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Revisiting Bora fallow agroforestry in the Peruvian Amazon: Enriching ethnobotanical appraisals of non-timber products through household income quantification

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Abstract Indigenous fallow agroforestry systems play an important role in Amazonian livelihoods by providing food security, cash income, and overall risk mitigation. However, the substantial contribution of fruits, construction materials, handicraft inputs, and myriad other fallow products are not only ignored in many national statistics, they have received little attention from policy makers to date. This study estimates the economic importance and perceived household utility of species in managed indigenous (Bora) fallows using a combination of income data for all harvested products, fallow inventory observations, and free list data. The research represents an important follow-up to Denevan and Padoch's approximately thirty-year old qualitative description of Bora fallow management in the same area. Results highlight the importance of agroforestry environments (primarily fallows) for providing well over 100 non-timber resources for easily accessed medicines, essential vitamins and nutrients, and cash-generating products such as handicraft materials. Crop staples and promoted native forest species each contribute 14 % of household income and other miscellaneous crops contribute an additional 6 %, for a total income share of 34 %. Chambira (*Astrocaryum chambira*) handicrafts alone contribute 16 % of household cash income (9 % of total income) in surveyed villages. When considering cash and subsistence importance, plant products harvested from agroforestry environments contribute more than double the income of those from unmanaged forests. Agroforestry can also safeguard biodiversity and ecosystem services while promoting climate change resilience. Study results will enhance research and development initiatives which typically focus on forests or agriculture, but less often on intermediate, managed environments in Amazonian forests.

Keywords Indigenous fallow management · Household income · Food security · Handicrafts · Livelihoods

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Introduction

Livelihood importance of fallow agroforestry

A wide variety of agroforestry systems have been highlighted across the globe (Burgers et al. 2005; Ouinsavi and Sokpon 2008; Scales and Marsden 2008), including intensive plantations, cultivated homegardens, and managed forest fallows. Well-developed fallow systems, often associated with agroforestry activities, are particularly prominent in the Amazon, especially within indigenous communities (Posey 1985; Coomes and Burt 1997; Toledo and Salick 2005). In managed fallows, where agricultural sites are reverting to forest, households minimize livelihood risk by promoting wild and cultivated plants for subsistence use and market sale. These fallows, in addition to homegardens containing similar species, provide year-round nutritional benefits (Eden and Andrade 1987; Gliessman 1990; Perrault 2005; Padoch and Sunderland 2014) in the form of fruits, vegetables, tubers, and other edibles. Fallows also provide handicraft and construction materials, fuelwood, medicines, and multiple products to supplement periods of low agricultural production or cash insufficiency (Padoch et al. 1985; Hammond et al. 1995; Burgers et al. 2005; Maroyi 2009). In addition, forest regeneration and fallow enrichment with trees species (e.g., *Pouteria caimito* (Ruiz & Pav.) Radlk., *Pourouma cecropiifolia* Mart., *Inga* spp, *Macaranga denticulata* (Blume) Müell. Arg., among others) restore soil nutrient quality for future cropping (Unruh 1988; Yimyam et al. 2003; Pitman et al. 2004; Burgers et al. 2005) and fruit trees attract game and seed dispersers to fallows (Unruh 1990; Redford et al. 1992; Gavin 2007) which, in turn, enhances farm production and household income. Agroforestry harvest from fallows and homegardens has also been shown to strengthen social ties through the sharing and bartering of fruit and other cultivars (Shackleton et al. 2008; Guuroh et al. 2012). Finally, regenerating fallows hold significant cultural value for many indigenous groups (Denevan 1971; Bennett 1992; Bayrak et al. 2015).

Factors influencing agroforestry production

The diversity of useful plants and income derived from agroforestry environments, such as managed fallows, is influenced by various site- and household-level characteristics. For example, plant cultivation and harvest differs according to soil type, and is less prominent in periodically flooded forest areas (Padoch and Jong 1991; Haglund et al. 2011; Couly and Sist 2013; Kawa et al. 2015). In other words, agroforestry production is dependent, in part, on household access to upland sites. In addition, a higher level of education in the household often correlates with lower reliance on agroforestry or other environmental production (Stoian 2005; Haglund et al. 2011), due to more lucrative income generating options available to more educated individuals. Older household heads may cultivate or harvest a higher diversity of agroforestry species than younger heads (Perrault-Archambault and Coomes 2008; Kawa et al. 2015; Monfared and Armaki 2015), which may reflect increased agricultural or forestry knowledge gained over time. Research has also shown that higher dependency ratios and greater labor availability positively influence cultivated plant diversity and total income from agroforestry, as well as natural forest harvest (Hegde and Enters 2000; Fisher 2004; Winters 2006; Perrault-Archambault and Coomes 2008; Monfared and Armaki 2015). Proximity to markets influences household reliance on products harvested within the agriculture-forest mosaic in two key ways: (i) households farther from markets rely more on the surrounding environment for subsistence needs due to decreased access to purchased staples and other income generating opportunities and (ii) profitability of product sale declines as transport time and expense increases (Ghate et al. 2009; Haglund et al. 2011; Cotta 2015). Other activities such as hunting, fishing, and livestock production can supplement subsistence and commercial production from agroforestry environments (Coomes et al. 2010; Takasaki et al. 2010; Monfared and Armaki 2015). It is also possible that engagement in these other activities simply draws household labor away from fallow sites, thus, income increases in these sectors may result in a decrease in observed agroforestry income and vice versa. Finally, agroforestry income and plant diversity may reflect total household wealth (Coomes and Ban 2004).

Bora fallow management in Peru and current knowledge gaps

Nearly 30 years ago, Denevan and Padoch (1987b) highlighted the importance of young managed fallows for indigenous livelihoods within the *Bora Agroforestry Project* (BAP), in the indigenous Bora village Brillo Nuevo, in the Peruvian Amazon floodplain. The study, conducted in 1981, described Bora influence on fallow regeneration, abandonment processes, and species dominance at various stages of regrowth. In Chapter 2 of Denevan and Padoch's complete monograph, Denevan and Treacy (1987) describe agroforestry activities including (i) sparing useful species during clearing for staple crop cultivation, (ii) intercropping with food staples, and (iii) thinning competitors to promote desirable species. Though the BAP study revealed the diversity of cultivated areas (fallows, orchards, young and old fallows) and species contributing to livelihoods in one indigenous village, the fallow inventories were not replicated. Furthermore, the research did not quantify the economic importance of each product, or the percentage of households harvesting particular species in the village. Moreover, the BAP data do not allow for a direct comparison of the relative economic contribution of fallow products versus those harvested from mature, unmanaged forest sites. Though ethnobotanical studies in indigenous communities abound in the literature (Posey 1985; Joshi and Joshi 2000; Purwanto 2002; Macía 2004; Reyes-García et al. 2008), and contributions of agroforestry systems to conservation and improved livelihoods have gained attention in recent decades (McNeely and Schroth 2006; Fifanou et al. 2011; Porro et al. 2012), in-depth income data for individual agroforestry products are lacking, particularly in the Amazon. Furthermore, aside from a few highly valuable crops, the myriad products harvested from agroforestry environments (as well as unmanaged forests) are substantially undervalued in national accountings of resource use (Vantomme 2003). Economic analyses in agroforestry studies offer an indispensable complement to extant ethnobotanical surveys (Torquebiau and Penot 2006). Reyes-García et al. (2006) have contributed innovative methodology in this area, where they applied a multi-method approach to forest product valuation by simultaneously assessing cultural, practical, and economic values of wild species. Science in this area could be further advanced by combining species abundance, free list, and income data for agroforestry products and, moreover, assessing economic importance within the context of the entire household income portfolio which includes agriculture, wild forest extraction, agroforestry harvest, fishing, and other off-farm income.

