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Are Agricultural Production and Forest Conservation Compatible? Agricultural Diversity, Agricultural Incomes and Primary Forest Cover Among Small Farm Colonists in the Amazon

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Summary. — This paper presents an empirical analysis that addresses recent work seeking "win–win–win" scenarios for economic development, poverty reduction and environmental sustainability. I focus on arguments for "productive conservation" in forest frontier regions, namely raising rural incomes while conserving the forest resource base. The analysis examines the impacts of agricultural product and income diversity on agricultural incomes and primary forest cover. The findings show that net of other factors, more diversified farms have higher agricultural incomes, but not significantly less forest cover. This finding is consistent with recent work in other study sites and suggests that initiatives promoting agricultural diversity can at least partially compatibilize production and conservation.

Key words — agriculture, diversity, sustainable development, land use, Latin America, Brazil

1. INTRODUCTION

In recent years, there has been a confluence of scholarship that suggests that agricultural diversification can serve as a strategy for simultaneously promoting poverty reduction, economic development and environmental sustainability in poor regions with fragile ecosystems (Angelsen & Kaimowitz, 2001; Ellis, 2000; Lee & Barrett, 2001; Pichón, Uquillas, & Frechione, 1999). Similarly, agricultural diversification in forested regions has been held out as a means for achieving *productive conservation*, defined here as the generation of higher and less variable incomes while conserving forest cover (Hall, 1997, 2000). Central to such ideas is the question of whether agricultural diversity provides a means of *compatibilizing* distinct goals involving economic development and environmental sustainability, which have often proven to be countervailing and required tradeoffs. [1]

This paper takes up the case of the Brazilian Amazon, a frontier region experiencing rapid but uneven economic growth in tropical forest ecosystems that are showing signs of increasing degradation (e.g., Browder & Godfrey, 1997; Hall, 2000; Wood & Porro, 2002). Given this context, I focus on the question of how agricultural diversity affects components of productive conservation. Specifically, I draw on data from a recent survey of small farm colonists to model gross agricultural incomes (i.e., welfare generated by production) and primary forest cover (i.e., conservation of the resource base) using indicators of the diversity of agricultural products and income sources and an array of control variables. If greater agricultural diversity generates higher and more stable incomes while avoiding additional forest clearing, it could be argued that such diversity

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promotes productive conservation, i.e., it renders development compatible with sustainability. The findings of this analysis bear implications for current discussions about productive conservation in forest frontier regions, and more generally for initiatives seeking to promote "win–win–win" strategies for poverty reduction, economic development and environmental sustainability.

2. BACKGROUND

(a) *Strategies for "compatibilizing" production and conservation*

Below I review strategies aiming in some fashion to compatibilize goals concerning poverty, development and the environment, in order to provide some context for proposals focused on agricultural diversification and productive conservation. The literature on such strategies has become enormous since the Brundtland report (WCED, 1987), and so to strive for manageability, the review that follows focuses on rural development via agriculture, especially in humid tropical forest regions. Even then, depending on how widely one reads, one encounters numerous proposals grounded in distinct disciplinary and area studies literatures, so the review to follow will be cursory and suggestive rather than exhaustive.

Longstanding policy strategies for rural development, such as credit lines and subsidies targeted for agricultural and extractive products, have increasingly focused on nontimber forest products (NTFPs) and nontraditional agricultural exports (NTAEs), which in some instances have been proposed as environmentally sustainable. NTFPs, including palm oils, medicinal plants and other such income sources, have been held out as products that can be produced sustainably for growing markets (e.g., Anderson, 1990; Broekhoven, 1996, IUCN, 1997). NTAEs have also been suggested as means of increasing national incomes, especially products for temperate markets in the off-season, though their environmental impacts have been debated since they vary among products (e.g., Collins, 1995; Damiani, 2003).

Recent years have also seen proposals for markets in natural capital and environmental services (e.g., Costanza *et al.*, 1997; Fearnside, 1997). With respect to forested regions, carbon markets are of central importance (e.g., Palo, 1999; Zhang & Justice, 2001), and comprise a key element of the clean development mechanism (CDM) in the Kyoto Protocol (e.g., Fearnside, 1999; UNCTAD, 2000). While the debate over ratification and implementation of the Kyoto Protocol has received substantial attention with respect to the environmental implications, questions have also been raised about the economic benefits to populations in regions sequestering carbon or maintaining key environmental services (e.g., Fearnside, 2001a).

Beyond market-based proposals for development with conservation, research has emphasized participatory approaches to sustainable development, often featuring the virtues of community institutions and common pool resource management. Out of participatory rural appraisal emerged a broader agenda of inclusive strategies for governance of resources, emphasizing local and indigenous perspectives, knowledge, data collection and management expertise (e.g., Pichón *et al.*, 1999; Selfa, 2001). Participatory sustainable development involves collaboration between local people and outside institutions for, e.g., land use planning, or transfers of technology and knowledge (e.g., IDRC, 2000; Uphoff, 2002). As a complement to this work on participatory development, the literature on communities has recently focused on the social and cultural capital of local peoples as assets for sustainable management (e.g., Agrawal, 1997; Agrawal & Gibson, 1999; Colfor & Byron, 2001). Similarly, empirical work on common-pool resource use and its social and environmental implications has expanded vertiginously (e.g., Burger, Ostrom, Norgaard, Policansky, & Goldstein, 2001; NRC, 2002).

Another active literature with ramifications for development and conservation in tropical forest regions concerns proposals for improved forestry practices, including reduced-impact logging (RIL) and timber certification. RIL has been shown to reduce damage to forests while generating higher profits to logging firms and landholders (e.g., Boltz, Carter, Holmes, & Pereira, 2001; Johns, Barreto, & Uhl, 1996; Pinard & Putz, 1996). Timber certification seeks to promote sustainable logging practices via independent certification of timber for export to specialty markets for high value-added products (e.g., FSC, 2003; Vogt, Larson, Gordon, Vogt, & Fanzeres, 1999).

A final body of work that merits mention is research on agricultural intensification and technology diffusion. Both have longstanding roots in the economic development literature, for example, work on induced innovation (e.g., Binswanger & Ruttan, 1978; Feder, Just, & Zilberman, 1985), which emphasized the capacity for emerging markets to facilitate technology adoption and rising agricultural productivity. This generated theoretically broader work on induced intensification, which considered tenure regimes, environmental gradients and other factors affecting aspects of agricultural intensification beyond technology adoption (e.g., Goldman, 1993; Turner II, Hyden, & Kates, 1993). The literature on agricultural intensification and technology adoption has focused increasingly on humid tropical forest regions (e.g., Clay, Reardon, & Kangasniemi, 1998; Godoy, 2001; Shriar, 1999). Substantively, such work has centered upon the environmental impacts of agricultural intensification and technology adoption, now the subject of some debate (e.g., Perz, 2003). These concerns emerged alongside discussions seeking "win–win–win" scenarios for economic development, poverty reduction and environmental sustainability, which have in turn raised the possibility of agricultural diversification as a potentially important means for achieving this goal.

(b) *Agricultural diversity and "productive conservation"*

Despite their focus on agricultural intensification as a means for compatibilizing development and sustainability in rural areas, the discussions in Lee and Barrett (2001) also emphasize agricultural diversity (see also Angelsen & Kaimowitz, 2001). For example, if by intensification one means intensification of labor inputs, this is often for the sake of adding new enterprises to an agricultural production system. After reviewing numerous case studies, Lee, Barrett, Hazell, and Southgate (2001, pp. 458–460) suggest that agricultural diversification can reduce poverty and foster economic growth while also sustaining environmental services and natural capital, thereby avoiding tradeoffs. They cite several examples of diversified agricultural systems, most of them involving Latin American cases, that are suggested as "best bets" for jointly addressing production and conservation goals (Gockowki, Nkamleu, & Wendt, 2001; Pender, Scherr, & Durón, 2001; Schipper *et al.*, 2001; Staal, Ehui, & Tanner, 2001; Tomich *et al.*, 2001; Vosti, Witcover, Carpentier, Magalhães de Oliveira, & Carvalho dos Santos, 2001a; see also Angelsen & Kaimowitz, 2001).

This work corresponds to arguments from other quarters. First, Ellis (2000) draws on the regional diversification and household economic literatures, and arrives at a similar conclusion about livelihood diversity. He notes that, on balance, agricultural diversity, as a key element of livelihood diversity, reduces risks of income variability across seasons and may raise incomes, thereby promoting regional development. At the same time, agricultural diversity may afford greater nutrient uptake and cycling that sustains production on existing plots, potentially reducing pressures to expand use of land and other resources. Second, the agroforestry literature makes similar noises about diversity. Agroforestry research also emphasizes diversification in production systems, in large part by highlighting their capacity to smooth incomes over time while maintaining biodiverse vegetation cover that provides environmental services (e.g., Anderson, May, & Balick, 1991; Nair, 1993; Smith, 2000). Third, the Lee *et al.* (2001) discussion dovetails with local initiatives in tropical regions such as the Amazon focused on attaining productive conservation (Hall, 1997, 2000). This is because productive conservation proposes to compatibilize the poverty, development and environmental goals by identifying production systems that can raise and stabilize incomes while conserving forest cover. Examples from Hall (1997, 2000) and other research in tropical frontier areas (e.g., Smith, Serrão, Alvim, & Falesi, 1995; Trinidade de Almeida *et al.*, 1996) often emphasize highly diversified agricultural systems with multiple crops and livestock.

