A case study of smallholder eucalyptus plantation silviculture in Eastern Paraguay

by Jake J. Grossman[1]

ABSTRACT

Smallholder eucalyptus (*Eucalyptus* species) plantation forestry is common among rural farmers in Eastern Paraguay. Yet there has been no systematic study of the silvicultural practices utilized by smallholder plantation owners in the region. In response, I conducted a case study of semi-structured interviews with 45 eucalyptus-owning smallholders. My study characterizes the households that have adopted eucalyptus forestry and the management of these plantations. Silvicultural practices varied among households and, for some parameters, among regions. Improved extension efforts could enable eucalyptus plantation owners in the study population to improve production both for commercial sale and domestic use.

Key words: plantations, smallholder forestry, exotic forestry, eucalyptus, silviculture

RÉSUMÉ

La foresterie propre aux plantations d'eucalyptus (*Eucalyptus* sp.) réalisées par de petits propriétaires est une chose courante parmi les agriculteurs ruraux de l'est du Paraguay. Cependant, il n'existe aucune étude systématique des pratiques sylvicoles utilisées par les petits propriétaires de plantation de la région. En conséquence, j'ai entrepris une étude de cas à partir d'entrevues semi-structurées menées auprès de 45 petits propriétaires de plantation d'eucalyptus. Mon étude établit le portrait des propriétaires qui ont entrepris de cultiver l'eucalyptus et d'aménager ces plantations. Les pratiques sylvicoles variaient entre les propriétaires et, dans le cas de quelques paramètres, entre les régions. Des efforts accrus de diffusion de l'information pourraient permettre aux propriétaires de plantation d'eucalyptus dans la population sous étude d'améliorer leur production tant au niveau de la vente commerciale que de l'utilisation domestique.

Mots clés : plantations, foresterie des petits propriétaires, foresterie exotique, eucalyptus, sylviculture

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Introduction

Paraguay has long manifested some of the highest rates of deforestation internationally, with estimated rates of losses of 1.64% annually from 1984 to 1997 and a 0.9% deforestation rate today (Hansen and DeFries 2004, FAO 2011). The most recent FAO (2011) estimates put remaining forest coverage in Paraguay at 17 582 000 ha, 44% of the country's land area. Yet aggregate data conceal a much more troubling reality: roughly 80% of this remnant forest is located in Paraguay's Occidental (Western) region, a sparsely inhabited and less agriculturally productive zone encompassing 60% of the country's surface area but less than 5% of its population (Macedo and Cartes 2003, FAO 2010a). In distinction, Paraguay's Oriental (Eastern) region is home to the vast majority of the country's population and less than a quarter of its forest coverage, including the remaining Paraguayan extent of the endangered Interior Atlantic Forest ecoregion ("Atlantic Forest"). According to 1997 estimates (Cartes 2003), only 200 800 ha—much of it degraded—of an original coverage of over 880 500 ha of the Atlantic Forest remained in Eastern Paraguay. This highly biodiverse and productive landscape has certainly shrunk in the intervening years as a result of intense pressure from a rapidly growing and developing society (Macedo and Cartes 2003, Hansen and DeFries 2004, Wright *et al.* 2007).

Deforestation in Paraguay is driven by a variety of interacting factors. Most commentators (JICA 2002, Cartes 2003, FAO 2004) concur that the expansion of agriculture in the form of peasant subsistence farming, large-scale, mechanized cash crop plantations, and cattle pasture is the major driver of deforestation in Eastern Paraguay. Environmental policy failures—most notably, rampant corruption and concomitant insufficient monitoring/enforcement—hinder the responsible management, much less conservation, of existing forest resources (JICA 2002, Yanosky and Cabrera 2003, FAO 2004, Quintanta and Morse 2005, Wright *et al.* 2007). Given this policy milieu, and the historical importance of cash cropping among smallholders (Weisskoff 1992), rural farmers increasingly deforest their own land (Hamilton and Bliss 1998), sell it to large farming or ranching interests who do so (Cartes 2003), or seek out economically sustainable alternatives to customary subsistence farming of annual crops coupled with exploitation of remnant natural forest.

