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ORIGINAL ARTICLE

An experiment in strengthening the networks of remote communities in the face of environmental change: leveraging spatially distributed environmental memory

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Abstract
Agrarian communities in different regions develop diverse coping strategies to address the environmental changes they face. In this work, we test how to stimulate farmers' social learning across diverse regions to promote informed responses to soil degradation. We invited 117 randomly selected members of 16 randomly selected Sumatran communities to three 3-day networking and training events in regions with diverse socio-environmental histories. One event was held in the respondents' remote rural district (Tanggamus), the second was held in a more densely populated region on Sumatra Island (Kalianda), and the third was held in a heavily populated region on Java Island (Garut and Ciamis). Eighteen months later, we surveyed the information-sharing networks and agricultural practices of 370 members of these communities. The participants had become popular sources of agricultural advice, but the strength of this impact depended on the region in which their networking intervention was conducted. The participants in the event on Java had become the most central members of their communities. Although all the participants received the same formal information, those who interacted with the farmers in a region with the longest history of population pressure and land degradation management were more likely to adopt the recommended practices. The participants in this intervention doubled their odds of adopting organic fertilizers compared with those who networked only with peers in their local environment. Environmental memory of coping with change can be shared between regions through social learning, which can be stimulated by simple interventions.

Keywords Environmental memory · Network interventions · Soil degradation · Social network · Remote communities · Organic fertilizers

Introduction

Informal social networks are crucial for generating and disseminating reflective environmental knowledge (Barnes et al. 2016; Berkes 2009; Carlsson and Berkes 2005; Kapoor 2001; Newig et al. 2010; Pahl-Wostl 2009; Plummer 2009; Plummer and Fitzgibbon 2004). A combination of external and internal informal networks forms a knowledge foundation for community-based adaptive agricultural management in rural areas (Isaac et al. 2007). Because peoples' experiences of environmental change and environmental memory vary by region (Barthel et al. 2010; Easdale et al. 2016; Isaac et al. 2014), interregional social contact, in particular, has the potential to access experience with adapting to environmental change that is not locally available.

We have evidence from urbanized and industrialized contexts that whereas intragroup social network links tend to emerge from everyday life and work, the creation of links to more distant groups may require a special occasion (Burt et al. 2000). In general, long links are the most instrumental for members of "peripheral communities" that are constrained by information and resource scarcity (Letina 2016). The practical question that follows is how to facilitate social networks and social contact across diverse regions to help inhabitants of

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remote rural communities cope with environmental change. It is challenging to intervene in people's social networks because "networks are often formed for a myriad of individual, relational, attitudinal, and environmental reasons" (Valente 2012, p. 51). Can social interventions stimulate interregional information exchange between individuals? Can externally organized events affect the structures of remote communities?

In this study, we attempted to stimulate interregional social contact by inviting randomly selected people to short networking and training events in different locations and measured the impact of the respective interventions on the participants' personal networks and adaptive agricultural practices.

Theoretical framework: Social networks and spatially distributed environmental memory

Formal and informal networks of information-sharing relationships between individuals and groups play important roles in the facilitation of natural resource management, the encouragement or prevention of changes in land use, agricultural innovation, and the diffusion and adoption of farming practices (Bodin et al. 2006; Cadger et al. 2016; Conley and Udry 2001; Demiryurek 2010; Hoang et al. 2006; Isaac 2012; Isaac et al. 2014; Klerkx et al. 2010; Leeuwis 2004; Matous and Todo 2015; Matouš et al. 2013; Prell et al. 2009, 2010; Rogers 2003; Solano et al. 2003; Spielman et al. 2009, 2011; Tengö and Belfrage 2004).

On the one hand, cohesive networks of local bonding reciprocal relationships contribute to the resilience of rural communities (Moser 1996; Prior and Eriksen 2013). On the other hand, external bridging links are useful for accessing locally unavailable information about sustainable natural resource management (Bodin and Crona 2009; Demiryurek 2010; Isaac et al. 2007; Isaac and Matous 2017; Newig et al. 2010; Newman and Dale 2007). "Boundary-spanning individuals" (i.e., individuals who connect different networks) and external links to outreach professionals are known to contribute to the innovativeness of agricultural systems (Klerkx et al. 2010; Lubell et al. 2011). Bridging ties across distinctive groups can diffuse insular land management techniques by exposing network members to different practices (Cadger et al. 2016; Klerkx and Leeuwis 2008; Klerkx and Leeuwis 2009; Newman and Dale 2005). Agricultural producers with links to external actors are more successful at managing agrodiversity (Isaac 2012).

