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Seed Sharing in Amazonian Indigenous Rain Forest Communities: a Social Network Analysis in three Achuar Villages, Peru

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Abstract Farmer-to-farmer seed transfers are important for plant domestication, the dissemination of improved crops and in building and maintaining agricultural diversity. Seed sharing may be conceptualized as networks through which planting material flows and landraces are disseminated and conserved. To date, research on seed sharing networks has focused on sociograms and network measures to describe their structure and key actors within them; their bivariate or multivariate correlates have been studied using conventional statistics. We conducted a study of home garden agrobiodiversity and seed networks in three Achuar communities along the upper Corrientes River in Peru. We examine the distribution of home garden crop species within and across communities and apply multivariate techniques *within* Social Network Analysis (SNA) to analyse the formation and structure of seed networks and to identify key actors in seed sharing. Of particular interest is the relationship among crop diversity, farmer expertise, kinship, and seed sharing behavior. Our results point to the importance of kinship relations, community size, and the 'knowledge-plant transfer' nexus in shaping seed networks.

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Introduction

Farmers in developing regions rely on self-provisioning of seed and 'informal' access through gifting, bartering and purchase to planting material that is vital for agricultural production (Almekinders *et al*. 1994; Dyer *et al*. 2011; Jarvis *et al*. 2011). The importance of farmer-to-farmer exchange of seeds, cuttings and other plant propagules is increasingly recognized for its contributions to agriculture (Coomes *et al*. 2015). Seed exchange is a key pathway for domestication as farmers bring plants 'in from the wild' to their gardens and fields and share seed (Jarvis and Hodgkin 1999), as well as for the dissemination of improved crop breeds through hybrid seed delivery systems (Gyawali *et al*. 2010; Gibson 2013). Importantly, seed exchange influences crop diversity dynamics, enabling the building and maintenance of in situ agrobiodiversity so that farmers can conserve landraces that are locally adapted to environmental conditions (Bellon and Risopoulos 2001; Thomas *et al*. 2011).

Increasingly, farmer-to-farmer seed sharing is conceptualized as 'networks' through which planting material flows and landraces are disseminated and conserved (see Pautasso *et al*. 2013).[1] In many studies, seed networks are seen as embedded

[1] For example, crops such as barley (Abay *et al*. 2011; Jensen *et al*. 2013), millet (Allinne *et al*. 2008), sorghum (Barnaud *et al*. 2008; McGuire 2008; Labeyrie *et al*. 2015), wheat (Bishaw *et al*. 2010; Thomas *et al*. 2012), rice (Subedi *et al*. 2003), potatoes (Zimmerer 2003), quinoa (Fuentes *et al*. 2012) and manioc (Dyer *et al*. 2011; Delêtre *et al*. 2011; Fu *et al*. 2014).

in a web of rural social relations where seed movement is both contingent on and constitutive of bonds of kinship, marriage, and friendship, and plays an important role in reproducing cultural identities, meanings and consensus (Boster 1986; Delêtre *et al*. 2011; Leclerc and Coppens d'Eeckenbrugge 2012; Labeyrie *et al*. 2014; Wencélius *et al*. 2016). Other scholars construe seed exchanges as social networks *ipso facto* (Subedi *et al*. 2003; Abay *et al*. 2011; Calvet-Mir *et al*. 2012; Kawa *et al*. 2013; Reyes-García *et al*. 2013; Poudel *et al*. 2015; Ricciardi 2015). Borrowing tools from Social Network Analysis (SNA), these studies focus on descriptions of network structure and the role of key actors, typically defined as households (cf. Wencélius *et al*. 2016), within a network as 'nodal', 'broker' or 'bridging' and their bivariate or multivariate correlates using conventional statistics. As yet, however, social seed networks have not been analyzed using multivariate techniques within SNA to ascertain the relative importance of factors that shape their formation, the flow of planting material and the role of central actors.

This paper addresses agrobiodiversity and seed networks in three Achuar communities along the upper Corrientes River in the northern Peruvian Amazon, a region identified as an important centre of crop genetic diversity and plant domestication (Clement 1989). Our focus is on home gardens, identified here as the peri-domestic area in which useful plants are grown, including adjacent forest edges where plants are often transplanted and tended and riverside areas used to launch canoes, bathe, or fetch water. We use SNA to analyze farmer-to-farmer transfers of planting material across households to determine what factors condition network formation and patterns of seed flow. We use the term 'seeds' to refer to planting material broadly, including true seeds, seedlings, propagules such as cuttings, pseudostems, and tubers. The paper makes three contributions. First, we report the distribution of crop species diversity in the home gardens of Achuar households within and across the study communities and explore the links with the structure of seed sharing networks. Home gardens are the sites of highest crop diversity in Amazonia, and serve as both repositories of plant and genetic material, and important sites for plant management, domestication and experimentation (Smith 1996; Coomes and Ban 2004). Second, we apply for the first time a multivariate technique within SNA to analyse the formation and structure of seed networks. Networks are described and analyzed using visualization tools and dyadic regression modeling with SNA software, which allows us to discern which features are most influential in shaping network formation, seed flow patterns and the respective roles of different actors in the network. Lastly, we offer new insights through the analysis of home garden-based seed networks among the Achuar into the general relationship between crop diversity, farmer expertise, kinship, and seed sharing behavior.

Seed Sharing in Amazonia

Research on farmer seed sharing in rural Amazonia is limited compared to societies in semi-arid or mountainous environments where threats to seed supply are more obvious (Coomes 2010). Following the pioneering work of James Boster among the Aguaruna Jívaro (1984, 1986), researchers have focussed on explicating the (hyper) diversity of manioc varieties in the fields of Amerindian and folk peoples (e.g., Salick *et al*. 1997; Pujol *et al*. 2007; Cabral de Oliveira 2008; Emperaire and Peroni 2007; Heckler and Zent 2008; Kawa *et al*. 2013). These studies point to the influential role of propagule transfer in manioc diversity dynamics, a finding echoed in research on other crops in the basin (Adin *et al.* 2004; Coomes and Ban 2004; Cole *et al.* 2007; Stromberg *et al.* 2010). Intriguingly, Kawa *et al*. (2013) work among folk communities (*caboclos*) found that farmers with the highest varietal diversity in manioc were not among the most active in distributing cuttings – these farmers were instead those considered most knowledgeable about growing manioc and active in manioc production. The few studies of seed sharing as networks per se suggest that in Amazonia they can be extensive, moving planting material from a broad diversity of crops – sometimes in large quantities among/across many actors and sociocultural groups – over long distances (Cole *et al*. 2007; Emperaire and Peroni 2007; Coomes 2010; Eloy and Emperaire 2011; Emperaire and Cabral de Oliveira 2011). These studies focus on exploring the dimensions of social seed networks as a first step towards identifying the factors that condition seed network formation and structure.

Study Area

The three study communities – Nuevo Pucacuro (henceforth Pucacuro), Valencia and Santa Rosa – are situated along the upper Corrientes River, a clear water tributary of the Tigre River in the northeast Peruvian Amazon (Fig.1). The Corrientes rises in the Ecuadorean Andes and flows down through the Pastaza MegaFan which is comprised of deep alluvium of volcanic origin (Räsänen *et al*. 1992) below which are important reserves of oil and gas (Finer *et al*. 2015). All three communities are located upriver of the district town of Villa Trompeteros, a major centre for oil production since the 1970s about 200 km west of the largest city of the Peruvian Amazon, Iquitos. Situated on the *terra firme* overlooking the river, the communities are unaffected by seasonal flooding. The remote Corrientes River is a region of high cultivated plant species diversity: a large-scale survey of home gardens in 15 communities along a 150 km reach listed 309 useful species, the largest number reported for the Amazon basin (Perrault-Archambault and Coomes 2008).

