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Research

Market integration and cooperative resource harvesting among kin, clan, and neighbors in rural China

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ABSTRACT. Non-timber forest products, such as wild mushrooms, are important in rural livelihoods worldwide. As resource pressures and environmental goals change, land tenure and harvesting arrangements also create novel conditions influencing local communities' resource access. When commons governance encourages (or discourages) cooperative resource harvesting, this may also impact other social ties among community members. Attention to social relationships that are created or limited under particular commons governance regimes is a key part of holistically understanding their social and ecological impacts. We investigate cooperative mushroom harvesting ties in the context of local forest governance in a Yi community in rural Yunnan, China. We use quantitative and qualitative descriptions, regression analysis, and network community detection to investigate how cooperative harvesting partnerships created through the local wild mushroom management system interact with kinship, distance between households, clan affiliation, and networks of social support. The community detection results indicate that social support and cooperative harvesting are highly interdependent. Although social support ties are themselves predicted by household proximity, kinship, and clan membership, kinship ties are surprisingly a poor predictor of co-harvesting. The results suggest that a multiplex network approach is needed to understand how new natural resource management systems may impact community-level social structure and cooperation.

Key Words: *commons governance; community-based natural resource management; cooperation; non-timber forest products; social network analysis; wild mushrooms*

INTRODUCTION

Disentangling relationships between governance, harvesting of natural resources, and local social organization is important for successful, equitable governance of complex social-ecological systems. Cooperative networks, social capital, repeated interactions, and shared social norms are critical factors for overcoming collective action dilemmas and supporting sustainable, long-term governance of common pool resources (Ostrom 1990, 2009, Ostrom et al. 1999, Pretty 2003, Prell et al. 2009). The importance of cooperation for promoting sustainable harvesting has been demonstrated in both theoretical models (Gifford and Hine 1997, ten Broeke et al. 2019) and empirically (Bollig and Menestry Schwieger 2014, Bodin et al. 2017). To investigate how governance arrangements interact with social relationships and cooperative ties, we examined wild mushroom harvesting in a Yi community in Southwest China. Our case study demonstrates how, in the context of global resource commodification, local institutions can potentially collectively manage resources and maintain cooperation in rural communities simultaneously.

Cooperation occurs on at least two levels in resource governance. First, cooperation happens through the process of agents adhering to social norms and system rules. This form of cooperation is extensively studied by scholars interested in collective action and governance institutions (e.g., Olson 1965, Axelrod 1984, Gifford and Hine 1997). Group-level collective action and cooperation in resource governance is associated with long-term sustainable and adaptive management of natural resource commons (Pretty 2003). A second form of cooperation involves the formation of ties between agents in the context of resource governance or use (Crona and Hubacek 2010, Downey 2010). Resource governance arrangements may encourage or limit multi-household cooperation, altering other social and economic outcomes. When resource-use is cooperative, it can boost collective productivity, buffer against risk of household resource shortages, promote indirect reciprocity, and enhance opportunities to diversify livelihood strategies (Alvard 2003, Pereda et al. 2017, ten Broeke et al. 2019).

In addition to influencing common property management outcomes, social relationships structure economic and social outcomes for households. When resource governance norms include opportunities for improved communication and the formation of stronger social relationships, they can also improve other aspects of social life such as connection to cultural identity, sense of place, social capital, and connections across diverse stakeholders (Pretty 2003). Management arrangements may allow for cooperative partnerships to form around resource gathering, which either create new ties or strengthen existing relationships. In contrast, in open access situations, competition over natural resources may limit cooperation (Rogers 2020). The ways in which cooperative partnerships form around resource use and management (and are influenced by and influence other social relationships, e.g., kinship, friendship, social support) are important for sustainable and equitable resource management.

Considerable research in anthropology suggests that cooperation in resource procurement and distribution is often linked to risk reduction (e.g., through reciprocity), assisting kin, or increasing individual harvesting returns (Gurven et al. 2002, Alvard 2003, Hooper et al. 2015, Jaeggi et al. 2016, Ready 2018). In some cases, market integration and resource commodification have been shown to erode local cooperative networks; for instance, if wealthier households withdraw from cooperative labor networks because they have less need for risk pooling (Kasper and

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Borgerhoff Mulder 2015). Particularly in small communities, people tend to interact in a variety of contexts, e.g., recreation, religious communities, and work; moreover, these contexts may not be highly distinguished from one another (Schnegg 2018; C. Atkisson and M. Borgerhoff Mulder, *unpublished manuscript* https://doi.org/10.48550/arXiv.2012.07669). For example, in rural China, kin obligations encompass economic interdependence, such as mutual assistance in farmwork, as well as ritual obligations for important life events such as marriages and funerals. Kin also tend to interact in the context of civic obligations such as ditch digging and community meetings. The concept of multiplex networks, in which actors share multiple different kinds of ties and the patterns of overlap across different domains, shape outcomes for and behaviors of those actors (Kapferer 1969, Baggio et al. 2016, Schnegg 2018). Better understanding how relationships in multiple domains interact and influence resource-use opportunities and distributive outcomes is therefore critical to understanding the broader social and economic consequences of natural resource management regimes (Schnegg 2018, Cumming et al. 2020).

We investigate the relationship between cooperative mushroom harvesting and social structure in a rural Yi community in Yunnan, China, where wild mushrooms are managed through a locally developed system. In rural China, land tenure regimes, common-pool resource management, and community-level social ties continue to change in the context of novel resource commodification and economic opportunities, leading to questions about how this process unfolds and how existing social structures shape or are shaped by novel resource management regimes. To examine this process, we use social network analysis, which provides a set of concepts and analysis techniques for investigating the relationships between individual-level attributes and relationships between actors (Scott 2017, Borgatti et al. 2018). A network approach allows us to effectively visualize and quantitatively describe both the relationship between household characteristics and network position as well as the overlap between different kinds of social ties in communities. We focus on the relationship between partnerships created through the local mushroom governance system and other kinds of social connections in the community (kinship, lineage, spatial proximity, and social support). We begin with a descriptive analysis of the mushroom harvesting networks. Who harvests together, how much do the harvesting networks change from year-to-year, and how do locals describe their decisions about cooperative harvesting? Second, we investigate whether mushroom harvesting, either alone or cooperatively, is associated with increased social support. Finally, we investigate how harvesting partnerships are structured with respect to other kinds of ties in the community.

SITE BACKGROUND

Forest governance and market integration in Yunnan, China

From the mid-1950s to early 1980s, forests in China were regulated through centralized state control, which mandated collective management and state ownership of land and resources (Liu 2001). Starting in the early 1980s, the central government began redistributing forest land to households and communities, following agricultural land decentralization initiatives (Liu 2001).

These decentralization policies led to three primary forest tenure categories that are managed at different levels (Yeh 2000, Xu and Ribot 2004): (1) state-owned forest (*guoyousenlin*); (2) community or collective forest (*jitilin*); and (3) household responsibility or freehold forest (*zerenshan* or *ziliushan*). Formal and informal forest regulations shape who can access particular types of resources within each forest category. For example, since the 1998 implementation of the National Forest Protection Program, commercial logging has been prohibited in much of Yunnan, increasing rural reliance on non-timber forest products (Yang et al. 2008, Menzies and Li 2010). Other than logging and hunting regulations, the central government imposes few top-down restrictions on how forest resources should be managed. This means that many community forests in Yunnan are primarily managed through local level norms, called *xiangguiminyue* (Yeh 2000, Yang et al. 2009, Brown 2020). These local norms vary along a spectrum of private property to open access and exist in sometimes uncertain relation to formal state management categories. Local management norms shape community-members' access to and use of a variety of non-timber forest products, grazing areas, and recreational opportunities. Moreover, access and management norms may differ based on resource type, season, resource user, or other variables, even within the same community (Brown 2020). We examined one such local management system for a specific resource type (wild mushrooms).