Peers who belong to the same community and live in the same environment may be likely to possess farming knowledge directly applicable with little adaption to plots of their neighbors (Matous 2015). However, without new external inputs, much of this knowledge might have been already known and shared within the community. Linking only to similar actors through internal bonding ties leads to a reliance on redundant information and can hinder sustainable environmental management (Newman and Dale 2007; Prell et al. 2009). People tend to lock into the same behavior as peers in their group, which may lead to the rigid continuation of maladaptive practices and avoidance of innovative change (Scheffer and Westley 2007). Linking to people in different, and especially more distant, districts is valuable because such people may have encountered diverse environmental situations and may have access to different institutions and locally embedded knowledge and experience that cannot be accessed locally.

From a general perspective, social capital theory explains that different resources are likely to be embedded in different parts of social networks (Lin 2001); therefore, topologically long ties that cut across "structural holes" or create shortcuts to topologically distant parts of the network structure can reach diverse and valuable resources, as indicated in Fig. 1 (Burt 1995; Granovetter 1973). Similarly, different tangible and intangible resources are available in different geographical areas, and geographically long links that connect people in distant spatial locations can provide access to otherwise unavailable information.

In relation to adaption to environmental change, Isaac et al. (2014) showed that farmers who migrate from regions in which they have experienced environmental conditions unknown to local farmers leverage their environmental experience and adopt practices that are useful but not widely known in their new destination. Similarly, Easdale et al. (2016) argued that pastoralists who have experienced diverse ecosystems in different locations develop a more diverse portfolio of adaption strategies.

However, environmental experience is not isolated within the memories of individuals. Barthel et al. (2010) theorized the concept of social or collective memory in relation to ecological practices, knowledge, and experience transmitted among individuals. According to the authors, community "social-ecological memory" is enhanced by social networks reaching individuals beyond the group. Spatially extensive information-sharing social networks can connect diverse environmental experiences of distant farmers, and individuals with geographically long links may access highly valuable non-redundant information and diverse environmental memory embedded in different locations. However, such long links are rare. In remote agrarian communities, links between individuals who do not frequent the same locations are unlikely to emerge without external intervention. The probability of interpersonal social interactions decreases with distance and across administrative boundaries (Grauwin et al. 2017), especially within populations characterized by limited physical mobility (Matous 2017; Matous et al. 2013). Researchers can never completely uncover the structure of social networks across entire regions, but in door-to-door communities, geographically long links are also inevitably topologically long, which is not always the case in other contexts.

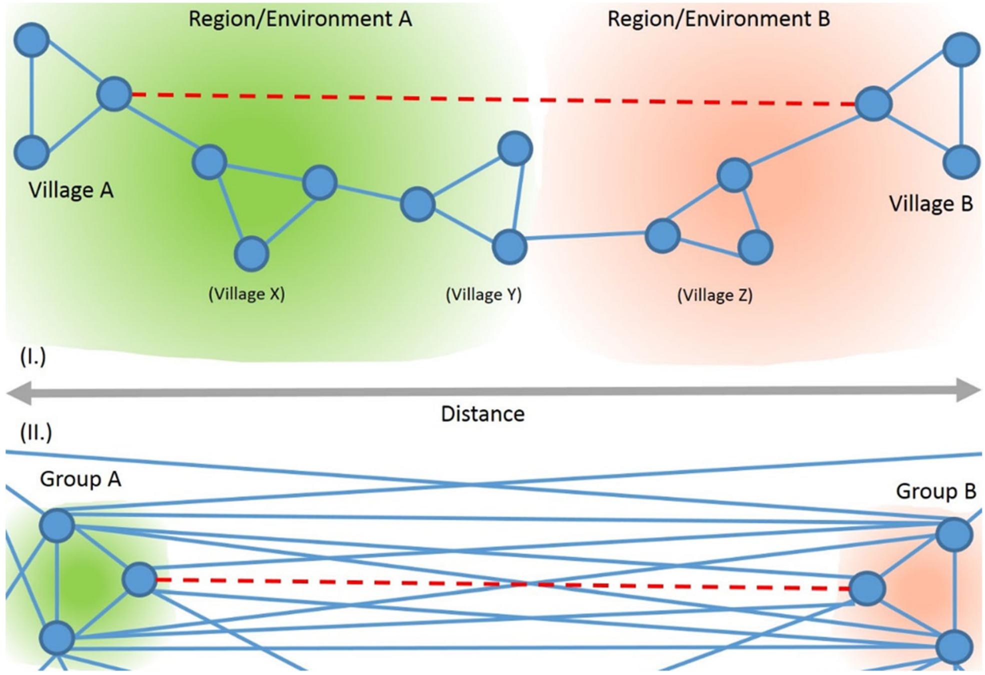

Fig. 1 Geographically long links can enable social learning between groups in different regions with diverse environmental memory. "Topologically long" links create shortcuts in the structure of the social network and access otherwise unavailable non-redundant knowledge in different parts of the social network. Circles in this figure symbolize people distributed in space, and lines symbolize their information-sharing relationships. The dashed lines highlight geographically long links connecting people in different regions. The geographically long dashed link creates a topological shortcut in case I, in which geographically long relationships are rare, but not in case II in the bottom part of the diagram, in which geographically long links are abundant