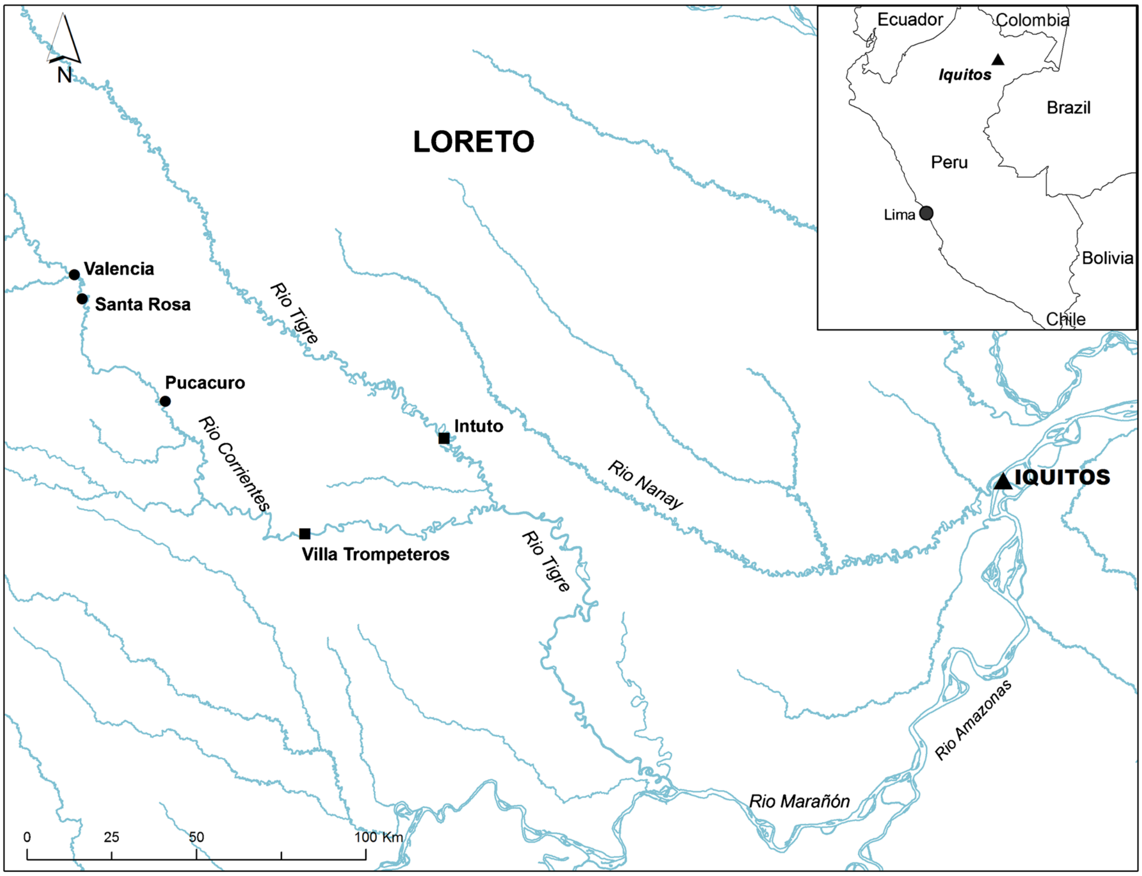

Fig. 1 Map of study area

Valencia is located furthest upstream from Villa Trompeteros, some 9 h by motorboat (25 hp) and Pucacuro is the closest at 5.5 h upstream. Despite several changes of location, Valencia is one of the oldest settlements in the basin and 'mother-community' of nearby villages including Santa Rosa. Both Santa Rosa (17 households in 2003) and Valencia (25 households) are comprised primarily of self-denominated Achuar, members of the Jívaro ethno-linguistic family and the largest native group of the upper Corrientes. Although many Achuar heads of household have Quichua ancestors, they identify as Achuar and use the Achuar language to communicate within and between family units. Pucacuro is comprised of Achuar, Quichua and mestizo families and is the largest of the three communities (68 households, 305 inhabitants), having grown significantly since the early 1990s with an influx of people from nearby villages and from the Tigre River to work with the oil company (Pluspetrol). Eighty-nine percent of garden tenders in Pucacuro reported some Achuar ancestry.

Households are comprised of 5–7 members and all are poor in income and assets. Total annual incomes range between from 315 to 10,000 $US per household, with mean incomes by community on the order of 2300–3000$/household (Table 1). Agriculture is the main economic activity, supplemented by fishing, forest product extraction, hunting, livestock, and periodic wage labor (Supplementary Material Table S1). Households typically hold 3–5 ha of land and about 500$ in non-land assets. Each household has a home garden of about 700-1000 m^2 where they cultivate plants obtained from natural sources and through social relations within and outside the community (Fig. 2). Opportunities for education are limited to a primary school in each community and basic health services are provided by nurses paid for by Pluspetrol at the oil bases in Pucacuro and San José. Families must travel downstream to the towns of Trompeteros or Intuto on the neighboring Tigre River for access to secondary school, to sell their produce at market, and to purchase basic household supplies and goods. Local produce and basic goods are also traded with river merchants (*regatones*) who visit the villages periodically.

Methods

Data Collection

Data were gathered originally through household and garden surveys conducted in 2003 (see Perrault-Archambault and Coomes 2008). A sketch map was drawn for each community and a household census was conducted. Following a

Table 1 Selected household and home garden characteristics in three Achuar villages, Corrientes River, Peru, 2003

	Pucacuro (*n* = 54)			Valencia (*n* = 21)			Santa Rosa (*n* = 14)		
	Mean	Std. dev.	Range	Mean	Std. dev.	Range	Mean	Std. dev.	Range
Age of household head (years)	13.7	12.3	0–50	16.9	11.8	0–46	12.2	12.9	1–39
Household size	5.2	1.9	2–9	6.7	2.9	2–12	5	2.2	2–10
No. of adults	2.4	0.9	1–5	2.9	1.5	1–6	2.5	1.6	1–7
No. of dependents	2.8	1.7	0–7	3.8	2.3	0–8	2.5	1.2	1–5
Total land holdings (ha)	3.1	2.6	0–10	5.1	3.7	0–13.3	3.8	3.3	0.1–12
Total number of fields	4.4	2.2	1–10	6.7	3.5	1–14	4.9	2.8	1–10
Non-land assets ($US)*	574	523	0–2016	475	218	0–921	463	539	0–2072
Total annual income ($US)*	2719	1667	316–9885	2960	1731	829–6641	2313	1291	733–5245
Home garden size (m^2)	940.3	787.8	50–3100	879.3	1625.2	10–6000	735.7	706.1	100–2800
Garden age (years)	6.3	4.9	0–20	11.1	7.5	2–30	4.9	2.1	2–8
Garden tender is female (1 = yes 0 = otherwise)	0.9	0.3	0–1	0.9	0.3	0–1	1	0	1–1
No. of plant spp. in home garden	29.8	11.9	5–72	29.7	14.7	6–65	39.8	11.7	19–62
Fruits (%)	40	10	15–70	51	13.2	17–74	45	4.9	39–57
Food (%)	24	10.2	9–60	20	7.4	7–33	17	4.4	10–24
Medicinal (%)	21	8.5	0–38	14	9.9	0–36	17	7.8	5–34
Others (%)	15	5.4	0–25	15	6.9	5–33	20	6.8	4–31
Total number of plant spp. in all home gardens in village	161			146			122		

* Exchange rate (2003) $1.00 (US) = 3.47 S/. (Peru)

community assembly and permission being granted to proceed, all households in the three communities were invited to participate in the study. A comprehensive socioeconomic questionnaire was administered to one or both heads of household soliciting information on household demography, history, cultural background, economic production and asset holdings. The primary home garden tender in each household (typically female) accompanied the interviewer (M.P-A) to their garden where they were asked to identify each useful plant by vernacular name and describe its uses. The tender was also asked about the social and geographic origins of each plant, i.e., where and from whom the plant was acquired, and how it was acquired (i.e., gift, barter or purchase). Garden diversity was defined as the total number of plant species found in the garden; intraspecific variation is not considered. Species names were determined from the vernacular name by reference to Duke and Vasquez (1994) and Mejía and Rengifo (1995), and in consultation with botanists at the *Instituto de Investigaciones de la Amazonía Peruana* (IIAP) in Iquitos. Whereas identification through voucher specimen collection would have been

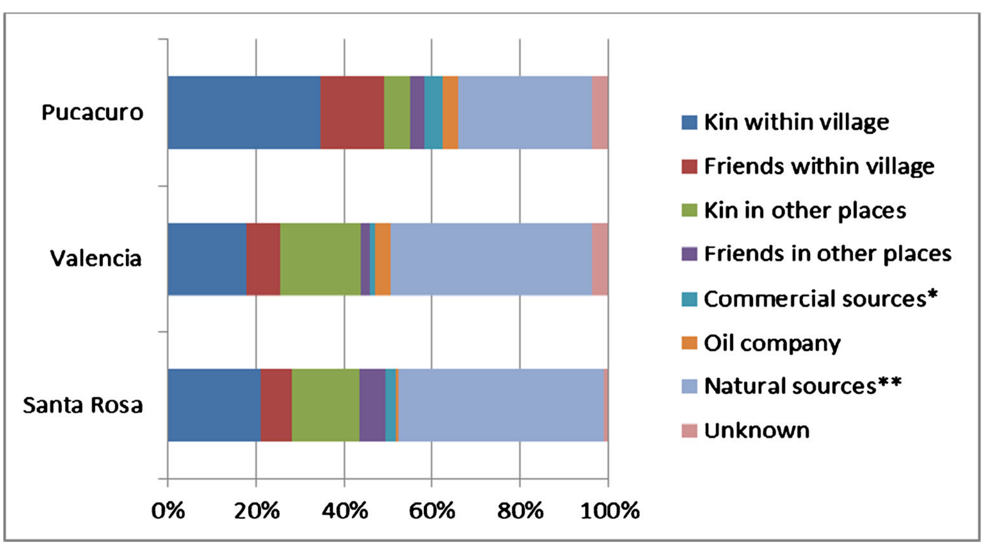

Fig. 2 Sources of planting material for three Achuar villages, Corrientes River, Peru. * Bought in market or from river traders; ** From the forest, grew spontaneously in field, or brought from other fields

preferable – as the most accurate method for developing a definitive botanical inventory – data based on common name identification are sufficient for our purposes, i.e., assessing *relative* plant diversity and patterns of seed sharing among farmers. Our use of common names also facilitates comparisons with previous studies from Amazonia (e.g., Coomes and Ban 2004; Peña-Venegas *et al*. 2014; Díaz-Reviriego *et al*. 2015). A list of the most common species found in the study communities can be found in (Perrault-Archambault and Coomes 2008, Appendix).

A second questionnaire was administered to the garden tender regarding the history of the garden, their knowledge of gardening, and who they consider around them to be most knowledgeable about plants, pests and agrobiodiversity management. As part of the questionnaire, participants were asked to complete a knowledge test, which included questions on plant (and plant variety) identification using pictures (and free lists), garden management and medicinal uses of plants. To assess expertise, respondents were asked questions including "[w]ho would you ask for help if there was a pest outbreak in your garden or fields?"; "[w]ho could identify this plant [picture shown]; and, "[w]ho taught you most about garden tending?" Responses were triangulated to establish a measure of socially-recognized expertise in gardening and identify networks of expertise within each community. Garden visits typically took about one hour to complete, but in several instances discussions around plant origins and form of acquisition made for significantly longer visits. Overall, participation rates were high among households in all communities: Pucacuro (88 %, $n = 54$), Valencia (91 %, $n = 21$) and Santa Rosa (93 %, $n = 14$), after excluding teachers with temporary appointments.

Data Analysis

Seed sharing within each community was explored first using GEPHI to visualize our seed networks and identify the centrality of key actors as seed givers. GEPHI is open source software (http://gephi.org) designed for network visualization and interpretation using a 3D render engine that enables interactive exploration of network structure (Bastian *et al*. 2009). When applied to seed networks, GEPHI sociograms can indicate the direction and intensity of seed flows as well as the number of plants contributed by individual farmers in the network.