Globally, landowners and governments have relied on plantation forestry as one way to meet commercial and domestic demand for wood products—the most recent FAO

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estimates put global plantation cover at 7.0% of the world's total forested area (FAO 2010b). Paraguayan smallholders and commercial forest operations have doubled their investment in planted forest coverage to 48 000 ha since 1990 (FAO 2010a,b). And in 2011, an estimated 80% (Carmelo Sosa, Instituto Nacional Forestal, Oficina Regional Central, San Lorenzo, Paraguay, personal communication, 2011) of Paraguayan plantations included "fast-wood forestry" (*sensu* Cossalter and Pye-Smith 2003) of eucalyptus. Though concern over the environmental impacts of eucalyptus plantation forestry has undermined its popularity as a valuable investment and source of fuelwood (Doughty 2000, Couto and Dubé 2001, Evans and Turnbull 2004, Kohli *et al.* 2006), such criticism has not prevented the development of a eucalyptus "boom" in Eastern Paraguay.

The objective of this study is the characterization of the silvicultural practices and objectives associated with eucalyptus plantation forestry among smallholders in Eastern Paraguay. Though prescriptive guides and, to a lesser extent, descriptive accounts of large-scale plantation forestry abound both in the gray (Whitesell *et al.* 1992, Cossalter and Pye-Smith 2003) and academic literature (Couto and Dubé 2001, West 2006), empirical accounts of the realized, on-the-ground silvicultural practices of smallholders are rare. This is a major gap in the forestry and development literature (Byron 2001). By speaking with smallholders about their eucalyptus plantations and conducting site visits when possible, I have constructed a preliminary sketch of small-scale silviculture in eight communities in Eastern Paraguay. This analysis will prove especially useful for forestry extension and development workers in Paraguay and will inform current discussions about the adoption of eucalyptus silviculture among rural smallholders.

Methods

To meet the objective of this study, I conducted a case study (Yin 2003) of smallholder eucalyptus plantation forestry in Eastern Paraguay. The case study methodology is apt given that my study topic is a real-life phenomenon structured by a variety of historical, political, economic, psychological, technical, and biological factors that cannot be disentangled from one another or their "context".

Study population

I developed a study population consisting of all accessible smallholder eucalyptus plantation-owning families in eight rural, Eastern Paraguay villages inhabited by volunteers in the Environment and Agriculture sectors of the U.S. Peace Corps.[2] A Peace Corps volunteer (either me or a colleague) would approach the head of a family in his or her village, informally suggesting participation in the study. After receiving consent, we would arrange a follow-up encounter, during which I would conduct an interview and plantation visit if this was still amenable to the head(s) of family. I attempted to contact all eucalyptus-growing smallholders in a village. In each of the eight villages, I was able to survey all or the majority of plantation-owning smallholders, though there were some households that I could not reach. Because of this shortcoming and my process for selecting villages to visit, my study population can be thought of as an "incomplete census" (Gorard 2003) with villages selected by convenience sampling.

For the purposes of delimiting the study population, I operationalized several definitions. "Eastern Paraguay" consisted of all Paraguayan departments except Alto Paraguay, Boqueròn, and Presidente Hayes, and the capital district. "Smallholders" were families for which a primary economic activity was farming or ranching and who did not rely primarily on hired labor to manage fields, livestock, or tree crops. "Eucalyptus plantations" were considered to be spatially contiguous collections of individuals of *Eucalyptus* species planted intentionally to provide one or more benefits other than adornment and managed toward that end.

Eight other volunteers (two of whom lived in the same community) and I located a total of 45 households in our villages that met the criteria of smallholders with eucalyptus plantation forests in Eastern Paraguay. The study population, therefore, consisted of 45 participants living in eight villages, corresponding to seven municipalities in four departments (Table 1). I assigned each village a code letter (A–H) to protect the confidentiality of participants, but have otherwise identified municipality and department locations (Fig. 1). Five of the eight participating villages were located in two of the three departments with the highest rates of eucalyptus plantation forestry: Caazapà and San Pedro (C. Sosa, personal communication). I was not able to interview participants in the other center of eucalyptus cultivation, Alto Paranà, because the Peace Corps seldom assigns Environment and Agriculture volunteers there and because of travel constraints.