We explain this phenomenon using an example. Imagine two distant villages with little access to transportation. Farmers with geographically constrained networks are unlikely to know anyone in the other village. Moreover, they are unlikely to know anyone who knows anyone in the other village because everyone they know lives nearby, and the same is true for all their friends (Fig. 1, upper part). In contrast, in contexts with abundant communication and transportation infrastructure, in which geographically long links are common, geographically long links are not necessarily topologically long. Imagine two intensively collaborating research groups in two distant cities. If two new members of the respective groups created a new interpersonal link to one another, it would be geographically long, but it would not be topologically long because there were already other links present between individuals in the two groups. Thus, the new link would not significantly decrease the average path lengths between actors in this network (Fig. 1, lower part). Importantly, such a new link would be relatively less likely to improve access to non-redundant knowledge between the two groups because of the already ongoing active information exchange through other relationships.

Due to the rarity of long links in most empirical studies of human-environment interactions, these studies tend to treat social interactions as self-contained, assuming that the few links to the external world are sufficiently weak to neglect (Brondizio et al. 2009). This approach is not ideal. A single long link, even if not as strong as the local links, can significantly decrease distances within the entire network (Watts 1999; Watts and Strogatz 1998) and increase the overall community capacity for pro-environmental management (Isaac et al. 2014).

Based on the reviewed theory that diverse social-ecological memory is embedded in diverse regions, we hypothesize that farmers who are given an opportunity to develop social network links with peers in different regions will become (1) pioneers of adaptive agricultural practices and (2) important sources of information in their communities. We test these hypotheses by comparing randomly selected groups of farmers who were given an opportunity to develop social network links with peers at different locations. We expect interventions that bring farmers in contact with peers in locations with a longer history of population pressure on agricultural land will have a stronger impact than comparable interventions in their home environment.

Land degradation and organic fertilizer use in Sumatra and Java

The importance of organic inputs to restore soil fertility has been generally recognized in Indonesia (Food and Agriculture Organization 2005). However, soil health and attitudes towards land management vary across the country. Agricultural development in Indonesia has followed the growth of population and its geographical distribution (Food and Agriculture Organization 2005). Most of Indonesia's population inhabit the inner islands of Java, Madura, Bali, and Lombok, which comprise only approximately 8% of Indonesia's landmass. Java, in particular, has a long history of coping with population pressure on farming land and soil degradation (Lukas 2014; Verburg et al. 1999). Javan farmers had to start searching for adaptive land management responses before farmers on less densely populated outer islands. Despite the history of intense farming in Java, the soil health is currently considered to be relatively better managed and a significantly lower proportion of the cultivated land is considered nutrient deficient compared to that of the outer islands, such as Sumatra (Food and Agriculture Organization 2005).

One method to restore soil health is to add organic matter to the root zone (Kassam et al. 2009). Increasing soil organic matter is often the principal means via which N, P, and K are held in the soil (Breman et al. 2001). However, organic fertilizers are still not universally adopted in Sumatra. Although chemical fertilizers have been used on the island for decades, organic fertilizers have become popular only within the last several years. Until relatively recently, the addition of organic nutrients was non-systematic, and the potential of this practice as a mechanism to address soil degradation is not yet sufficiently appreciated by many Sumatran farmers (Matous 2015). Farmers who have begun systematic use of organic fertilizers typically learned the technique from external sources. Several farmers adapted the technique to the local conditions by experimenting with different types of leaves and plant residuals, goat urine, and water in different proportions based on their experience and that of their peers (Matous 2015). Dried animal manure is the most popular organic fertilizer in Sumatra. Animal manure releases N slowly and consistently and supplies nutrients and organic material that are not included in chemical fertilizers (Seufert et al. 2012). Manure and organic materials conserve soil and water, improve soil structure, prevent erosion, reduce nutrient leaching, strengthen the mechanisms of elemental cycling, and support biodiversity in the soil (Matson et al. 1997; Cassman 1999).

Yield restoration is the main motivation for farmers in southern Sumatra who have adopted organic fertilizers. The local farmers do not typically consider the environmental conditions outside of their plot in their decisions to complement or (partially) replace chemical fertilizers with organic fertilizers (Matous 2015). Nevertheless, their adoption of organic fertilizers has the potential to offset environmental degradation beyond their field. Soil organic carbon functions as a biomembrane that filters pollutants, reduces sediment loads and hypoxia in surrounding waters, and degrades contaminants. Organic fertilizers are a sink for atmospheric carbon dioxide and methane and may reduce N emissions from cropland and nitrous oxide emissions from animal management (Lal 2004; Scott et al. 2002). Thus, in addition to positive local impact, the application of organic fertilizers can help to mitigate climate change. According to representatives of the Forestry and Crop Estate Service Department of Tanggamus district in Sumatra, the adoption of organic fertilizers is one of their main priorities.

