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Research, part of a Special Feature on Social Network Analysis in Natural Resource Governance

Can Properties of Labor-Exchange Networks Explain the Resilience of Swidden Agriculture?

Sean S. Downey [1]

ABSTRACT. Despite the fact that swidden agriculture has been the subject of decades of research, questions remain about the extent to which it is constrained by demographic growth and if it can adapt to environmental limits. Here, social network analysis is used to analyze farmer labor-exchange networks within a chronosequence of five Q'eqchi' Maya villages where swidden agriculture is used. Results suggest that changes in land-use patterns, network structure, reciprocity rates, and levels of network hierarchy may increase the resilience of these villages to changes in the forest's agricultural productivity caused by ongoing agricultural activity. I analyze the suitability of subsistence- versus market-oriented agricultural labor for reciprocal labor exchange and develop a novel interpretation of labor reciprocity that highlights how unreciprocated exchanges, when they occur within the context of a network, may limit overexploitation of the forest. The variability observed in labor-exchange network structure across villages suggests that Q'eqchi' swidden can maintain its identity under changing conditions. This important characteristic of resilient systems is explored by analyzing a village case study where a serious demographic exodus dramatically impacted their labor network. The resulting picture of Q'eqchi' swidden agriculture is one of resilience rather than homeostasis. Reorganization of labor-exchange networks helps to maintain a village's cohesion, and ultimately this limits pioneer settlements and may slow overall rates of deforestation.

Key Words: *adaptive cycle; common-property resource management; labor exchange; Maya; panarchy; Q'eqchi' resilience; social network analysis; swidden*

INTRODUCTION

Traditional views of swidden agriculture describe it as highly constrained by a linear relationship between population growth and land use (Malthus 1826, Boserup 1965, FAO 1987). In contrast, C. S. Holling's adaptive-cycle model predicts resilience in homeostatic cycling as coupled human–natural systems learn about fluctuations and adapt to them through time (Gunderson and Holling 2002). Holling's model has been used to explain how resilience is maintained in diverse systems such as pastoralism in Australia, Africa, and the United States (Walker and Abel 2002), North American lake eutrophication (Carpenter et al. 1999), and boreal-forest succession (Drever et al. 2006). However, swidden agriculture has proven more difficult to model because our understanding of its dynamic properties is limited, and relatively few studies have examined its adaptive properties (Alcorn and Toledo 1998, Robichaud et al. 2001, Dalle and de Blois 2006). Alcorn and Toledo proposed that the adaptive-cycle model fits annual planting practices used by Mayan swidden farmers in Mexico, and that the resilience of these communities could be increased if the national government provided support for strong community-level property rights. The idea that swidden could be adaptive in a contemporary socioeconomic context is important, but the authors did not address the fundamental tension between resilience and carrying capacity. Thus, the central question of swidden agriculture is whether it is simply limited by carrying capacity, or if it exhibits resilience as predicted by panarchy theory. To explore this question, I use social-network analysis to expose unexpected hierarchical and dynamic properties within Q'eqchi' swidden labor-exchange networks. I analyze why the development of network properties correlate with decreased land-use rates,

[1]Stanford University

and propose an alternative model to explain how these features can increase the resilience of swidden agriculture.

The adaptive-cycle model is one of the foundations of panarchy theory, and attempts to explain the nature of resilience in coupled human–natural systems (Gunderson and Holling 2002). “Resilience” is the capacity of a system to withstand perturbation without collapsing or changing into a qualitatively different state. Here, the system in question is a network of labor relations among swidden farmers within a village. The adaptive cycle is a conceptual model designed to explain how systems like this accumulate resilience over time. It proposes that systems cycle between four key phases: growth (*r*), conservation (*K*), collapse (Ω), and reorganization (α). In any one system, there may be multiple adaptive cycles operating at different temporal and spatial scales, and cross-scale links help the system retain flexibility and increase resilience. However, so far in the development of panarchy theory, the adaptive cycle has remained essentially a heuristic device. In part, this is because we lack general analytical tools to assess variation in resilience, particularly in social portions of coupled systems. Although this level of abstraction was originally intended to accommodate substantive differences between human and natural systems, application to the analysis of real systems requires a more quantitative approach.