That said, there are caveats, doubts, and debates concerning the capacity for agricultural diversification to compatibilize production and conservation. Regarding the caveats, many authors cited in the previous paragraph (e.g., Anderson *et al.*, 1991; Ellis, 2000; Lee *et al.*, 2001; Nair, 1993; Trinidade de Almeida *et al.*, 1996) have emphasized the importance of *labor-intensive* activities as crucial to allowing for diversification in rural households who may have limited land and/or capital. Further, many authors highlight the need for diversification to involve more than one high value commercial product, often those that require intensive husbandry as in small-scale or gardening operations, such as many perennial crops (e.g., Lee *et al.*, 2001; Smith, 2000). If these conditions obtain, then diversification can generate smooth and profitable returns to labor while focusing production on small plots of land, avoiding the need for forest clearing and the consequent environmental impacts. That said, other caveats apply. Lee *et al.* (2001, pp. 458–460) caution that win–win–win scenarios involving agricultural diversity may also require moderate population densities, off-farm employment opportunities, appropriate technology, reliable infrastructure, secure property rights, and effective local institutions, among other things. They also note the high initial cost of implementing diversified systems, and the difficulties of successfully applying them in many places or on larger scales (Lee *et al.*, 2001, pp. 460–462). In a related vein, Ellis (2000) notes that the capacity of households to engage in productive conservation depends on their assets and strategies (e.g., Reardon, Taylor, Stamoulis, Lanjouw, & Balisacan, 2000) and resilience to external shocks (e.g., Goldman, 1995).

Aside from caveats, there have been doubts that agroforestry and other diversified systems can generate higher incomes than alternatives such as pastoral systems for beef or dairy cattle. But such doubts are increasingly being questioned in light of data about diversified production systems with high incomes per hectare (Browder & Pedlowski, 2000; Trinidade de Almeida *et al.*, 1996; Yamada & Gholz, 2002).

A complement to the discussion about incomes from diversified production systems is a debate about the environmental implications of agricultural intensification and diversity (Perz, 2003). On the one hand are arguments that intensification featuring diversified agroforestry or agropastoral systems will raise incomes per hectare while also absorbing labor, thereby reducing pressure to clear forests (e.g., Sánchez, 1994; Serrão & Homma, 1993; Smith *et al.*, 1995; Trinidade de Almeida *et al.*, 1996; Uhl & Nepstad, 2000). On the other hand are arguments that intensification featuring monocultures or extensive beef cattle systems will lead to expanded land use and forest loss (e.g., Fearnside, 2002; Pichón, Marquette, Murphy, & Bilsborrow, 2001; Vosti, Carpentier, Witcover, & Valentim, 2001b; White, Holmann, Fujisaka, Reategui, & Lascano, 2001). While this debate features intensification, it begs the question of whether more diversified production systems actually garner higher incomes while conserving forest cover.

3. STUDY CASE, METHODS AND DATA

(a) *The Uruará survey*

To address questions about agricultural diversity and productive conservation, I draw on data from a recent survey of small farm households in the Brazilian Amazon. The study case is the municipality of Uruará, a frontier community situated on the Transamazon highway with a township located at Lat. 03°42′54″S, Long. 53°44′24″W in the Brazilian state of Pará. Uruará was established in the early 1970s as a colonization project in the central-eastern Brazilian Amazon to resettle landless rural families from the impoverished Brazilian Northeast. The state surveyed and demarcated land into lots of 100 ha, on which an initial wave of colonists began to settle and implement small-scale farming systems (IDESP, 1990).

From the 1970s to the 1990s, farm operations expanded and diversified in Uruará (IDESP, 1990). Farm households in Uruará began by cultivating annual crops (i.e., food crops such as rice, beans, corn, and manioc). This reflected the need of pioneers to establish land claims by clearing forest as well as the necessity of producing food to feed families. During the 1980s, due to high commercial crop prices, colonists diversified into perennial crops (i.e., tree crops such as cocoa, coffee, black peppers, and oranges). Prices made cocoa and black peppers especially important as cash crops. At the same time, many households converted cropland to pasture for beef and dairy cattle. This occurred due to new credit lines for smallholders, high prices for beef, the limited labor absorbed by ranching, and the "insurance" function of cattle, which can be sold any time to pay for medical and other expenses (Tourrand, da Veiga, Quanz, Ferreira, & Simão Neto, 1998). By 1990, Uruará exhibited agricultural diversification along with many of the conditions noted by Lee *et al.* (2001) as important for win–win–win scenarios for productive conservation—a moderate population density, tenure security, active local institutions (FUNDASUR, 1996; IBGE, 1998a, 1998b; IDESP, 1990). That said, incomes in the area have fluctuated, and many farms cleared substantial forest areas, only to fail later, leaving colonists in dire straits (Hamelin, 1991). During the 1990s, farm households faced increasingly difficult circumstances due to price declines for cocoa and black peppers, compounded by the spread of fungal attacks and other pests. By the mid-1990s, farm households in Uruará confronted the prospect of limited incomes from key cash crops as well as degradation of land where forest was cleared for pastures (Perz, 2001, 2002). This turn of events rendered the prospects for productive conservation via agricultural diversity somewhat more doubtful.

In June and July 1996, a nine-member research team consisting of North American and Brazilian social and agricultural scientists administered a survey questionnaire to farm households in Uruará. The questionnaire was divided into two parts: the first part addressed household characteristics and the second part concerned agricultural practices. Household questionnaire items addressed cultural background, migration and work histories, durable goods and housing assets, ownership of agricultural implements, hiring and selling of labor, and family age composition. Agricultural questionnaire items concerned land availability, access to credit and extension assistance, land use, annual and perennial crops cultivated, and heads of cattle. The sample includes 261 farm households, or 12% of all rural establishments in Uruará at the time (IBGE, 1998a). The sampled households owned 347 lots, and the same questions were asked for each lot owned by a household. Systematic sampling proved intractable because houses on many lots were not visible from roadsides, and sampling the "*n*th" house encountered was problematic because residents were frequently absent. Instead, the team sampled on the basis of "first opportunity" and employed a cadastral map from the Brazilian Amazon's regional agricultural agency, EMBRAPA/CPATU, to ensure that interviews were not clustered spatially or selective of households by socioeconomic status. [2] Of the households sampled, 81% earned more than half of their incomes from agriculture.

(b) *Measurement, description and relationships among explanatory and outcome variables*

(i) *Control variables*

Table 1 presents descriptive statistics and expected effects of explanatory variables on productive conservation. To identify explanatory variables, I drew on household economic frameworks from rural development and economic anthropology (Ellis, 1993, 2000; Netting, 1993; Singh, Squire, & Strauss, 1986). Such frameworks focus on small-scale agricultural systems that involve some mix of subsistence production for household consumption and commercial production for markets. Central in such frameworks are indicators of costs of market access that determine profitability, such as market distance and infrastructure quality, as well as factors of production, namely indicators of land, labor and capital availability. This is reflected in the organization of the explanatory factors into four groups: infrastructure, land assets, labor assets and various types of capital assets. In addition, I drew on theoretical and empirical models of small farm land use in the Amazon (e.g., Ozório de Almeida & Campari, 1995; Perz, 2002; Pichón, 1997; Walker, Perz, Caldas, & Teixeira da Silva, 2002). This helped identify specific variables relevant to frontier colonist households, in reflection of the local availability of land, labor and capital, the presence of relevant institutions, and key livelihood strategies used by households in the study site.

Infrastructure refers to the (average) distance in kilometers (km) to Uruará town from a household's lot(s) along unpaved roads, as well as two binomial variables indicating if the road quality is "good" or "fair" (as opposed to "bad") as appraised by the interviewee. These infrastructure variables account for the effects of market accessibility. Farms closer to Uruará town or along better roads should earn higher incomes due to greater profitability, and conversely, they should also have less primary forest cover. Table 1 shows that farms were on average nearly 30 km from Uruará town, though this varied substantially in the sample, and that only 18% of households resided on "good" roads, though another 52% lived on "fair" roads.

Land assets is operationalized as the number of hectares (ha) held in a household's lot(s), transformed into a natural log (ln) to obtain a normal distribution. More land should allow for higher incomes via a larger production system, and given the abundance of land relative to labor and capital, having more land should allow for proportionally larger areas in forest. For purposes of modeling forest cover, I also include a variable indicating whether a farm had one or more lots with fire damage to vegetation. Previous work on land allocation in Uruará showed that fire damage reduced the area under primary forest (Perz, 2002). Table 1 shows that farms on average held 117 ha because 25% of households held more than one

Table 1. *Descriptive statistics for agricultural income, forest cover, and agricultural diversity and other explanatory factors, farm households, Uruará, Pará, 1996*

	Mean	Standard deviation	Skewness	Expected effect on	
				Ln Agricultural income	Percentage forest cover
Infrastructure					
Average distance to Uruará Town (km)	29.35	14.04	0.26	–	+
"Good" road quality (0 = No, 1 = Yes)	0.18	0.39	1.64	+	–
"Fair" road quality (0 = No, 1 = Yes)	0.52	0.50	−0.07	+	–
Land assets					
Ln hectares (ha) of land held	4.77	0.48	0.75	+	+
Fire damage to vegetation (0 = No, 1 = Yes)	0.28	0.45	1.01	N/A	–
Labor assets					
Number of adults (ages 15–65)	4.10	2.55	1.07	+	–
Adults squared	23.24	29.21	2.67	–	+
Ln days of labor hired	1.92	1.98	0.21	+	–
Number of children (Age < 15)	2.85	2.74	1.57	?	?
Capital assets					
Natural capital					
Ln ha cleared upon acquisition	0.51	2.40	−0.03	+	–
Cultural capital					
Region of birth (0 = Other, 1 = Amazon)	0.17	0.38	1.78	?	+
Human capital					
Years of schooling completed	2.03	2.17	0.93	+	N/A
Previous agricultural experience (0 = No, 1 = Yes)	0.66	0.48	−0.66	N/A	+
Years of residence in Uruará	12.05	6.78	0.24	+	–
Technological capital					
Agricultural capital upon arrival (factor index)	0.00	1.21	4.90	+	?
Labor-saving capital (factor index)	0.00	1.57	1.32	+	?
Institutional capital					
Credit (0 = No, 1 = Yes)	0.59	0.49	−0.37	+	–
Extension assistance (0 = No, 1 = Yes)	0.21	0.41	1.46	+	?
Social capital					
Nonagricultural income (0 = No, 1 = Yes)	0.41	0.49	0.35	+	–
Neighborhood organization (0 = No, 1 = Yes)	0.32	0.47	0.79	+	?
Agricultural diversity					
Agricultural products					
S	4.75	2.07	−0.17	+	?
*M*6	3.94	1.48	−0.20	+	?
Agricultural income sources					
S	3.30	1.89	0.65	+	?
*M*6	2.96	1.50	0.73	+	?
Productive conservation					
Natural log (ln) agricultural income (R$)	7.49	2.02	−2.11	1	?
Primary forest cover (%)	62.41	18.15	−0.67	?	1

100-ha lot. About 28% of farms had experienced fire damage to vegetation.