Study objectives

This study aims to document the current contribution of agroforestry products to Bora livelihoods. Key questions are: (i) Which non-timber/non-fuelwood agroforestry plants (hereafter referred to as AFPs) are currently most valued by Bora residents, according to cash and subsistence income contributions, observed presence in actively managed fallows and free-list salience (prominence)? (ii) What household characteristics influence the diversity of AFPs harvested and total agroforestry income derived by Bora households? (iii) What is the relative importance of cultivated/managed (versus wild) environments for household income in Bora villages?

Materials and methods

Study area and Bora livelihood activities

Research was carried out approximately 120 km from Iquitos (Loreto, Peru) in three Bora villages (Brillo Nuevo, Nuevo Peru, and Boras of Pucaurquillo) which are situated along the Ampiyacu and Yaguasyacu Rivers (Fig. 1). In 2011, 61, 13, and 20 households occupied the three villages, respectively. At the time of the BAP study (1981), 43 families lived in Brillo Nuevo, nearly all descendants of Bora brought to the Ampiyacu by a patrón following Perús loss of a border war with Columbia in 1934. Bora were granted land previously occupied by other tribes and have gradually been assimilated into Peruvian society, however they maintain many traditional practices including swidden agriculture, agroforestry production, and forest extraction (Denevan and Padoch 1987a). Peak rains occur between December and May, precipitation reaches over 2700 mm per year (Pitman et al. 2004), and soils are predominantly ultisols (Denevan and Padoch 1987a). Livelihood strategies are influenced by flooding regimes which determine natural resource availability, access to fields and forests, and access to markets; all transport occurs via waterways. Key economic activities include swidden agriculture, agroforestry, hunting, timber and other miscellaneous forest harvest, handicraft production, and fishing (Vormisto 2002; Pitman et al. 2004). Mature, unmanaged forest areas are found north of Brillo Nuevo (more than 5 h by motorboat from Pucaurquillo, which is situated less than 30 min from the local market town of Pevas). Timber, game, and useful subsistence and cash-generating products such as palm heart (*Euterpe precatoria*, Mart.) and irapay leaves (*Lepidocaryum tenue* Mart.; for roof thatch) are more abundant in mature forests. A mosaic of regenerating

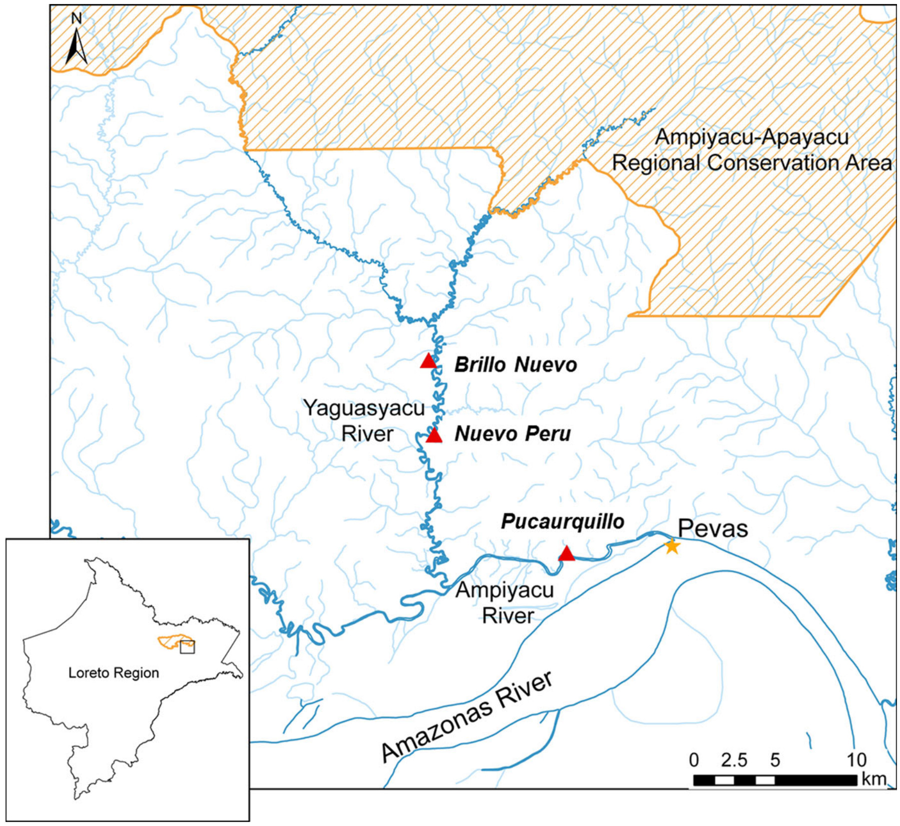

Fig. 1 Bora village locations along the Ampiyacu and Yaguasyacu Rivers. Locations shown in relation to Río Amazonas, the nearest local market town of Pevas, and the recently declared *Ampiyacu-Apayacu Regional Conservation Area*

forest patches surround the villages, as a result of a long history of shifting cultivation (Denevan and Treacy 1987). Two villages are located in terra firme (upland), while Nuevo Peru is seasonally flooded, with little upland area available for cultivation. A variety of species are cultivated and promoted in fallows, and to a small degree in homegardens; the chambira palm (*Astrocaryum chambira* Burret) is particularly noteworthy for its prominence in fallows due to its importance in the production of frequently marketed handicrafts.