All villages were located in rural areas in which the main economic activities were farming and ranching. Dominant subsistence crops in the region were cassava, corn, peanuts, and beans. Family gardens for vegetable production, cattle ranching, and small animal production (of chickens, ducks, guinea fowl, pigs, sheep, and goats) also contributed to the provision of domestic food needs. Cash cropping of corn, sesame, cotton, soy, wheat, watermelon, pineapple, banana, citrus, yerba mate, and tung, and production forestry of a variety of exotic species were also common in the study region. The smallest surveyed villages consisted of only a few dozen households, with larger villages not exceeding 200 to 300 households. In some villages, few (e.g., 5 of 120 in Village A) smallholders had adopted eucalyptus plantation forestry while in others (e.g., 11 of ~25 in Village D), adoption was quite prevalent.

Data collection and analysis

I met with study participants at their own or a neighbor's home or in their fields or plantations and, after introductions, conducted an interview lasting from 15 to 90 minutes. The interviews were semi-structured, consisting of open- and close-ended questions and were conducted in the language of choice of the participant—either Guaranì (n = 44) or Spanish (n = 1). In many cases, participants were not able or did not wish to answer all of the questions in the interview instru-

[2]The U.S. Peace Corps is an independent agency of the U.S. federal government through which American volunteers spend two years living abroad in communities that have requested their presence. I lived in Eastern Paraguay from 2009 to 2011, working as an agroforestry extension volunteer in "Village A."

Table 1. Characteristics of municipalities and departments in the study region

Municipality	Department	Villages	Number of participants	Calculated 2012 population
General Higinio Morìnigo	Caazapà	A	5	1 964
Tobatì	Cordillera	B	4	11 324
San Juan Nepomuceno	Caazapà	C, D	16	11 347
Guayaibì	San Pedro	E	4	3 171
San Estanislao de Kostka	San Pedro	E	2	20 327
San Pedro de Ycuamandiyù	San Pedro	F	2	14 291
Alto Verà	Itapùa	G, H	12	1 085

Department	Villages	Calculated 2012 population	Area (km²)	Population density (per km²)
Caazapà	A, C, D	15 8162	9 496	16.66
Cordillera	B	27 2569	4 948	55.09
San Pedro	E, F	39 2864	20 002	19.64
Itapùa	G, H	59 3024	16 525	35.89

Adapted from The World Gazetteer (2012)

Fig. 1. Villages where study participants lived are indicated by stars. Map adapted from http://newspaper.li/paraguay/.

ment. Additionally, I occasionally omitted questions that I believed would not be appropriate for a given participant. I took hand-written notes while conducting the interviews and used an Olympus Digital Voice Recorder WS-600S (Olympus Imaging Corp., Tokyo) to record each encounter. In most interviews conducted in villages B–H, the resident Peace Corps volunteer accompanied me to each interview to provide me with germane background information and help build rapport with local participants. Interviews were conducted with one or two heads of household of the participating family, though I will refer to each family or household as a "participant" for the purposes of this report. Each participant was assigned a code consisting of the pertinent village code and a number (e.g., A1 was the first interview I conducted and H6, the last). I made sure that every interview was preceded by a discussion with the participant of the voluntary, exploratory nature of the process and his/her freedom to refuse to answer a question or end the interview at will.

In most cases, I was able to visit a participant's eucalyptus plantation with him/her following the interview. I did not record these site visits, but did take written notes, which I later used to supplement and/or correct data mined from interview transcripts.