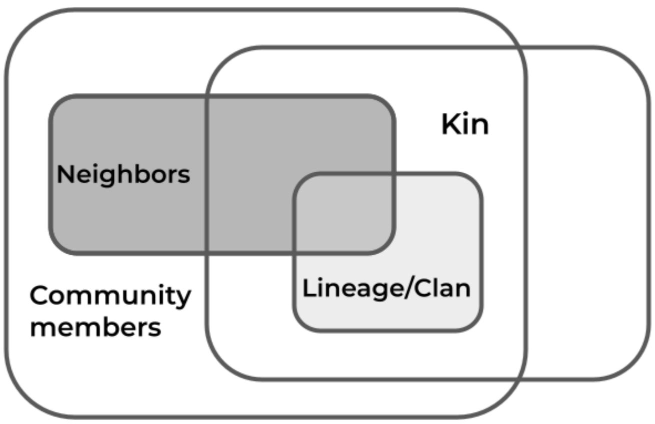
In recent decades, wild mushroom harvesting has become a major income source for many rural communities in Yunnan. Economically important species include *Tricholoma* spp. (matsutake), *Tuber indicum* (Asian black truffle), *Ophiocordyceps sinensis* (caterpillar fungus), *Thelephora ganbajun* (ganbajun), and *Boletus edulis* (porcini), though hundreds of edible mushroom species are collected in the region (Wang et al. 2004, Winkler 2008, He et al. 2011, Mortimer et al. 2012). In Yunnan, communities manage wild mushroom access through a variety of systems. Local forest management norms and institutions are important not only for their ecological and economic impacts, but also for how they shape social relationships and structures. Although market integration and commodification are sometimes noted as degrading social relationships and inciting conflict (Yeh 2000, Kasper and Borgerhoff Mulder 2015, but see also Gurven et al. 2015), the commodification of wild resources can also create new opportunities to form and strengthen social ties.

Study community

Baihua (pseudonym) is a primarily Yi ethnicity community in Nanhua County, Chuxiong Yi Autonomous Prefecture, Yunnan Province, China. Classed as a "natural village" (*zirancun*), Baihua includes 73 resident households. Livelihoods primarily depend on agricultural products such as potatoes, beans, daikon, pigs, and goats, which are both sold and consumed at home. Some households also run small sundry goods stores, motorcycle repair shops, or crop trading businesses. Increasingly, community members participate in both local and migrant wage labor. Wild mushroom harvesting has been an important source of income for community members in recent decades.

At the broadest level, all community members in Baihua are linked by their common identity as village residents (Fig. 1). Households are also organized into 11 lineages or clans (*benjia*), based on descent from a common patrilineal ancestor who first moved to the community. Generally, when locals use the term benjia they are referring to other households within the same community. Households in Baihua are often multi-generational, with one adult child living in their parents' home and farming their parents' land. Land can also be divided between siblings, although they may continue to work as a larger cooperative unit. Even when agricultural land is divided between siblings, their forest land is still often held by an extended family unit. Most families raise several pigs and a small herd of goats, which require daily care.

Fig. 1. Social context of mushroom harvesting in Baihua.



Livelihood strategies and local customs in Baihua lead to substantial interdependence among households. Households will often ask others to watch their livestock if there are circumstances that prevent them from being at home, such as visiting other communities, illness, or engaging in *zuoke* responsibilities. Vehicles are often lent or borrowed because not all households own a vehicle or the particular kind of vehicle that might be needed for a certain task. Most households in the community raise agricultural crops, some of which may be harvested and processed more efficiently with multiple people.

The custom of zuoke, glossed as "to be a guest," involves formally visiting another household in recognition of an important life event. Events during which one is expected to zuoke include births, deaths, marriage, and housewarmings. Zuoke also involves giving gifts of money, with the amount varying as a function of a visitor's relationship to the hosts. People who are part of the same lineage are expected to bring a higher amount than those who are relatives but not in the same lineage. Relatives in turn are expected to bring a higher amount than unrelated community members. The amount given is usually written down by the hosts, who aim to give an equivalent or higher amount in return the next time they zuoke at the other family's house. For some households, the cost of attending these events is considered a significant financial burden. Hosting these events also requires significant time and resources. In general, members of the same lineage spend multiple days helping hosts prepare for events, whether by cooking, butchering livestock, or setting up tables. This is one of the primary ways in which lineage ties are mobilized locally on a regular basis. Lineage members are also expected to support and help one another in case of family emergencies or other needs. In China, the importance of lineages in social life has been well-researched (Cohen 1990, Harrell 1990, Herberer 2005, Swancutt 2012), but the role of lineages in cooperation and resource-management in Indigenous Yi communities and how these descent-based affiliations influence cooperation patterns in rural mixed-subsistence communities is less well understood.

Mushroom harvesting system

Mushroom harvesting is sometimes characterized as a secretive process, in which individuals visit undisclosed locations where they alone know mushrooms emerge (e.g., Choy et al. 2009, Yang et al. 2009, Knight 2014). In Yunnan, mushroom harvesting in some communities follows this pattern. In these cases, harvesters wake up early, sometimes before dawn, to go out into the forest and gather mushrooms alone, attempting to avoid detection from other harvesters. This may be the case when mushrooms are considered open or community access. In some cases, communities attempt to improve rent capture and reduce competition through minimum mushroom size restrictions or rest days for all or part of the forest (Yang et al. 2009, Robinson et al. 2013, Brown 2020). In areas with private forest landholdings (*ziliushan*), mushroom harvesting may be an arena for enforcement of private property rights, with owners placing signs, bear traps, or dogs on their property to discourage poachers.

In Baihua, mushroom harvesting is governed through a collective contracting system that was first adopted in 2001. Mushroom harvesting in Baihua is a highly social affair requiring coordination at both the community and household levels. Each year, mushroom harvesting contracts are auctioned off several weeks before the matsutake mushroom season, usually in early to mid-July. Both collective (jitilin) and household forest (ziliushan) landholdings are included in the auction. However, local names and delineation of forest parcels do not directly overlap with property boundaries as defined by the state. Instead, forest parcels, as delineated within the auction system, are dynamic use-rights parcels whose exact spatial boundaries may shift based on changing local norms and perceptions of the forest. These parcels include all forest lands to which the community as a whole has access to. During the auction, these parcels are treated as community property, regardless of their state-defined forest management categories.

The auction has three phases: (1) community census, (2) parcel bids, and (3) redistribution payments; all of which take place in person over one to two days. In the first phase, all households report the current number of individuals in their household. Second, households place bids for contract use-rights to forest parcels, either alone or in groups. Finally, the auction concludes with the redistribution of auction revenue evenly to all community members. This means that regardless of landholdings or whether or not a household chooses to harvest mushrooms, each resident receives the same amount of money from the mushroom harvesting auctions (Brown 2017, 2020). Such revenue redistributions may limit harvesting pressure on local forests (because income can be earned even when choosing not to harvest mushrooms) and offer greater equality of benefits for households who may be unable to harvest mushrooms (e.g., due to lack of labor or funds to participate in the system).

This governance system has several notable features. First, mushroom harvesting contracts are superimposed over existing land tenure categories, consequently rewriting boundaries of forest access for the majority of the mushroom harvesting season (typically July to November). During non-contract months, access rights return to formal state-defined land tenure categories. Second, all households in the community forfeit rights to individually profit from their household forest landholdings by participating in the auction. Instead, all household and collective forest parcels are treated as community property for the mushroom harvesting auction and all auction revenue is distributed evenly across community members. This means that there are no household-to-household bids or transactions, with the auction instead operating as a community-level activity. Finally, this governance arrangement includes opportunities for multi-household cooperation in non-timber forest product harvesting.

In Baihua, several patterns are suggestive of an equitable management system. First, all households receive an equal per capita share of forest auction revenue regardless of whether they participate in harvesting. In contrast, alternatives to this arrangement include enforcement of private property or open access, which might increase income inequality and resource competition. Second, this system enables high levels of household participation in mushroom harvesting at the community level, with nearly all households participating in some years, while also avoiding requiring the same level of participation in mushroom harvesting from all households over a multi-year time period, thereby enabling adaptive decision making based on changing household conditions (Brown 2020). Finally, there is a spatial component to resource access equity in which harvesting groups tend to have access to similar quality forest patches (see Brown 2017).