Bora agroforestry in the study area

According to Denevan and Padoch (1987a, p. 1), agroforestry is "a sustainable management system that combines agriculture and/or livestock with tree crops and/or forest plants on the same unit of land, either simultaneously or sequentially". Furthermore, they explain that "Bora agriculture becomes an agroforestry system during the early stages of forest fallow" (Denevan and Treacy 1987, p. 41). In the Bora agroforestry system, manioc (*Manihot esculenta,* Crantz) is first intercropped with other cultivars such as plantain (*Musa* spp.) and pineapple (*Ananas* spp.). After 2–3 years of cultivation, less intense management ensues, and competing species are selectively removed while desired species are cultivated or promoted in regenerating fallow. Residents return in subsequent years to gather fruits and other useful products and more frequently visit the younger, more intensively managed fallows (see Fig. 2). In general, only a few highly desired products such as pijuayo fruit (*Bactris gasipaes,* Kunth), chambira fibers or small game are harvested from older fallows which constitute a type of "orchard". Smaller-scale agroforestry activity is observed in many Bora homegardens, where households cultivate small quantities of manioc and other crops, fruit trees, medicinal plants and handicraft materials. There is substantial overlap in the species found in Bora homegardens and fallows. Small livestock such as pigs and chickens are maintained around dwellings however livestock are not integrated in the swidden fallow mosaic in the study area.

Fig. 2 Bora agroforestry environments. **a** Agricultural field preparation in fallow site, **b** walking between fallows, **c** and **d** 3 year-old fallows, **e** 6 year-old fallow. *Photo* **a** taken in Brillo Nuevo, all others taken in Pucaurquillo. All *Photos* by author

Data collection and analysis

Villages were first surveyed in 2011 as part of a larger income study of eleven villages situated along the Ampiyacu, Yaguasyacu, and Apayacu Rivers (Cotta 2015). Local indigenous associations and village committees were consulted prior to the commencement of research and residents were updated regularly until the study was completed. In 2012, Brillo Nuevo fallows were purposely inventoried to enable a direct comparison with the BAP inventory data. Two additional Bora villages located along the same tributary were included to increase geographic coverage for fallow inventories and income data (described subsequently). Agroforestry product importance was assessed using three methods described below: household income surveys, free-lists, and fallow inventories.

Household income surveys

Cash and subsistence incomes from productive activities and all other sources were quantified at 6 month intervals over 1 year, 2011, to assess the relative importance of natural and managed environments. Survey sample sizes were 19, 7, and 27 households for Pucaurquillo, Nuevo Peru and Brillo Nuevo, respectively. Income surveys were adapted to the local context from questionnaires developed within the Center for International Forestry Research's Poverty and Environment Network study (CIFOR-PEN 2007). Details regarding the complete income survey can be found in Cotta (2015). Net income is defined as the sum of all cash or subsistence income minus all inputs (e.g., fertilizer, purchased capital, paid labor). Household productive income is defined as all farm plus extractive (terrestrial and aquatic) income. Product prices were obtained using own-reported values verified in focus groups. For products with no known market price, respondents estimated a village exchange price or price based on close substitutes. Two key environments were distinguished in the larger income survey (i) old-growth, unmanaged forest sites and (ii) agroforestry environments including fields, managed fallows of any age, and homegardens. A few species are harvested from both unmanaged forests and agroforestry sites and, in these cases, product incomes were broken down between these two harvest environments. Miscellaneous non-timber forest plants harvested from unmanaged forests are defined as NTFPs here. Within agroforestry environments, economic plants are discussed according to the following use categories: food or beverage, handicraft, construction, medicinal, and ritual. Field versus fallow income could not be distinguished, as there is no defined shift from swidden field to fallow, and due to intercropping of various species. Homegarden production was included within agroforestry income due to the overlap of species promoted in these sites, as described in the section on Bora agroforestry. Coca cultivation related to illegal trade has been reported in the study area in recent decades, however nearly all such cultivation within the surveyed villages is for subsistence use. Because of the sensitive nature of the activity, coca production was not probed when households reported no such income. Purely ornamental species are not considered in this paper.

Fallow and homegarden free-lists

In this study, "local value" for the most important AFPs is determined according to free-list salience. This local value can reflect a combination of consumption preferences, cultural values, number and nature of use categories per product, general species abundance and product abundance at the time of free-listing (Phillips and Gentry 1993; Reyes-García et al. 2006; Castaneda and Stepp 2007), as well as the total economic value of each product. In the same 54 households, two free-list exercises were carried out in 2011 with household heads (both male and female when possible) to evaluate the most valued AFPs harvested from (i) actively managed fallows and (ii) homegardens. Salience scores were assigned using Smith's S scores (Smith 1993).

Fallow inventories

In October 2012, the presence of all non-wood species (AFPs) considered economically important (providing either subsistence or cash income benefits) was recorded in four fallows in each village (n = 12). The research team first identified a key informant native to each village and over 50 years in age. Each informant was asked to locate fallows representing typical managed Bora fallows between three and 10 years based on regrowth time since being cleared for cultivation. Ten years was the selected age cutoff, as Denevan and Treacy (1987) reported that fallows under ten years are the most actively managed; local residents confirmed this assertion. As in the BAP study, only upland fallows, those not typically subjected to intense flooding, were assessed. Surveyed fallows, each roughly 0.5 ha in size, were located between 20 and 45 min from village centers. The research team entered and walked the perimeter of all fallows with the landowner to verify all species reported economically important. A local botanist familiar with the study area verified all plants to the species or genus level. This information and all free-list species reports were cross-checked with the Amazonian Ethnobotanical Dictionary (Duke and Vasquez 1994). Individual species harvested exclusively for timber or fuelwood were not assessed in transect inventories or free-listing, as the primary focus of the study was to identify the diversity of distinct products harvested for subsistence use or market sale, however, total income contributions for timber and fuelwood are presented.

Data analysis

Different species considered by local residents as one unique product are grouped by genus in this study (e.g. all *Inga* species). Incomes were adjusted for adult

Table 1 Summary of Bora household characteristics

Household characteristic	Mean (SE)	Min	Max
Time to market (min)	173.7 (116.4)	15	360
Hhd head age (years)	46.8 (11.8)	28	77
Hhd head education (years)[a]	8.4 (5.6)	0	20
Labor (total adults)	5.9 (2.7)	1	14
Dependency ratio[b]	0.5 (0.3)	0	1
N = 53			

[a] The individual with 20 years of education is a local professor

[b] Dependents are individuals >15 and <55 years old

equivalence unit (aeu), following Cavendish (2002) and converted to USD according to a 2011 exchange rate of 1PEN:0.36USD. Market access is quantified as reported time from the household to the local market. *T*-tests compared agroforestry plant diversity and incomes between (i) households with flood-prone cultivation sites and those without and (ii) *market proximate* (Pucaurquillo) and *market distant* (Brillo Nuevo and Nuevo Peru) households. Market distant villages were grouped due to analysis limitations for the small sample in Nuevo Peru (n = 7). Pearson's correlation analyses were performed to assess relationships between agroforestry incomes and plant diversity and household variables such as age and education of the household head, available labor, household dependency ratios, fishing, forest and livestock incomes, and total household wealth. A summary of household characteristics appears in Table 1.