Labor assets includes terms for the number of adults in a household (which may include more than one family), the number of days of labor paid per lot in the previous year (logged to obtain a normal distribution), and the number of children present. The number of adults is of particular importance, because farm households in Uruará rely primarily on family labor, especially for key tasks such as clearing forest and planting and harvesting crops. I also consider a squared term for the number of adults since households with particularly large labor pools may increasingly allocate labor to non-agricultural activities. Thus, adult labor may lead to higher incomes and less forest cover, but with declining marginal effects. The day labor variable is included to account for the effects of Uruará's labor market, which can offset household labor scarcity, particularly at times when labor demand peaks during clearing, planting and harvesting. As a substitute or complement to family labor, more days of labor hired should lead to higher incomes and less forest cover. Finally, I include a term for children because they may also contribute labor, but they also constitute dependents who require care that may withdraw adult labor from agricultural tasks. These two effects are countervailing and inseparable, and the inclusion of children as a variable allows an assessment of which effect dominates, if any. If the child labor effect is stronger, then having more children in the household should have the same effect as more adults and allow for higher incomes and less forest cover; if the child dependency effect is more important, then having more children will have the opposite impacts. Table 1 shows that households on average had over four adults, hired about seven days of labor in the previous year per lot held, and had nearly three children, though these labor indicators varied among households in the sample.

Capital assets refers to a broad array of factors that may enhance agricultural production by injecting resources into a farming system. I consider indicators of natural, cultural, human, technological, institutional and social capital. *Natural capital* is measured as the hectares of cleared land upon acquisition of the lot(s) held by a household. I employ this indicator because cleared land is considered a capital improvement in Brazilian law (Alston, Libecap, & Mueller, 1999) and because buying a lot with land already cleared reduces the costs of implementing a farming system, leading to potentially higher incomes and less forest cover. Table 1 suggests that cleared land upon acquisition averaged less than 2 ha, though this varied among households.

Cultural capital is operationalized as a binomial variable indicating whether the head of the household was born in the Brazilian Amazon or not. Heads born in the Amazon should be more acquainted with regional land use practices, allowing them to avoid land degradation and more forest clearing once a production system is in place. But region of birth has ambiguous implications for income; while more efficient land use could lead to higher incomes, it may also correspond to less of a market orientation in production as per traditional farming systems. Table 1 indicates that 17% of household heads were born in the Amazon, suggestive of the large contingent of interregional migrants in Uruará.

Human capital refers to whether the head of a household had previous agricultural experience, the head's years of schooling completed, and how long the household had resided in Uruará. I employ the years of schooling variable as a determinant of income, and expect greater educational attainment to lead to higher income levels. Conversely, agricultural experience serves as an explanatory variable for primary forest cover, and may allow for greater forest cover via less land degradation. Length of residence is included to capture the effects of learning locally appropriate agricultural techniques by experimentation and experience. Over time, households experiment with different agricultural techniques and crops, which results in higher incomes but less forest cover as families implement their farming systems (Moran, 1989). Table 1 shows that household heads averaged about two years of schooling completed, that 66% of household heads had agricultural experience before coming to Uruará, and that households averaged 12 years of residence in Uruará, though this varied substantially.

Technological capital is measured using two factor-weighted indexes of agricultural capital. The first index reflects whether a household had, upon their arrival in Uruará, a chainsaw, cocoa dryer, or a tractor, measured as one if so and zero if not in each case. Principle components analysis generated factor loadings used to weight the relative importance of *z*-scores of these three indicators, which were then added together to form an index with a mean of zero.[3] This index captures initial inequalities among households in Uruará in terms of agricultural capital, which should facilitate the implementation and expansion of farming systems, thereby leading to higher incomes and less forest cover. The second index focuses on labor-saving technological inputs used by a household in the year prior to the survey. The use of technologies specifically intended to save labor may also foster higher incomes as well as forest cover. I drew on typologies of agricultural technologies (see Angelsen & Kaimowitz, 2001; Binswanger, 1986; Lee & Barrett, 2001) to identify four labor-saving technologies: chainsaws, insecticides, fungicides, and herbicides. Each is measured as one if not used and zero if not. Another principle components analysis generated factor loadings, used to weight *z*-scores of the four indicators, which were summed together forming an index with a mean of zero.[4] Table 1 shows that both indexes vary among households, suggesting inequalities in agricultural technological capital.

Institutional capital not only refers to the use of bank credit, but also whether a household had been visited by local extension agents. Both are binomial variables. Credit injects additional funds into a farming system, which should raise incomes to pay for loans. But because credit in Uruará is often used for planting pasture and buying cattle (Toni, 1999), it should also reduce forest cover. Extension assistance should improve agricultural practices and thereby raise incomes, but it is less clear if help from extension agents will lead to better practices that reduce the need for further clearing or reduce forest cover for the sake of expanding a farming system. Table 1 indicates that 59% of households had received agricultural credit, an indication of an established local credit market, while only 21% of households were visited by extension agents, indicative of limited extension resources.

Social capital here refers to nonagricultural income and whether a household held one or more lots in a neighborhood organization. Both of these are also binomial variables. I include nonagricultural income under social capital since this variable indicates whether a household received any income from remittances, retirement pensions, a family business, a patron, or "other" sources, i.e., monetary transfers largely based on social ties. Research on rural household livelihood strategies has established that nonagricultural incomes provide capital that makes agriculture more productive (see Ellis, 2000), which should raise agricultural incomes and reduce forest cover. In Uruará and elsewhere, neighborhood organizations have formed along feeder roads off the Transamazon highway corridor (e.g., FUNDASUR, 1996; Hall, 1997). Such organizations serve as mechanisms for mutual aid among neighbors, who may establish producer cooperatives to secure better prices, alert each other when setting fires, and guard against poaching and incursions on established land claims. Neighborhood organizations therefore help producers realize profits, protect assets from losses and damage, and informally provide tenure security. Via these mechanisms, neighborhood organizations should foster higher incomes, but it is less clear whether they will reduce forest cover (e.g., Fearnside, 2001b). Table 1 shows that 41% of households received nonagricultural income and 32% were in neighborhood organizations.

(ii) *Agricultural diversity*

I adopt a quantitative approach to assessing agricultural diversity, drawing on conceptual and methodological discussions of measuring diversity in economics (Haughton & Mukerjee, 1995), ecology (Magurran, 1988) and sociology (Gibbs & Poston, 1975).[5] Conceptually, diversity has at least two aspects. First, it signifies the *number of categories present* (e.g., different agricultural products), which is variously referred to as *richness* or *structural differentiation*. Second, diversity encompasses *the relative distribution of units among those categories* (e.g., kg or income from each agricultural product), referred to as *evenness* or *distributive differentiation*. As the number of categories present and/or the evenness of the distribution of units among those categories rises, diversity increases. In the case of agriculture, a farming system with more products can be said to be more diversified, and among two farms with the same number of products, the one with more evenly distributed production or income among those products can also be said to be more diversified.

Preliminary testing of over a dozen diversity measures revealed many with disadvantages, such as poor discriminant ability, instability at high or low levels, or large losses of cases due to undefined values. I use two complementary measures that avoid computational problems: the number of products (S) and the 6th Gibbs–Poston index ($M6$).

The number of products S is calculated as

$$S = \sum_{i=1}^{c} a, \tag{1}$$

where i represents a count variable for the categories, a is a dichotomous variable that takes a value of 1 if a category is represented by a case and 0 otherwise, and c is the number of categories. S varies from 0 to c, the total possible number of products. Because S refers to the number of products actually produced or sold out of a given set of possible products, it is a purely *structural* measure of diversity, and does not take account of the importance of a given product. I nonetheless use S because it is easy to interpret and serves as a benchmark for comparisons with measures that also capture *distributional* aspects of diversity.

Gibbs and Poston's $M6$ is calculated as

$$M6 = c\left[1 - \frac{\sum_{i=1}^{c} |x_i - \bar{x}|/2}{\sum_{i=1}^{c} x_i}\right], \tag{2}$$

where x_i is the number of units in a category, and $\bar{x}$ is the mean number of units across all categories. $M6$ captures both *structural and distributive* aspects of diversity, that is, it increases as the number of categories with units rises as well as when the units are more evenly distributed among categories. In this way, $M6$ not only accounts for the number of products, but also their relative importance. $M6$ varies from a minimum of 1.0 to a maximum of c, but unlike S, $M6$ often takes values other than integers, making interpretation somewhat less clear.