METHODS

Data collection

Data were collected over 13 months of fieldwork between 2014-2016 in Yunnan Province, China. During fieldwork, the first author (MB) lived with a family and participated in daily life including mushroom harvesting, spending time at fields, grazing sites, markets, and attending events. Participant observation and interviews were conducted in Mandarin. When necessary, research assistants from the community assisted with translating questions and answers between Yi and Mandarin. Human subjects research protocols for this research were approved by the Stanford University and University of Florida Institutional Review Boards (IRB).

Initial household interviews were conducted in 2014 with 72 households. Households were defined by participants, generally following the household registration system (*hukou*). We take households as the unit of analysis and as the nodes in the networks because of the coordination of economic activity within households in the community. The initial interviews covered household demographics, economic assets, mushroom harvesting practices, and the interviewee's history of mushroom contracting partners. In autumn 2014, MB also conducted interviews about household social support and labor networks (n = 70). For example, social support questions included "If you need extra help with farm labor, who do you ask to help out?" (see Appendix 1). These questions generated the names of individuals whom the interviewee considered to be someone who helped or interacted with their household in this domain.

From May-July 2015, MB conducted a second round of household interviews with the majority of households (n = 69). In these interviews, respondents reflected on the previous mushroom harvesting season, provided information about their economic assets, and answered multiple social network questions. A slightly different set of social support ties were elicited in 2014 and 2015 (see Appendix 1). In the analyses, we excluded data from one question in 2015 (digging a well), which elicited few ties and turned out to be a community-wide activity rather than one involving specific social ties. Despite the near complete network data collected, not all households were available at each stage of data collection. Whenever comparisons are made across datasets, we include households present in both datasets.

Kinship data were collected during initial household interviews and checked with input from community members and during subsequent interviews in 2018. This information was used to produce a network of relatedness among households. Again, households are the network nodes, and edges denote the presence or absence of a kinship tie. We generated several kinship networks using different thresholds for relatedness: > 0.5, which indcludes parents and full siblings, > 0.25 which extends to relatives such as aunts/uncles, nieces/nephews, and grandparents, and > 0.125 which includes all relatives as closely related as a full first-cousin. These thresholds are based on local understandings of kinship and kin distance. Although lineages typically capture male-based descent groups, local conceptions of kin (*qinqi*) includes both male and female family relations. To generate these networks, we used the highest relatedness coefficient between any two members of a pair of households; for example, the highest relatedness coefficient between the households of two sisters with unrelated husbands would be 0.5. The lineage networks are based on interviews with community members who are knowledgeable about local history. All households within the same lineage are considered to have a network tie.

Mushroom contract records are written down by the village leader during the annual auction. These documents were consulted during each observed mushroom season (2014-2016) and clarified through conversations with locals. For each year, the mushroom harvesting data consist of a list of whether or not each household was part of a contract and which households contracted together. We use the latter record to generate the mushroom harvesting network for each year, where the nodes are households and the edges (ties) represent the presence or absence of co-harvesting relationships. Because sharing a contract involves a division of labor and profits among co-contractors, contracts also represent cooperative bonds between households.

Finally, distances between households were calculated with ArcGIS based on point data collected at each place of residence. Because the community-detection methods we use do not work with a combination of binary and weighted network data, we converted the distances between households into a network of "neighbors" in which any households within 250 meters of each other were considered to be neighbors (and thus to have a network tie), based on ethnographic insight into peoples' perceptions of the spatial layout of the village.

Analysis

We began with a qualitative and quantitative description of the mushroom harvesting networks and social interaction in the context of mushroom harvesting. Qualitative interview responses were thematically coded and tabulated in R (R Core Team 2021). Narrative descriptions of local experiences and practices related to mushroom harvesting from field notes are also collated and synthesized.

We subsequently investigated whether households with more social support ties in 2014 and in 2015 (the years for which social support data are available) are more likely to be mushroom harvesters and to cooperate in mushroom harvesting, using Bayesian logistic regressions with Freeman degree (the total number of other households a household is connected to) in each year of social support network data as a predictor of harvesting and cooperative harvesting. With these regressions, we asked if having more social support partners made it easier for households to either harvest at all or to harvest cooperatively (for instance, because they can count on receiving support in other domains, or because they have more potentially available partners), regardless of the specific network structure. To do this, we used two linked logistic regressions. The first regression model focuses on the relationship between social support and harvest contracting; then, for the households that did harvest mushrooms, the second model examines whether households with more social support were more likely to harvest cooperatively. Each model contains household-level intercepts (i.e., random effects) as well as correlated intercepts and slopes (for social support) for each year of data. The model parameters (household intercepts and the year- intercepts and slopes) are also correlated across the two regression models to control for the non-independence of the data and the decisions that we model. We additionally ran these regressions using total network strength of households in the social support network. This means that, instead of treating edges as binary, we used the nominations of households for different types of social support as a measure of edge weight. Regressions were performed in R using rstan (Stan Development Team 2020) and the rethinking package (McElreath 2020).

We then examined how the co-harvesting partnerships are structured with respect to other kinds of relationships in the community (including social support, kinship, lineage, and spatial proximity) using "multitensor," a multilayer community detection algorithm (De Bacco et al. 2017). The multitensor method uses a mixed-membership stochastic block model to detect latent communities within and across network layers. Nodes are probabilistically assigned to latent communities on the basis of similarity in interaction patterns (i.e., ties to the same nodes in the same layers). Key advantages of multitensor are that it allows for community detection across multiple input layers, enables link prediction (i.e., it predicts the existence of ties between nodes in a network layer), and, through link prediction, allows the interdependence of network layers to be assessed. Multitensor also calculates affinity scores that index the relative strength of the association of network layers to the latent communities.

We ran multitensor on a battery of layer combinations, focusing on examining the interdependence of the social support network with kinship, lineage, and neighborhoods in Baihua and on the interdependence of harvesting ties and all of the aforementioned layers. To perform these analyses, we generated four different undirected, unweighted networks (because the other network layers were also undirected and unweighted) using the reported social support ties. These included an overall social support network that includes all of the reported social support ties in each year of the study, as well as three networks that represent different domains of exchange and support, based only on the questions asked in both years of the study: (1) farmwork, (2) socialization, and (3) information, which included both the discussion of important matters and information about forest products (the latter two questions were combined because both elicited relatively few ties).

To investigate the relationship between relatedness and cooperative ties, we also examined several different "cut-off" levels for relatedness between households. We calculated between-household relatedness based on the highest relatedness level between any pair of individuals in the two households. Because we expected ties in all the layers to be homophilous (i.e., positive assortativity, or similar nodes being more likely to have ties), we ran multitensor using the "assortative" setting, which greatly increases the speed of model fitting. A subset of model runs with the disassortative setting confirmed that the affinity weights were primarily on the diagonal of the community affiliation matrices; meaning that the assumption of assortativity is reasonable.

We performed cross-validation of the results to examine the usefulness of community partitions generated from different sets of network layers for predicting links in the harvest and social support layers. We compared model performance using 2- through 5-fold cross-validation and using different random starting seeds for dividing the data into test and training samples, to examine the sensitivity of the results to data splitting (due to our relatively sparse networks for some tie types). The results were consistent across different model runs. We assessed prediction accuracy using AUC (area-under-the-curve, a common metric in machine learning applications; for its use in this case see De Bacco et al. 2017), as well as precision and recall (see Appendix 1). Area-under-the-curve assesses whether a link that is a "true positive" is assigned a higher link prediction score than a randomly chosen "true negative." In this analysis, there is no ground-truth community membership that we are attempting to predict. Consequently, to determine the best-fit model for each set of network layers, we compared AUC results for different numbers of latent communities (from 2 to 15). We present results for only up to 10 communities because larger numbers did not further increase model performance. Finally, we qualitatively assessed how harvesting ties interact with other kinds of social affiliation in Baihua using visualizations of the community partitions and by examining the affinity of different layers to detected communities.