The Q’eqchi’ Maya of southern Belize use swidden for both subsistence and market-oriented production, and throughout the colonial period, access to government land for these purposes was a largely unregulated common property resource. In these situations, robust institutions sometimes develop to protect natural resources from over exploitation (Ostrom 1990) and, indeed, the traditional Q’eqchi’ belief system—Q’eqchi’ cosmology—embodies key principles of commons management. However, empirical evidence suggests that Q’eqchi’ social institutions do not actively protect common forest resources (Downey 2009). Instead, labor exchanges are the main social process involved with swidden agriculture in most villages (Wilk 1997). These occur when a farmer asks a group of men to help with a difficult or dangerous task such as planting or clearing the forest for a new agricultural field. After the workgroup, the farmer is expected to return a day of labor to each man who helped him, closing the debt in a form of reciprocal exchange. The questions that arise are: how the social norms that govern labor exchange affect land-use rates, and if there are conditions when they reduce land use and increase resilience. If so, it is possible that labor-exchange norms could substitute for institutional environmental stewardship in maintaining the productivity of forest commons.

To understand the resilience of Q’eqchi’ swidden, it may be useful to conceive of these labor relationships as social networks, a view supported by several authors who have recently argued that social-network analysis offers a rigorous statistical framework from which certain aspects of resilience can be defined and tested (Bodin et al. 2006, Janssen et al. 2006). To do this, I formalize normative labor-exchange networks within a chronosequence of five Q’eqchi’ villages, and use social-network analysis to explore the emergence of hierarchical properties and the tendency for unreciprocated exchanges to increase in later stages of the village life cycle. In the context of panarchy theory, social-ecological resilience is shown to inhere not in social institutions but, rather, in the sequence of changes in the structure of labor networks through time. The pattern of these changes is found to have a statistical relationship to cycles of forest exploitation. Hierarchical labor relationships are found embedded within the structure of labor networks, and reciprocity appears not to be an equilibrium state but, rather, a contingent process that can, when occurring asymmetrically, prevent overexploitation of the forest commons in lieu of institutional environmental stewardship.

BACKGROUND AND APPROACH

Globally, it is thought that the sustainability of swidden agriculture is limited by the availability of land and constrained by high population-growth rates, and if either of these requirements is violated, deforestation will rapidly ensue (FAO 1987, Brady 1996). With regard to Q’eqchi’ swidden, Atran (2002) argued that their agricultural practices developed in a fertile highland environment, resulting in ecological knowledge and social network structures that exacerbate deforestation in the lowland tropics: he reports higher rates of clearing near a Q’eqchi’ village than near an Itzà village purportedly more adapted to a lowland environment. However, cross-cultural comparison of land-use statistics cannot provide insight into a system’s resilience because it does not capture history or dynamic properties. This is a problem not just with Atran's study, but also with studies of swidden agriculture generally, which typically portray it as static, incapable of adaptation, and ultimately driven by demographic growth.

Does this mean that the Q'eqchi' swidden is inherently exploitative, or is it possible that effective natural resource management can be accomplished through other means? My first analysis challenges the basic assumption that swidden offers few alternatives beyond those dictated by demographic growth and environmental limits. I test this by plotting an historical chronosequence of Q'eqchi' land use and analyzing where the growth, development, and collapse phases of the adaptive-cycle model fit these patterns; I also assess where the model is inadequate. If differences in land-use rates are significant and the sequence resembles the adaptive cycle, social-network theory may provide a quantitative framework for explaining how the Q'eqchi' maintain the resilience of forest commons without institutional management.

Elinor Ostrom presents a framework for analyzing coupled social–ecological systems that highlights how social networks and social norms, among other factors, can be important in effective stewardship (Ostrom 2007). She also acknowledges a key insight from panarchy theory, that socioecological systems are often complex, nonlinear, and dynamic (Holling and Gunderson 2002). I use Ostrom's framework to analyze whether Q'eqchi' institutions increase resilience by actively protecting the forest commons. After finding little support in historical and ethnographic sources, and because labor exchanges appear to be a fundamental social activity underpinning swidden, the following question is posed: can changes in the structure of Q'eqchi' labor networks increase socioecological resilience? If so, what kinds of network properties might be implicated?

Discussions of agricultural labor exchange typically give primacy to "reciprocity" as the basis for its organization (Sahlins 1972). However, social networks can evolve over time, and the resulting topology provides a flexible matrix on which social processes can occur and adapt to changes in local ecology. None of the farmers in the study villages or elsewhere in Belize have formal rankings related to the organization of swidden labor, but some have noted that other relatively "flat" social organizations sometimes contain primordial hierarchies (Guetzkow and Simon 1955). It is possible that "embedded hierarchies" also exists within Q'eqchi' labor-exchange networks, so the third analysis presented here explores whether Q'eqchi' labor-exchange networks are purely reciprocal, as Sahlins suggested, or if they contain elements of hierarchical organization.