To measure agricultural production diversity in Uruará, I drew on agricultural production data from the 1996 survey and supplemental data from the 1995–96 Brazilian agricultural census (IBGE, 1998a). I gathered production data for all identifiable annual and perennial crops and for cattle. [6] This allowed for calculation of agricultural diversity based on 18 products: eight annual crops (rice, beans, corn, manioc, pineapples, sugar cane, tomatoes, and watermelons), nine perennial crops (cocoa, coffee, black pepper, bananas, oranges, coconuts, cupuaçu, mangos, and guaraná) and beef. Production values were given in (or converted to) kg. [7] I estimated beef production on the basis of the reported cattle herd size and assumptions from state data sources about the annual off-take rate in Uruará in 1996 and average kg per head. [8] Hence, the 18 products serve as the categories and production in kg serves as the units for calculating S and $M6$ for each household in the Uruará sample.

I also drew on additional information about product prices in Uruará in 1996 to estimate the diversity of gross agricultural incomes for the same 18 products. This is important because measuring diversity in terms of brute production of rice, coffee and beef does not capture price-per-kg differences among the products, and because households only sell some proportion of their production, and these proportions vary among products. First, I obtained data indicating the proportion of a product sold. The Uruará survey provides such data for rice, beans, corn, and manioc. [9] State-level data for Pará from the 1995–96 Brazilian agricultural census indicated the proportion of production sold for the other products (IBGE, 1998a). [10] Second, I used the 1996 Uruará survey data and 1995–96 agricultural census data for Uruará to calculate prices per kg (in 1996 Brazilian Reais (R$), where R$1 $\sim$ US$1) for each of the 18 products using income generated, production figures, and estimates of production sold (IBGE, 1998a). [11] For each of the 18 products in every household, I then multiplied total production by the proportion sold and the price per kg to obtain gross income values, and used these income values to again calculate S and $M6$ for each household in the sample.

Table 1 shows somewhat limited agricultural diversity in Uruará. Of the 18 products considered, S indicates that households on average produced less than five and sold slightly more than three products. When we take distributive differentiation into account, $M6$ indicates even lower diversity, suggesting that households tended to emphasize certain products. Additional analysis (not shown) indicates the most widespread products produced were: rice (produced by 78% of the households surveyed), corn (77%), cattle (68%), black peppers (56%), beans (55%), manioc (54%), cocoa (34%), and coffee (33%); the other 10 products were produced by less than 10% of the households sampled. That said, the large standard deviations for S and $M6$ for both agricultural production and incomes indicate substantial variation in agricultural diversity in the Uruará sample.

(iii) *Productive conservation*

I operationalize the "production" side of productive conservation as the gross agricultural income summed from the 18 products sold by the households surveyed, logged to normalize the distribution. [12] This measure focuses on income from agricultural land use practices, which are the center of environmental concerns embedded in discussions about productive conservation and triple-win proposals with goals for poverty reduction, development and sustainability. [13] Table 1 shows that gross agricultural incomes averaged about R$1,800, though this varied substantially in the sample.

"Forest conservation" is measured as the percentage of reported primary forest cover on the lot(s) held by households in the 1996 Uruará survey. [14] This indicator affords the opportunity to assess the environmental aspects of productive conservation in terms of the primary forest remaining on a household's lot(s). As Table 1 shows, percentage forest cover averaged 62%, and varied substantially among households. The variation in household agricultural diversity, agricultural income and forest cover raises the question of whether diversification corresponds to productive conservation via higher incomes as well as more forest.

4. FINDINGS

(a) *Agricultural diversity and productive conservation: bivariate relationships*

Are agricultural production and forest conservation compatible via agricultural diversity? If one views productive conservation as an argument for such a compatibility, then agricultural diversity should raise and stabilize incomes while avoiding reductions in forest cover. Put another way, agricultural diversity should exert a positive effect on agricultural incomes and no effect (or a positive effect) on forest cover. Given that agricultural diversity as observed here emphasizes annual and perennial crops, which are labor intensive and can generate higher incomes per hectare than cattle (e.g., Perz, 2001; Trinidade de Almeida *et al.*, 1996), one might expect greater diversity to correspond not only to higher agricultural incomes, but also more forest cover. On the other hand, given the prevalence of annual crops and pasture among the households surveyed, diversity may force a tradeoff between production and conservation, such as via agropastoral systems with crop rotation and extensive pastures. In that case, agricultural incomes should exhibit a negative correlation with forest cover, and agricultural diversity should exhibit a positive effect on incomes and the opposite effect on forest cover.

Table 2 presents correlation coefficients between agricultural diversity, agricultural incomes and forest cover. Income and forest cover show a strong negative association ($r = -0.34$, $p < 0.01$). Further, agricultural diversity, however measured, exhibits a very strong positive relationship with agricultural income ($r \sim 0.55$, $p < 0.01$), and shows weaker negative correlations with forest cover ($r \sim -0.18$, $p < 0.05$). These findings suggest that there is a tradeoff between incomes and forest cover which agricultural diversity does not modify.

Table 2. *Correlations between agricultural diversity, agricultural income and primary forest cover among farm households, Uruará, Pará, 1996*

Correlations	Production: agricultural income (ln R$)	Conservation: primary forest (Pctg.)
Agricultural income (ln R$)	1.00	
Primary forest (Pctg.)	−0.34[a,**]	1.00
Agricultural product diversity		
S	0.60[**]	−0.16[*]
*M*6	0.54[**]	−0.20[**]
Agricultural income diversity		
S	0.63[**]	−0.18[**]
*M*6	0.51[**]	−0.18[**]

[a] $+p < 0.15$.
[*] $p < 0.05$.
[**] $p < 0.01$.

Table 3. *Means analysis of agricultural product and income diversity, agricultural income and primary forest cover, farm households, Uruará, Pará, 1996*

		Agricultural income (ln R$)			Primary forest (Pctg.)		
		Mean	Standard deviation	*n*	Mean	Standard deviation	*n*
Agricultural product diversity							
S	0–3 Products	5.49	3.07	54	68.60	20.87	55
	4 Products	7.75	1.35	59	60.28	20.47	62
	5 or 6 Products	7.85	0.99	94	61.41	15.34	94
	7–11 Products	8.67	0.94	50	60.15	15.60	50
	Total	7.49	2.02	257	62.41	18.15	261
F-score		34.39[a,**]			2.83[*]		
*M*6	1.00–2.99	5.45	3.24	50	69.05	20.83	50
	3.00–3.99	7.71	1.46	69	64.01	19.07	69
	4.00–4.99	7.90	1.01	73	58.99	17.34	73
	5.00–7.36	8.36	0.72	64	60.31	14.40	64
	Total	7.49	2.02	256	62.64	18.17	256
F-score		29.76[**]			3.65[*]		
Agricultural income diversity							
S	0–3 Products	6.01	2.59	91	67.18	18.43	92
	4 Products	8.00	1.00	56	57.49	20.62	58
	5 or 6 Products	8.28	0.64	81	61.74	16.47	82
	7–11 Products	8.94	0.97	29	59.03	12.91	29
	Total	7.49	2.02	257	62.41	18.15	261
F-score		38.49[**]			4.05[**]		
*M*6	1.00–2.99	5.12	3.16	50	70.65	16.53	51
	3.00–3.99	7.55	1.20	66	63.79	19.18	66
	4.00–4.99	8.22	0.86	72	58.43	18.80	72
	5.00–7.24	8.40	0.67	69	60.22	15.76	68
	Total	7.49	2.02	257	62.67	18.14	257
F-score		47.52[**]			5.29[**]		

[a] $+p < 0.15$.
[*] $p < 0.05$.
[**] $p < 0.01$.

That said, the relationships between agricultural diversity and productive conservation may not be linear, and this may reduce the degree to which there is a tradeoff between incomes and forest cover. Table 3 presents the results of means analyses for agricultural incomes and forest cover using categorizations of the agricultural diversity measures. The left side of the table shows that households with greater agricultural diversity indeed have significantly higher agricultural incomes, but there is more going on than just this. The standard deviations in incomes are smaller in households with greater diversification, which suggests that incomes become more stable (i.e., less variable) at higher levels of agricultural diversity, consistent with the productive conservation thesis. Further, the rise in average incomes declines as one moves toward categories denoting greater diversity. This indicates that the marginal effect of diversity on incomes declines with rising diversity. The right side of Table 3 shows that forest cover does decline as diversity rises, but only at low levels of diversity. As one moves from the first to the second diversity category, forest cover declines from ~70% to ~60%, but as one moves to categories denoting higher levels of diversity, forest cover remains around 60%. This also indicates a nonlinearity in the impact of diversity on forest cover, and suggests that at higher levels of diversity, forest cover does not decline. This in turn implies that there is actually some compatibility between incomes and forest cover, for at high levels of diversity, high incomes stabilize and forest clearing stops declining at fairly high percentage levels of forest cover. While these results are intriguing, they beg the question of whether the effects of diversity on incomes and forest cover remain when controlling for other variables.

(b) *Models of agricultural diversity and productive conservation*

Table 4 presents five ordinary least squares (OLS) models of logged agricultural income regressed on agricultural diversity and the other explanatory variables. [15] Because the findings in Table 3 indicated that the agricultural income data are heteroskedastic, *p*-values for coefficients in this table are based on robust standard errors. [16] A "base model" appears in column 1, and considers only the effects of the control variables. Households had significantly higher agricultural incomes ($p < 0.05$) if they (i) had more adults, though this effect is nonlinear and attenuates, (ii) hired more labor, (iii) had more children, (iv) arrived in Uruará with more agricultural capital, and (v) had received credit. These findings correspond to expectations.