The analysis of seed networks to capture both the characteristics of networks and the factors that shape network formation and the flow of planting material was undertaken using dyadic multiple regression analyses (DRA) in UCINET. UCINET is a proprietary software program for network visualization but also for statistical analyses of network structure and properties (Borgatti *et al*. 2002, 2013). Initially key properties are calculated that describe the seed networks, including centrality and reciprocity. DRA then allows us to explore interdependent relations among households in seed sharing, based on household dyads (pairs) as the unit of analysis rather than individual households as in conventional multiple regression modeling. DRA is used increasingly in the fields of microdevelopment economics (Fafchamps and Gubert 2007; Barr *et al*. 2015), economic geography (Broekel and Boschma 2012) and rural livelihood studies (Abizaid *et al*. 2015) and can be readily adapted to the study of seed sharing. Data are organized in matrices that capture the seed sharing network (dependent variable) and the relational factors that may influence seed sharing (explanatory variables). Each cell in the matrix captures a dyadic relationship between two households. UCINET's Double-Dekker semi-partialling method is used for multiple quadratic assignment procedure regression (MRQAP) analysis of the matrices (Borgatti *et al*. 2002; Dekker *et al*. 2007).

Unlike many applications of dyadic regression analyses that treat node and link-attribute data similarly, we follow recent econometric studies of network formation that distinguish attributes specific to the nodes (i.e., garden diversity, being an expert, household age and land holding size) and relational attributes between the links (i.e., kinship relations and kin group affiliation) as explanatory variables (see Fafchamps and Gubert 2007; D'Exelle and Holvoet 2011; Barr *et al*. 2015). Dyadic regressions require that regressors be entered in a symmetrical form (i.e., $\beta X_{ij} = \beta X_{ji}$) (Fafchamps and Gubert 2007). Specifically, we use the following specification for dyadic regressions:

$$Y_{ij} = \alpha + \beta_1 (z_i - z_j) + \beta_2 (z_i + z_j) + \gamma w_{ij} + u_{ij}$$

where i and j are households; Y_{ij} is an N x $(N-1)$ matrix that accounts for the dependent variable; X_{ij} is K sets of N x $(N-1)$ matrices that account for the explanatory variables (N is the number of households and K is the number of explanatory variables; N^2 is the total number of possible $_{ij}$ pairs but self-ties are omitted); and u_{ij} is an error term that is interdependent because of the presence of household-specific factors common to all observations involving that household. Each cell in a matrix represents a dyadic relation between nodes i and j.

First, we estimate this equation to explain the probability of household i sharing seed with household j and then estimate it for the number of plants given by household i to j. β_1 and β_2, respectively, measure the effect of differences in and combined effect of node-attributes z_i and z_j, and γ captures the effect of link-attributes w_{ij} on Y_{ij}. Entering our regressors in the form of $(z_i - z_j)$ and $(z_i + z_j)$ not only respects the symmetry requirement but also is a natural transformation that allows ready interpretation of results. In this way, our modeling approach enables us to investigate not only whether households sharing a particular attribute tend to share seed with each other (directed link formation) but also to assess whether such households give (or receive) more planting material (intensity and direction of flows). For more detail on the method in a related application using relational data (cooperative rural labor sharing), see Abizaid *et al*. (2015).

The independent variables used in the MRQAP/dyadic regressions to explain the propensity to share seed and the intensity of seed sharing were selected based on the findings of previous ethnographic studies of seed exchange, our field experience, and peasant and agricultural economics theory. Household/farmer characteristics – or node attributes – include the household age, total area of land holdings, plant diversity in the home garden, and whether or not the farmer was considered by peers to be a plant expert. The age of the household (i.e., number of years since the birth of the first child) was included as older farmers have been found to give seeds to younger farmers (Alvarez *et al*. 2005; Wencélius *et al.* 2016). The total area of land is used as a measure of household wealth (a productive asset) but also of the potential diversity of biotopes available to the household, both of which have been associated with crop diversity and exchange (Zimmerer 2003; Coomes and Ban 2004; Kawa *et al*. 2013). The diversity of plants in the home garden and farmer expertise are key variables of interest. Crop diversity and exchange behavior are thought to be related, as exchanges are needed to build diversity and crop diversity enables further seed sharing (Coomes and Ban 2004). Farmer expertise and knowledge have been both shown to be related to seed exchange behavior (Kawa *et al.* 2013; Reyes-García *et al*. 2013). Insufficient variation in gender of the garden tender was found (~92 % are female) to include as an independent variable, although women have been identified in the literature as key agents of seed exchange in some settings (Boster 1984; Brown 1986; Pinton 2002; Ban and Coomes 2004; Emperaire and Peroni 2007; Cabral de Oliveira 2008; Wencélius *et al*. 2016).

Relational characteristics – or link attributes – focused on kinship and affine relations among women and among men, and on kin group affiliation. Kinship relations are often found to be influential in conditioning seed sharing (Delêtre *et al.* 2011; Leclerc and Coppens d'Eeckenbrugge 2012; Díaz-Reviriego *et al*. 2015; Labeyrie *et al*. 2015). The Achuar tend to be uxorilocal and vertical ties (mother-daughter) are expected to be particularly important in seed flow (see Descola 1994); we sought nonetheless to capture a fuller gamut of direct kinship relations. For simplicity, we refer to the most direct kinship ties, both vertical and horizontal (i.e., mother-daughter, father-son, sisters, and brothers). Data on *compadrazgo*[2] bonds were not systematically gathered. Kin group size and affiliation may also be an important condition in the sharing of seed for home gardens. Analyses were conducted for each community separately given that seed circulation dynamics can be distinct even among nearby communities (see Ricciardi 2015) (Table 2).

Results

Distribution of Agrobiodiversity in Home Gardens

One-way ANOVA results show that home garden agrobiodiversity varies markedly both across and within our study villages ($F[2, 86] = 3.06$, $p = 0.052$). In general, the total number of plant species found in home gardens increases with village size, with Pucacuro (the largest) holding 161 species and Santa Rosa (the smallest) showing only 122 species. Interestingly, when examining home garden diversity at the household level, we find that gardens in Santa Rosa are the most diverse among our study sites, containing on average ten more species than home gardens in Pucacuro and Valencia (40 vs. 30 spp., Table 1). Within study sites, the most and least diverse home gardens were reported in Pucacuro (i.e., 5 and 72 spp.). In contrast, home garden species are more evenly distributed among households in Santa Rosa; the least diverse garden there contains more than three times the number of species found in the poorest home gardens in Pucacuro and Valencia (19 vs. 5–6 spp.). Home garden composition is, however, remarkably consistent across villages. Fruit species are the most common (40–51 %), followed by non-fruit food species (17–24 %), and medicinal (plants used for hallucinogenic, magic, and ritual purposes) (14–21 %). Other species are grown for seasoning, handicrafts, construction, as ornamentals, fish poisons and weapons, dyes, varnish, forage and firewood.

Planting Material Flow within Communities

Our Achuar informants repeatedly commented that planting material is difficult to find and they rely on a variety of sources to furnish their home gardens. Home garden diversity is built from seeds brought in from the forest, fallow land, or from agricultural fields (natural sources) (Fig.2). Importantly, more than half the planting stock found in home gardens is obtained through social (kin) and personal (friends) relations. Plants that originate elsewhere are generally brought back from trips along the Corrientes, its tributaries, or other rivers in the Amazon. Some seeds sourced from distant cities like Yurimaguas, Pucallpa and even Lima had been received as gifts from kin and evangelical friends who come from distant places to preach and pray in the region. Generally, some plants acquired by individual farmers from external sources are subsequently shared with others in the village. On average, 60 % of the seed acquired through these informal networks was from within the community, and women were cited as the source of seed in 80 % of the transfers reported.

[2] An important social institution throughout Latin America, *compadrazgo* literally means co-parenthood and is typically related to the Catholic practice of infant baptism. Importantly and beyond religious commitments and secular practices, *compadrazgo* represents an important relation between the godparents and the parent of the child (Killick 2008).

Table 2 Descriptive statistics for variables used in dyadic regressions for seed sharing networks in three Achuar villages, Corrientes River, Peru

Variable name	Description	Pucacuro (n = 2862)		Valencia (n = 420)		Santa Rosa (n = 182)	
		Mean (*SD*)	Range	Mean (*SD*)	Range	Mean (*SD*)	Range
Dependent variables							
Probability of seed sharing (0/1)	Probability of household *i* sharing seed with household *j* (1 = *i* shares with *j*, 0 = otherwise)	0.08 (0.27)	0–1	0.14 (0.35)	0–1	0.18 (0.38)	0–1
No. of plant transfers	Number of plant transfers from household *i* to household *j*	0.19 (1.07)	0–22	0.20 (0.60)	0–6	0.78 (2.69)	0–20
Explanatory variables							
Node attributes							
Home garden diversity (difference)	Difference in number of plant species in the home gardens of households *i* and *j*	0 (16.78)	-67-67	0 (20.81)	-59-59	0 (16.59)	-43-43
Plant expert (1/0) (difference)	1 = if household *i* is expert but *j* is not, 0 = if either both households are experts, or not, −1 = if *i* is not an expert but *j* is	0 (0.42)	-1-1	0 (0.66)	-1-1	0 (0.70)	-1-1
Household age (yrs.) (difference)	Difference of the age of households *i* and *j* (yrs)	0 (17.40)	-50-50	0 (16.72)	-45.9-45.9	0 (17.95)	-38-38
Total land holdings (ha) (difference)	Difference in the amount of land in swidden and fallow held by households *i* and *j* (ha)	0 (3.19)	-10-10	0 (5.26)	-13.3-13.3	0 (4.68)	-11.9-11.9
Home garden diversity (sum)	Sum of all plant species in the home gardens of households *i* and *j*	59.52 (16.46)	15–121	59.33 (19.79)	18–126	77.57 (15.36)	42–117
Plant expert (1/0) (sum)	2 = if both households are experts, 1 = if one hhld is expert, 0 = otherwise	0.19 (0.41)	0–2	0.57 (0.62)	0–2	0.71 (0.65)	0–2
Household age (yrs.) (sum)	Sum of the age of households *i* and *j* (yrs.)	27.43 (17.08)	0.5–95	33.83 (15.91)	0.2–85	24.43 (16.62)	3–72
Total land holdings (ha) (sum)	Sum of land in swidden and fallow held by hhlds. *i* and *j* (ha)	6.13 (3.13)	0.3–18	10.14 (5.00)	1.20–16.32	7.63 (4.33)	0.33–20
Link attributes							
Women's kinship relations							
Vertical ties (matrilineal)	Female heads of *i* and *j* have matrilineal ties (1 = if female head of *i* is mother of female head of *j*, 0.5 = if *i* is grandmother of female head of *j*, 0 = otherwise)[a]	0.00 (0.11)	0–1	0.01 (0.20)	-1- 1	0.00 (0.24)	-1- 1
Horizontal ties (sisters)	1 = if female heads of *i* and *j* are sisters, 0 = otherwise)	0.02 (0.15)	-1-1	0.05 (0.22)	0–1	0.02 (0.15)	0–1