RESULTS

Interviews with community members and participant observation clearly indicate that mushroom harvesting contracts are significant financial, social, and time investments. Households who share a contract harvest and sell mushrooms together for about five months (July-November, for much of the rainy season). This means gathering mushrooms together multiple days a week and even daily during high production periods. Households jointly invest large amounts of money in purchasing their contract, which they must work together to earn back. This type of partnership is therefore a significant bond between households, entered into with deliberation.

Although the majority of households in Baihua (55 out of 73) harvested mushrooms during at least one year of the study period (2014-2016), there are certain households (n = 8) that did not harvest mushrooms in this period. These households generally fall into several categories: those who run businesses (e.g., selling potatoes or repairing motorcycles), those who engage in migrant labor elsewhere, and those with circumstances limiting their available labor or finances for investing in contracts.

In 2015, harvesters were asked what they liked about working in groups or working alone. Responses about working in groups (n = 20) included that they like working in groups because it is fun, more efficient, and that they are used to it. Some harvesters noted that groups of households can place a contract on a bigger forest parcel than a single household, which holds the possibility of more mushroom returns. Because certain forest parcels are large, some harvesters consider it more efficient or easier to search for mushrooms in these large parcels when working in a multi-household group. Working in groups also increases information sharing about mushroom production between households. Reasons for working alone are less clearly articulated, but generally refer to reduced labor inputs required for smaller parcels and flexibility. For example, when working alone, a household does not have to coordinate their livelihood activities with another household nor feel obligated to harvest mushrooms based on another household's schedule.

Responses varied when harvesters were asked about how they choose who to collect mushrooms with. Some stated they worked with relatives or people with whom they often socialize or get along well with. Others stated that they work with households with whom they also cooperate on farmwork. Some individuals cited experience previously working together for many years as the reason that they continue to work with certain households.

Table 1. Characteristics of harvesting contracts, 2014–2016. Note: HH = household.

Harvesting network characteristics	2014	2015	2016
Total contracts	15	16	18
Individual contracts	6	8	8
Group contracts	9	8	10
Average group size	3.67	3.50	2.80
Total households participating	39	36	36
HH harvesting alone	6	6	8
HH harvesting in groups	33	28	28
Total cooperative ties	48	43	28

We now describe the general characteristics of mushroom harvesting ties as they relate to other social ties. Table 1 provides descriptive statistics of the harvesting networks from 2014-2016 (note again that social support data were only collected in 2014 and 2015). Each year, roughly half of the 73 resident households participated in mushroom harvesting. Over the three observed seasons (2014-2016), 15 to 18 contracts were held by local community members. Within these contracts, the proportions held by multi-household groups versus individual households were similar from year-to-year, with slightly more multi-household groups than individual contracts overall. Only three households foraged alone in more than one year. We note that between 2014 and 2016, both the average group size and the number of cooperative ties declined. Though long-term data are needed to fully understand these potential trends, they may be related to decreasing market prices for mushrooms.

Figure 2 shows the 2014 and 2015 social support networks and their relationship to mushroom co-harvesting. In both years, the social support ties produced a single, connected network component. Figure 2 suggests that, for some co-harvesting groups, support and co-harvesting ties are highly overlapping, but this is not the case for all co-harvesting groups. Additionally, there appears to be considerable change in both co-harvesting partnerships and social support ties from year to year. Of the harvest partnerships from 2014, 56% occurred again in 2015; 46% of social support edges from 2014 were repeated in 2015. Figure 3 shows mushroom co-harvesting ties mapped over the clan membership networks, with the layout of the network based on kinship ties. This visualization reveals the clustering of clans within the kinship network, as well as the numerous co-harvesting ties linking households who are not closely related.

Next we compare ties across network layers (Table 2). Specifically, we provide the average relatedness between pairs (dyads) of households (based on the maximum relatedness between any two people between those households), the proportion of dyads that have a clan tie, the median distance between households, and the proportion of dyads that have any support ties, or different kinds of support ties, for different subsets of the village (i.e., among co-harvesters and among those with social support ties) and for the whole village. As an example, in 2014, the mean relatedness of co-harvesters was 0.14, whereas the mean relatedness of all households in the village was 0.03. In addition, 31% of ties in the support network were between members of the same lineage, whereas only 11% of all household dyads in the village were co-lineage members. Table 2 suggests that households that share either co-harvesting or social support ties tend to live closer together than the average pair of households in the village. However, co-harvesting dyads tend to live further apart compared to social support dyads. Relatedness and clan membership also appear to be more associated with social support ties than with co-harvesting ties. For example, the mean maximum household relatedness was greater among households with social support ties than among households with co-harvesting ties; yet, relatedness between households with either co-harvesting or support ties was greater than among households in the village in general. Co-harvesting and social support ties overlap considerably in 2014 (54%), but somewhat less in 2015 (38%). All three of the different types of social support overlap considerably with co-harvesting. Nevertheless, a large proportion of harvesting ties are not overlapping with any of the kinship, lineage, or social support networks: 33% in 2014 and 48% in 2015. The overall density of the social support network in 2015 is somewhat lower than in 2014, which may be related to measurement issues (e.g., respondent fatigue in the longer 2015 survey) as well as differences in which household members responded to the survey and/or were present in the community across the sample years.

We now investigate the relationship between harvesting and social support in more detail, using linked logistic regressions to examine whether households with more social support were more likely to

Fig. 2. Baihua social support networks in 2014 and 2015. Red and blue ties show 2014 and 2015 mushroom co-harvesting ties between households. Colors of the nodes represent harvesting contracts (15 in 2014 and 16 in 2015; several households contracted alone in each year). Households that did not participate in harvesting are shown in white. Node size is proportional to in-degree (number of incoming ties) in the social support network (ranging from 0 to 8); nodes are shown in the same position each year. The network layout is force-based (Fruchterman-Reingold), with nodes sharing more ties plotted closely together.

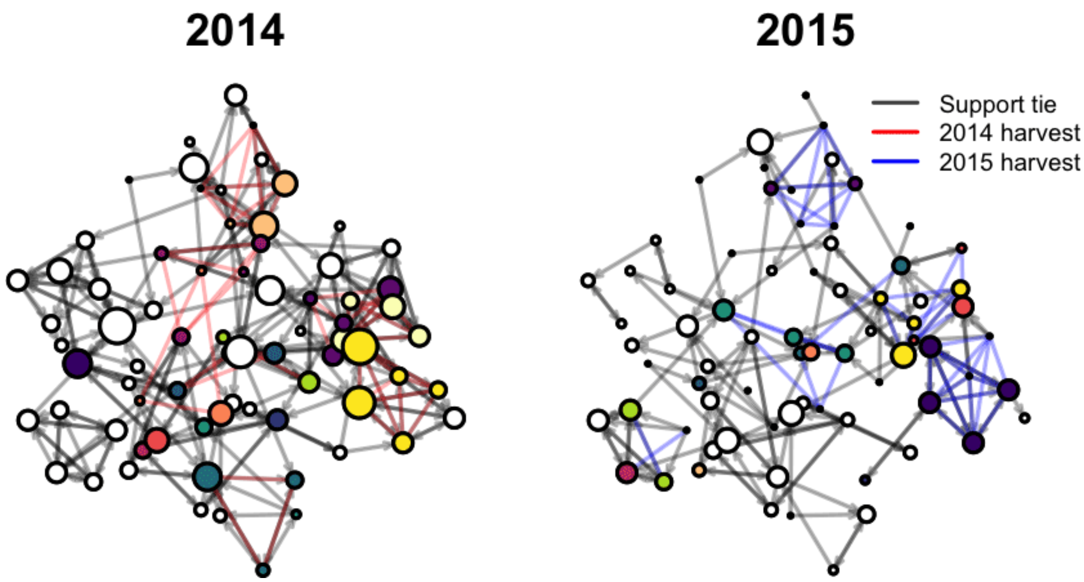
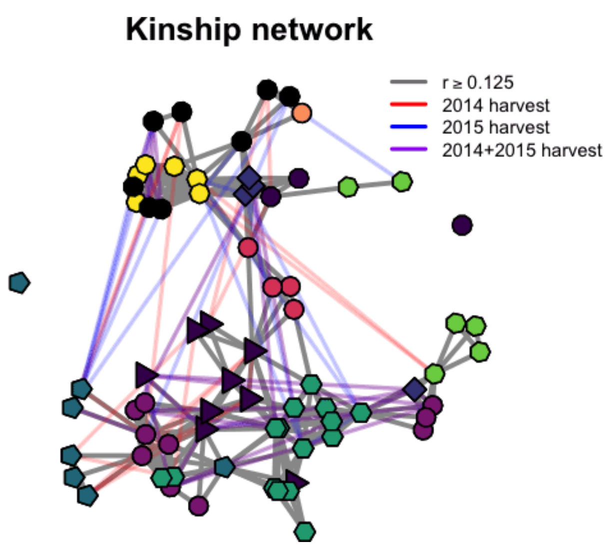