The addition of diversity measures for agricultural production and income substantially improves explanatory power and changes the findings somewhat. Model 2 includes S for agricultural production, as well as a squared S term to account for nonlinearity in the impact of diversity on logged income. This model is much stronger than the base model ($R^2 = 0.61$ *vs.* 0.31). [17] Households had significantly higher agricultural incomes ($p < 0.05$) if they (i) resided longer in Uruará, (ii) arrived in Uruará with more agricultural capital, (iii) had been visited by extension agents, and (iv) produced more agricultural products S, though this effect is nonlinear and attenuates at high levels of S. Model 3 replaces S and its square with $M6$ and its square, and also produces a model stronger than the base model. A comparison of Models 2 and 3 shows that the significant control variables are somewhat different. In Model 3, children and labor-saving capital are significant, while visits from extension agents is not. That said, Model 3 like Model 2 shows a strong positive but nonlinear impact of diversity on income. Model 2 is stronger than Model 3 ($R^2 = 0.61$ *vs.* 0.53), which suggests that it is primarily structural diversity (i.e., more agricultural products) rather than distributive diversity (i.e., more equal production among products) that drives up agricultural incomes.

Models 4 and 5 replace the product diversity variables with measures of agricultural income diversity. These models are also stronger than the base model ($0.55 < R^2 < 0.72$), and the model with S (Model 4) is stronger than the model with $M6$ (Model 5), again suggesting that structural more than distributive diversity leads to higher agricultural incomes. Like Models 2 and 3, Models 4 and 5 show strong, positive and nonlinear effects of agricultural income diversity on agricultural incomes. Overall, Table 4 confirms the "production side" of the productive conservation argument for agricultural diversity: more agriculturally diversified farms in the Uruará sample earned higher agricultural incomes.

Table 5 presents five ordinary least squares (OLS) models of percentage forest cover to examine the effects of agricultural diversity on forest conservation. The base model is strong ($R^2 = 0.47$) and reveals significant effects of several control variables ($p < 0.05$). Households had proportionally more land under primary forest if they (i) were farther from Uruará town, (ii) held more land, (iii) had not experienced fire damage to vegetation, (iv) hired less labor, (v) had less cleared land upon acquisition of their properties, (vi) had resided for less time in Uruará, and (vii) had not received credit. These findings are consistent with expectations.

Models 2–5 add the diversity measures. In every model, agricultural diversity shows a negative impact on forest cover. However, this effect never reaches statistical significance ($p > 0.15$), and the explanatory power of the models does not rise above that of the base model. [18] Moreover, the control variables show basically the same effects on forest cover in all five models in Table 5. These findings indicate that greater agricultural diversity, whether measured in terms of production or incomes or emphasizing structural or distributive diversity, does not reduce forest cover among households in Uruará. This confirms the "conservation side" of the productive conservation argument for agricultural diversity: more agriculturally diversified farms in the Uruará sample did not have less forest cover. This carries the caveat however that other factors reduce forest cover (e.g., fire damage, hired labor, length of residence, credit). This implies that agricultural diversity does not offset forest clearing due to other factors.

Table 4. *OLS models of logged agricultural incomes regressed on agricultural diversity and other explanatory factors, farm households, Uruará, Pará, 1996*

	Base model	Product diversity		Income diversity	
	1	2	3	4	5
Model R^2	0.31	0.61	0.54	0.72	0.55
Wald test	5.38[a,**]	11.08**	7.74**	14.97**	8.41**
Valid n ($n = 261$)	236	236	235	236	236
Infrastructure					
Average distance to Uruará town (km)	−0.02	−0.01	−0.01	−0.003	−0.01
"Good" road quality (0 = No, 1 = Yes)	−0.33	−0.31	−0.27	0.12	0.02
"Fair" road quality (0 = No, 1 = Yes)	−0.12	−0.01	−0.05	0.01	−0.06
Land assets					
Ln hectares (ha) of land held	−0.02	0.19	0.26	0.11	0.13
Labor assets					
Number of adults (ages 15–65)	0.48**	−0.19	−0.13	0.04	0.18
Adults squared	−0.03*	0.01	0.01	0.0002	−0.01
Ln days of labor hired	0.21**	0.09+	0.09+	0.04	0.08+
Number of children (age <15)	0.11*	0.06+	0.09*	0.04+	0.09**
Capital assets					
Natural capital					
Ln ha cleared upon acquisition	0.01	0.05	0.07+	0.05	0.07
Cultural capital					
Region of birth (0 = Other, 1 = Amazon)	−0.005	0.24	0.13	−0.05	−0.05
Human capital					
Years of schooling completed	0.03	0.05	0.03	0.06	0.05
Years of residence in Uruará	0.01	0.03*	0.04*	0.01	0.02
Technological capital					
Agricultural capital upon arrival (factor index)	0.25**	0.23**	0.22**	0.23**	0.26**
Labor-saving capital (factor index)	0.11+	0.11+	0.16*	0.16**	0.19**
Institutional capital					
Credit (0 = No, 1 = Yes)	0.58**	0.27	0.14	0.13	0.14
Extension assistance (0 = No, 1 = Yes)	0.24	0.45*	0.25	0.43*	0.33
Social capital					
Nonagricultural income (0 = No, 1 = Yes)	−0.20	0.07	0.02	−0.02	−0.07
Neighborhood organization (0 = No, 1 = Yes)	0.25	−0.16	−0.12	0.003	−0.01
Agricultural diversity					
Agricultural products					
S		1.53**			
S squared		−0.11**			
*M*6			2.34**		
*M*6 squared			−0.22**		
Agricultural income sources					
S				1.77**	
S squared				−0.14**	
*M*6					1.99**
*M*6 squared					−0.19**

[a] $+p < 0.15$.
[*] $p < 0.05$.
[**] $p < 0.01$.

Table 5. *OLS models of percentage primary forest cover regressed on agricultural diversity and other explanatory factors, farm households, Uruará, Pará, 1996*

	Base model	Product diversity		Income diversity	
	1	2	3	4	5
Model R^2	0.47	0.47	0.48	0.47	0.48
Wald test	13.25[a],**	13.46**	13.80**	13.06**	13.05**
Valid n ($n = 261$)	251	251	246	251	247
Infrastructure					
Average distance to Uruará town (km)	0.16*	0.16*	0.15+	0.16*	0.13+
"Good" road quality (0 = No, 1 = Yes)	3.18	3.17	3.53	2.80	3.54
"Fair" road quality (0 = No, 1 = Yes)	0.62	0.60	0.56	0.56	0.46
Land assets					
Ln hectares (ha) of land held	15.01**	15.03**	14.58**	14.99**	14.75**
Fire damage to vegetation (0 = No, 1 = Yes)	−8.62**	−8.49**	−9.22**	−8.37**	−8.75**
Labor assets					
Number of adults (ages 15–65)	−0.24	−0.05	0.44	0.04	0.43
Adults squared	−0.10	−0.11	−0.15+	−0.12	−0.14+
Ln days of labor hired	−1.52**	−1.46**	−1.35*	−1.36*	−1.28*
Number of children (age <15)	−0.51+	−0.49+	−0.55+	−0.44	−0.55+
Capital assets					
Natural capital					
Ln ha cleared upon acquisition	−1.58**	−1.60**	−1.60**	−1.62**	−1.63**
Cultural capital					
Region of birth (0 = Other, 1 = Amazon)	0.32	0.27	−0.17	0.43	0.06
Human capital					
Previous agricultural experience (0 = No, 1 = Yes)	−3.09+	−3.12+	−3.70+	−3.05+	−3.51+
Years of residence in Uruará	−0.40*	−0.41*	−0.42*	−0.40*	−0.44*
Technological capital					
Agricultural capital upon arrival (factor index)	−1.03+	−1.05+	−1.01+	−1.05+	−1.06+
Labor-saving capital (factor index)	−0.96	−0.95	−0.99	−0.96	−1.16+
Institutional capital					
Credit (0 = No, 1 = Yes)	−6.78**	−6.69**	−7.10**	−6.58**	−6.77**
Extension assistance (0 = No, 1 = Yes)	−2.24	−2.31	−2.13	−2.33	−2.31
Social capital					
Nonagricultural income (0 = No, 1 = Yes)	0.30	0.17	−0.16	0.12	−0.33
Neighborhood organization (0 = No, 1 = Yes)	−2.09	−1.95	−1.91	−1.86	−1.81
Agricultural diversity					
Agricultural products					
S		−0.09			
S Squared		−0.02			
$M6$			−2.30		
$M6$ Squared			0.24		
Agricultural income sources					
S				−0.49	
S Squared				−0.01	
$M6$					−2.41
$M6$ Squared					0.22

[a] $+p < 0.15$.
* $p < 0.05$.
** $p < 0.01$.

5. CONCLUSIONS AND DISCUSSION

Overall, the findings indicate that farms with greater agricultural diversity have significantly higher agricultural incomes but not significantly less primary forest cover. However, while agricultural diversity and other factors raise agricultural incomes, it is factors other than agricultural diversity that reduce forest cover. The somewhat ambiguous finding concerning forest cover raises the question of to what extent agricultural diversity can compatibilize conservation with production.

The extent of compatibility of productive conservation via diversity depends on one's operational definition of conservation in the present context. On the one hand, if we understand conservation in terms of "limited land use," then agriculturally diversified farms constitute examples of productive conservation, because they have higher incomes but not less forest. This implies *full compatibility* between production and conservation. On the other hand, if we understand conservation more in terms of "preservation of more forest land," then the findings do not clearly indicate productive conservation, since more diversified farms have higher incomes but not more forest than less diversified farms. This implies *partial compatibility* between production and conservation, for while more diversified farms do not have more forest, neither do they have less, which would have indicated a tradeoff. I conclude that the findings indicate that agricultural diversity allows for at least partial compatibilization of production and conservation.