Table 2 (continued)

Variable name	Description	Pucacuro (n = 2862)		Valencia (n = 420)		Santa Rosa (n = 182)	
		Mean *(SD)*	Range	Mean *(SD)*	Range	Mean *(SD)*	Range
Men's kinship relations							
Vertical ties (patrilineal)	Male heads of *i*and *j* have patrilineal ties (1 = if male head of *i* is father of male head of *j*, head of *j*, 0.5 = if *i* is grandfather of male head of *j*, 0 = otherwise)[a]	0.00 (0.10)	-1-1	0 (0.15)	-1- 1	0.00 (0.21)	-1- 1
Horizontal ties (brothers)	1 = if male heads of *i* and *j* are brothers, 0 = otherwise)	0.02 (0.13)	0–1	0.06 (0.23)	0–1	0.03 (0.18)	0–1
Kin group affiliation							
Member of large kin group A (1/0)	1 = if one of the heads of households *i* and *j* are part of kin group A, 0 = otherwise	0.038 (0.19)	0–1				
Member of large kin group B (1/0)	1 = if one of the heads of households *i* and *j* are part of kin group B, 0 = otherwise	0.06 (0.24)	0–1				
Member of large kin group C (1/0)	1 = if one of the heads of households *i* and *j* are part of kin group C, 0 = otherwise			0.10 (0.30)	0–1		
Member of large kin group D (1/0)	1 = if one of the heads of households *i* and *j* are part of kin group D, 0 = otherwise			0.01 (0.12)	0–1	0.03 (0.18)	0–1
Member of large kin group E (1/0)	1 = if one of the heads of households *i* and *j* are part of kin group E, 0 = otherwise					0.03 (0.18)	0–1

a. Negative values (i.e., −1 for daughter/son and −0.5 for granddaughter/grandson) are used to preserve the required symmetry (Fafchamps and Gubert 2007)

Interestingly, the share of plants obtained from local sources in Pucacuro is much higher than in the other two communities (84 %, see Fig. 2). This is explained in part by the fact that Pucacuro is the largest of the three communities, contains the largest aggregate plant diversity (Table 1), and has a larger pool of households of diverse origins attracted by job prospects with Pluspetrol. Finally, households in all three villages occasionally purchase planting material at markets in Trompeteros and Iquitos, or from river traders; they also obtain them from Pluspetrol workers, flower beds of the oil company, or from other undetermined sources.

Seed Network Structure

Participation is almost universal in the local seed sharing networks in the study villages — most households have either given or received seed to/from others in the village (Fig. 3 and Table 3). Yet our analysis of centrality and reciprocity measures suggests that access to planting material through these networks is highly differentiated and that the structure of seed sharing networks varies across communities. Households in Pucacuro have a larger number of seed sharing partners than those in Valencia and Santa Rosa; they and households in Santa Rosa share planting material more often than households in Valencia as indicated by the raw outdegree/indegree values (10.1 vs. 4 transfers).

Seed sourcing is centered among a small number of individuals. Indeed, a single household was identified as the source in 19 % of the seed transfers in Pucacuro (104 out of 559 transfers), 14 % in Valencia (12 out of 83 transfers), and 25 % in Santa Rosa (36 out of 142 transfers). In Pucacuro, the main plant giver households were those with some prestige in the community associated with their role as healers or as truly Achuar. Yet the degree of network centralization is relatively low (i.e., 8–12 % relative to a pure star network in which each actor is directly linked to all others, Table 3) suggesting that there are several channels for seed acquisition within each of these seed networks. Although some households truly 'exchange' seeds our results on group and node-level reciprocity suggest that most planting material flows are unidirectional and reciprocity is rare (Table 3). Only in Santa Rosa do the main seed sources also obtain considerable amounts of seed (indegree) from others in their village. Like other groups, the Achuar are selective about who they share with and how many and which specific plants they share (Fig. 3).

The structure of seed sharing networks varies notably across villages. In particular, the way planting material circulates in Santa Rosa is strikingly different from the other two villages in that the network is the most centralized and least reciprocal of the three. Seed is sourced from a relatively small pool of households who tend to share prodigiously (Table 3). Indeed, we found that the top three plant givers share with 78 % of all households and provide on average two-thirds of all the seed procured within the village; the one or two plant givers in Pucacuro and Valencia transfer seed to 62–67 % of households and are the source of only 30–36 % of all the seed acquisitions within their respective villages. In contrast almost half of our respondents in Santa Rosa reported obtaining seeds from three or four plant givers. In Santa Rosa plant givers are also recipients of seeds. Seed sharing in Pucacuro and Valencia is marked by networks divided into relatively well-defined clusters around individual plant givers who are the primary source of seed for a subset of households. Overall, these results suggest that there are fewer barriers to seed flows in Santa Rosa. Nevertheless, the main plant givers are typically older, wealthier, and occupy a position of traditional importance, expressed by their lower level of

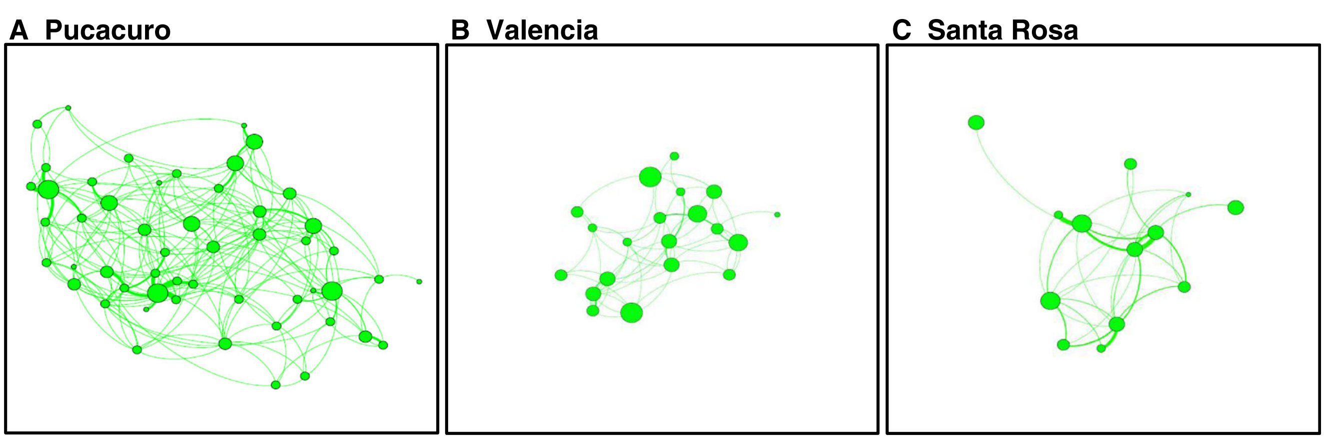

Fig. 3 Seed sharing networks for home garden plants in three Achuar villages, Corrientes River, Peru. Notes: *Green circles* (nodes) represent households in each village. Node size is proportional to the number of seed transfers to others in the village. *Lines* denote planting material flows; line-width is proportional to intensity of flows and direction is indicated by a clockwise orientation emanating from the planting material source. Households that do not participate in the seed network within their respective village have been omitted (i.e., 2 hhlds. In Pucacuro, and 1 hhld. each in Valencia and Santa Rosa)

Table 3 Characteristics of seed sharing networks in three Achuar villages, Corrientes River, Peru

	Pucacuro (n = 54)		Valencia (n = 21)		Santa Rosa (n = 14)	
	Mean *(SD)*	Range	Mean *(SD)*	Range	Mean *(SD)*	Range
Centrality						
No. of households with whom planting material is shared (Ego network size)	7.5 (4.1)	0–18	4.9 (2.4)	0–9	4.0 (2.8)	0–8
No. of households to whom planting material is given (Ego size-out)	4.1 (3.8)	0–16	2.8 (2.0)	0–9	2.3 (3.0)	0–8
No. of planting material transfers to other households (Outdegree)	10.1 (16.6)	0–104	4.0 (3.3)	0–12	10.1 (14.3)	0–36
No. of planting material transfers to other households (Normalized outdegree)	0.9 (1.4)	0–8.9	3.3 (2.8)	0–10	3.9 (5.5)	0–13.8
No. of households from whom planting material is received (Ego size-in)	4.1 (3.0)	0–13	2.8 (2.1)	0–7	2.3 (1.3)	0–4
No. of planting material transfers from households (Indegree)	10.1 (7.7)	0–37	4.0 (3.2)	0–10	10.1 (7.9)	0–23
No. of planting material transfers from households (Normalized indegree)	0.9 (0.5)	0–3.2	3.3 (2.7)	0–8.3	3.9 (3.1)	0–8.8
Network centralization						
Outdegree	8.4		7.4		11.6	
Indegree	2.4		5.6		5.8	
% of households that share planting material with others in the village	83		86		50	
% of households that receive planting material from others in the village	89		86		93	
Reciprocity						
Node Level						
% of undirected contacts with whom seed is given and received (reciprocated ties)	4 (8)	0–29	6 (10)	0–25	0	
% of planting material transfers (given) that are not reciprocated*	46 (31)	0–100	50 (32)	0–100	37 (42)	0–100
% of planting material tranfers (receive) that are not reciprocated*	60 (30)	0–100	58 (32)	0–100	72 (31)	25–100
Group level						
% of households involved in reciprocal seed exchanges (dyad reciprocity)	9		14		14	
% of planting material transfers that are reciprocal (arc-reciprocity)	17		24		25	

*Calculated only for households that participate in the seed network in each community as follows Pucacuro (n = 53); Valencia (n = 20); and Santa Rosa (n = 13)

formal education and preference for the Achuar language for communication, and are often identified as traditional healers (Perrault-Archambault 2005).