Fig. 3. Baihua kinship network overlaid with 2014 (red) and 2015 (blue) mushroom co-harvesting ties; co-harvesting ties between households that occurred in both years appear purple. Edges represent a relatedness coefficient of 0.125 or more between households, where relatedness is taken as the closest relationship between any two persons across the two households. The clan membership of each household is shown by node shape and color. The network layout is force-based (Fruchterman-Reingold), with nodes sharing more ties plotted closely together.



participate in harvesting and to harvest cooperatively. Posterior parameter estimates for the main model terms are summarized in Table 3, which indicates that none of the parameters have 89% probability intervals excluding zero. Figure 4 shows model predictions, for the mean and 89% posterior distributions of the mean estimate for an example household with different numbers of social support ties. The results suggest that the number of social support ties is at best a very weak predictor of harvesting and cooperative harvesting. Households with more social support ties may be slightly more likely to participate in harvesting than those with fewer ties (the blue line in Fig. 4). The effect of social support on cooperative harvesting (given that a household is harvesting) is very uncertain, given the small number of households that harvest alone. We also ran these regressions using the total strength (i.e., counting repeat nominations for different kinds of social support), and for only labor ties (the support question that generated the most ties), and obtained the same null results.

Finally, community detection analysis allows us to investigate the interdependence of co-harvesting with the other network layers (kinship, clan, neighbors, and social support) in Baihua. Figure 5 shows out-of-sample prediction accuracy in cross-validation analysis for various combinations of network layers and different numbers of latent communities. An AUC of 0.5 (on the y-axis) reflects random prediction accuracy, whereas grey dots connected by dotted lines indicate prediction performance using only the training layer (i.e., no information from other layers), and thus can be used as a basis for comparing how the information contained in other layers improves model performance.

Table 2. Kinship, clan, proximity and social support relationships between co-harvesters, between households with support ties (Sup. net) and between all villagers, 2014–2016. Social support data was not collected in 2016. “Prop. dyads support ties” refers to the proportion of dyads among active harvesters or within the village as a whole who also had social support ties. The distribution of specific types of social support (labor, socialization, and information) are also shown. Note: HH = household.

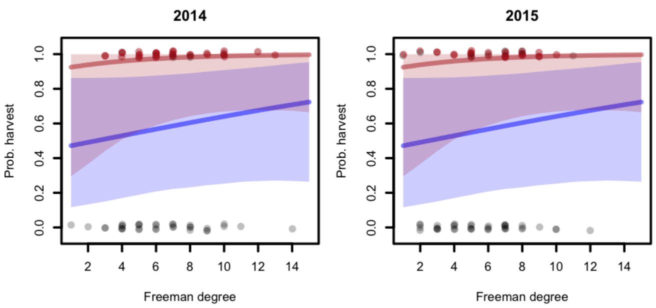
	Co-harv.	Sup. net.	Village
2014			
Mean max. HH relatedness	0.14	0.18	0.03
Prop. dyads clan members	0.27	0.31	0.11
Median dist. between HH (m)	188.3	127.9	795.4
Prop. dyads support ties	0.54	-	0.07
Prop. dyads labor ties	0.35	0.72	0.05
Prop. dyads social ties	0.23	0.53	0.04
Prop. dyads information ties	0.31	0.15	0.01
2015			
Mean max. HH relatedness	0.13	0.19	0.03
Prop. dyads clan members	0.23	0.39	0.11
Median dist. between HH (m)	189.2	124.5	795.4
Prop. dyads support ties	0.38	-	0.05
Prop. dyads labor ties	0.35	0.81	0.05
Prop. dyads social ties	0.35	0.54	0.03
Prop. dyads information ties	0.15	0.15	0.01
2016			
Mean max. HH relatedness	0.16	-	0.03
Prop. dyads clan members	0.27	-	0.11
Median dist. between HH (m)	190.8	-	795.4
Prop. dyads support ties	-	-	-

Table 3. Summary of posterior estimates for logistic regressions of harvest participation and cooperative harvesting on social support, with household and year intercepts. Note: PI = probability intervals.

	Mean	SD	5.5% PI	94.5% PI
Contract? (yes/no)				
Intercept 2014	-0.020	0.713	-1.179	1.094
Intercept 2015	-0.204	0.691	-1.300	0.888
Slope social support 2014	0.077	0.103	-0.091	0.240
Slope social support 2015	0.082	0.106	-0.089	0.246
If contract, cooperative? (yes/no)				
Intercept 2014	0.471	0.836	-0.854	1.807
Intercept 2015	-0.006	0.808	-1.280	1.271
Slope social support 2014	0.220	0.235	-0.103	0.628
Slope social support 2015	0.147	0.196	-0.145	0.478

First, we considered the interdependence of social support with the other network layers. Panels in row (a) of Figure 5 indicate that social support is not easily predicted from the other layers in the dataset. Although the neighbor network very slightly improves prediction of social support for some *n* communities, in general, adding network layers does not improve prediction of social support compared to using only 75% of the social support data to predict the remaining 25%. However, in 2-fold cross-validation (i.e., using a 50/50 test/training split), other layers, particularly the neighbor network, do improve predictions about social support ties (see Appendix 1, Fig. A1.1). When layers for labor, socialization, and information are included separately in the analyses, we obtain largely the same results as when these are grouped into a single layer.