Methodological caveats

Fallow plant inventories were carried out in only twelve plots in 2012 and the complete 2011/2012 assessment is not exhaustive in terms of species presence or instances of household harvest for the entire study area. Not only do households harvest multiple fallows over a given year to complete their income portfolio, fallow plant composition varies across households. Thus, some rarely utilized or highly seasonal products may be unreported. However, the summation of all species found across three village inventories, combined with free-list and income data, provides a reasonable estimation of the most universally harvested and highly valued products in young Bora fallows. The six-month recall period for income may also influence reporting of rarely harvested species, however, cross-checking methods were used to achieve the most accurate data possible.

Results

Species lists

Online Resource 1 lists all economically important AFPs observed in 2011/2012 surveys and highlights which of these were (i) reported in the BAP study as key cultivated, planted, and protected species or (ii) observed in BAP fallows (Denevan and Treacy 1987). Household harvest frequency in 2011, current plant uses, product markets, and plant free-list scores are also included. This list emphasizes non-wood species *additions* to the BAP study. Species observed in BAP cultivated environments, but not in this study, can be found in Denevan and Treacy (1987). Each row in the Online Resource list represents a unique "plant", as defined in the data analysis section. Many products are discussed subsequently according to local names, with all species names and botanical authors included in the Online Resource. The top twenty agroforestry income contributors appear in Table 2, along with their mean income contribution, subsistence and cash income ranks, salience score, harvest frequency and share of productive income.

Additions to BAP plant list

Of the 126 economically important AFPs in this study, only 50 were listed with the same local name and species identification in the aforementioned tables presented by Denevan and Treacy (1987); see Online Resource 1, column 7). Twenty-six plants cited in the 2011/2012 surveys were not reported in the BAP fallow inventories. Nine unidentified plants in this study (see next section) were not compared with BAP observations. Five other plants were observed for the same genera in both studies, and likely have similar uses however they were not identified by the same local name (e.g., *Eschweilera* spp., *Piper* spp.). Excluding these five, 35 non-wood plants (AFPs) can be considered entirely new additions to the BAP plant list. This number might have been higher if ornamental plants had been assessed in the current study. The species additions include six observations

Table 2 Top 20 income contributors from agroforestry environments

Income rank[a]	Genus/species	Common name	Product	Mean hhd income (USD per aeu)		Subsistence rank[b]	Cash rank[c]	Salience score		% Hhds harvesting	% Productive income
				Subsistence	Sale			Fallow	Homegarden		
1	*Astrocaryum chambira*	Chambira	Handicrafts[d]	0.49 ± 0.75	71.06 ± 87.49	24	1	0.57	0.01	100	10.7
2	*Musa* spp.	Plátano, guineo	Fruit	48.6 ± 40.63	13.78 ± 20.95	1	3	0.12	0.19	100	9.2
3	*Manihot esculenta*	Yuca	Tuber	37.69 ± 32.31	14.97 ± 31.57	2	2	0.13	0.01	100	7.8
4	*Ananas comosus*	Piña	Fruit	14.79 ± 14.09	5.36 ± 11.37	3	4	0.21	0.05	96	2.9
5	*Bactris gasipaes*	Pijuayo	Fruit	10.66 ± 12.85	0.65 ± 1.80	4	11	0.47	0.09	96	1.6
6	*Erythroxylum coca*	Coca	Powder/paste	29.27 ± 29.82	0.59 ± 2.45	5	18	0.03	–	28	1.2
7	*Zea mays*	Maíz	Grain	12.97 ± 34.1	0.97 ± 3.56	6	12	–	–	53	1.1
8	*Poraqueiba sericea*	Umarí	Fruit	4.28 ± 4.3	1.25 ± 2.67	7	9	0.18	0.12	94	0.8
9	*Euterpe oleracea/E. precatoria*	Huassaí	Fruit	2.4 ± 5.44	1.45 ± 2.48	11	8	0.25	0.52	75	0.5
10	*Pourouma cecropiifolia*	Uvilla	Fruit	3.04 ± 3.93	1.59 ± 4.12	12	10	0.22	0.1	68	0.5
11	*Saccharum officinarum*	Caña	Cane stalk	4.15 ± 5.87	0.01 ± 0.06	8	38	0.02	0.05	72	0.4
12	*Pouteria caimito*	Caimito	Fruit	3.24 ± 3.22	0.15 ± 1.39	9	22	0.26	0.15	85	0.4
13	*Carludovica palmata*	Bombonaje	Petiole fibers	0.52 ± 0.98	6.11 ± 20.53	31	5	–	0.03	42	0.4
14	*Inga* spp.	Shimbillo/ guava	Fruit	2.85 ± 3.17	0.10 ± 3.02	10	24	0.25	0.29	83	0.4
15	*Dioscorea trifida*	Sachapapa	Tuber	3.23 ± 3.87	0.16 ± 0.46	13	23	0.05	–	58	0.3
16	*Crescentia cujete*	Huingo	Gourd-like fruit	0.18 ± 0.51	5.34 ± 8.66	45	6	–	0.07	32	0.3
17	*Theobroma bicolor*	Macambo	Fruit	2.65 ± 2.93	0.10 ± 0.41	14	28	0.07	0.09	64	0.3
18	*Carica papaya*	Papaya	Fruit	2.91 ± 3.61	1.15 ± 3.94	16	14	0.02	0.04	40	0.3
19	*Lonchocarpus* spp.	Barbasco[e]	Leaves	3.3 ± 5.13	–	15	–	0.04	–	42	0.2

Table 2 continued

Income rank[a]	Genus/species	Common name	Product	Mean hhd income (USD per aeu)		Subsistence rank[b]	Cash rank[c]	Salience score		% Hhds harvesting	% Productive income
				Subsistence	Sale			Fallow	Homegarden		
20	*Oenocarpus* spp.	Bacaba, sinamillo	Fruit	1.52 ± 2.14	0.28 ± 0.70	17	19	–	0.04	55	0.2

[a] Species ranked according to total harvest value from all agroforestry environments (active agricultural fields, managed fallows and, to a small degree, homegardens) across 53 households

[b] Rank based on total harvest value for home consumption

[c] Rank based on total harvest value of marketed products

[d] Chambira income data reflect value of final processed handicraft, which is adorned with small quantities of other plant materials (e.g. cudi coloring)