Differential Seed Sharing

Our findings suggest that certain households play a key role in seed sharing. To examine the links between seed sharing, plant diversity, plant knowledge and seed circulation, we identify households in each village that are exceptional with respect to their peers, i.e., they hold an outstanding collection of plant species in their gardens ('high diversity'); were identified as exceptionally knowledgeable about plants by others in the village ('experts'); or were reported as the source in a high number of seed transfers ('plant givers'). We define 'exceptionality' in plant diversity, knowledge and circulation in statistical terms, as those values that are at least 3.5 times the inter-quartile range above median. Given our interest in seed sharing, we focus on plant givers with respect to whether they hold high species diversity in their gardens, or are recognized as experts by others in the village.

Pooled data for the three villages show that seed giving is positively correlated with both plant diversity and expertise, but the coefficient is greater for expertise ($r = 0.30$, $p < 0.01$ vs. $r = 0.49$, $p < 0.01$), which is consistent with our field observations of more generous plant sharing among those identified as experts by others in the village. Recognition as an expert is also positively correlated with holding a higher number of plant species in the home garden. Interestingly, households with more diverse gardens also tend to be recipients of seeds, whereas experts appear to obtain fewer seeds from others in the village.

When we examine the diversity-expertise-circulation nexus at the village level we see a much tighter association between diversity, expertise and seed sharing in Santa Rosa, i.e., experts have the most diverse gardens ($r = 0.58$, $p = 0.03$) and are the main sources of seeds ($r = 0.97$, $p < 0.01$)(Fig. 4). These two variables are also positively correlated in Pucacuro, though less strongly ($r = 0.30$, $p = 0.035$ and $r = 0.59$, $p < 0.01$) and in Valencia, plant giving is correlated and statistically significant only with being identified as an expert ($r = 0.46$, $p = 0.035$ vs. $r = 025$, $p = 0.28$). Network visualization techniques further illustrate the links among plant diversity, knowledge and seed circulation, focusing on the ego (individual) networks of plant givers (Fig. 5). High-diversity households do share seed, especially in Pucacuro and Santa Rosa, but they are not the main sources of seed in the village. In Pucacuro, for example, households Pu06, Pu28, Pu51 and Pu73/35 all share with a larger number of households and are the source of more seed transfers than Pu17, the highest diversity household in the village (Fig. 5). A similar pattern occurs in Valencia and Santa Rosa, although perhaps Ro12 –

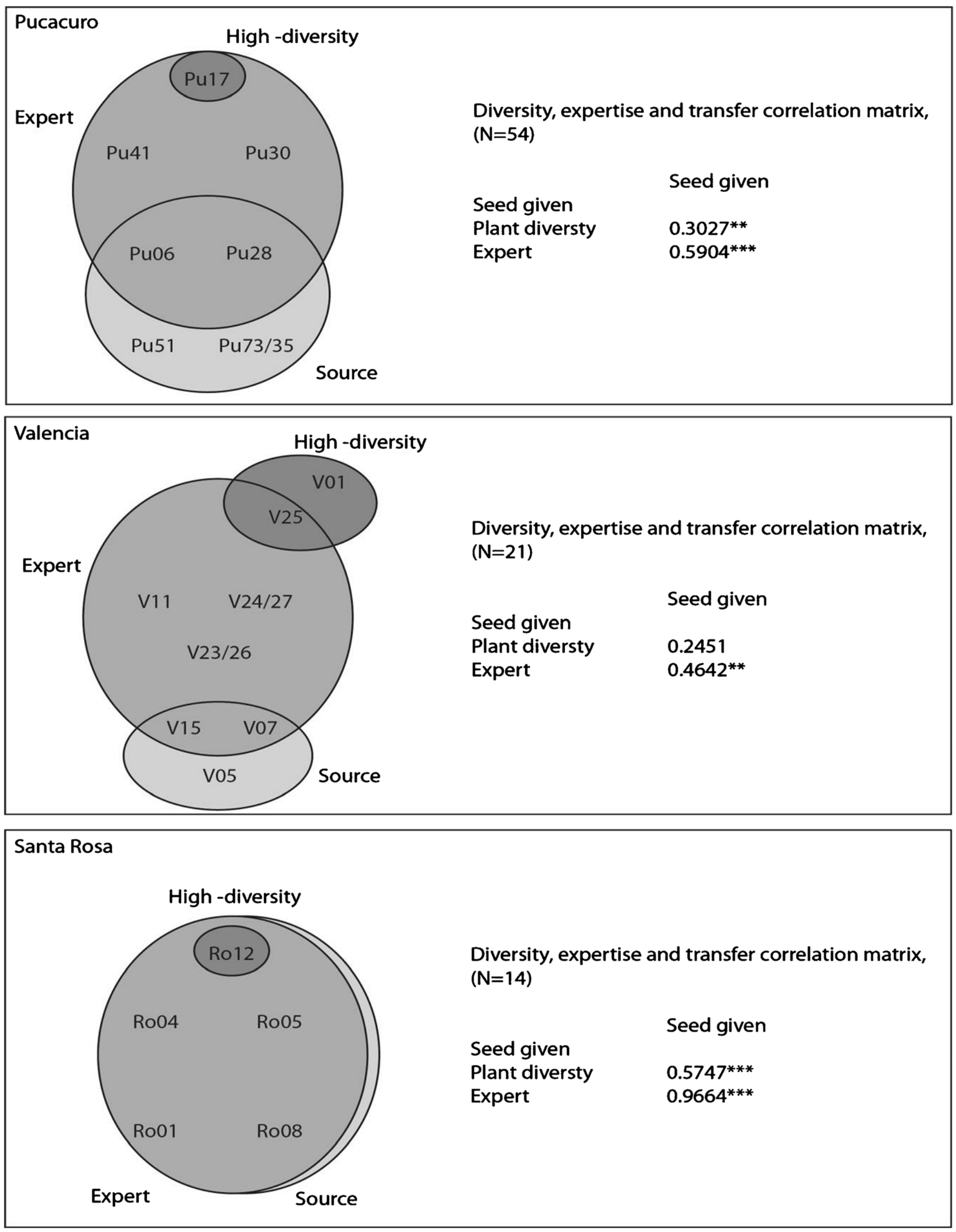

Fig. 4 Venn diagrams and correlation matrices for high-diversity, experts and top plant givers in three Achuar villages, Corrientes River, Peru

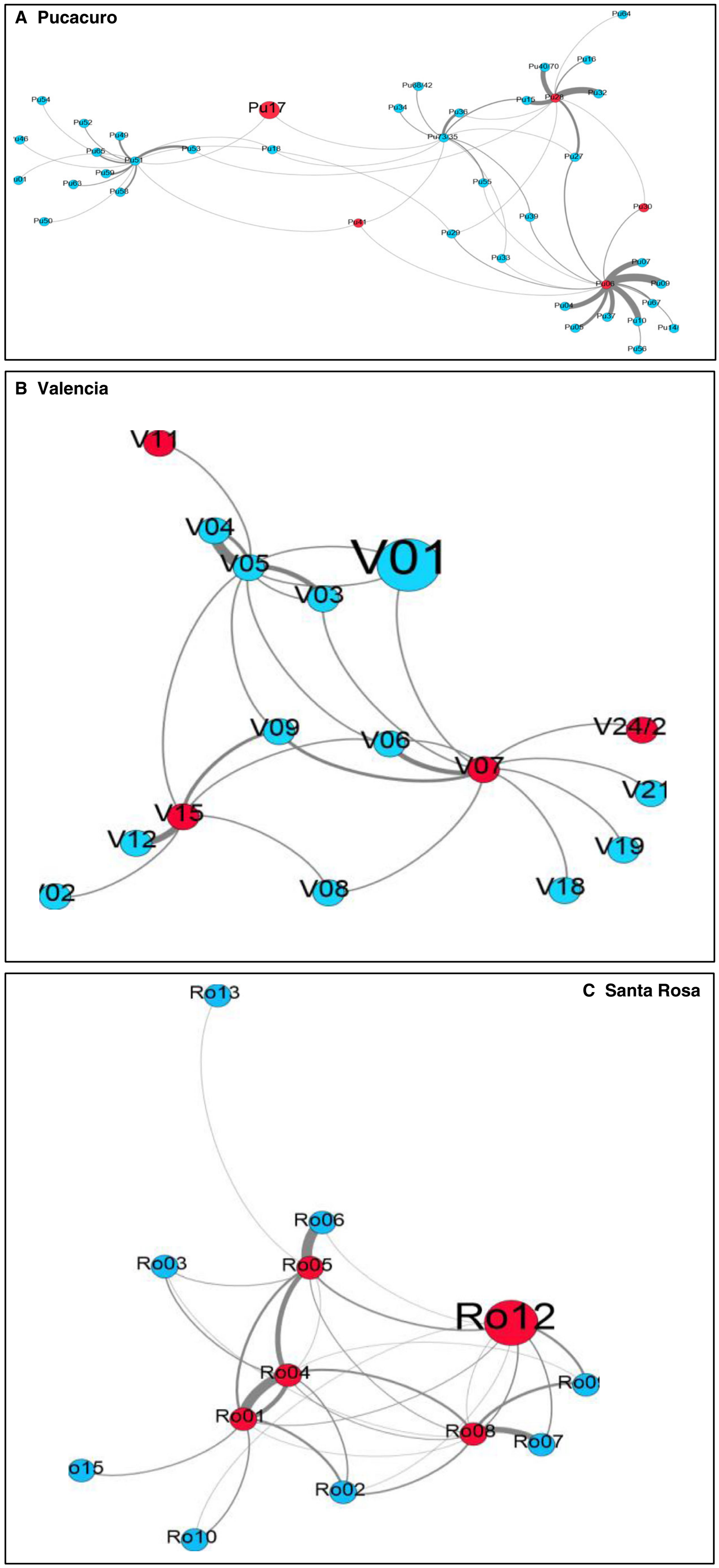

Fig. 5 Diversity, expertise and seed flows in three Achuar villages, Corrientes River, Peru. Notes: *Red circles* (nodes) represent 'expert' households; *blue nodes* denote 'non-expert' households. Larger nodes are households of exceptional plant diversity in their home garden; for illustration purposes, node sizes were set independently for each village. *Lines* denote planting material flows; line width is proportional to the number of seed transfers. Direction of seed flows is indicated by a clockwise orientation emanating from the source of the planting material. Household that are not connected to 'plant givers' are not shown