Methods

Environmental training and network interventions

The interventions described in this study were conducted in February 2013 (18 months before administering the network survey described below). One hundred and fifty-six local residents were randomly selected and invited to participate in a 3-day training; 117 accepted the invitation and participated. Each of the participants was randomly assigned to one of three events held in different regions (Fig. 2). Thus, this study provided three types of treatment, and each was compared separately to the control group. The differences between the three types of treatment A, B, and C are as follows. Training A was held in Gisting, which is a town in the center of the research area in the Tanggamus district. The population of Tanggamus is 478,568, the area is 3357 km^2, and the population density is 143/km^2. Training B was held in Kalianda in the South Lampung district. The population of South Lampung is 959,126, the area is 2109 km^2, and the population density is 455/km^2. Training C was held in Garut and Ciamis on Java Island, which has a total population of 3,974,837, a total area of 4508 km^2, and a population density of 882/km^2. Training A was within 10 km of the surveyed villages, Training B was approximately 140 km from the surveyed villages, and Training C was approximately 570 km from the surveyed villages. In each case, the participants were transported to these locations collectively by chartered buses (and a ferry in the case of Training C). Except for the different locations, the events' programs and content were identical.

The official purpose of the events was education about resource-conserving agricultural practices. The Tanggamus district is currently characterized by unsatisfactory agricultural productivity caused by land degradation (Matous 2015). The soil quality is deteriorating, and many of the local coffee and cocoa plants are experiencing declining yields. Some producers attempt to offset the decline in productivity on their plots by deforestation and by converting more land to agriculture. Local coffee and cocoa growers have attempted to improve their productivity through an excessively intensive application of chemical fertilizers, a strategy that can further deteriorate the soil quality and negatively impact water quality in the surrounding environment (Hufnagl-Eichiner et al. 2011). Given these challenges and the priorities of the Forestry and Crop Estate Service Department in the Tanggamus district, the training explained the general importance of resource-

Fig. 2 **a** Location of the surveyed Tanggamus district and the nearest intervention, **b** location of the intervention in Kalianda, and (**c**) location of the furthest intervention in Garut and Ciamis (Backdrop: Google Maps)

conserving practices, such as partial substitution of chemical fertilizers with organic alternatives. Importantly, the training participants could observe agricultural practices on the farms of their local counterparts in each location.

Although the networking component of the interventions was not emphasized in the invitations to the participants, the program allowed sufficient time for discussion and socializing at the training locations. The training was designed around collective activities with local farmers to enable the development of friendly new relationships and included social games and sightseeing.

A similar number of local farmers to the number of the experiment participants were invited to the events by the extension office in each location. These were volunteers who were interested in spending time with the visitors. This allowed the participants to create informal information-sharing links with farmers in different villages, which would rarely occur under natural conditions without this intervention. The local farmers participated in the training and brought the visitors to their farms to demonstrate their practices. The selection of the farmers in the target location was not random. It is likely that the farmers who were invited by the local officials to meet with the visitors and bring them to their farmers are considered more successful farmers. Unfortunately, we were not able to survey the farmers in the visited areas. It is one of the limitations of this study that we do not have quantitative data characterizing the visited farmers in each location.

Another limitation is that unlike randomized controlled trials in medicine, there is no perfect placebo in network interventions in the field. Naturally, the participants knew where their training was held, but they were not informed about the theoretical relevance of the location and the networking component of the intervention. Moreover, there was 18 months between the interventions and the survey of networks and practices. This time gap decreased the probability that the participants' answers would be influenced by short-term impressions from their trips or their awareness of being part of the treatment group.

Survey data

In 2014, the research team administered face-to-face fixed-form questionnaires in the respondents' language and collected network data on 1270 relationships among 370 heads of household. In this agricultural region, each respondent belongs to one of 16 local coffee- and cocoa-producing farmer groups. The farmer groups were selected from a list of the 36 coffee and cocoa farmer groups in the Pulau and Sumber Rejo subdistricts of Tanggamus by generating random numbers. To enable valid comparisons among farmers who grow similar crops, only coffee- and cocoa-producing farmer groups were targeted; this sample is considered representative of these two subdistricts. This group also represents the same sample from which the training participants were randomly selected.

The main purpose of the farmer groups is to share agricultural information, especially experiences with resource-conserving practices such as the application of organic fertilizers. The group members are expected to meet monthly to discuss how to address issues encountered on their farms. Although all the members of each farmer group know one another, they do not consciously learn from every other member of the group, which was confirmed by the survey. Not all group members communicate or socialize with each other outside of compulsory events. Nevertheless, the government encourages active collaboration and information exchange within the groups to promote better-informed resource-conserving practices and sustainable agricultural technologies in remote rural areas. Although some farmer groups have existed informally for decades, most of the groups were formalized in 2007 and 2008 in response to a new governmental policy regarding information dissemination and the provision of agricultural support. The typical size of a farmer group is approximately 20 households.