I transcribed all participant interviews and then translated them into English, consulting Krivoshein de Canese and Acosta Alcaraz (2006) when necessary. I undertook all transcription, translation, and formatting in Microsoft Word (Microsoft Corporation, Redmond, WA). After completing the formatting of all 45 interviews, I created a Microsoft Excel workbook to use in the mining and organization of quantitative data from the interview transcripts. I reviewed each transcript's English translation and recorded data, when available, for a variety of parameters. I was able to assess these parameters in terms of the global study population as well as at the level of the department.

I followed Zar (2010) in calculating descriptive and inferential statistics in order to further explore the possibility of geographic structure in the quantitative data collected from the study population. Because participants in the study population were recruited non-randomly through a census-style procedure, I treated the observations of all participants as independent and thus subject to inferential statistical analysis, as long as inference is not inappropriately extended beyond the study population. However, because the quantitative data I derived from interviews fail to follow a normal distribution, they are not ideally suited to parametric tests. As a result, I have relied on non-parametric procedures.

When exploring parameters for which I had ratio data, I used the non-parametric Kruskal-Wallis test to assess difference in central location among populations consisting of all participants living in the same department. When the tests showed significant non-equality of central tendency at the .05 level of type-one error, I partitioned the resulting variation

Table 2. Mean values for household economy parameters across villages (A–H) and departments in the study region

Location	Household size	Land owned (ha)	Fields (ha)	Cattle pasture (ha)	Forest (ha)	Having subsistence crops	Having cash crops	Having cattle
A	3.6	12.8	1.7	5.0	1.0	60%	40%	80%
B	5.3	3.0	1.9	0.3	0.3	50%	25%	25%
C	8.8	7.2	37.4	4.8	16.3	100%	100%	100%
D	5.6	26.9	4.8	10.1	4.7	100%	45%	82%
E	4.3	10.8	5.0	1.6	0.7	100%	83%	83%
F	6.0	12.0	2.8	7.5	0.5	100%	50%	100%
G	6.5	16.3	6.5	3.6	4.9	100%	83%	83%
H	5.2	7.3	5.8	0.3	0.6	100%	83%	33%
Caazapà	5.5	26.7	4.3	10.3	7.4	90%	57%	85%
Cordillera	5.3	3.0	1.9	0.3	0.3	50%	25%	25%
San Pedro	4.8	11.1	4.4	3.1	0.7	100%	75%	88%
Itapùa	5.8	11.8	6.2	2.0	2.8	100%	83%	58%
Population	5.4	17.7**	4.6	5.7**	4.4**	91%	64%	73%

** = significant non-equality among the four departments at the α = .05 level, per a Kruskal-Wallis test.

using the Tukey Test of Honest Difference ("Tukey test"), also at a type-one error level of .05. I used SPSS, ver.14 (IBM, Armonk, NY) to perform all Kruskal-Wallis and Tukey tests.

When exploring parameters for which I had nominal and ordinal data, I constructed contingency tables displaying the frequency of participant responses in each department and then carried out chi-squared tests for non-equality among frequencies within the table. I performed all calculations by hand, using Excel for arithmetic, and compared calculated test statistics to critical values (Zar 2010) at the .05 and .01 levels of type one-error.

Results and Discussion

Household economies

Study participants lived in households with a mean of 5.4 inhabitants situated on holdings of a median of 10 ha of land (Table 2). Although land ownership among participants ranged from only half a hectare to 110 hectares, with a mean value of 17.7 ha, some of the larger reported values may represent *de facto* use of untitled lands by a few families who were, in reality, smallholders. Participants devoted an average of 4.6 ha to annual and tree crop fields, with 91% participating in subsistence farming and 64% engaging in cash cropping; 73% owned cattle. They devoted an average of 5.7 ha to pasture and corrals. Mean coverage of remaining "natural forest" on participants' land was 4.4 ha.