Table 4 MRQAP regressions for the probability of seed sharing and intensity of seed flows between a household dyad in three Achuar villages, Corrientes River, Peru

	Pucacuro				Valencia				Santa Rosa			
	Propability of seed sharing (1/0)[a]		Number of seed transfers		Propability of seed sharing (1/0)[a]		Number of seed transfers		Propability of seed sharing (1/0)[a]		Number of seed transfers	
	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.	Coeff.	Sig.
Intercept	-0.0577		-0.1830		-0.0523		-0.0426		0.1139		0.9667	
Node attributes												
Differences in:												
Home garden diversity	-0.0001		-0.0027	**	0.0024	**	0.0056	***	0.0024		0.1160	*
Plant expert (1/0)	0.0288	*	0.2043	***	0.1384	***	0.2073	***	0.1224	**	0.1843	
Household age (yrs.)	0.0013	***	0.0030	**	0.0009		0.0020					
Total land holdings (ha)	0.0067	***	0.0227	***	-0.0109	**	-0.0213	***				
Sum of:												
Home garden diversity	0.0016	***	0.0031	**	0.0018	**	0.0015		0.0022		-0.0185	*
Plant expert (1/0)	0.0176		0.1516	**	-0.0111		0.0019		0.3148	***	1.5695	***
Household age (yrs.)	0.0002	***	0.0024	*	0.0018		0.0027					
Total land holdings (ha)	0.0029		0.0099		0.0001		0.0010					
Link attributes												
Women's kinship relations												
Vertical ties (matrilineal)	0.2942	***	3.0069	***	0.0305		0.3912	***	0.1508	*	4.4613	***
Horizontal ties (sisters)	0.1434	***	0.1675		0.1323	*	0.0831		0.1410		1.0025	
Men's kinship relations												
Vertical ties (patrilineal)	-0.0805	*	-0.6365	***	0.0302		-0.0773		0.1238		0.7441	*
Horizontal ties (brothers)	0.2418	***	0.4343	**	0.1261	**	0.2046	*	-0.2380	*	-1.5363	**
Kin group affiliation												
Member of large kin group A (1/0)	0.0472	*	-0.0064									
Member of large kin group B (1/0)	0.0561	**	0.3471	***								
Member of large kin group C (1/0)					-0.0053		0.0154					
Member of large kin group D (1/0)					0.4179		2.1569	***	0.0453		0.2868	
Member of large kin group E (1/0)									0.3037	**	4.5538	***
Adjusted R^2	0.089	***	0.159	***	0.141	***	0.235	***	0.348	***	0.393	***
P^b	0.001		0.001		0.001		0.001		0.001		0.001	
No. of observations	2862		2862		420		420		182		182	

[a] This is a linear probability model (dyadic)

[b] *P* denotes the proportion of random trials (permutations) yielding an r-square as large or larger than the observed r-square value

[c] Given constraints due to sample size in Santa Rosa, household age and total land in swidden and fallow were excluded from the regressions for that village

* $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$

the only high diversity household in Santa Rosa – is a more prominent source of planting material than its counterparts in Pucacuro and Valencia (Fig.5).

Seed Network Formation and Transfer Flows

Our models on seed sharing and the number of transfers are all statistically significant, explaining between 9 % and 35 % of the observed variation in the probability of seed sharing and 16 % and 39 % of the variation in transfers in the three communities (Table 4). Dyadic regression results confirm the key role of kin relations, plant knowledge, plant diversity, household age and wealth for seed sharing at the dyad (or pair) level.

As expected, kinship relations are of upmost importance. Matrilineal relations (i.e., mother-daughter) are particularly salient in conditioning the probability of sharing seed and the number of seed transfers across villages. This result is intuitive given the uxorilocal organization of the Achuar and the predominance of women as both seed sources and garden tenders. One unanticipated finding, however, is that men's kinship ties also contribute to seed sharing networks. Indeed, in Pucacuro and Valencia, households are more likely to share seeds with their brothers and less with their father's household, although in Santa Rosa the reverse pattern is observed. One explanation is that our male-related kinship variables may be capturing transfers involving women, i.e., the wives of two brothers, or mother-in-law with daughter-in-law. In any event, women's relations with their own kin are of greater importance than men's as reflected by the magnitude of regression coefficients. We also find that seed circulates more freely along kin group lines, especially if households are affiliated to one of the largest kin groups in the community (Kin group B in Pucacuro, C in Valencia, and D in Santa Rosa). The fact that results are not significant for all large kin groups suggests that it may not be kin group size that matters per se but rather the structure of kin group or other unobservable factors.

Consistent with insight gained through ethnographic work in the three villages, our DRA results indicate that seed flows relatively freely between expert and non-expert households. Expert-to-expert seed flows, however, are comparatively less frequent and are only significant in Santa Rosa and to some extent Pucacuro (Fig. 5). Whereas in Pucacuro and Valencia we can identify different subgroups, many of which gravitate around an individual expert, subgrouping is less evident in Santa Rosa (see also Fig. 4).

Similarly, we find that households with species-diverse home gardens are active in the seed sharing networks, but overall, the effect of plant diversity on seed sharing is comparatively less than that of plant expertise in all villages. Specifically, seeds are shared generously among households with some diversity in their garden. It is notable that whereas in Pucacuro seed is shared primarily among "high diversity" farmers, in Santa Rosa 'high diversity' farmers share mainly with lower diversity farmers, and in Valencia they share more freely (i.e., with both higher and lower diversity farmers). This result is also indicative of some social barriers to the movement of seed.

While we were unable to include household age and land in swidden and fallow in the regression models for Santa Rosa due to sample size limitations, our results indicate that in Pucacuro, seed is shared between generations, i.e., from older to younger households, and from wealthier to poorer households. The coefficients for these variables, however, are comparatively smaller than those for the expertise and kinship variables. The effects of household age or land wealth on the seed network are not statistically significant in Valencia.

Discussion and Conclusion

Results from our study of home garden and seed networks in Achuar villages along the Corrientes River suggest that plant species diversity is positively related to community size, such that the largest communities have the greatest home garden species diversity. Larger villages present a broader pool of home gardens and the likelihood of containing unique plants is enhanced by the increased social and cultural diversity of larger settlements. At the garden level, however, we find that the highest average diversity (and the most even distribution of species) is found not in the largest community, but in the smallest community. This may be related to the constancy observed in the share of species by purpose, i.e., that home gardens play a similar function and perhaps planting material circulates more freely in smaller kin-based communities. This would explain the more homogenous distribution of home garden species in the smallest community.

Seed sharing networks along the Corrientes River are largely unidirectional with a small number of farmers providing most of the seed, suggesting that it may be more appropriate to refer to 'seed sharing' or 'seed transfer' rather than 'seed exchange', a term that is commonly used in the literature (Boster 1986; Coomes and Ban 2004; Coomes 2010; Jensen *et al*. 2013; Reyes-García *et al*. 2013). This finding also points to the existence of differentiated roles within seed networks, where some households are best characterized as 'sources' of seed and others as 'sinks' (Alvarez *et al*. 2005).

The architecture of seed networks varies notably across villages. In larger communities, planting material flows through relatively narrow channels in which certain households ('plant givers') are the primary source of planting material for a subset of households but do not significantly acquire plants from others in the village. In the smallest community, in contrast, seed circulates more freely. 'Plant givers' are the main source of seeds but they also acquire seed from other villagers, and importantly from each other. Most households in Santa Rosa procure planting material from multiple sources, thus improving their access to seed. This also opens the possibility for specialization in seed sourcing with some households becoming the preferred source of specific plants.

Within Achuar communities, seed sharing networks are shaped primarily by kinship and gender relations. In particular, mothers tend to be more generous in sharing home garden plants with their daughters and more generally with others in their kin group. In larger communities, planting material is also shared among brothers. Plant expertise, garden diversity, household age, and land holdings are also important factors shaping the circulation of planting material locally. The central farmers (main seed givers) in our study are not farmers that stand out for having the most species-diverse home gardens. Instead, the central farmers tend to be those recognized as 'experts' by their peers; they have relatively but not exceptionally diverse home gardens. Although our data were collected in 2003, our findings are indicative of social relations of seed sharing among the Achuar, with attendant implications for agrobiodiversity conservation.

Our study contributes to the broader understanding of seed networks in three important ways. First, this study illustrates the value of applying multivariate techniques *within* SNA to understand seed sharing networks. Conventional regression analyses in which network data are used either as a dependent or independent variable are problematic because they do not account for the fact that the data are relational (i.e., observations are interrelated) and are thus prone to inconsistent estimates and problems with inference (Abizaid *et al.* 2015). Our use of dyadic regression analysis (DRA) allows us to account for such interdependencies and for the first time to parse out the differential role of various factors previously identified in the literature.

The suite of variables found to shape seed sharing in our study is consistent with ethnographic accounts and previous seed network studies (Boster 1986; Brown 1986; Subedi *et al.* 2003; Coomes and Ban 2004; Alvarez *et al.* 2005; Cabral de Oliveira 2008; Emperaire and Cabral de Oliveira 2011; Delêtre *et al.* 2011; Leclerc and Coppens d'Eeckenbrugge 2012; Kawa *et al.* 2013; Díaz-Reviriego *et al.* 2015; Wencélius *et al.* 2016). We ascertain that the structure and function of seed networks is influenced specifically by the degree of interest people take in plants (both in terms of expertise and the number of plant species held), their age and wealth; but ultimately, the circulation of seed is mediated most strongly by kinship relations, i.e., people are more likely to share seed (and possibly plant knowledge) along kin lines. In small tight-knit communities, kin relations are an important channel that enables the circulation of seed; in larger villages, however, kin relations may constitute an important social barrier to seed transfer for farmers with fewer kin ties.