We collected data on the inhabitants' most important sources of agricultural information both inside and outside of the groups. Our interviewers asked self-identified household heads to name persons from whom they received agricultural information. Specifically, the English translation of the network prompt is as follows: "Please list all people you can recall from outside this household from whom you seek advice, from whom you can learn, or who can generally provide useful information about farming practices." The location of the information sources was identified.

The interviewers also asked whether the respondents used any organic fertilizers on their farms. Optimal dosages for organic fertilizers are not agreed upon in Indonesia, and the exact fertilizer amounts that farmers apply are difficult to ascertain (Food and Agriculture Organization 2005). Therefore, instead of dosage, we examined only adoption vs. non-adoption of organic fertilizers, which is the most relevant and most reliably obtainable measure.

Previous surveys of farmer groups in Sumatra did not find any correlation between observable characteristics, such as education and cultivated land, with internal vs. external links (Matous 2015), and we do not focus on personal variables in this study. In the case of the present experiment, randomization mitigates any potential effect of socio-economic, geographic, or unobservable variables. We confirm that the three groups of participants exposed to the intervention and the control group did not noticeably differ in terms of their members' experience prior to the intervention. We tested the outcomes of randomization by focusing on the participants' ages and formal education. Both of these variables are potentially related to knowledge, experience, and attitude towards innovative practices (Rogers 2003). However, because age and previous years of formal education are not affected by our intervention, these must also be the same across all groups after the intervention. If we found a difference in the average age or education levels between the groups, it would mean that the randomization was erroneous. This was not the case, as explained in the section "Results."

Measures and analysis

The farmer groups are an important element of this analysis. We are interested in the interplay of external long links that have the potential to bring new knowledge to these groups and internal links that enable the network members to locally share and adapt the knowledge within the group, thus fulfilling the purpose for which these groups were established.

The present network analysis is at the level of interpersonal relationships between individuals. Although social network analysis has recently become a popular tool for examining interorganizational relationships for effective regional environmental governance (Baird et al. 2016; Ingold and Leifeld 2016; Klein et al. 2016; Luthe et al. 2012; McConney et al. 2015; Schoon et al. 2017; Varela-Ortega et al. 2016), analyses of the role of interpersonal relationships in adaption to regional environment change at the individual level remain rare (Isaac and Matous 2017).

Previous field studies have shown that network density is generally an important social network metric for natural resources management (Bodin and Prell 2011). In a network of a given size (i.e., the number of members in each farmer group), the network density is determined by the number of links possessed by each network member (i.e., the degree of each network node). Because it is informative to differentiate information seekers from information providers, we distinguish between the incoming and outgoing links of each node. Incoming links to a node signify those who seek an individual for information, and outgoing links signify those whom the individual seeks. Considering the link direction, we calculated the outdegree and indegree measures.

The outdegree is the number of outgoing links from a node, i.e., the number of information sources named by a respondent. When computing the outdegree, we distinguish between sources of information within and outside of the respondent's farmer group. The sum of outgoing links within the group is the respondent's "internal outdegree." In addition to this metric, we consider the number of outgoing links that reach outside of the group. From those links, we identify the subset of geographically longest ties that reach information providers in other administrative districts (i.e., links longer than 30 km). The outdegree may be subject to a recollection bias and may reflect the level of the respondent's cooperation during the interview. More active respondents and respondents who consider the researched network highly important to them may name more network partners (Robins 2015).

In contrast, the indegree is not related to the answers of the individual in focus—it is calculated from the responses of all other respondents in the network. Indegree is the number of people in the network that have identified the respondent in focus as a useful information source. Because each indegree value is aggregated from the answers of multiple respondents and because the value is not affected by self-reports, it is considered a highly reliable popularity measure (Wasserman and Faust 1994). If a large number of respondents identify a particular individual as an important source of information, that person is a highly popular advisor in the group.

Note that the indegree of a person in the treatment group depends on the personal networks of the people in the control group and vice versa. Thus, comparison of the indegree values enables us to assess the effects of the intervention beyond the treatment group. The indegree values capture the connections between the treatment and control groups (which are disregarded in traditional randomized controlled trials), thus enabling us to understand the effect of the intervention beyond the treatment group.