If hierarchical properties are found, a question would arise as to the relationship between hierarchy and resilience. Panarchy theory suggests that hierarchies become brittle and subject to collapse as systems move out of an exploitation phase and into conservation. If this happens whole systems can fall apart and reorganize during the adaptive cycle's omega–alpha phase. Thus, the adaptive cycle would predict that land-use rates decrease, at least temporarily, if a village's labor network collapses and tries to reorganize.

The fragility implied by panarchy theory would seem to apply to traditional institutional hierarchies where leadership and organization is sometimes based on charisma and social capital. However, are the hypothetical embedded hierarchies within Q'eqchi' labor-exchange networks also subject to collapse, or could they be a more resilient alternative to traditional—and fragile—institutional hierarchies? One idea is that embedded hierarchies are one way Q'eqchi' labor networks maintain connectedness, another property of social networks, within each village, and this is important because it enables a form of "graduated sanctioning."

For Ostrom, monitoring and sanctioning are undertaken to protect a common resource understood to be vulnerable to overexploitation, and violations are tolerated only under extreme circumstances, if they are temporary, and when they do not threaten the survival of common resources. Such oversights fall under what Ostrom called "graduated sanctioning" (Ostrom 1990:94–100). The question that arises is how social networks with embedded hierarchies relate to what she calls "proprietor–monitors," that is, individuals who benefit from a common resource and who at times also act to protect it from overuse. Could their belief system provide a framework that guides how Q'eqchi' farmers relate to the forest and to other farmers? As previously noted, traditional Q'eqchi' cosmology symbolizes many of the aspects of the commons: the "Tzuultak'a'," the spirits of the hills and valleys, must be appeased through ritual activity before planting, hunting, or gathering; otherwise, a farmer risks supernatural punishment (Haste and de

Ceuster 2001). However, our current understanding suggests few links between actual management of the Q'eqchi' commons and its cosmological framework. Perhaps for the Q'eqchi', "conservation" is not an institutional mandate as it is in a western context, but rather a collective enterprise similar to the process of graduated sanctioning. How might this work?

A network perspective shifts focus from the reciprocal exchange of labor between pairs of farmers to the global effects the village's network of labor relations has on potential land-use rates. A network that leverages reciprocity to clear land can, under some circumstances, limit clearing when exchanges are unrequited. I will show that the social norm for labor reciprocity among the Q'eqchi' creates dependencies that can also limit the ability of individuals from overusing shared forest resources. Although socially costly, avoidance of labor obligations is an efficient way to enforce commons management in the absence of institutional management. I will test this hypothesis by measuring levels of reciprocity, hierarchy, and connectedness in each village's labor network. Under the proposed model of graduated sanctions, a decrease in reciprocity rates in older villages where land is degraded would indicate that rates of informal sanctioning have increased to preserve the productivity of the commons. However, to maintain this effect, labor networks must adapt to a tension between the connectedness needed for effective labor groups and the fragmentation needed for conservation. Under the proposed model, embedded hierarchies provide this flexibility. The following analyses are designed to explore the possibility that the structural evolution of Q'eqchi' labor networks has a quantifiable effect on rates of forest exploitation. The resilience of this coupled human–natural system is increased when social reciprocity and network connectivity are maintained and, this in turn, may have feedback effects that ultimately determine the system's historical development.