Second, our study suggests that the architecture of intra-village seed sharing networks and plant flows, like plant diversity, vary according to community size, i.e., the smallest community in our study presents a tighter seed network, the lowest aggregate diversity, and the highest average diversity at the household level; the opposite is true for the largest village. As such, in spite of the similarities found across the three seed sharing networks, their structure differs significantly, a finding also reported by Ricciardi (2015). Although tighter network structures found in small communities might not favor higher levels of aggregate agrobiodiversity, they can facilitate plant flows in ways that enable farmers to benefit from access to agrobiodiversity in a more equitable manner. This finding will resonate with those interested in differentiated access to planting material (McGuire 2008; Delêtre *et al.* 2011; Jarvis *et al.* 2011; Ricciardi 2015), and challenges those working on (in situ) conservation to treat with caution common assumptions about the role of seed networks in building aggregate plant diversity. Ultimately, a deeper understanding is needed of seed networks structure, function and change in order to better grasp how seed flows through social networks act to build or sometimes socially restrict agrobiodiversity (Leclerc and Coppens d'Eeckenbrugge 2012; Labeyrie *et al.* 2014, 2015; Coomes *et al.* 2015; Díaz-Reviriego *et al.* 2015).

Finally, our results point to the need for further attention to the notion of 'nodal' or 'key' farmers and their role in seed networks (Subedi *et al.* 2003; Abay *et al.* 2011; Calvet-Mir *et al.* 2012; Poudel *et al.* 2015). As shown in this study, although plant diversity, expertise and seed circulation are related, the common assumptions that 'nodal' farmers necessarily hold the greatest levels of agrobiodiversity, are the most knowledgeable, and constitute the primary source of seed may be problematic. In our study, and consistent with findings among Amazonian *caboclos* by Kawa *et al.* (2013), the central actors in seed networks are households recognized as experts and not those that hold richly diverse home gardens; this finding is also consistent with recent research on cultural adaptation, which suggests that people are more prone to learn from those perceived as more successful or knowledgeable (Henrich and Broesch 2011). Reyes-García *et al.* (2013) also find a strong relationship between (agroecological) knowledge and seed flows, and other studies indicate that plant knowledge is often transmitted in the process of seed sharing (Kipkot *et al.* 2006; Badstue *et al.* 2007; Keleman *et al.* 2009). In our study, direct and close kin shared knowledge in sharing seeds, sometimes secret knowledge, and people were reluctant to ask for advice on plants and plant management from others that are socially more distant, preferring a possibly lower quality seed from kin than non-kin. Indeed, field observations confirmed the importance bestowed by gardeners on ethnobotanical knowledge as a marker of Achuar cultural identity (Descola 1994); that revealing one's ignorance in plant-related matters to others beyond close kin can bring derision and humiliation.

An important practical implication of this 'knowledge-plant transfer' nexus is that researchers interested in in situ conservation and seed sharing networks should aim to work with those deemed most knowledgeable about plants rather than with those with the most diverse plant holdings. Typically, knowledge tests are used to assess farmers' ethnobotanical knowledge (e.g., Reyes-García *et al.* 2013), however, we found them to be problematic to use in our field context. Specifically, farmers well known in the community for their agroecological knowledge achieved low scores on the knowledge test. In some cases, this result was due to problems recognizing plants from photographs, especially among the least schooled Achuar women. In others, given that it was impossible to conduct the interviews in private, the informant sought to deflect attention from herself, letting members of the impromptu audience chime in on responses. Interestingly, informants often feigned ignorance about plants and plant management, especially about those used in medicinal and ritual practices. As such, we found triangulation on expertise by relying on farmers to identify the 'experts' among them to be more useful than objective knowledge assessments. More research is needed to better understand: (1) what types of knowledge are transferred and how, when seed is shared; (2) whether certain plant sharing roles may be important at critical times (e.g., when a community moves and resettles, or after a major flood or crop failure); and, (3) how specific plant sharing roles change over time.

Overall, the use of multivariate techniques within SNA holds much promise in furthering our understanding of seed sharing networks—how they emerge, function and change over time, and on the different roles farmers may play within them.

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Compliance with Ethical Standards

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Conflict of Interest The authors declare that they have no conflict of interest.

References

Abay F., de Boef W., and Bjørnstad A. (2011). Network analysis of barley seed flows in Tigray, Ethiopia: supporting the design of strategies that contribute to on-farm management of plant genetic resources. Plant Genetic Resources: Characterization and Utilization 9(4): 495–505.

Abizaid C., Coomes O. T., Takasaki Y., and Brisson S. (2015). Social network analysis of peasant agriculture: cooperative labor as gendered relational networks. The Professional Geographer 67(3): 447–463.

Adin A., Weber J. C., Sotelo Montes C., Vidaurre H., Vosman B., and Smulders M. J. M. (2004). Genetic differentiation and trade among populations of peach palm (*Bactris gasipaes* Kunth) in the Peruvian Amazon – implications for genetic resource management. Theoretical and Applied Genetics 108: 1564–1573.

Allinne C., Mariac C., Vigouroux Y., Bezançon G., Coutron E., Moussa D., Tidjani M., Pham J. L., and Robert T. (2008). Role of seed flow on the pattern and dynamics of pearl millet (*Pennisetum glaucum* [L.] R. Br.) genetic diversity assessed by AFLP markers: a study in South-Western Niger. Genetica 133: 167–178.

Almekinders C. J. M., Louwaars N. P., and de Bruijn G. H. (1994). Local seed systems and their importance for an improved seed supply in developing countries. Euphytica 78: 207–216.

Alvarez N., Garine E., Khasah C., Dounias E., Hossaert-McKey M., and McKey D. (2005). Farmers' practices, metapopulation dynamics, and conservation of agricultural biodiversity on-farm: a case study of sorghum among the Duupa in sub-sahelian Cameroon. Biological Conservation 121: 533–543.

Badstue L. B., Bellon M. R., Berthaud J., Ramirez A., Flores D., and Juarez X. (2007). The dynamics of farmers' maize seed supply practices in the Central Valleys of Oaxaca, Mexico. World Development 35:1579–1593.

Ban N., and Coomes O. T. (2004). Home gardens in Amazonian Peru: diversity and exchange of planting material. Geographical Review 94(3): 348–367.

Barnaud A., Joly H. I., McKey D., Deu M., Khasah C., Monné S., and Garine E. (2008). Gestion des ressources génétiques du sorgho (*Sorghum bicolor*) chez les Duupa (Nord Cameroun). Cahiers. Agricultures 17: 178–182.

Barr A., Dekker M., and Fafchamps M. (2015). The formation of community-based organizations: an analysis of a quasi-experiment in Zimbabwe. World Development. 66: 131–153.

Bastian M., Heymann S., Jacomy M. (2009). Gephi: an open source software for exploring and manipulating networks. International AAAI Conference on Weblogs and Social Media. Proceedings of the Third International ICWSM Conference.

Bellon M. R., and Risopoulos J. (2001). Small-scale farmers expand the benefits of improved maize germplasm: a case study from Chiapas, Mexico. World Development 29: 799–811.

Bishaw Z., Struik P., and van Gastel A. J. G. (2010). Wheat seed system in Ethiopia: farmers' varietal perception, seed sources, and seed management. Journal of New Seeds 11: 281–327.

Borgatti, S.P., Everett M.G., and Freeman L.C. (2002). UCINET for Windows (Version 6.436): Software for social network analysis. Analytic Technologies, Harvard, MA.

Borgatti, E., Everett M.G., and Johnson J.C. (2013). Analyzing social networks. SAGE.

Boster J. S. (1984). Inferring decision making from preferences and behavior: an analysis of Aguaruna Jivaro manioc selection. Human Ecology 12(4): 343–358.

Boster J. S. (1986). Exchange of varieties and information between Aguarana manioc cultivators. American Anthropologist 86: 428–436.

Broekel T., and Boschma R. (2012). Knowledge networks in the Dutch aviation industry: the proximity paradox. Journal of Economic Geography 12: 409–433.

Brown, M.F. (1986). Tsewa's gift: Magic and meaning in an Amazonian society. Smithsonian Institution Press, Washington.

Calvet-Mir L., Calvet-Mir M., Molina J. L., and Reyes-García V. (2012). Seed exchange as an agrobiodiversity conservation mechanism. A case study in Vall Fosca, Catalan Pyrenees, Iberian peninsula. Ecology and Society 17(1).

Clement C. R. (1989). A center of crop genetic diversity in western Amazonia. BioScience 39(9): 624–631.

Cole D. M., White T. L., and Nair P. K. R. (2007). Maintaining genetic resources of peach palm (*Bactris gasipaes* Kunth): the role of seed migration and swidden-fallow management in northeastern Peru. Genetic Resources and Crop Evolution 54: 189–204.

Coomes O. T. (2010). Of stakes, stems and cuttings: the importance of local seed systems in traditional Amazonian societies. The Professional Geographer 62(3): 323–334.

Coomes O. T., and Ban N. (2004). Cultivated plant diversity in home gardens of an Amazonian peasant village, northeastern Peru. Economic Botany 58(3): 420–434.

Coomes O. T., McGuire S. J., Garine E., Caillon S., McKey D., Demeulenaere E., Jarvis D., Aistara G., Barnaud A., Clouvel P., Emperaire L., Louafi S., Martin P., Massol F., Pautasso M., Violon C., and Wencélius J. (2015). Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. Food Policy 56: 41–50.

D'Exelle B., and Holvoet N. (2011). Gender and network formation in rural Nicaragua: A village case study. Gender Economics 17(2): 31–61.

de Oliveira J. C. (2008). Social networks and cultivated plants; exchange of planting material and knowledge, Tipití. Journal of the Society for the Anthropology of Lowland South America 6(1–2): 101–110.