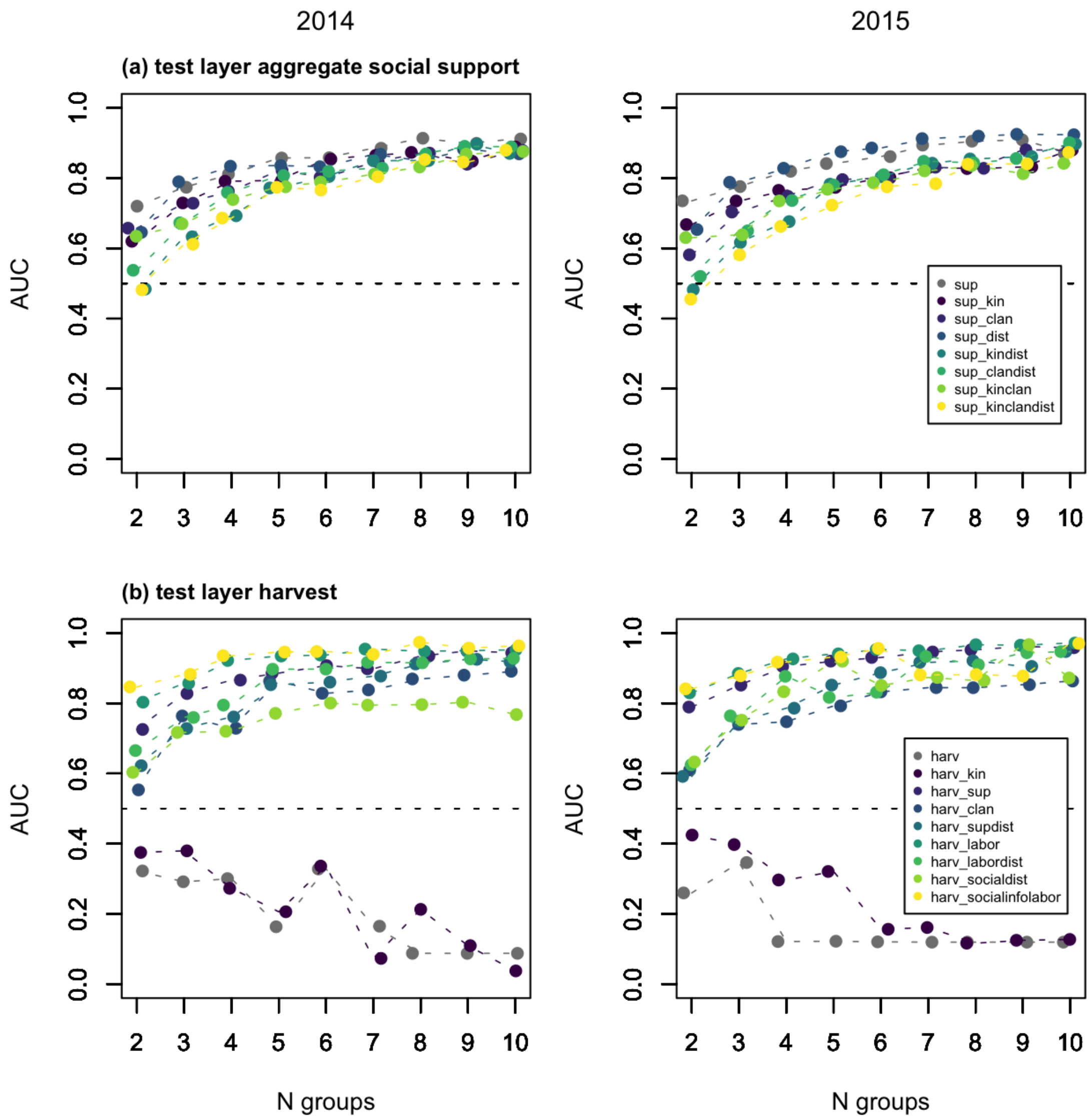
Fig. 4. Relationship between Freeman degree in the social support network, participation in harvesting and cooperative harvesting. Freeman degree is the total number of other households with which a given household had a social support tie. Households shown as red points harvested cooperatively, households shown as gray points harvested alone. Blue line and shading is the posterior distribution (mean and 89% interval) for probability of harvesting; red line and shading is the posterior distribution (mean and 89% interval) for cooperative harvesting among those that harvested (i.e., did they harvest with a group or alone).



We examined the interdependence of co-harvesting ties and other network layers. Row (b) of Figure 5 shows the results for predicting harvesting ties based on 75% of the harvest data plus other combinations of network layers. The figure shows several of the best-performing models, as well as the results for kinship, for illustrative purposes. The best models for predicting harvesting ties appear to be the social support network alone (aggregated or disaggregrated) with four or more latent communities, or the social support and neighbor networks with five or more communities. Prediction accuracy for the harvesting layer did not improve when more layers were considered in the models. Perhaps surprisingly, communities detected using the kinship layer were not very useful for predicting co-harvesting. Precision and recall results are presented and discussed in Appendix 1, Figure A1.2. Model recall is high, indicating that the communities detected (based on the social support and neighbor networks) are very good at recovering “true” co-harvesting ties. Model precision is low, but given the inferential goals of this work, low-model precision does not undermine our takeaway message about the interdependence of social support, being neighbors, and co-harvesting.

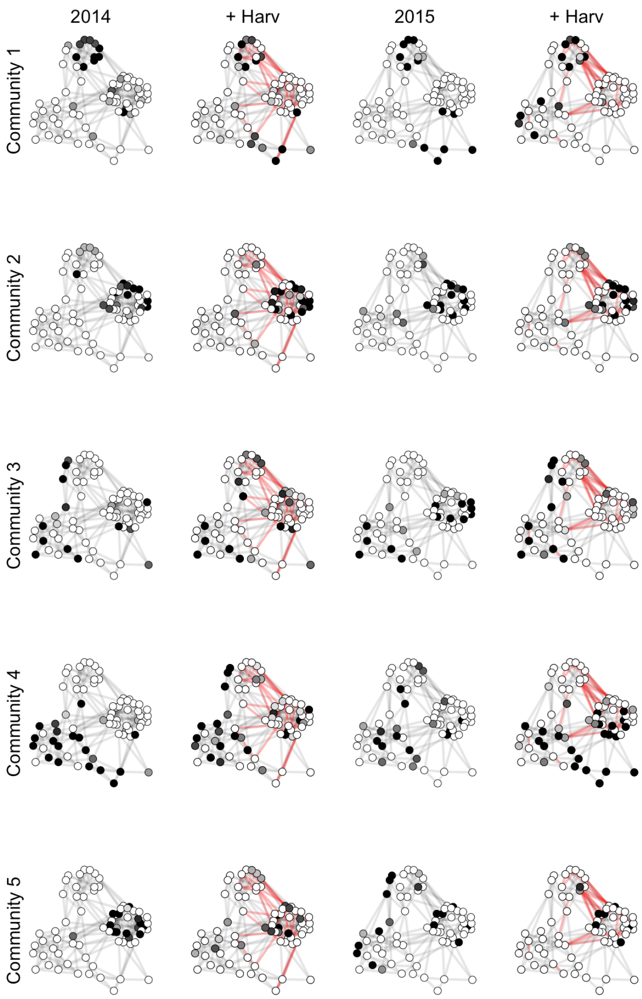
Using one of the best performing models for predicting harvesting ties (n communities = 5, using the disaggregated social support networks), Figure 6 compares the composition of communities detected with and without the inclusion of the harvesting layer. What is notable in Figure 6 is the substantial similarities in the assignment of many nodes to communities across the two years and regardless of the inclusion of the harvesting layer (note that the ordering of communities is arbitrary). When the harvest

Fig. 5. Cross-validation analysis of communities detected using multitensor, for different combinations of network layers and different numbers of latent communities, in 2014 and 2015. AUC = area-under-the-curve. The black dotted line at AUC = 0.5 represents random performance in tie prediction. For social support, the gray points and dashed line show the performance of communities detected based on 75% knowledge of a single network layer (aggregate social support or harvest) at predicting the other 25% of data points. Thus, we can assess the improvement (or not) in prediction accuracy from using more network layers relative to this line. sup = support layer; harv = mushroom harvesting; clan = lineage, dist = neighbor network, kin = any kin r > 0. We show performance for different numbers of latent communities because in the absence of ground-truth communities, we used AUC to inform the choice of which model best fits the data, in terms of both the specific layers included and the number of latent communities.



network is included in the model, community 2 has the stronger affinity with this layer (see Appendix 1, Fig. A1.3). Additionally, the force-based algorithm used to assign the position of nodes in Figure 6 included the neighbors network, and it is this network that produces the clusters in the top, left and right side of the network diagram. This layout demonstrates how, although the neighbors network itself was not very useful for predicting harvesting ties, the social support ties that predict harvesting are themselves structured by residence patterns in the community (Fig. 5). In fact, although 71% (2014) and 63% (2015) of harvesting ties occur within the communities detected by the algorithm on the basis of the disaggregated social support networks, 88% (2014), and 93% (2015) of harvesting ties occur within the communities detected by the algorithm on the basis of the neighbor and support networks. Thus, although social support ties (which vary from year-to-year) may be the most

Fig. 6. Communities detected by multitensor with and without the inclusion of the harvesting layer, using best performing models for predicting harvesting ties (n communities = 5, using layers social support and neighbors), for 2014 and 2015. Darker shading of nodes indicates stronger membership to a group. Social support ties shown in gray and harvest ties in red. Nodes (households) are plotted with a force-based algorithm (Fruchterman-Reingold; closely associated households are plotted close together) based on kinship lineage, harvest, and neighbor layers.



accurate way to predict who harvests with whom; residential patterns in the community capture longer-term patterns of interaction that structure mutual aid and cooperation.