Land use, however, was not homogenous across the study population (Table 2). Participants did not own equivalent amounts of land ($\chi^2 = 16.17$, $p = .001$) and intact forest ($\chi^2 = 12.94$, $p = .005$) or devote equivalent amounts of land to cattle ranching ($\chi^2 = 12.82$, $p = .005$) across regions. Mean land ownership (or, as noted above, *de facto* appropriation) was highest among participants in predominantly rural Caazapá (26.7 ha), intermediate in Itapúa (11.8 ha) and San Pedro (11.1 ha), and lowest in Cordillera (3.0 ha). The Caazapeñan participants also owned more forested land and devoted more land to cattle ranching than participants in other departments. Forested land holdings were especially limited—an average of a hectare or less—in Cordillera and San Pedro and in Caazapá village A and Itapúa village H, representing high local and regional rates of deforestation. Participants in the other Caazapá and Itapúa villages, however, reported higher ownership of forested land, suggesting that these communities may be located at or beyond the rapidly diminishing agricultural frontier in the two departments.

I asked participants to rate the scarcity of firewood, fencepost wood, and construction-quality wood in their home region. These three classes were perceived as scarce by 28%, 41%, and 51% of the study participants respectively, without significant partitioning among regions (Table 3). These perceptions suggest the tendency for high-quality wood resources to be exhausted first: the perceived scarcity of firewood, which can be made from a variety of low- and high-quality sources, is much lower than the perceived scarcity of construction wood, which comes from high-diameter individuals of a few species. I also spoke with participants about relative prices of firewood, fence posts, and charcoal in their regions.

Most (96%) respondents used firewood to cook as opposed to gas stoves, which were used by only 16% of the surveyed families. Most participants also gathered firewood (87%) and post wood (82%) from their own land and used purchased charcoal on occasion (84%), usually to cook barbeque ("asado"). No participants used charcoal as a primary source of fuel.

Eucalyptus was not heavily used for fence posts (4% of participants), but was used sometimes for firewood (22%) and construction (10%). Though 9% of participants made their own charcoal, none of them had used eucalyptus wood to produce charcoal. Several noted that eucalyptus produced low-quality, light, or smoky charcoal.

Plantation design

Though plantation size varied from just a few dozen trees to two hectares in size, mean plantation size for the study population was just over 600 trees on three-quarters of a hectare. This produced a mean stocking rate of roughly 824 stems per hectare. However, the mean distance between trees was 2.67 m, with a mean distance between rows of 3.13

Table 3. Mean wood use parameters across villages (A–H) and departments in the study region

Location	Reporting firewood scarce	Reporting firewood moderate	Reporting firewood abundant	Reporting fence post scarce	Reporting fence post moderate	Reporting fence post abundant	Reporting construction scarce	Reporting construction moderate	Reporting construction abundant
A	0%	100%	0%	75%	25%	0%	100%	0%	0%
B	50%	0%	50%	67%	0%	33%	50%	0%	50%
C	40%	0%	60%	20%	20%	60%	25%	25%	50%
D	20%	0%	80%	30%	20%	50%	30%	10%	60%
E	33%	33%	33%	17%	17%	67%	75%	0%	25%
F	0%	0%	100%	50%	0%	50%	0%	0%	100%
G	20%	20%	60%	60%	20%	20%	60%	0%	40%
H	50%	17%	33%	50%	50%	0%	80%	20%	0%
Caazapà	21%	21%	58%	37%	21%	42%	41%	12%	47%
Cordillera	50%	0%	50%	67%	0%	33%	50%	0%	50%
San Pedro	25%	25%	50%	25%	13%	63%	50%	0%	50%
Itapùa	36%	18%	45%	55%	36%	9%	70%	10%	20%
Population	28%	20%	53%	41%	22%	37%	51%	9%	40%

Table 4. Mean propagule type and plantation establishment parameters across villages (A–H) and departments in the study region

Location	Produced seedlings	Bought/received seedlings	Mean plantation age (years)	Oldest plantation (years)	Youngest plantation (years)
A	20%	80%	4.00	6	2
B	25%	75%	7.75	20	3
C	20%	80%	2.20	3	1
D	27%	100%	2.73	8 1	
E 1	7%	83%	5.67	9	1
F	50%	100%	5.00	10	0
G	0%	100%	10.20	15	6
H	33%	100%	6.00	11	2
Caazapà	24%	83%	2.90	8	1
Cordillera	25%	75%	7.75	20	3
San Pedro	25%	88%	5.50	10	0
Itapùa	17%	100%	7.91	15	2
Population	22%	91%	5.07**	20	0