[e] Barbasco's toxic leaves are utilized to stun fish

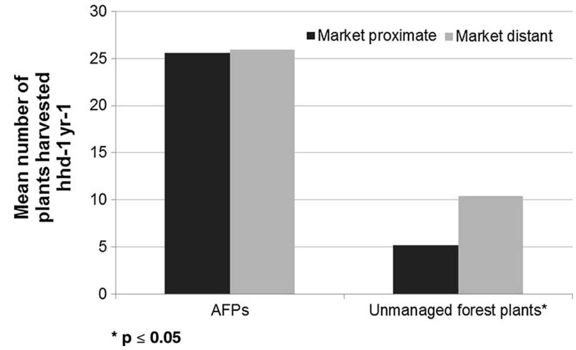

Fig. 3 Comparison of non-wood plant diversity in agroforestry sites and unmanaged forests according to market access

of plants primarily used for handicrafts, in addition to two genera of handicraft plants observed in the BAP without the 2011/2012 reported local name. These plants include guisador, lancetilla, achira, bombonaje, and shacapa, and these were each harvested by at least 5 % of households in 2011 (Online Resource 1). At least twelve medicinal species from 2011/2012 were not cited in the BAP study, seven of which were harvested by at least 5 % of households. Fallows surveyed in 2012 did not contain many of the medicinal species mentioned in the 2011 free-lists and income surveys, however such cultivation occurs primarily in homegardens and a small quantity of each species are cultivated by any one household.

Species diversity and product salience

A total of 103 distinct economically important AFPs were reported in the income surveys alone and 126 plants were recorded across the three 2011/2012 survey methods (including nine locally named, unidentified plants). Arecaceae was the most prominent of 38 plant families, and included 16 plants. In the income survey, Bora households harvested between 13 and 35 different useful AFPs (mean = 25). This included a total of 25 food plants; the rest were harvested for handicrafts, construction (e.g. vines), medicines or ritual purposes. A total of 47 medicinal plants (whose total economic value was negligible) were harvested from any environment (forest or agroforestry site) in 2011, and only 22 were cited by more than one household.

There was no significant difference in the total number of distinct AFPs harvested between market

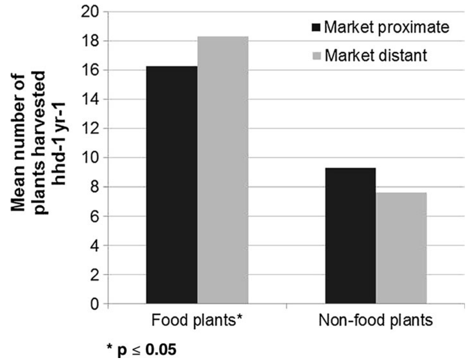

Fig. 4 Comparsion of household food and non-food AFP diversity according to market access

proximate and distant households over a 1 year period (Fig. 3), however distant households harvested significantly more food plants (mean = 18.3 plants) than proximate households (16.3 plants; Fig. 4). In addition, market distant households, which are located nearer to extensive mature forests, harvested a greater number of distinct non-wood plants from unmanaged forests than market proximate households (Fig. 3). According to Pearson's correlation analyses, the total number of distinct plants harvested was significantly positively correlated with total available adult labor, particularly available male labor; these relationships held for number of food plants harvested (Table 3). In addition, the number of food plants harvested was positively related to household distance to market. The primary agroforestry cultivation site is prone to severe inundation in only 13 % of surveyed households therefore it was not possible to identify a strong relationship between AF site vulnerability to flooding and agroforestry plant diversity or incomes.

Chambira was the most salient plant elicited in the fallow free-list exercise, with a Smith's S value of 0.57. Pijuayo ranked second at 0.47, followed by caimito, shimbillo/guava, huassaí (*Euterpe* spp.), uvilla, pineapple, umarí, and manioc. All but four of the twenty highest income generating products harvested from agroforestry environments (Table 2) were observed in both the 2011 fallow inventory and the BAP inventory. Most of these high income contributors also ranked high in 2011 fallow free-listing (Online Resource 1). Corn was not observed in 2012 fallow inventories because it is cultivated only in regularly flooded plots, which were not surveyed. Of the top twenty income contributors, all but coca, papaya, barbasco, huingo and bombonaje were harvested by over half of surveyed residents in 2011. More than 30 different plants utilized for handicraft materials were promoted by Bora residents in either fallows or homegardens. Cudi and guisador (natural dyes) were the most frequently harvested for chambira handicraft adornment, followed by achiote, huito, purma caspi, huitillo, achira and rifari. Few of these handicraft resources were prominent in the free-listing exercise.

Economic importance of agroforestry products

Not only do Bora agroforestry environments harbor a diversity of useful products (some shown in Fig. 5), they contribute substantially to total household income. Figure 6 shows the summed subsistence and cash contributions of all cultivated and wild products, as well as all other off-farm cash income (e.g., miscellaneous wage labor, small cottage

Table 3 Pearson's correlation coefficients between household variables and number of AFP plants harvested

Variable	All AFPs	Food AFPs	Non-food AFPs
Time to market (min)	0.225	0.302*	−0.108
Household head education (years)	−0.182	−0.149	0.069
Household head age (years)	0.219	0.206	0.040
Adult male labor[a]	0.317**	0.271*	0.197
Adult female labor[a]	0.124	0.130	0.152
Total adult labor[a]	0.274**	0.249*	0.215
Dependency ratio	0.203	0.330*	−0.201
Total net income[b]	−0.082	−0.169	0.127
Net hunting income[b]	−0.025	−0.027	−0.035
Net fishing income[b]	−0.092	−0.096	0.208
Net livestock income[b]	0.193	0.206	−0.232*

[a] Refers to total number of economically active adults in the household

[b] Income values reported as total annual household income (USD) per aeu

N = 53. * $p \leq 0.10$, ** $p \leq 0.05$

Fig. 5 Examples of promoted AFPs in Bora villages. **a** Bacaba fruit (*Oenocarpus bataua*) in homegarden, **b** inga (*Inga* spp.) tree in homegarden, **c** maturing *Astrocaryum chambira* stem, **d** Raquel Lopez planting chambira seedling in fallow, **e** young achiote (*Bixa orellana*) plant in fallow field, **f** mishquipanga (*Renealmia alpinia*) fruits and flower growing in fallow field. Photo **a** taken in Pucaurquillo, **b–f** taken in Brillo Nuevo. Photo **a** by author. Photos **b–f** courtesy of Campbell Plowden/Center for Amazon Community Ecology (CACE)

businesses). To place AFP income contributions in the context of the overall income portfolio, mean household (net) income (USD per aeu) was 813 and mean productive income was 673. Mean household incomes for AFP food products were 157 (for subsistence use) and 41 (for market sale) and mean AFP non-food product incomes were 5 (subsistence) and 73 (market sale). AFP production contributed 43.4 % of total household subsistence income and 26.1 % of total cash income (not shown explicitly in Fig. 6). In comparison, a total of 53 miscellaneous NTFPs harvested from unmanaged forests (e.g., aguaje fruit (*Mauritia flexuosa*, L.f.), irapay leaves, palm heart, other fruits and fibers) represented just 5 % of total household income. Fuelwood gathered in fallows contributed 8 % of household income.