DISCUSSION

Mushroom contracting partnerships link the livelihoods and economic well-being of households and require daily coordinated activity for an entire rainy season. Group members decide which days to harvest mushrooms and which to engage in other activities (e.g., farming, wage labor, or visiting markets). Although actual mushroom harvesting may or may not be undertaken collectively, each evening, partners pool their matsutake and porcini together and sell them to mushroom traders. Both transparency at the point of sale and recordkeeping practices keep group members equally informed about how their economic investment is faring. On days when groups do not harvest mushrooms, they often work together on each other's farmland. Choosing a contracting partner to work with for an entire mushroom season is consequently a significant decision. Further reflecting the importance of these ties, mushroom contractors could often clearly remember their contract partners and contracted forest parcels going back many years and, in some cases, even to the earliest years of the contract system.

Despite the importance of trust in harvesting partnerships, ethnographic observations suggest that diversifying the relationships shared with harvesting partners can be beneficial. This is illustrated by one harvesting group, made up entirely of relatives, but only some of whom are in the same lineage. This group composition was explicitly recognized as an arrangement that facilitated mushroom harvesting at times when one clan was faced with time-consuming social obligations, including funerary customs that require several days of preparation. For a resource like wild mushrooms, it can be critical to gather mushrooms almost every day during the rainy season because the time from first emergence to eventual decay may be a matter of days. Without diversified clan ties, mushroom harvesting income could be lost due to the need to fulfill familial obligations.

Given the need for both trust and coordination of scheduling in mushroom harvesting, it is not surprising that wild mushroom harvesting ties reflect other kinds of social ties in Baihua. Our regression analysis showed only a very slight and uncertain relationship between a household's number of social support ties and their participation in mushroom (co-)harvesting, indicating that the number of social support partners alone is not sufficient to explain why some households participate in (cooperative) mushroom harvesting and others do not. However, community structure detected on the basis of the social support networks (either aggregated or disaggregated) was the most effective for predicting co-harvesting ties, out of all the networks we considered (kinship, neighbors, and clan membership). The relationship between mushroom harvesting and social support is thus not simply one of quantity. Measurement issues could play a role in this finding, that is, our data may not (accurately) measure the type(s) of social support ties most relevant to the decision to harvest mushrooms. This finding is nevertheless important because network degree is perhaps the most common measure of social capital employed in the network literature (Borgatti et al. 1998).

The descriptive analysis as well as the multitensor results suggest that households often choose to work with households with whom they have social support ties, the most important of which are help in farmwork. We note that although in 2014 the social support data were collected during the mushroom season, social support ties in 2015 were collected prior to the mushroom season, meaning that farmwork ties observed were not simply a consequence of the contracts observed in that year. In our investigation of the interdependence of harvesting and other networks, we found that adding additional layers (besides social support) to the models did not improve prediction accuracy: in other words, once social support ties are known, information about the other network layers was redundant or even counterproductive for predicting co-harvesting ties. However, social support ties (either both aggregated or considering farmwork alone) were themselves well-predicted by the other network layers (kinship, clan, or neighbors). An additional unexpected finding was that kinship alone is a poor predictor of harvesting ties. This occurs despite the fact that the kinship network performed relatively well at predicting social support. Kin and clan members often provide social support to each other and live near each other, meaning that mushroom harvesting ties are often with kin even if being kin may not be the reason for which people decide to work together. Indeed, broadly similar underlying community structures predict social support and harvesting ties in both years (Fig. 6). These findings highlight the importance of multiplexity in cooperative relationships (Atkisson et al. 2020): understanding co-harvesting ties requires an understanding of social support; but social support in turn is at least partly structured by kinship.

In commons governance contexts, social networks are core factors promoting sustainable and equitable resource management outcomes (Crona et al. 2011, Bodin et al. 2017), although past research has tended to focus on overall network properties rather than on dyadic relationships between actors (Schnegg 2018). In contrast, cooperation in resource use and management is often approached through evolutionary frameworks or as an outcome of overcoming collective action dilemmas. Linking these approaches to consider intra-community multiplex networks has the potential to enhance understanding of dynamic resource governance systems. In particular, understanding how governance arrangements variably encourage or limit the formation of cooperative ties has implications for community and individual outcomes in other domains of social life.

The commodification of wild mushrooms creates new economic and cooperative opportunities in Yunnan. We show that the mushroom contracting system in Baihua leads to the formation of inter-household cooperative harvesting ties that are correlated with social support ties, which themselves also overlap with kinship, clan and neighbor ties, findings which demonstrate the embeddedness of this commons governance system within the community. The fact that harvesting partnerships change from year to year, and that most households participate in harvesting in some years, indicates that this resource has not been monopolized by a few households, that households are able to participate flexibly in the system, and have many potential cooperative partners among existing networks of kin, neighbors, and friends who provide social support, particularly, those who engage in cooperative farmwork together, which is an important component of local livelihoods.

The contracting system in Baihua thus allows people to take advantage of new market opportunities while also building on existing trust without undermining local customs. Although the Baihua mushroom contracting system has been in place since 2001, we note that in recent years, both prices of wild mushrooms and harvesting group sizes have declined, suggesting that poor market conditions may discourage cooperative harvesting. The long-term effects of, and possible causal relationships between, these changes remain to be seen and point to a broader challenge in understanding governance of commons systems during periods of change.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/13601

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Data Availability:

Code used in this study is available at: https://github.com/elspethr/mushroom_harvesters. The data that support the findings of this study are available on request from the first author, MB. The data are not made publicly available due to confidentiality concerns. Ethical approval for this research study was granted by Stanford University (Protocol #27699) and the University of Florida (Protocol #IRB201801518) IRB.

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Appendix 1. Network data and additional analyses

Table A1.1 Network questions.

Network question	Year asked
If you need extra help farming, who do you ask?	2014, 2015
Who do you usually socialize with?	2014, 2015
If you wanted information about forest or mushroom production, who do you ask?	2014, 2015
With whom do you discuss important matters? (anything that is important to you)	2014, 2015
When you have needed to borrow a little money, whom have you borrowed from? Who have you lent a little money to before?	2015
When you have needed someone to help watch your kids, who have you asked? Whose kids have you watched before?	2015
When you have been looking for a wage labor job, whom have you asked?	2015
When you have needed someone to help watch your pigs, whom have you asked? Whose pigs have you helped watch before?	2015
When you have needed to borrow a car, who have you borrowed from? Who have you lent a car to before?	2015
When you need help carrying crops to market, who helps? Who have you helped bring crops to market?	2015

Table A1.2 Network layers

Layer	Data source	Description
Kinship	Interviews	Kinship ties between households based on coefficients of relatedness (*r*).
Lineage	Interviews	Patrilineal descent-based affiliations between households.
Aggregate social support	Interviews	Interactions between households. Includes all questions in Appendix Table A1.1.
Labor	Interviews	Interactions between households. Farmwork question in Appendix Table A1.1.
Socialization	Interviews	Interactions between households. Socialization question in Appendix Table A1.1.
Information	Interviews	Interactions between households. Important matters and information questions in Appendix Table A1.1.
Harvesting	Community documents	Mushroom harvesting partnerships between households.
Neighbors	Spatial data	Distance between household residences. Households are considered “neighbors” if they live within 250 meters.

Figure A1.1 Additional results of cross-validation analysis of communities detected using *multitensor*, for different combinations of network layers, and different numbers of latent communities, in 2014 and 2015. AUC = Area-Under-the-Curve. The black dotted line at AUC=0.5 represents random performance in tie prediction. Row (a) show results for 2-fold cross-validation for aggregate social support, demonstrating that, with less information about the social support layer provided, the communities detected on the basis of the neighbors network (dist) provide the best predictions for social support. Row (b) shows 2-fold cross-validation analysis using only labor ties as the training layer; overall the results are similar to aggregate social support, although the relationship between the types of social support is com. This is likely related to the relative sparsity of these layers.

