly prized species for fine wood products demonstrate that current management mechanisms are not adequate to protect remaining natural forests and to continue the provision of high-quality fuelwood. Coercion-based mechanisms to ensure sustainably harvested fuelwood are difficult to implement in Nicaragua, however. Market-based incentives could involve tax structures applied to farms with managed forests or fuelwood plantations and promotion of efficient cooking technologies. Nicaragua has a unique opportunity to continue the development of native species-based fuelwood supply instead of turning to *Eucalyptus* and other exotics as has been done in other countries. We recommend community-based forestry management that unites, informs, and involves the fuelwood market-level merchants, farm- and forest-based fuelwood producers, and transporters as stakeholders along with conservation professionals and government or non-governmental representatives (Ribot, 2002). Although some levels of self-organization clearly exist surrounding this market chain, we present that its effectiveness in preventing forest destruction through implementation of alternative, sustainable fuelwood sources is deficient (Ostrom, 1999).

Acknowledgments

We thank Lorenzo Lopez and Harold Silva for assistance in data collection. This work was supported by the College of Natural Resources of Virginia Tech, Asociación Gaia and by a grant from the Conservation, Food and Health Foundation. Preliminary work on this report was supported by USAID and by a Fulbright Fellowship to J.K.M. Three anonymous reviewers aided greatly in the manuscript.

References

Biodiversity Support Program, 1995. A Regional Analysis of Geographic Priorities for Biodiversity Conservation in Latin America and the Caribbean. World Wildlife Fund, Washington, DC, 116 pp.

Boomgard, J.J., Davies, S.P., Haggblade, S.J., Mead, D.C., 1992. A subsector approach to small enterprise promotion and research. World Dev. 20, 199–212.

Cannon, P.G., Galloway, G.E., 1995. Fostering regional unity: The Madeleña Project of Central America. J. For. 42, 32–35.

Carneiro de Miranda, R., 1998. Forest replacement schemes in Latin America: an effective model to achieve sustainability of supply for industrial fuelwood consumers. Unasylva 49, 62–65.

Carneiro de Miranda, R., van den Broek, R., 1996. Power generation from fuelwood by the Nicaraguan sugar mills. Energy Sustain. Dev. 3, 64–68.

FAO, 1985. Tropical Forest Action Plan. Food and Agriculture Organization of the United Nations, Rome, Italy, 159 pp.

FAO, 2002. Estado de la información forestal en Nicaragua, Monografías de Países: Nicaragua, vol. 12. Food and Agriculture Organization of the United Nations, Santiago, Chile, 228 pp. (Chapter 7).

Gillespie, T.W., Nicholson, K.E., McCrary, J.K., 2001. Patterns of vertebrate species richness and conservation in Nicaragua. Nat. Areas J. 21, 159–167.

Hadikusumah, H.K., Balla, M.K., Chaudhary, S., Karkee, T.B., Cruz, F.A., Ortega-Espaldon, M.V., Juma, J.C., Polthanee, A., Suphanchaimat, N., Na-Lampang, P., 1991. Wood Fuel Flows: Rapid Rural Appraisal in Four Asian Countries. FAO, Bangkok, Thailand, 222 pp.

Hammett, A.L., McCrary, J.K., Bauer, G.P., 1999. Forest products in Nicaragua. For. Prod. J. 49, 12–20.

Ladrach, W.E., 1996. Evaluation of the Plantation Forestry Potential in the Republic of Nicaragua. Zobel Forestry Associates, Inc., Raleigh, North Carolina, Developed for USAID Nicaragua, 22 pp.

McCrary, J.K., Hammett, A.L., Barany, M.E., Machado, H.E., García, D.J., Barrios, J.I., 2004. Illegal extraction of forest products in Laguna de Apoyo Nature Reserve, Nicaragua. Caribbean J. Sci. 40, 169–181.

Ostrom, H., 1999. Self-governance and forest resources. CIFOR Occasional Paper No. 20, Jakarta, Indonesia, 15 pp.

Ozzane, L.K., Smith, P.M., 1993. Strategies and perspectives of influential environmental organizations toward tropical deforestation. For. Prod. J. 43, 39–49.

Pérez, A.M., McCrary, J.K., 2003. An ecological networks proposal to benefit the forests and farmers of Nicaragua's Pacific Slope. Ecoforestry 18, 20–24.

Ribot, J., 2002. Democratic Decentralization of Natural Resources: Institutionalizing Popular Participation. World Resources Institute, Washington, DC, 31 pp.

Sáenz, L., 1999. Usos de la tierra y producción. Biodiversidad en Nicaragua: Un Estudio de País, MARENA/PANIF, Managua, Nicaragua, pp. 89–144.

Salas, J.B., 1993. Arboles de Nicaragua. IRENA, Managua, Nicaragua, 390 pp.

Shankar, U., Hegde, R., Bawa, K.S., 1998. Extraction of non-timber forest products in the forests of Biligiri Rangan Hills. India. 6. Fuelwood pressure and management options. Econ. Bot. 52, 320–336.

Smith, V.K., 1993. Nonmarket valuation of environmental resources: an interpretative appraisal. Land Econ. 69, 1–26.

van Buren, A., 1990. The woodfuel market in Nicaragua: the economics, sociology, and management of a natural energy resource. Centre for Latin American Research and Documentation (CEDLA), Amsterdam, 257 pp.

Walsh, B., Castillo, M., 1999. Análisis (Estudio) Impacto Ambiental E.I.A. de la Oferta del Sector Energético Leña en la Ecoregión del Pacífico de Nicaragua. Report to Instituto Nicaragüense de Energía, Managua, Nicaragua, 55 pp.