The analyses in this study focus only on direct comparisons of the outcomes of the social experiment in terms of the most fundamental network measures mentioned above. Because of the unique design of the experiment and the identical content of the trainings at all locations, we can directly observe the relevance of the newly created external links for agricultural practice in relation to their geographical length. Using *t* tests, we compare the respondents in the control group with respondents who received the three types of treatment. The comparison is conducted in terms of (1) the indegrees within the farmer groups, (2) the outdegrees within the farmer groups, (3) the number of links reaching outside the farmer group, (4) the number of geographically long links outside the administrative district, and (5) the adoption of recommended organic fertilizers. We report fully all *p* values of all conducted comparisons. We do not use any arbitrary threshold of "significance" to categorically dismiss results slightly above some traditional thresholds used for *p* values, and we also treat with caution results with *p* values below tradition thresholds. We also present the distribution of the impact of the intervention across the sample in the form of kernel density diagrams in the "Supplementary Material." All of the analyses were conducted using R (R Development Core Team 2008).

Results

Descriptive statistics

First, we present descriptive statistics for the entire sample (top part of Table 1). A typical local farm representative has received 9 years of formal schooling. Six persons had no formal education; one participant had 18 years of formal schooling. The average age of people in the sample was 45 years old. Two people in the sample were at the bottom of the age range, at 24 years old; the oldest participant was 85 years old. Importantly, we confirmed that the means of these variables are virtually identical for all groups. This result supports the assumptions that the randomization was executed correctly and that, overall, there were no significant differences among the groups of participants prior to the training. Specifically, in all cases, the *t* test rejected the hypothesis that any of the group members differed from the treatment group in terms of the compared measures. All *p* values were greater than 0.6.

In terms of the descriptive network statistics, the local inhabitants typically consider two other members of their groups as important sources of information. However, some do not find anyone in the group to be a useful source of agricultural information and on the opposite end of the spectrum, one person mentioned approximately half of the group members (9) as useful advisors. The indegree values, i.e., nominations received from others, are even more unevenly distributed. Whereas the median number of nominations is 1 (i.e., a "typical" local inhabitant is considered by one other group member to be a useful source of information on farming), the most popular advisor received 24 nominations (see also the "Supplementary Material").

Although long-distance links to other districts are rare, each of these rare long links can greatly increase the connectivity between people in the society (Watts 1999). Whereas the respondents had on average 1.6 information sources outside of the farming group, only 0.12 of those sources were in other districts (i.e., they represented links longer than 30 km).

Seventy-two percent of the farmers in the entire sample used some type of organic fertilizers on their plots at the time of the survey. The next section will reveal that the prevalence of fertilizer usage differed significantly between the participants in the long-distance intervention and others.

Intervention outcomes: Social network reinforcement and land management practices

This section compares the network intervention outcomes for each of the three treatments with the control group of the non-participants (Table 1). This approach allows us to discern which type of treatment impacts which variable and how much. The text below describes the main findings.

It appears that the participants in the training on Java approximately tripled the number of their long-distance links compared to the local-event participants and non-participants and retained these new links for at least 18 months after the events. These participants (intervention C in Table 1) had an average of 0.32 out-of-district long links during the post-survey, whereas the control group had an average of 0.09 ($p = 0.066$). The participants in interventions A and B did not have significantly more long links than the control group after the intervention (see the *t* test *p* values listed in Table 1).

The higher number of reported long links among the participants in intervention C is unlikely to be an artifact of the research design. The intervention participants did not become overall more cooperative during the data gathering, nor did they provide more names during the interviews. There is no significant difference in the number of reported information sources within the communities (i.e., the internal outdegrees) between the treatment groups and the control group. The average internal outdegree of the participants in the training in Java is only very slightly less than that in the control group

Table 1 Intervention results. The top part of the table describes the overall sample. The remainder of the table displays the results split by the training intervention groups in locations A, B, and C and the results for the control group (0). The presented *p* values are an outcome of *t* tests examining whether the respective interventions increased the number of incoming, outgoing, external, and interdistrict social links per person and whether the interventions increased the rates of organic fertilizer adoption