Food plants contributed 24 % of all net agroforestry income and manioc and plantain alone contributed 59 % of this share. Chambira handicraft sale contributed 59 % of all AFP income, other handicrafts contributed an additional 10 %, and the remainder derived from plants harvested for construction, medicinal, or ritual uses. Marketed agroforestry food products generated more income in market proximate households (mean = 73) than in market distant households (mean = 22) however no income difference was observed between these groups for subsistence use of food plants. In addition, AFP incomes were negatively correlated with adult labor availability for both food and non-food plants, and positively correlated with total household income (Table 4). Household time to market was

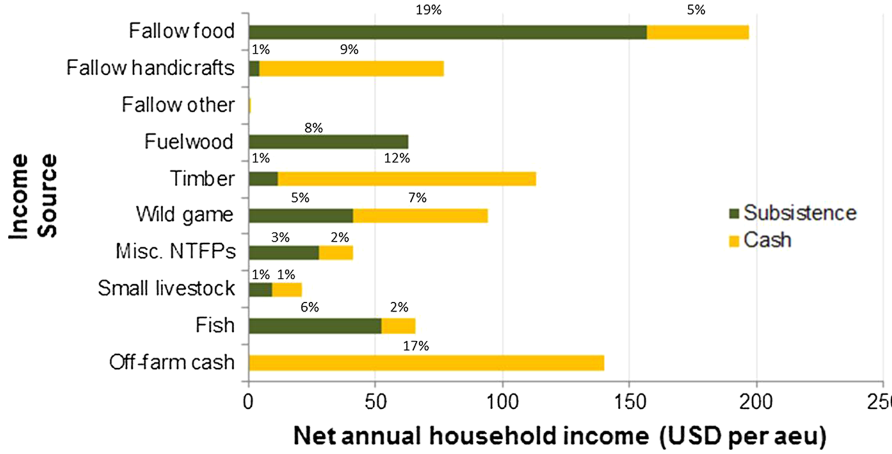

Fig. 6 Breakdown of cash and subsistence extractive incomes and income shares. *Percentage* represents share of total annual net household income. n = 53. *Fallow other* includes plants harvested for construction, medicinal, and ritual purposes. Fuelwood is gathered from recently cleared fields and regenerating fallows. Wild game is primarily harvested from remote, unmanaged forest areas, but some subsistence game is found in fallows near villages. Timber and other miscellaneous forest products are harvested from remote, unmanaged forests

Table 4 Pearson's correlation coefficients between household variables and AFP cash and subsistence incomes

Variable	AFP food income		AFP non-food income	
	Subsistence	Cash	Subsistence	Cash
Time to market (min)	0.144	−0.362***	0.213	−0.297*
Household head education (years)	−0.156	−0.268*	−0.116	−0.137
Household head age (years)	0.263*	0.164	0.124	0.064
Adult male labor[a]	−0.244*	−0.195	−0.147	−0.288**
Adult female labor[a]	−0.365***	−0.229*	−0.225	−0.223
Total adult labor[a]	−0.370***	−0.259*	−0.226	−0.315**
Dependency ratio	0.279*	−0.028	0.093	−0.097
Total net income	0.429***	0.137	0.324**	0.522***
Net hunting income[b]	0.169	−0.099	0.173	0.032
Net fishing income[b]	0.156	0.054	0.168	0.413***
Net livestock income[b]	−0.077	0.238*	0.057	0.107

[a] Refers to total number of economically active adults in the household

[b] Income values reported as total annual household income (USD) per aeu

N = 53. * p ≤ 0.10, ** p ≤ 0.05, *** p ≤ 0.01

negatively correlated with AFP cash incomes. Marketed chambira handicrafts (examples displayed in Fig. 7) contributed over half of agroforestry cash income and their sale generated 8.2 % of total annual household income. This income was twice as high in market proximate households (mean = 104) as in the market distant households (mean = 49). In this survey, the maximum annual household income earned from these crafts was 484 USD per aeu. Furthermore, total household income was found to be significantly positively correlated with chambira handicraft income ($p < 0.001$). In comparison with the 15 % contribution of chambira handicrafts to total cash income, timber, game, and fish sale contributed 23, 12 and 3 %, respectively.

Discussion

The cultivation of multipurpose tree species and crops in fallows and homegardens for diverse livelihood benefits has been documented across multiple Amazonian countries (Posey 1985; Irvine 1989; Hammond et al. 1995; Coomes and Ban 2004; Reyes-García et al. 2006; Bohn et al. 2014), not to mention other tropical sites around the globe (Maroyi 2009; Kalaba et al.

Fig. 7 Chambira handicraft production. **a** Rigoberto Salas Tello and Celia Flores Lopes stripping chambira fibers from petiole, **b** Angelica Pinedo dyeing chambira fibers, **c** Alejandrina Benites weaving chambira handbag, **d** Gisela Ruiz weaving chambira hammock, **e** Felicita Butona Chichaco weaving chambira belt, **f** Angelica Pinedo and Ortensia Arirama holding chambira placemats. Photo **1** taken Pucaurquillo, all others in Brillo Nuevo. Photos **3**, **5**, and **6** courtesy of Campbell Plowden/CACE, all others by author

2010; Guuroh et al. 2012; Dawson et al. 2014; Deb et al. 2014). Moreover, a recent study demonstrated that nearly 46 % of the world's agricultural land is associated with agroforestry environments, according to a definition of 10 % tree cover in such sites; this corresponds to nearly 560 million people worldwide (Zomer 2009). The authors indicate that nearly all of the agricultural land in Central America falls under this category, while 82 % of SE Asian and 81 % of South American agriculture corresponds with this land use type. In light of the widespread influence of agroforestry systems, this research is highly relevant to rural populations worldwide, particularly considering the scarcity of studies which combine cultural and ecological data with a detailed economic valuation of both wild and cultivated products. The discussion below demonstrates how agroforestry production contributes to indigenous livelihoods by providing food security, risk mitigation, and cash benefits. Lastly, implications for safeguarding biodiversity and ecosystem services and promoting climate change resilience are considered.