Whether the findings constitute evidence of full or partial compatibility, they require some interpretation of the mechanism by which agricultural diversity generates higher incomes but not less forest cover. I interpret the findings as indicating the effects of farms diversifying by adopting products that generate more income but not more demand for cleared land. Perennial crops and some annuals grown entirely for market, such as tomatoes, pineapples, and watermelons, fit these requirements. Perennials and market-oriented annuals constitute the majority of the products considered here, they were not (except black peppers) grown by most households, they absorb substantial labor but do not require much land, and they generate more income per hectare than cattle (e.g., Perz, 2001; Serrão & Homma, 1993; Trinidade de Almeida *et al.*, 1996). This interpretation also holds in dynamic terms, for it fits the history of land use in Uruará, which at first featured annuals grown for food, and later increasingly emphasized perennial crops grown for market (IBGE, 1998a; IDESP, 1990). Agricultural diversity makes productive conservation possible when the products in question, such as perennials, generate income and absorb labor without requiring substantial forest clearing.

Having offered a theoretical interpretation, some methodological caveats are in order. Because I did not have data on production costs, total agricultural income refers to gross and not net income. There is some evidence from other colonies in the Amazon that households with the most assets incurred the largest debts, and while they enjoyed larger gross incomes, they had lower or negative net incomes (Ozório de Almeida, 1992). Other evidence from the Amazon suggests, however, that more diversified production systems yield larger net positive incomes per hectare than alternatives (Trinidade de Almeida *et al.*, 1996). Perhaps of greater concern are the findings about diversity and forest conservation. In Uruará as elsewhere in the Brazilian Amazon, small producers are joining large ranchers in clearing more forest for cattle pasture (Toni, 1999; Walker, Moran, & Anselin, 2000) and this has generated debate about the economic and ecological ramifications, which have usually been found to be decidedly negative (Faminow, 1998; Fearnside, 2002; Serrão & Homma, 1993). Compared to other farming options available to smallholders, cattle require more forest area cleared and produce less income per hectare (Perz, 2001; Trinidade de Almeida *et al.*, 1996). Paired with credit and cattle expansion, this could foreshadow specialization rather than diversification, as well as stagnant incomes with expanding forest clearing. Indeed, while the findings here apply to smallholders, diversification may be less viable for larger commercial operations and more consolidated regions where specialization for comparative advantages in national or international markets is more important (Pingali & Rosegrant, 1995). Thus, diversity may be a more efficacious strategy for productive conservation in developing regions than for regions with more consolidated economies. A final issue concerns the linkages between agricultural diversity, income and forest cover through time. The findings reported here are based on cross-sectional data, and the dynamics of agricultural diversity, income and forest cover might reveal different relationships between diversity and components of productive conservation. While the history of Uruará involves rising diversification over time, incomes have fluctuated, and forest cover has declined (Hamelin, 1991; IBGE, 1998a, 1998b; IDESP, 1990). It remains to be determined if a rise in diversity is followed by both rising income and steady (or rising) forest cover.

That said, the central finding here is consistent with the studies cited by Lee *et al.* (2001), who note agricultural diversity as a means of compatibilizing (or in their terms, "synergizing") developmental and environmental goals (pp. 458–460). The welfare benefits of higher and more stable incomes, alongside the environmental services afforded by conserving natural capital in standing forest, are a result of agricultural diversity not only in Uruará, but elsewhere in Latin America and in Africa as well (Hall, 1997; Lee & Barrett, 2001).

The consistency of such findings across sites suggest that support of agricultural diversification, whether via state policies or local initiatives and partnerships, holds some potential as a means for compatibilizing the goals of poverty alleviation, economic development and environmental conservation. That said, because of the limited sites for which findings are available, and because this and other studies used cross-sectional data, there are caveats for policy applications across sites and over time. The means of stimulating diversification will very likely depend on local levels and inequalities in land, labor and capital endowments among producers, making the content of diversification initiatives highly variable from one place to another. Further, we must beware of unintended consequences of policy packages and local initiatives in developing regions. If new supports are provided for a crop deemed an emergent commodity and prices rise for another crop, many producers may happily diversify and greatly benefit. But market saturation often occurs for new crops with high prices, leading to boom-bust dynamics and perhaps even more forest clearing as some producers seek to maximize their output through volume. Conversely, if new supports for a crop fail to generate much response to due a lack of market demand, producers may continue to shift into cattle and even use those supports to clear more forest for pasture. Diversification merits consideration in agricultural policy as a means of achieving developmental and environmental goals, but incentives for agricultural diversity must take into account the ability of producers to add new enterprises, the market potential for new regional products, the strength of local institutions, and other factors. Otherwise, the efficacy of advocating agricultural diversification will be limited for compatibilizing policy goals via productive conservation.

NOTES

1. While others have addressed these issues with the term *synergy*, I employ the term *compatibility* here given my use of cross-sectional data. As one reviewer noted, "synergy technically refers to an ongoing interaction in which expansion of strengthening in one component enhances the expansion or strengthening of another component, and then the strengthening of the second component feeds back into further expanding or strengthening of the first." In contrast, the term *compatibility* invokes instead a state of affairs, or correspondence at a point in time, which is more germane to a discussion based on cross-sectional data.

2. "First opportunity" sampling raises questions about sampling bias. Brazilian researchers familiar with the Transamazon corridor found distributions on key variables in the sample (age of household head, length of residence, number of cattle, land area deforested, etc.) to be as they expected. Comparisons between the survey data and agricultural and demographic census data for the same year for Uruará (IBGE, 1998a, 1998b) yielded similar figures. For example, rural family sizes were the same (5.6 people), as was the percentage of land under primary forest (65%). Both sources also agreed on the primary agricultural products (e.g., rice, beans, corn, manioc among annuals, and cocoa, black pepper, and coffee among the perennials). I conclude that bias is minimal.

3. The factor weights from principal components analysis were: 0.785 for chainsaws, 0.499 for cocoa dryers, and 0.588 for tractors. The factor dimension associated with these loadings had an eigenvalue of 1.21 and explained 40.4% of the common variance of the three indicators.

4. The factor weights from principal components analysis were: 0.604 for chainsaws, 0.654 for insecticides, 0.628 for fungicides, and 0.617 for herbicides. The factor dimension associated with these loadings had an eigen-

value of 1.57 and explained 39.2% of the common variance of the four indicators.

5. Quantitative measures of diversity have been criticized by Ellis (2000) and others on the grounds that they do not distinguish between qualitatively different kinds of diversification. While this critique is well taken, critics also acknowledge limitations to qualitative categorizations of diversification types (cf. Ellis, 2000, p. 215). Conclusions from qualitative distinctions among categories of livelihood diversification strategies are sensitive to the way in which the distinctions are made, how many distinctions are made, and whether the distinctions generate categories that are not mutually exclusive.

6. In a handful of cases ($n = 10$), crops were unidentified, and these were excluded from calculation of the diversity measures. One might object that the only livestock considered are cattle. Indeed, the research team observed but did not record chickens, goats and pigs during fieldwork. This will generate some downward bias in agricultural diversity estimates, but this bias should be limited since households focused primarily on cattle. The 1995–96 agricultural census shows that in Uruará, 84% of agricultural income from livestock was from cattle (IBGE, 1998a). One could similarly object that milk production from dairy cattle is excluded. This is another oversight of the Uruará survey. Hence, one should view the diversity measures presented here as conservative.

7. In the cases of pineapples, bananas, cupuaçu, oranges and mangos, production values were given in units other than kg (such as bunches or individual fruit). I consulted publications on tropical fruit to obtain estimates of kg per bunches or fruit for these products (e.g., Morton, 1987), and converted production values given into kg using low estimates from those available, on the assumption that frontier produce will be of relatively low quality. In addition, in some cases, minor annual and/or perennial crops (e.g., sugar cane and mangos) were indicated as productive, but production values were not indicated. In these cases, I used 1995–96 Brazilian agricultural census data for Uruará (IBGE, 1998a) on productivity (yield per ha for annuals and yield per plant for perennials) and multiplied this by the appropriate unit (ha or plants) to estimate production for that crop.

8. The 1995–96 Brazilian agricultural census indicates an off-take and sale rate of 12% of the total herd in Uruará (IBGE, 1998a). Based on estimates by local agricultural extension agents in Uruará, I assumed an average off-take weight of 200 kg per head, and calculated beef production B as $B = hrw$, where h is reported herd size, r is the off-take rate in Uruará in 1996, and w is the off-take weight in kg per head.

9. The proportions sold were as follows in Uruará in 1996: rice 55%, beans 40%, corn 39%, manioc 36%.

10. The proportions sold were as follows in Pará in 1996: pineapples 91%, sugar cane 91%, tomatoes 93%, watermelons 64%, bananas 73%, cocoa 94%, coffee 65%, oranges 82%, black pepper 97%, coconuts 88%, cupuaçu 71%, mangoes 34%, guaraná 75%. The cattle off-take in Uruará in 1996 was 12%.

11. I calculated prices as $P_d = i_d/(p_d s_d)$, where P_d refers to the price per kg for a given product d, i_d is income from d in Uruará in 1996, divided by the product of municipal production p_d in kg and the proportion of production sold s_d. Prices per kg ran as follows: rice R$0.28, beans R$1.52, corn R$0.32, manioc R$0.43, pineapples R$1.08, sugar cane R$0.30, tomatoes R$0.55, watermelons R$2.16, bananas R$2.10, cocoa R$0.85, coffee R$1.01, oranges R$0.08, black pepper R$1.36, coconuts R$0.22, cupuaçu R$0.81, mangos R$0.26, guaraná R$3.86, and cattle, R$1.23. Prices are given in 1996 Brazilian Reais (R$), at the time roughly equivalent to US$1.