Entire surveyed sample ($N = 370$)					
Respondents in Pulau Panggung subdistrict			222		
Respondents in Sumber Rejo subdistrict			148		
Number of groups			16		
	Minimum	Median	Mean	Maximum	*p* value
Respondents per group	11	22	23.1	39	
Formal education [years]	0	9	8.51	18	
Age [years]	24	45	46.27	85	
Internal indegree	0	1	1.84	24	
Internal outdegree	0	2	1.84	9	
Number of all external links per respondent	0	1	1.55	9	
Number of out-of-district links per respondent	0	0	0.12	5	
Organic fertilizer adoption (1 = adopted; 0 = did not adopt)	0	1	0.72	1	
(A) Participants in the same district ($N = 38$)					
Internal indegree	0	1	2.53	24	0.054
Internal outdegree	0	2	2.11	7	0.259
Number of all external links	0	1	1.18	5	0.927
Number of out-of-district links	0	0	0.11	3	0.448
Organic fertilizer adoption (1 = adopted; 0 = did not adopt)	0	1	0.71	1	0.427
(B) Participants in different district on Sumatra Island (N = 37)					
Internal indegree	0	2	2.57	11	0.012
Internal outdegree	0	2	1.89	5	0.527
Number of all external links	0	1	1.76	9	0.216
Number of out-of-district links	0	0	0.08	2	0.558
Organic fertilizer adoption (1 = adopted; 0 = did not adopt)	0	1	0.81	1	0.056
(C) Participants on Java Island ($N = 42$)					
Internal indegree	0	1	3.21	17	0.006
Internal outdegree	0	1	1.55	7	0.914
Number of all external links	0	2	1.95	8	0.074
Number of out-of-district links	0	0	0.32	4	0.066
Organic fertilizer adoption (1 = adopted; 0 = did not adopt)	0	1	0.83	1	0.019
(0) Non-participants ($N = 263$)					
Internal indegree	0	1	1.41	14	
Internal outdegree	0	1	1.84	9	
Number of all external links	0	1	1.50	6	
Number of out-of-district links	0	0	0.09	5	
Organic fertilizer adoption (1 = adopted; 0 = did not adopt)	0	1	0.70	1	

(1.55 vs. 1.84). The training participants who gained contacts outside of the group might need to seek less information within their group, but this difference is not statistically significant. Importantly, the interventions had the most significant positive impact on the participants' indegrees, which are calculated from the answers of other respondents and are independent of the answers of the focal respondent.

The difference between the mean indegrees of the intervention participants and the control group increases with the distance of the intervention and the corresponding change in the intervention context. Additionally, the intervention effects on the participants' indegrees are more clearly significant at longer distances because the corresponding *p* values gradually decrease with distance (0.05, 0.01, < 0.01). The networking event in Java had the largest impact on the participants' popularity within their communities; the average indegree of the participants of this intervention was 3.2, whereas the average indegree of the non-participants was 1.4 ($p = 0.006$).

A comparison of the control group and treatment group C suggests that the training in Java decreased the proportion of group members who were not considered useful sources of information by anyone from 40 to 26%. This means that the odds of not being considered a useful information source were approximately halved by the intervention. (The original odds of $0.40/0.60 = 0.67$ decreased to $0.26/0.74 = 0.35$.) The decrease in the proportion of people who had no out-of-district links is visually depicted in the "Supplementary Material."

Importantly, Table 1 shows that the region in which the networking event occurred is related not only to the resulting participants' network geography but also to the ultimate outcome of interest, i.e., the farmers' land management practices. Whereas only 70% of the farmers who were not selected for any training and 71% of the farmers who were selected for the training near their villages use organic fertilizers, the proportion is 81% ($p = 0.056$) and 83% ($p = 0.019$) for the farmers selected for trainings B and C conducted in other districts, respectively. The long-distance intervention in Java more than doubled the odds of organic fertilizer adoption. The odds of organic fertilizer adoption after the intervention in group C were $0.83/0.17 = 4.88$, whereas the odds of adoption in the control group were $0.7/0.3 = 2.33$. The odds of adoption in group A were $0.71/0.29 = 2.44$. Thus, the estimated increase in odds was more than double for the intervention in Java compared to that for no intervention ($4.88/2.33 = 2.09$) and double that obtained for the local intervention ($4.88/2.44 = 2$). This estimate is a lower bound on the real effect of the intervention. Because the members of the control group disproportionately seek individuals with links to different regions for new information, some of the effects of the intervention presumably spill over. Therefore, the proportion of adopters in the control group might have been lower had there been no intervention in the treatment group.

Overall, the set of statistical tests on the three treatments supports the previously stated hypotheses. Those who participated in the network event in Java created interregional information-sharing links that remained active 18 months later, and other people sought information from those who received the opportunity for interregional social learning. Moreover, the exposure to practices in different regions contributed to the adoption of the recommended agricultural practices.

Discussion

Research regarding social networks in natural resource management and environmental conservation has made significant progress in explaining when and how social networks matter. Communities need both external and internal social networks. External links channel new information from the outside, which is shared, recombined, and locally adapted within internal networks for the purpose of the community (Isaac and Matous 2017). After the case for the importance of networks in natural resource management has been made, the next practical question is, what can we do? How can we enhance existing network structures?

This experiment comprised three treatment types and demonstrated that short-term exposure to diverse regions, environments, and people can have long-term impacts on the networks and practices of remote rural communities. The participants in the training in Java created interregional information sharing links and increased their likelihood of adoption of suitable environmental practices. Moreover, the interregional intervention participants became more in-demand sources of information, likely because they could access diverse tacit knowledge that is not available in their communities by learning from farmers practicing agriculture in different environments. The intervention did not only help the better-connected individuals; the least-popular community members also benefited. For the participants in the intervention in Java, the odds that no one else in their farmer group would consider them as useful sources of information decreased by half.