** = significant non-equality among the four departments at the α = .05 level, per a Kruskal-Wallis test.

m. These distances, if maintained across a fully stocked hectare, would produce a tree density of more than a thousand trees per hectare. This density would be manageable for a smallholder and is typical of commercial plantations. However, the data and my anecdotal observations on site visits suggest that smallholder plantations generally consisted of denser patches of trees interspersed with open ground or "holes" where trees have died or been felled or were never planted in the first place.

Stocking rates were significantly different among the four departments represented in the study population ($\chi^2 = 10.17$, $p = .017$). Participants in Cordillera planted at a mean density of 333 stems per hectare, which a post-hoc Tukey test partitioned from the Itapúa mean of 1426 trees per hectare. Intermediate stocking rates in Caazapá and San Pedro grouped together with both of the extreme means.

Plantation owners showed mixed preferences for planting in wet (37%) versus "normal" or dry (63%) sites and on sloped (36%) versus flat (64%) ground. Beyond stocking, none of the other parameters of plantation design that I surveyed showed evidence of geographic structure.

Site preparation

A number of participants recognized the criticality of planting in a weed-free or low-weed site to the successful establishment of the seedlings. This was accomplished through dedicated machete clearing (31%), plowing (13%), and hoeing (11%), but also, through the use of "taungya" (*sensu* Nair 1993) agroforestry systems (49%).

Propagule type

Study participants established their plantations using two kinds of propagules: seeds gathered from mature eucalyptus in the community (22%) or seedlings purchased or received from a variety of sources (91%; Table 4). Several participants both grew their own seedlings and also used bought or gifted

seedlings. Farmers producing their own seedlings used a variety of techniques, most of them variations on a germination box filled with forest soil and manure. Seeds were never purchased and were usually collected from a neighbor's mature eucalyptus. Those who used this "vivero" ("nursery") method of growing their own seedlings generally transplanted them directly from germination boxes or kept them in "macetas" (black plastic bags used commonly as seedling containers) for some months prior to transplanting. The standard propagule for farmers receiving containerized seedlings was a plant of roughly seven to eight cm in a maceta.

Plantation establishment

Though plantation age ranged from recently planted to 20 years, half of the participants had established a plantation in the last five years (Table 4). There was significant ($\chi^2 = 13.56$, $p = .004$) regional non-equality of plantation age. Participants in Caazapà had fairly young plantations (mean age of 2.90 years), which a post-hoc Tukey test partitioned from the Itapùa mean plantation age (7.91 years). The intermediate ages of the San Pedro and Cordillera plantations were such that the Tukey test grouped them with both Caazapà and Itapùa. This may reflect the relatively recent origins of the Caazapà timber boom. In village G, no new plantations had been established over the last six years—a higher figure than for other villages. This is suggestive of the important role of an NGO-backed development project in promoting bursts of eucalyptus adoption in the community.

Because participant estimates of seedling mortality within the first few months of plantation establishment were often imprecise, vague, or possibly exaggerated, I did not assess these data statistically. However, anecdotally, it appears that many participants lost large portions of their newly planted seedlings to drought, ant predation, competition with weeds, and other factors. Estimates of 10% to 50% losses were not uncommon. Eucalyptus notoriously requires intensive care after planting (Lamprecht 1989), though, as some participants noted, it is quite hardy after exceeding the height of surrounding understory vegetation.

Plantation management

Smallholders showed varying levels of investment in five critical plantation management strategies. Most (96%) cleaned weeds from their plantation at least once. Participants cleaned with hoes, machetes, and glyphosate herbicide and did so an average of 1.79 times a year. Pruning was also common, with 71% of participants using a saw, machete, or pruning shears to prune an average of 2.59 times over the life of the plantation. Fertilizing (not including initial fertilization at planting) with cow manure or chemical amendments occurred among fewer participants (38%) and less frequently (an average of 1.63 times over the life of the plantation). One-fifth (20%) of participants treated their plantation with pesticide at least once and only 11% thinned—usually doing so only once during the life of the plantation.