Livelihood diversification, agroforestry product diversity, and livelihood benefits

Bora residents spread their subsistence and cash generating labor across agriculture, floral and faunal harvest in forests and fallows, fishing, and other miscellaneous activities (Cotta 2015), as evidenced in Fig. 6. This diversity of productive environments and harvested products exemplifies the rural livelihood diversification ubiquitous throughout the tropics (Reardon 1997; Ellis 2000; Smith et al. 2001; Caviglia-Harris and Sills 2005; Turner and Michaud 2008). Furthermore, the 2011/2012 plant list (Online Resource 1) contains many useful species mentioned in previous indigenous Amazonian fallow and homegarden surveys (Denevan 1971; Eden and Andrade 1987; Hammond et al. 1995). A total of 126 economically important agroforestry plants were observed within a mere three Bora villages over one year. Cultivation activities vary yearly, due to differences in site ecology and other factors (Denevan 1971), therefore household product diversity over time is likely even higher in the study area than that which was observed in the survey year. Moreover, activities are somewhat limited by some household attributes. It is not surprising, for example, that labor availability positively influences the diversity of harvested AFPs, due to the labor-intensive nature of fallow cultivation and harvest.

Diversified harvest portfolios which include agroforestry products provide year-round nutrition and food security for many populations (Gladwin et al. 2001; Perrault 2005; Schreckenberg et al. 2006; Kalaba et al. 2010), and the Bora portfolio is no exception. To begin with, the domesticated peach palm, pijuayo, stands out as a dietary staple across the Amazon (Urpí et al. 1997) and represents the fifth most economically important Bora agroforestry product. Additionally, over half (76) of the plants harvested by these residents comprise a year-round supply of fruits and other edibles. Activity and product diversification can buffer household risk associated with seasonal or unexpected staple shortages or fluctuations in natural resource abundance (Anderson and Ioris 1992, Ellis 2000). Though subsistence food production is especially important for remote villages, where purchased foods are difficult to access, the substantial subsistence food plant diversity and income observed even within market proximate households hints at the importance of balancing production for market sale with nutritional self-reliance (Hammond et al. 1995; Perrault 2005). Diversification also mitigates economic shocks such as income loss, labor shortages (Ellis 2000), or even commodity price downturns (Cramb et al. 2009). In the surveyed villages for example, chambira handicrafts and seasonal fruits are frequently sold following hardships such as agricultural or livestock loss and labor shortages (Cotta 2015). The safety net role of agroforestry products has been similarly reported in Asia and Africa (Perrault 2005; Shackleton et al. 2008; Cramb et al. 2009).

Medicinal plant diversity in agroforestry environments appears to be decreasing in the surveyed villages. Although a recent ethno-pharmacological study in Brillo Nuevo reported nearly 100 known (and identified) medicinal species (Salgado 2010), the 2011 economic assessment indicates relatively low actual use across most Bora households. The diversity of plants prescribed by traditional healers (*curacas*), and how cultivated medicinal plant diversity has changed among curacas over time, were not assessed, thus conclusions regarding plant use are limited to general users. Even so, the research team witnessed a strong preference for pharmaceuticals during the survey and residents reported a significant decrease in reliance on natural medicine even since the BAP was carried out. Low medicinal plant use may relate to increased market integration and a focus on more marketable products, which has been observed in other Amazonian communities (Reyes-García 2001; Hofmeijer et al. 2013). Many agroforestry species hold additional cultural significance in Bora villages. For example, huito, llanchama, and coca are used in ritual activities. In this study, local importance can be inferred to some extent from: (i) harvest frequencies and (ii) free-list scores, and these data may capture species with low total income value. Ethnobotanical studies focused on cultural values would provide an excellent complement to this economic assessment.

Fallow cash income contributions and market opportunities

Species enrichment is a common strategy employed to generate cash income from fallow harvest throughout the tropics (Padoch et al. 1985; Burgers et al. 2005; Steffan-Dewenter et al. 2007). Income data reveal the high contribution of agroforestry to cash incomes (26 %) in Bora villages. Market integration has increased in the area since the BAP study and fallow product marketing has likely not only been encouraged, but necessitated by the increasing scarcity of wild forest products (discussed later). Many products are sold outside Bora villages (Online Resource 1), however few are marketed as far as Iquitos. This relates to product perishability and low economic value of fallow products compared to products such as timber. Indeed, correlation analyses show cash incomes from (perishable) AFP food products decrease farther from markets. Market distance even appears to have a negative effect on household cash income from non-perishable (non-food) AFP products, suggesting time and/or fuel expense constitute limiting factors to the sale of these relatively low-value resources. On the other hand, some non-food AFP products such as chambira handicrafts (discussed subsequently) could potentially be stored in market distant villages and sold at a producer's convenience.

Chambira handicrafts represent the most important cash generating agroforestry product in Bora villages and their livelihood importance is highlighted by the positive correlation observed between chambira handicraft income and total household income. In the mid-1900s, Bora residents began trading chambira hammocks for market goods (Vormisto 2002), and in the 1980s residents near Pevas sold hammocks, shoulder bags, and other crafts to tourists. Though chambira handicraft income was not quantified in-depth at the time of the BAP study, little handicraft production or sale was observed in Brillo Nuevo by the BAP team (Denevan, pers. communication). In 1997, however, substantial involvement in handicraft production was observed there (Vormisto 2002). Today, residents in the study area sell their handicrafts to independent buyers, the Center for Amazon Community Ecology (CACE), and occasionally to government agency representatives. CACE has been developing and marketing value-added non-timber forest products in Brillo Nuevo since 2009 and has purchased handicrafts from Pucaurquillo residents for many years, including Pucaurquillo in project activities since 2011. The higher chambira handicraft income generated in Pucaurquillo reflects a higher household participation rate, which relates to market proximity and the history of tourist activity near Pevas. Nearly all households in Pucaurquillo currently sell handicrafts, even despite the decline in tourists in recent years. A smaller proportion of the market distant villages participate in handicraft production and these residents remain more dependent upon intermediaries, including CACE, for product sale. Handicraft production, important in many Amazonian localities, often represents one of the only sources of cash income for indigenous communities (Jensen and Balslev 1995; Coomes 2004; García et al. 2015). In addition, production and sale is dominated by females and constitutes one of the only cash generating opportunities for women in the study villages, a phenomenon observed throughout the tropics (Barbier 1989; Schreckenberg 2004). In recent decades, small-scale projects, including efforts by CACE, have promoted chambira handicraft production (Pitman et al. 2004, Plowden pers. comm) while advocating enrichment of fallows with chambira and improved harvest techniques for long-term sustainability. In addition, agroforestry environments harbor a diversity of dyes, seeds, and other handicraft adornment materials. Such materials improve product quality while saving time (avoiding collection in distant forest) and money (reducing need to purchase inputs). The economic value of the handicraft is associated primarily with the main input, chambira fiber, therefore the monetary value of a diversity of plants is masked within chambira income. Unfortunately, CACE coordinators have reported a scarcity of handicraft dye plants in the study area. Such species could be included in projects targeting plant conservation and management in handicraft-dependent villages.