12. One might object that income per capita would be a better measure and perhaps alter the findings. I use total gross income as it is easier to interpret. I also ran models for income per capita and the results are substantively the same as those presented in the tables.

13. This measure excludes "income" from agricultural production unsold in order to focus on monetary income from market exchanges, which have generally been the focus of the literature on poverty and development. This measure also excludes nonagricultural income, though that is accounted for as an indicator of social capital.

14. It is important to note that relying on reported land areas has limited data validity relative to direct observations of land cover in satellite images. Remote sensing methods however have their own drawbacks (clouds, availability of images during field stays, etc.).

15. Early stages of modeling proceeded on the suspicion that agricultural diversity is endogenous with respect to both agricultural income and forest cover. While greater diversity may lead to higher incomes and less forest cover, one might also argue that higher incomes and/or less forest cover should facilitate diversification. I tested for this possibility using two-stage least squares estimation of diversity as an endogenous

regressor for income, as well for forest cover. As instruments I used selected explanatory variables described here that exhibited significant effects on the dependent variables, having found that different explanatory factors were important for diversity, income and forest cover. I then ran OLS models of income and forest cover with diversity and the relevant instruments, and conducted Hausman tests for consistency of coefficients between the 2SLS and OLS runs (Davidson & MacKinnon, 1993). For every diversity measure and for both incomes and forest cover, Hausman tests did not indicate significant inconsistency, which implies that 2SLS yields results no different from OLS, so I present the OLS models.

16. Robust standard errors are equivalent to White-corrected standard errors (e.g., Kmenta, 1993). They are calculated using the square of the residual for each observation, corrected for the sample size, which inflates the standard error in the presence of heteroskedasticity, yielding more robust estimates of statistical significance.

17. Models of agricultural incomes without squared diversity terms were weaker than those shown in Table 4. For example, Model 2 without S squared had an $R^2 = 0.51$. The higher explanatory power in Model 2 in Table 4 confirms the strong nonlinear effects of agricultural diversity on agricultural income.

18. Models of forest cover without squared diversity terms also showed negative but insignificant effects of agricultural diversity.

REFERENCES

Agrawal, A. (1997). *Community in conservation: Beyond enchantment and disenchantment*. Gainesville, FL: Conservation and Development Forum Discussion Paper.

Agrawal, A., & Gibson, C. C. (Eds.). (1999). Enchantment and disenchantment: the role of community in natural resource conservation. *World Development 27*(4).

Alston, L. J., Libecap, G. D., & Mueller, R. (1999). *Titles, conflict and land use: the development of property rights and land reform in the Brazilian Amazon frontier*. Ann Arbor: University of Michigan Press.

Anderson, A. B. (Ed.). (1990). *Alternatives to deforestation*. New York: Columbia University Press.

Anderson, A. B., May, P. H., & Balick, M. J. (1991). *The subsidy from nature: palm forests, peasantry, and development on an Amazon frontier*. New York: Columbia University Press.

Angelsen, A., & Kaimowitz, D. (Eds.). (2001). *Agricultural technologies and tropical deforestation*. New York: CABI/CIFOR.

Binswanger, H. P. (1986). Evaluating research system performance and targeting research in land-abundant areas of sub-Saharan Africa. *World Development, 14*(4), 469–475.

Binswanger, H. P., & Ruttan, V. W. (1978). *Induced innovation, technology, institutions and development*. Baltimore: Johns Hopkins University Press.

Boltz, F., Carter, D. R., Holmes, T. P., & Pereira, R. (2001). Financial returns under uncertainty for conventional and reduced-impact logging in permanent production forests of the Brazilian Amazon. *Ecological Economics, 39*(3), 387–398.

Broekhoven, G. (1996). *Non-timber forest products: ecological and economic aspects of exploitation in Colombia, Ecuador and Bolivia*. Gland, Switzerland: IUCN.

Browder, J. O., & Godfrey, B. J. (1997). *Rainforest cities: Urbanization, development and globalization of the Brazilian Amazonia*. New York: Columbia University Press.

Browder, J. O., & Pedlowski, M. A. (2000). Agroforestry performance on small farms in Amazonia: findings from the Rondonia Agroforestry Pilot Project. *Agroforestry Systems, 49*, 63–83.

Burger, J., Ostrom, E., Norgaard, R. B., Policansky, D., & Goldstein, B. D. (2001). *Protecting the commons: a framework for resource management in the Americas*. Washington, DC: Island Press.

Clay, D., Reardon, T., & Kangasniemi, J. (1998). Sustainable intensification in the highland tropics: Rwandan farmers' investments in land conservation and soil fertility. *Economic Development and Cultural Change, 46*(2), 351–377.

Colfor, C. J. P., & Byron, Y. (2001). *People managing forests: the link between human well-being and sustainability*. Washington, DC: Resources for the Future.

Collins, J. L. (1995). Farm size and non-traditional exports: determinants of participation in world markets. *World Development, 23*(7), 1103–1114.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, S., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature, 387*(6630), 253–260.

Damiani, O. (2003). Effects on employment, wages, and labor standards of non-traditional export crops in Northeast Brazil. *Latin American Research Review, 38*(1), 83–113.

Davidson, R., & MacKinnon, J. G. (1993). *Estimation and inference in econometrics*. Oxford: Oxford University Press.

Ellis, F. (1993). *Peasant economics* (2nd ed.). Cambridge: Cambridge University Press.

Ellis, F. (2000). *Rural livelihoods and diversity in developing countries*. Oxford: Oxford University Press.
Faminow, M. F. (1998). *Cattle, deforestation and development in the Amazon*. New York: CABI.
Fearnside, P. M. (1997). Environmental services as a strategy for sustainable development in rural Amazonia. *Ecological Economics, 20*(1), 53–70.
Fearnside, P. M. (1999). Forests and global warming mitigation in Brazil: opportunities in the Brazilian forest sector for responses to global warming under the "clean development mechanism". *Biomass and Bioenergy, 16*(3), 171–189.
Fearnside, P. M. (2001a). Saving tropical forests as a global warming countermeasure: an issue that divides the environmental movement. *Ecological Economics, 39*(2), 167–184.
Fearnside, P. M. (2001b). Land-tenure issues as factors in environmental destruction in Brazilian Amazonia: the case of southern Pará. *World Development, 29*(8), 1361–1372.
Fearnside, P. M. (2002). Can pasture intensification discourage deforestation in the Amazon and Pantanal regions of Brazil? In C. H. Wood & R. Porro (Eds.), *Deforestation and Land Use in the Amazon* (pp. 299–314). Gainesville: University of Florida Press.
Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: a survey. *Economic Development and Cultural Change, 33*, 255–298.
FSC, 2003. *Forest stewardship council.* Website available at <http://www.fscoax.org/>, March.
FUNDASUR. 1996. Pre-seleção das Iniciativas Promissoras de Manejo Florestal na Amazônia. Unpublished manuscript, Uruará, Pará, Brazil.
Gibbs, J. P., & Poston, D. L. (1975). The division of labor: conceptualization and related measures. *Social Forces, 53*, 468–476.
Gockowki, J., Nkamleu, G. B., & Wendt, J. (2001). Implications of resource-use intensification for the environment and sustainable technology systems in the Central African rainforest. In D. R. Lee & C. B. Barrett (Eds.), *Tradeoffs or synergies? Agricultural intensification, economic development and the environment* (pp. 197–220). New York: CABI.
Godoy, R. A. (2001). *Indians, markets, and rainforests: theory, methods, analysis*. New York: Columbia University Press.
Goldman, A. C. (1993). Agricultural innovation in three areas of Kenya: neo-Boserupian theories and regional characterization. *Economic Geography, 69*(1), 44–71.
Goldman, A. C. (1995). Threats to sustainability in African agriculture: searching for appropriate paradigms. *Human Ecology, 23*(3), 291–334.
Hall, A. (1997). *Sustaining Amazonia: grassroots action for productive conservation*. Manchester: Manchester University Press.
Hall, A. (Ed.). (2000). *Amazonia at the crossroads: the challenge of sustainable development*. London: Institute of Latin American Studies.
Hamelin, P., 1991. O fracasso anunciado. In: P. Léna, A. Engrácia de Oliveira (Eds.), *Amazônia: A Fronteira Agrícola 20 Anos Depois* (pp. 161–176). SCT /CNPq / ORSTOM, Belém.
Haughton, D. M. A., & Mukerjee, S. (1995). The economic measurement and determinants of diversity. *Social Indicators Research, 36*, 201–225.
IBGE (1998a). *Censo Agropecuário 1995/96.* Website available at <http://www.ibge.org>, June.
IBGE (1998b). *Contagem Populacional de 1996.* Website available at <http://www.ibge.org>, June.
IDESP (1990). *Uruará*. Belém, Brazil: IDESP.
IDRC, 2000. *Taking care of what we have: participatory natural resource management on the Caribbean Coast of Nicaragua*. Ottawa: International Development Research Center.
IUCN, 1997. *Non-timber forest products: value, use and management issues in Africa, including examples from Latin America*. Gland, Switzerland: IUCN.
Johns, J., Barreto, P., & Uhl, C. (1996). Logging damage during planned and unplanned logging operations in the eastern Amazon. *Forest Ecology and Management, 89*, 59–77.
Kmenta, J. (1993). *Elements of econometrics* (3rd Ed.). Ann Arbor: University of Michigan Press.
Lee, D. R., & Barrett, C. B. (Eds.). (2001). *Tradeoffs of synergies? Agricultural intensification, economic development and the environment*. New York: CABI.
Lee, D. R., Barrett, C. B., Hazell, P., & Southgate, D. (2001). Assessing tradeoffs and synergies among agricultural intensification, economic development and environmental goals: conclusions and implications for policy. In D. R. Lee & C. B. Barrett (Eds.), *Tradeoffs of synergies? Agricultural intensification, economic development and the environment* (pp. 451–464). New York: CABI.
Magurran, A. E. (1988). *Ecological diversity and its measurement*. Princeton: Princeton University Press.
Morton, J. F. (1987). *Fruits of warm climates*. Wintervillle, NC: Creative Resource Systems.
Moran, E. F. (1989). Adaptation and maladaptation in newly settled areas. In D. Schumann & W. Partridge (Eds.), *The human ecology of tropical land settlement in Latin America* (pp. 20–41). Boulder: Westview.
Nair, P. K. R. (1993). *An introduction to agroforestry*. Dordrecht: Kluwer Academic Publishers.
Netting, R. McC. (1993). *Smallholders, householders*. Stanford: Stanford University Press.
NRC (2002). *The drama of the commons*. Washington, DC: National Academy Press.
Ozório de Almeida, A. L. (1992). *The colonization of the Amazon*. Austin: University of Texas Press.
Ozório de Almeida, A. L., & Campari, J. S. (1995). *Sustainable settlement in the Brazilian Amazon*. Oxford: Oxford University Press.
Palo, M. (Ed.). (1999). *Forest transitions and carbon fluxes: global scenarios and policies*. Helsinki: World Institute for Development Economics Research.
Pender, J., Scherr, S. J., & Durón, G. (2001). Pathways of development in the hillside areas of Honduras: causes and implications for agricultural production, poverty and sustainable resource use. In D. R. Lee & C. B. Barrett (Eds.), *Tradeoffs or synergies? Agricultural intensification, economic development and the environment* (pp. 171–196). New York: CABI.