Rotation length

The study population included both participants who had harvested their eucalyptus plantation (33%) and those who had not. Among those who had harvested their plantation (or one of multiple plantations), two-thirds had coppiced, either intentionally or unintentionally, allowing stumps to regenerate. Only three out of ten participants expected to harvest from their plantation once it reached a specific age; the mean rotation age these smallholders envisioned was nine years. In the majority of cases, smallholders intended to make *ad hoc* harvests of a few trees at a time to use domestically or to sell and/or to coppice. Though a few participants planned to clearcut, it appears that selective harvesting was more common in practice.

Conclusions

I found evidence of diverse silvicultural practices among the smallholders participating in this study. Still, it is possible to draw some general conclusions about smallholder eucalyptus silviculture in the region. Except in the department of Itapùa, stocking rates were generally lower than optimal (Lamprecht 1989), suggesting that funds for or awareness of "blanking"—replanting to compensate for seedling mortality—may have been deficient (Evans and Turnbull 2004). Average spacing of roughly 2.5 m by 3 m is consistent with production of logs, but may need to be reduced for more efficient pole or firewood production. Site preparation was generally minimal, with many participants either focusing on weed cleaning of the plantation *per se* or of associated row crops. Most participants established their plantations with purchased or gifted seedlings, though 22% produced their own seedlings in germination boxes.

Plantation age varied significantly among regions included in the case study. Participants in Caazapà, the center of the country´s current eucalyptus boom, had the youngest plantations overall, suggesting the rapid adoption of eucalyptus plantation forestry in the department. Post-establishment rates of weed cleaning, pruning, and, especially, thinning were far below the standards recommended by both local extension workers (Raquel Acuña, Instituto Nacional Forestal, Oficina Regional Caazapà, San Juan Nepomuceno, Paraguay, personal communication, 2011) and the surveyed literature (Lamprecht 1989, Evans and Turnbull 2004). Especially in the early years of plantation development, smallholders should perform additional cleaning and thinning as well as blanking.

Finally, the mean rotation expected among participants who planned on managing their plantations as single-aged stands was nine years—an age consistent with log or large-diameter firewood production in the region (Lamprecht 1989, Cubbage *et al.* 2010). Historically, the focus of the Paraguayan government's extension programs has been to maximize agricultural yield (Hamilton and Bliss 1998), especially among medium- and large-scale, commercial farmers (Weisskoff 1992). While commercial forestry interests have relied on privately acquired expertise, smallholders invested in forest management or plantation forestry have had to resort to "informal experimentation"—they are forced to bear the costs and risks of new production techniques as they attempt to adapt them to local conditions (Weisskoff 1992).

Recent reorganization of extension services may, however, militate against this trend. Paraguay's Instituto Nacional Forestal (INFONA; "National Forestry Institute"), established in 2008, has made major strides in offering direct extension relevant to smallholders. Presently, one of the agency's most important projects is the promotion of forestry "asentamientos" (settlements) in rural Caazapà (R. Acuña, personal com-

munication). In this initiative, smallholders organize themselves into farmers' commissions and petition for assistance in reforesting degraded land and establishing commercial plantations—often of exotics such as eucalyptus. Programs like asentamiento-based extension could easily integrate findings such as those detailed above to improve extension services offered smallholder clients. If aware of the practices employed by rural smallholders experimenting with eucalyptus, extension providers can support good silvicultural practice, such as adequate spacing and appropriate use of agroforestry systems. When silvicultural practice is inadequate—as in the case of insufficient weeding or thinning—extension workers can help smallholders to improve production through educational outreach and the promotion of model plantations.

Gains in smallholder wood production would be a crucial step, not only in the fomentation of a productive forestry sector, but also in the development of strategies for fighting rural deforestation in the Atlantic Forest through more sustainable silviculture (Kangas and Rivera 1991).

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