Dekker D., Karkhardt D., and Snijder T. A. B. (2007). Sensitivity of MRQAP tests to collinearity and autocorrelation conditions. Psychometrika 72(4): 563–581.

Delêtre M., McKey D. B., and Hodkinson T. R. (2011). Marriage exchanges, seed exchanges, and the dynamics of manioc diversity. Proceedings of the National Academy of Science of the United States of America 108(45): 18249–18254.

Descola P. (1994). In the society of nature. Cambridge University Press, Cambridge, UK.

Díaz-Reviriego I., González-Segura L., Fernández-Llamazares Á., Howard P. L., Molina J., and Reyes-García V. (2015). Social organization influences the exchange and species richness of medicinal plants in Amazonian homegardens. Ecology and Society 21(1).

Duke J. A., and Vasquez R. (1994). Amazonian ethnobotanical dictionary. CRC Press, Boca Raton, Florida.

Dyer G. A., González C., and Lopera D. C. (2011). Informal "seed" systems and the management of gene flow in traditional agroecosystems: the case of cassava in Cauca, Colombia. Plos One 6: e29067.

Eloy L., and Emperaire L. (2011). La circulation de l'agrobiodiversité sur les fronts pionniers d'Amazonie (Région de Curzeiro do Sul, État de L'Acre, Brésil. L'Espace Geographique 40: 62–74.

Emperaire L., and Cabral de Oliveira J. (2011). Redes sociales y diversidad agrícola en la Amazonía Brasileña: un sistema multicéntrico. Tradiciones y Transformaciones en Etnobotánica Sección 5(03): 180–185.

Emperaire L., and Peroni N. (2007). Traditional management of agrobiodiversity in Brazil: a case study of manioc. Human Ecology 35: 761–768.

Fafchamps M., and Gubert F. (2007). The formation of risk-sharing networks. Journal of Development Economics 83(2): 326–350.

Finer M., Babbitt B., Novoa S., Ferrarese F., Pappalardo S. E., De Marchi M., Saucedo M., and Kumar A. (2015). Future of oil and gas development in the western Amazon. Environmental Research Letters. 10: 024003.

Fu Y.-B., Wangsomnuk P., and Ruttawat B. (2014). Thai elite cassava genetic diversity was fortuitously conserved through farming with different sets of varieties. Conservation Genetics 15: 1463–1478.

Fuentes F., Bazile D., Bhargava A., and Martinez E. A. (2012). Implications of farmers' seed exchanges for on-farm conservation of quinoa, as revealed by its genetic diversity in Chile. The Journal of Agricultural Science 150: 702–716.

Gibson R. (2013). How sweet potato varieties are distributed in Uganda: actors, constraints and opportunities. Food Security 5: 781–791.

Gyawali S., Sthapit B. R., Bhandari B., Bajracharya J., Shrestha P. K., Upadhyay M. P., and Jarvis D. I. (2010). Participatory crop improvement and formal release of Jethobudho rice landrace in Nepal. Euphytica 176: 59–78.

Heckler S., and Zent S. (2008). Piaroa manioc varietals: hyperdiversity or social currency? Human Ecology 36: 679–697.

Henrich J., and Broesch J. (2011). On the nature of cultural transmission networks: evidence from Fijian villages for adaptive learning biases. Philosophical Transactions of the Royal Society B 366: 1139–1148.

Jarvis D., and Hodgkin T. (1999). Wild relatives and crop cultivars: detecting natural introgression and farmer selection of new genetic combinations in agroecosystems. Molecular Ecology 8: S159–S173.

Jarvis D. I., Hodgkin T., Sthapit B. R., Fadda C., and Lopez-Noriega I. (2011). An heuristic framework for identifying multiple ways of supporting the conservation and use of traditional crop varieties within the agricultural production system. Critical Reviews in Plant Science 30: 125–176.

Jensen H. R., Belqadi L., De Santis P., Sadiki M., Jarvis D. I., and Schoen D. J. (2013). A case study of seed exchange networks and gene flow for barley (*Hordeum vulgare subsp. vulgare*) in Morocco. Genetic Resources and Crop Evolution 60(3): 1119–1138.

Kawa N. C., McCarty C., and Clement C. R. (2013). Manioc variety diversity, social networks, and distribution constraints in rural Amazonia. Current Anthropology 54(6): 764–770.

Keleman A., Hellin J., and Bellon M. R. (2009). Maize diversity, rural development policy, and farmers' practices: lessons from Chiapas, Mexico. Geographical Journal 17: 52–70.

Killick E. (2008). Godparents and trading partners: social and economic relations in Peruvian Amazonia. Journal of Latin American Studies 40: 303–328.

Kipkot E., Franzel S., Hebnick P., and Richards P. (2006). Sharing seed and knowledge: farmer to farmer dissemination of agroforestry technologies in western Kenya. Agroforestry Systems 68: 167–179.

Labeyrie V., Rono B., and Leclerc C. (2014). How social organization shapes crop diversity: an ecological anthropology approach among Tharaka farmers of Mount Kenya. Agriculture and Human Values 31: 97–107.

Labeyrie V., Thomas M., Muthamia Z. K., and Leclerc C. (2015). Seed exchange networks, ethnicity, and sorghum diversity. Proceedings of the National Academy of Sciences. 113(1): 98–103.

Leclerc C., and de'Eeckenbruggee G. C. (2012). Social organization of crop genetic diversity. The G x E x S interaction model. Diversity 4: 1–32.

McGuire S. J. (2008). Securing access to seed: social relations and sorghum seed exchange in eastern Ethiopia. Human Ecology 36: 217–229.

Mejía K., and Rengifo E. (1995). Plantas medicinales de uso popular en la Amazonía Peruana. Agencia Española de Cooperación Internacional and Instituto de Investigaciones de la Amazonía Peruana, Lima.

Pautasso M., Aistara G., Barnaud A., Caillon S., Clouvel P., Coomes O. T., Delêtre M., Demeulenaere E., De Santis P., Döring T., Eloy L., Emperaire L., Garine E., Goldringer I., Jarvis D., Joly H. I., Leclerc C., Louafi S., Martin P., Massol F., McGuire S., McKey D., Padoch C., Soler C., Thomas M., and Tramontini S. (2013). Seed exchange networks in agrobiodiversity conservation: concepts, methods and challenges. Agronomy for Sustainable Development 33(1): 151–175.

Peña-Venegas C. P., Stomph T. J., Verschoor G., Becerra Lopez-Lavalle L. A., and Struik P. C. (2014). Differences in manioc diversity among five ethnic groups of the Colombian Amazon. Diversity 6: 792–826.

Perrault-Archambault M. (2005). Who manages home garden agrobiodiversity? Patterns of species distribution, planting material flow and knowledge transmission along the Corrientes River of the Peruvian Amazon. Unpublished M.A. Thesis, McGill University, Montreal.

Perrault-Archambault M., and Coomes O. T. (2008). Distribution of agrobiodiversity in home gardens along the Corrientes river, Peruvian Amazon. Economic Botany 62(2): 109–126.

Pinton F. (2002). Manioc et biodiversité: exploration des voies d'un nouveau partenariat. Natures Sciences Sociétés 10(2): 18–30.

Poudel D., Sthapit B., and Shrestha P. (2015). An analysis of social seed network and its contribution to on-farm conservation of crop genetic diversity in Nepal. International Journal of Biodiversity. doi:10.1155/2015/312621.

Pujol B., Renoux F., Elias M., Rival L., and McKey D. (2007). The unappreciated ecology of landrace populations: conservation consequences of soil seed banks in cassava. Biological Conservation 136: 541–551.

Räsänen M., Neller R., Salo J., and Jungner H. (1992). Recent and ancient fluvial deposition systems in the Amazonian foreland basin, Peru. Geological Magazine 129: 293–306.

Reyes-García V., Molina J. L., Calvet-Mir L., Aceituno-Mata L., Lastra J. J., Ontillera R., Parada M., Pardo-de-Santayana M., Rigat M., and Vallès J. (2013). "*Tertius gaudens*": germplasm exchange networks and agroecological knowledge among home gardeners in the Iberian peninsula. Journal of Ethnobiology and Ethnomedicine 9:53.

Ricciardi V. (2015). Social seed networks: identifying central farmers for equitable seed access. Agricultural Systems 139: 110–121.

Salick J., Cellinese N., and Knapp S. (1997). Indigenous diversity of cassava: generation, maintenance, use and loss among the Amuesha, Peruvian upper Amazon. Economic Botany 51(1): 6–19.

Smith N. J. H. (1996). Home gardens as a springboard for agroforestry development in Amazonia. International Tree Crops Journal 9: 11–30.

Stromberg P. M., Pascual U., and Bellon M. R. (2010). Seed systems and farmers' seed choices: the case of maize in the Peruvian Amazon. Human Ecology 38: 539–553.

Subedi A., Chaudhary P., Baniya B., Rana R., Tiwari R., Rijal D., Sthapit B., and Jarvis D. (2003). Who maintains crop genetic diversity and how? Implications for on-farm conservation and utilization. Culture and Agriculture 25: 41–50.

Thomas M., Dawson J. C., Goldringer I., and Bonneuil C. (2011). Seed exchanges, a key to analyze crop diversity dynamics in farmer-led on-farm conservation. Genetic Resources and Crop Evolution 58: 321–338.

Thomas M., Demeulenaere E., Dawson J. C., Khan A. R., Galic N., Jouanne-Pin S., Remoue C., Bonneuil C., and Goldringer I. (2012). On-farm dynamic management of genetic diversity: the impact of seed diffusions and seed saving practices on a population-variety of bread wheat. Evolutionary Applications 5: 779–795.

Wencélius J., Thomas M., Barbillon P., and Garine E. (2016). Interhousehold variability and its effects onseed circulation networks: a case study from northern Cameroon. Ecology and Society 21(1): 44.

Zimmerer K. S. (2003). Geographies of seed networks for food plants (potato, ulluco) and approaches to agrobiodiversity conservation in the Andean countries. Society and Natural Resources 16: 583–601.