Our interpretation of the lower impact of networking with farmers in locations A and B is that the experiences and practices of farmers living in these relatively more similar regions overlap more with the experiences and existing practices of the intervention participants. The problem of redundant knowledge seems to be the strongest in the case of intervention A, during which the farmers networked with their peers in the same region. Partially because of a shorter history of soil degradation, the farmers in the studied region have not yet widely adopted strategies to address this environmental problem, and we do not see a significant impact of introducing local farmers to one another on the adoption of organic fertilizers. There seems to be less benefit in conducting a social network intervention aimed at meeting new people and learning new practices with people who have the same experience and practice the same techniques. However, it should be noted that although it was not as strong as the other interventions, even intervention A might have some positive effect on the perceived expertise of the participant within their communities, as measured by their indegrees ($p = 0.054$).

In terms of average indegrees, adoption of new soil management practices, and corresponding p values, the outcomes for the intervention B fit quantitatively between those of the intervention A and the intervention C. The results support the idea that there are benefits to farmers' exposure to different environments and to people with diverse environmental experience. Region B is between Region A and C not just in terms of geographical distance but also in terms of potentially relevant characteristics such as the history of coping with soil degradation. As described in "Methods," the location of intervention B is more densely populated than location A and although it is also on Sumatra, it is placed more centrally in Southern Lampung, which is the southern tip of Sumatra to which people come from Java. Networking with farmers in this location produced slightly more convincing outcomes than those of the training at home, but the outcomes do not seem as strong as for learning from farmers in the central and densely populated location on Java Island with a long history of coping with land degradation.

Previous cross-sectional research has shown that farmers with access to external information through their bridging links (1) tend to use more progressive resource-conserving practices and (2) are more popular as information providers in their communities (Isaac et al. 2007; Matous 2015). This experimental study contributes to the evidence that there is a causal relationship between access to external information outside of one's community and popularity as an information source inside the community. Farmers who received both training in resource-conserving practices and opportunities to interact about this topic with farmers in diverse regions have become more sought after advisors than farmers who received identical training but interacted only with other local farmers during the training. They have become "information gatekeepers" for the communities (Allen 1977; Bouhnik and Giat 2015). They were also significantly more likely to adopt organic fertilizers to cope with soil degradation on their land. This result demonstrates how interregional social contact can contribute to resource conservation and adaptive environmental practice adoption. Whereas all training participants received the same formal classroom training regarding the importance of resource-conserving practices, the participants who interacted with farmers in distant locations with the longest history of population pressure and land degradation management were significantly more likely to use this formal information in practice.

Compared to farmers in different regions and environments, the probability is lower that farmers next door will have knowledge of fundamentally different basic practices that are completely unknown to their neighbors. As we previously described, the regions objectively differ in terms of population density and the history of population pressures on soil. Whereas the experimental design allows us to prove that the region in which farmers learn from others matters, we cannot prove which of the differences among the regions caused the difference in the outcome of otherwise equivalent treatment. It is not the distance per se that makes the knowledge from more faraway regions more valuable. Overall, a plausible explanation of the substantial differences observed in the results of the three types of treatment in our social networking experiments is that communities in region C have environmental experience and the know-how of practices that are useful but not widely known in region A.

Conclusions

This article explored the role of interpersonal relationships and experimentally stimulated interregional social learning in adaption to environmental change in remote rural areas. Farmers who lack personal experience with alternative land management methods cling to practices that contribute to soil degradation on their plots, even if they are acutely aware of the deterioration of their local agroecosystem. Previous studies have shown that a smallholder's earlier experience of living and farming in a different environment can contribute to innovative pro-environmental management in their new location (Isaac et al. 2014). Our findings suggest that long-term migration is not necessary. Even a short intervention can promote social contact and learning from other people's experience in a different environment. However, the impact of training interventions seems to be smaller when organized in a familiar home environment with peers who have the same environmental experience and similar practices. Collective environmental experience is embedded in social networks, and interregional social contact can connect spatially distributed environmental memory of diverse individuals and groups and increase smallholder farmers' capacity for adaptive management.

The usefulness of environmental memory is not limited to the location where it was gained. Extended social networks lead to extended environmental experience and a more versatile and adaptive land management knowledge base. The by-product of expanding farmers' social space of interactions and informal information exchange is increased awareness of alternative agroecosystem management strategies. Social networks that span agrarian communities in different regions, climates, soils, and agricultural administrative systems are rich in complementary experience of environmental adaption. People who can connect non-redundant knowledge from diverse contexts are more likely to progressively respond to environmental changes. By enabling the exchange of alternative farming techniques and the transmission of agroecosystem management strategies between regions, farmers with access to information from diverse communities in which people have already developed necessary coping strategies act as agents of adaption to environmental change. Importantly, we can support the interregional exchange of environmental memory of coping with change by relatively simple interventions.

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