A particularly striking finding related to agroforestry product marketing is the high involvement in huassaí (*Euterpe* spp.) fruit sale, shown in Table 2. In Pucaurquillo, 89 % of surveyed households reported huassaí harvest in 2011. This reflects the recent emphasis on homegarden planting of huassaí in the village, stimulated by the installment of a small pulp processing plant by a foreign entrepreneur around 2010. The entrepreneur purchased and sold the high-grade processed pulp of locally harvested *Euterpe precatoria* and *E. oleraceae*, and awarded low-grade pulp to residents. *Euterpe oleracea* is exotic to Peru (Henderson 1997), however it was reported in Brillo Nuevo even during the BAP study, and is increasingly being cultivated in new Amazonian regions as the international market booms (Sabbe et al. 2009, Menezes et al. 2011). The processing plant was removed in 2012 due to financial difficulties faced by the entrepreneur, but locals will likely continue to harvest the fruit they have come to appreciate for home consumption. Though fallow and homegarden production throughout the Amazon is becoming more market-oriented and increasingly overshadowed by a few highly valued cash crops (Padoch et al. 1985; Hammond et al. 1995; Padoch et al. 2008; Useche and Blare 2013), fallow diversity in the study area has not yet been heavily displaced by such cash cropping. On the other hand, the enthusiasm demonstrated toward huassaí production suggests Bora residents can embrace new exotic products amid emerging market opportunities.

The value of fallow versus forest products

The data generated in this study facilitate a quantitative comparison of managed fallow versus unmanaged forest product income contributions. Table 2 and Fig. 6 highlight the importance of fallows in providing a diversity of resources for (i) commercial handicraft production, (ii) subsistence food, construction, and rituals, and (iii) market sale for supplemental income. When considering all plant-derived income, including forest timber and fuelwood harvested from fields and fallows, agroforestry environments contribute more than double the income of unmanaged forests in the study area. Other recent studies reveal similar findings, where transitional sites between field and forest sometimes provide higher incomes than forests (Coomes et al. 2000; Pouliot and Treue 2012). Moreover, natural environments contribute differentially to specific product use types (Gavin 2004). In this study, fallows represent more important sites for many nutritional resources, medicines, and handicraft inputs compared to unmanaged forests due, in large part, to ease of access to plants which thrive in regenerating secondary forest. Couly and Sist (2013) also reported plant gathering occurred more often in fallows than forests. The authors observed a greater dependence on homegardens for medicine and food, while climax forests were more important than regenerating fallows for medicine. Furthermore, they indicate that regenerating secondary forests are highly important environments for fuelwood and construction material. Though the diversity of timber and fuelwood species was not assessed, this survey verifies that Bora fallows are key environments for household energy production, as fuelwood is collected entirely from fallows. According to Bora residents, the more valuable forest products, timber and wild game (now found only in distant forests), have steadily declined in abundance (and overall income contribution), due to illegal extraction by outsiders and some unsustainable local harvest. The remainder of unmanaged forest income derives from a few key species such as aguaje, palm heart, and irapay and, according to residents and local NGO staff, these resources have also dwindled in abundance. Finally, some forest-based activities are only seasonally viable (e.g., timber is harvested during high water levels and aguaje has a short fruiting season). In light of these realities, managed fallows should not be underestimated in their role in providing year-round livelihood benefits in the form of easily accessed medicines, essential vitamins and nutrients, and cash-generating products (Fernandes and Nair 1986; Gliessman 1990; Abebe et al. 2006).

Biodiversity conservation, ecosystem service provisioning, and climate change in fallow agroforestry systems

The economic benefits provided to humans by fallow agroforestry systems have been demonstrated in detail above. However, the potential for these systems to safeguard biodiversity and ecosystem services, as well as promote resilience to climate change impacts, should not be overlooked. Research across agricultural and forest landscapes has focused increasingly on the importance and maintenance of associated biodiversity and ecosystem services for both improved livelihoods and environmental sustainability (McNeely and Schroth 2006; Chazdon 2008, Fifanou et al. 2011). Fallow enrichment, for example, has the potential to contribute to livelihoods while promoting botanical and faunal diversity (McNeely and Schroth 2006; Jose

2009; Bohn et al. 2014). Managed fallows serve as habitat refuges for game and other animals, and corridors for seed and pollen dispersal which, in turn enhances fruit and other crop production (Bhagwat et al. 2008; Scales and Marsden 2008; Hagen and Kraemer 2010). Agrobiodiversity also confers increased crop resilience to pests and promotes soil recovery (Eden and Andrade 1987) and tree enrichment near riparian areas can enhance watershed function (Jose 2009; Celentano et al. 2014). Finally, modeling exercises in regions such as the Peruvian Amazon have predicted a changing climate will impact the distribution/production of key agricultural species (Soudre et al. 2011) and agroforestry systems can provide a diversity of income options to mitigate such changes (Nair 2012).

Conclusion

This work provides a valuable complement to Denevan and Treacy's description of Bora agroforestry nearly 30 years ago. Data confirm the continued cultivation and promotion of a diversity of agroforestry species in the Peruvian Amazon for multiple livelihood benefits. Even so, future research could assess the economic value of different plant use categories across fallows of differing ages and site histories. Much remains to be learned about the implications for food security in households with little to no upland field access, since the majority of agroforestry production is carried out in upland sites. Studies across the globe have described the importance of fallow agroforestry, but this study provides one of the first in-depth assessments of the full suite of products including their economic values and local importance indicated by free-list and inventory data. The contribution of myriad fallow products is ignored in many national statistics and has received little attention from policy makers to date. Moreover, most research has focused on either forests or agriculture, and less on intermediate, managed environments such as fallows. Results presented here provide an opportunity to rethink current research and initiatives aimed at sustaining local livelihoods through cash income creation, improved food security, and increased livelihood benefits for vulnerable populations. Such projects should focus as much on agroforestry systems as on natural forests. Increased access to agroforestry credits, which could be facilitated through markets for environmental services, is one potential avenue for intervention. The integration of traditional knowledge with innovative approaches should also be maximized to confer optimal benefits to local communities. Finally, as external forces such as international commodity markets and national agricultural policies continue to shape smallholder production activities and the agroforestry land use mosaic throughout the tropics (Delang 2006; Steffan-Dewenter et al. 2007; Cramb et al. 2009; Okubo et al. 2010; Sayer et al. 2012; Dawson et al. 2014), it is imperative to explore options which can minimize vulnerability associated with product specialization and offer sustainable income generation in the long term.

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