Perz, S. G. (2001). From sustainable development to "productive conservation:" forest conservation options and agricultural incomes and assets in the Brazilian Amazon. *Rural Sociology, 66*(1), 93–112.

Perz, S. G. (2002). Household demography and land use allocation among small farms in the Brazilian Amazon. *Human Ecology Review, 9*(2), 1–16.

Perz, S. G. (2003). Social determinants and land use correlates of agricultural technology adoption in a forest frontier: a case study in the Brazilian Amazon. *Human Ecology, 31*(1), 133–165.

Pichón, F. J. (1997). Colonist land-allocation decisions, land use, and deforestation in the Ecuadorian Amazon. *Economic Development and Culture Change, 45*, 707–744.

Pichón, F., Uquillas, J., & Frechione, J. (Eds.). (1999). *Traditional and modern natural resource management in Latin America*. Pittsburgh: University of Pittsburgh Press.

Pichón, F. J., Marquette, C., Murphy, L., & Bilsborrow, R. (2001). Land use, agricultural technology and deforestation among settlers in the Ecuadorean Amazon. In A. Angelsen & D. Kaimowitz (Eds.), *Agricultural technologies and tropical deforestation* (pp. 153–166). New York: CABI/CIFOR.

Pinard, M. A., & Putz, F. E. (1996). Retaining forest biomass by reducing logging damage. *Biotropica, 28*, 278–295.

Pingali, P. L., & Rosegrant, M. W. (1995). Agricultural commercialization and diversification: processes and policies. *Food Policy, 20*(3), 171–185.

Reardon, T. J., Taylor, E., Stamoulis, K., Lanjouw, P., & Balisacan, A. (2000). Effects of nonfarm employment on rural income inequality in developing countries: an investment perspective. *Journal of Agricultural Economics, 51*, 266–288.

Sánchez, P. (1994). Alternatives to slash-and-burn: a pragmatic approach for mitigating tropical deforestation. In J. R. Anderson (Ed.), *Agricultural technology: policy issues for the international community* (pp. 451–479). Cambridge: CABI/World Bank.

Schipper, R. A., Jansen, H. G. P., Bouman, B. A. M., Hengsdijk, H., Nieuwenhuyse, A., & Sáenz, F. (2001). Integrated bioeconomic land-use models: an analysis of policy issues in the Atlantic zone of Costa Rica. In D. R. Lee & C. B. Barrett (Eds.), *Tradeoffs or synergies? Agricultural intensification, economic development and the environment* (pp. 267–284). New York: CABI.

Selfa, T. L. (2001). *From integrated rural development to participatory sustainable development*. Ann Arbor: UMI.

Serrão, E. A. S., & Homma, A. K. O. (1993). Brazil. In *Sustainable Agriculture and the Environment in the Humid Tropics* (pp. 265–351). Washington, DC: National Academy Press.

Shriar, A. J. (1999). *Agricultural intensification and resource conservation in the Buffer Zone of the Maya Biosphere Reserve, Petén, Guatemala.* Ph.D. Dissertation, University of Florida, Gainsville.

Singh, I., Squire, L., & Strauss, J. (Eds.). (1986). *Agricultural household models: extensions, applications, and policy*. Baltimore: Johns Hopkins University Press/World Bank.

Smith, N. J. H. (2000). Agroforestry developments and prospects in the Brazilian Amazon. In A. Hall (Ed.), *Amazonia at the crossroads: the challenge of sustainable development* (pp. 150–170). London: Institute of Latin American Studies.

Smith, N. J. H., Serrão, E. A. S., Alvim, P. T., & Falesi, I. C. (1995). *Amazonia: resiliency and dynamism of the land and its people*. New York: United Nations University Press.

Staal, S. J., Ehui, S., & Tanner, J. (2001). Livestock-environment interactions under intensifying production. In D. R. Lee & C. B. Barrett (Eds.), *Tradeoffs or synergies? Agricultural intensification, economic development and the environment* (pp. 345–364). New York: CABI.

Tomich, T. P., van Noordwijk, M., Budidarsono, S., Gillison, A., Kusumanto, T., Murdiyarso, D., Stolle, F., & Fagi, A. M. (2001). Agricultural intensification, deforestation, and the environment: assessing tradeoffs in Sumatra, Indonesia. In D. R. Lee & C. B. Barrett (Eds.), *Tradeoffs or synergies? Agricultural intensification, economic development and the environment* (pp. 221–244). New York: CABI.

Toni, F. (1999). *State-society relations on the agricultural frontier: the struggle for credit in the Transamazonica region*. Ph.D. Dissertation, University of Florida, Gainsville.

Tourrand, J. F., da Veiga, J. B., Quanz, D., Ferreira, L. A., & Simão Neto, M. (1998). Produção Leiteira em Área de Fronteira Agrícola da Amazônia: O Caso do Município de Uruará (PA), na Transamazônica. In A. K. O. Homma (Ed.), *Amazônia: Meio Ambiente e Desenvolvimento Agrícola* (pp. 345–365). Belém: EMBRAPA.

Trinidade de Almeida, O., Veríssimo, A., Toniolo, A., Uhl, C., Mattos, M. M., Barreto, P., & Tarifa, R. (1996). *A Evolução da Fronteira Amazõnica*. Belém, Pará: IMAZON.

Turner II, B. L., Hyden, G., & Kates, R. W. (Eds.). (1993). *Population growth and agricultural change in Africa*. Gainesville: University of Florida Press.

Uhl, C., & Nepstad, D. (2000). Amazonia at the millennium. *Interciencia, 25*(3), 159–164.

UNCTAD, 2000. *The clean development mechanism: Building international public–private partnerships under the Kyoto Protocol*. New York: United Nations.

Uphoff, N. (Ed.). (2002). *Agroecological innovations: increasing food production with participatory development*. London: Earthscan.

Vogt, K. A., Larson, B. C., Gordon, J. C., Vogt, D. J., & Fanzeres, A. (1999). *Forest certification: roots, challenges, and benefits*. Washington, DC: CRC Press.

Vosti, S. A., Witcover, J., Carpentier, C. L., Magalhães de Oliveira, S. J., Carvalho dos Santos, J., *et al.* (2001a). Intensifying small-scale agriculture in the western Brazilian Amazon: issues, implications and implementation. In D. R. Lee & C. B. Barrett (Eds.), *Tradeoffs or synergies? Agricultural intensification, economic development and the environment* (pp. 245–266). New York: CABI.

Vosti, S. A., Carpentier, C. L., Witcover, J., & Valentim, J. F. (2001b). Intensified small-scale livestock systems in the western Brazilian Amazon. In A. Angelsen & D. Kaimowitz (Eds.), *Agricultural technologies and tropical deforestation* (pp. 113–134). New York: CABI/CIFOR.

Walker, R. T., Moran, E. F., & Anselin, L. (2000). Deforestation and cattle ranching in the Brazilian Amazon: external capital and household processes. *World Development, 28*, 683–699.

Walker, R. T., Perz, S. G., Caldas, M., & Teixeira da Silva, L. G. (2002). Land use and land cover change in forest frontiers: the role of household life cycles. *International Regional Science Review, 25*(2), 169–199.

White, D., Holmann, F., Fujisaka, S., Reategui, K., & Lascano, C. (2001). Will intensifying pasture management in Latin America protect forests—or is it the other way around? In A. Angelsen & D. Kaimowitz (Eds.), *Agricultural technologies and tropical deforestation* (pp. 91–112). New York: CABI/CIFOR.

Wood, C. H.& Porro, R. (Eds.). (2002). *Deforestation and land use in the Amazon*. Gainesville: University of Florida Press.

WCED (1987). *Our common future*. Oxford: Oxford University Press.

Yamada, M., & Gholz, H. L. (2002). An evaluation of agroforestry systems as a rural development option for the Brazilian Amazon. *Agroforestry Systems, 55*(2), 81–87.

Zhang, Q., & Justice, C. O. (2001). Carbon emissions and sequestration potential of central African ecosystems. *Ambio, 30*(6), 351–355.