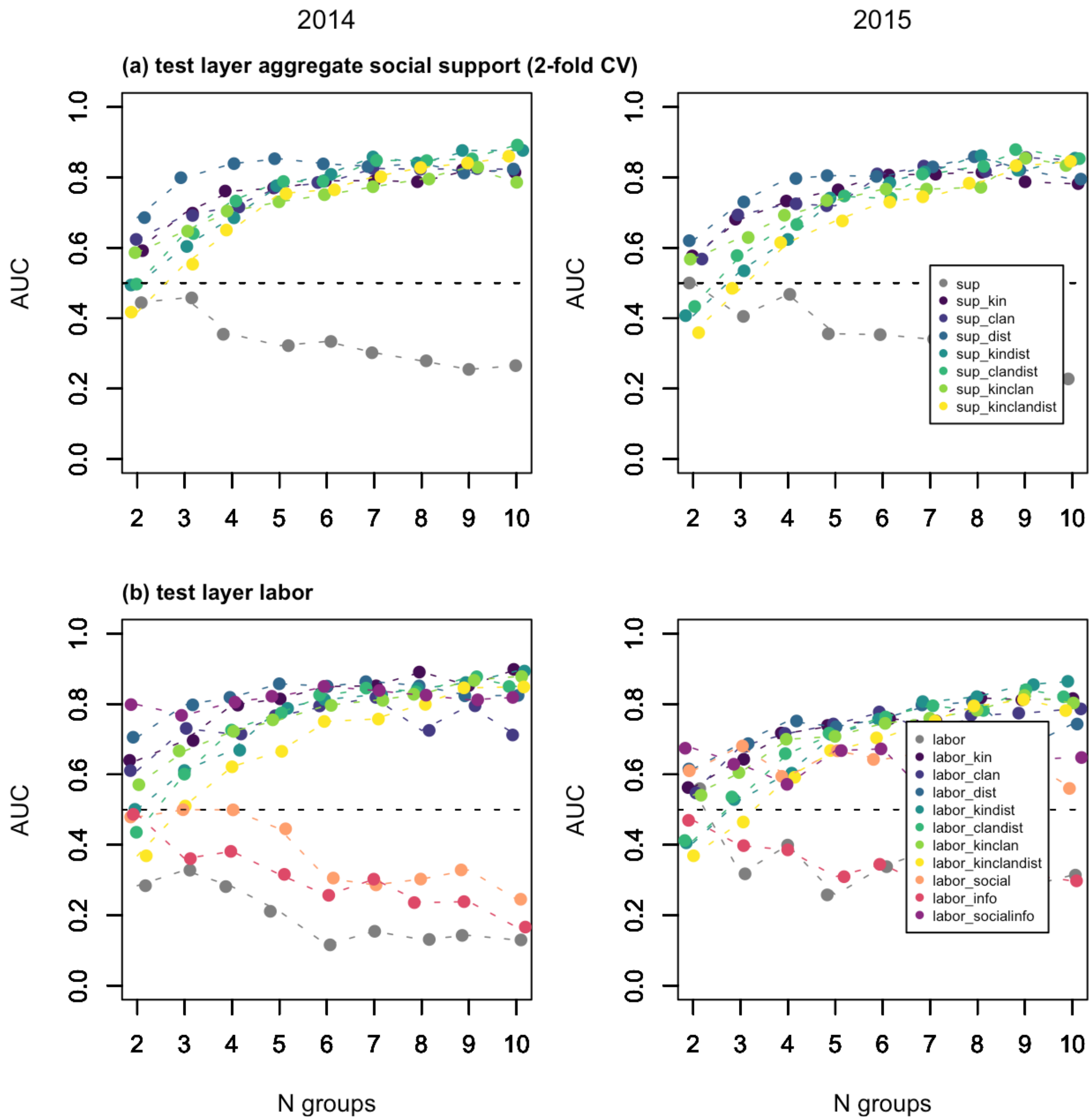

Figure A1.2 Additional model performance metrics for *multitensor* models including the social support (labor, socialization, and information) and harvest layers, with five latent communities. Recall, or "true positive rate," is the proportion of all true cases that were correctly predicted by the model. The false positive rate is the proportion of true negatives that were predicted to be positive. Precision is the fraction of true positives out of the total of true and false positives. Since *multitensor* returns expected mean scores for the existence of a tie between two nodes, link prediction with binary data requires selecting an arbitrary threshold for the existence of a tie based on the model scores. Because AUC evaluates performance directly based on model scores, it avoids the problem of choosing an arbitrary threshold, and is consequently our preferred performance metric in this case. Here, to provide additional information about model performance, we show model recall, false positive rate, and precision for link prediction in the harvesting layer for a range of model score thresholds. Overall, thresholds in the range of 0.05 to 0.1 produce recall over 80% and false positive rates below 10%. Lower thresholds can capture nearly 100% of true positives, but have a higher rate of false positives. However model precision tradeoffs steeply with model recall. This reflects a classic problem in predicting rare events: at low model score thresholds, the models detected based on these layers are very good at recovering the "true" co-harvesting ties, but the model also predicts ties between many households who did not actually harvest together. In our case, we think that our inferences about the interdependence of social support and co-harvesting are not undermined by low model precision (i.e., we think AUC and recall are more important metrics given our inferential goals). Better understanding why some sets of people who have a high predicted likelihood of harvesting together (because they are neighbors or have social support ties) do or do not choose to harvest together in a given year is an interesting topic for future investigation.

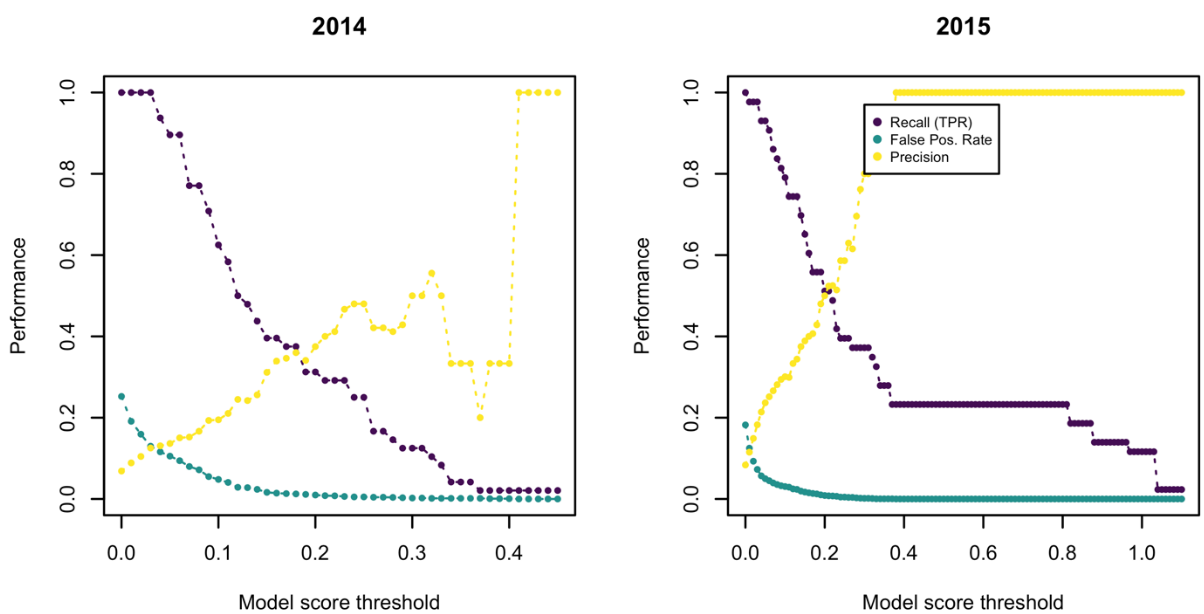

Figure A1.3 Layer affinity scores from *multitensor.* Affinities of latent communities to input network layers in the community detection analysis, for the communities shown in Figure 6. Low values (darker shades) indicate low affinity to a community; high values (brighter shades) indicate stronger affinity of a layer to a community.