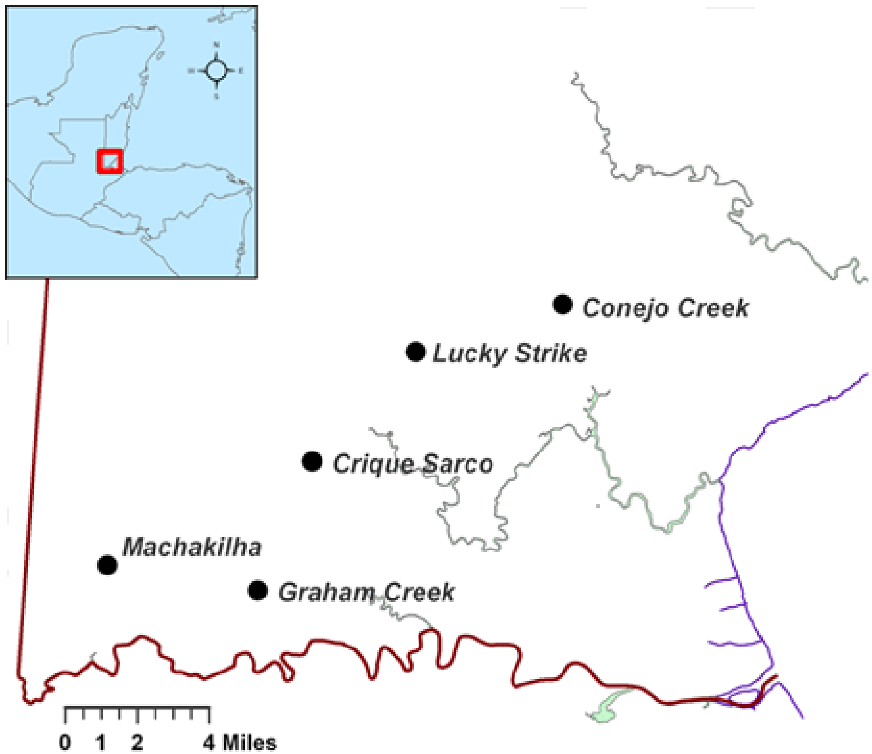
METHODS

The study was carried out in the Toledo District, Belize, Central America (Fig. 1). Here, the wet tropical rainforest that covers most of the district is remarkably well preserved, given that it has been subject to repeated phases of exploitation over hundreds of years by colonial loggers and other natural resource extraction enterprises. Although the region has been inhabited for long periods during ancient times, Spanish reductions during the 16th century removed all but an ephemeral Maya population (Thompson 1938, Wilk 1997), and most Mayan speakers now in southern Belize trace their lineages back to Guatemala some time during the past 175 yrs. Today, there are around 45 villages ranging in size from as few as eight households up to several hundred.

The five villages included in the study were chosen because they are spatially contiguous and represent a range of settlement dates from 1910–2005. The date of settlement is used as a proxy for the age and extent of a secondary forest mosaic of active and fallow agricultural fields that develops over time as the result of swidden agriculture. In 2007–2008, a household-level social-network survey was conducted in each village. Initially, a household census was taken, and significant effort was made to interview the principal farmer in each household. A total of 127 surveys were conducted, yielding an overall sampling rate of 84% (Table 1). To elicit social network information, the principal farmer in each household was asked the following hypothetical question: "If you needed 10 men to help you chop or plant a field, who would you ask?" From this list of names, directed networks were generated for each village. Networks are "directed" in the sense that arcs point from the farmer being interviewed toward each alter he would ask to participate in his labor group. Detailed land-use histories for the previous 3 yrs were collected including estimates of field size, crops planted, and productivity. All survey data were entered into a relational database and coded to ensure proper names were unique within villages. This step was required to accurately generate each village's labor network. Input files for each labor network were extracted from the database and analyzed using Ucinet 6. Statistical tests were conducted with SPSS 16.

During a visit to Graham Creek in 2008, I encountered a unique opportunity to record how a demographic shock affected the structure of the village's labor-exchange network. Months earlier, I had completed the initial survey and, during my return, I learned that eight households, nearly half the village, had recently departed because of a disagreement over a corn mill. I conducted several interviews to document the event and administered

Fig. 1. The study site in southern Belize, Central America.



Note: the red line indicates the Belize/Guatemala border.

a follow-up survey in the winter of 2009 to record the effect this exodus had on the village's labor-exchange network.

RESULTS AND DISCUSSION

Does the Adaptive-Cycle Model Fit Q'eqchi' Land-Use Patterns?

The most direct way to assess whether Q'eqchi' swidden agriculture fits the adaptive-cycle model is to look at historical land-use patterns. During the *r*–*K* phase, one would expect to see increasing rates of forest use followed by a period of reduced use. Figure 2 plots the average reported field size in each village, including Graham Creek before and after the split. Villages are arranged left to right in order of increasing age to highlight how average field sizes change after settlement. Forest-exploitation rates increase for at least 25 yrs (the age of Machakilha), after which they decrease, matching the expected pattern. 2009 results from Graham Creek are discussed below in the omega–alpha phase case study.

A one-way ANOVA confirmed that the field-size differences among all villages were significant, except for the comparisons between Conejo and Crique Sarco, and Graham Creek in 2008 and 2009 (Table 2). Significant differences in land-use rates suggest that each village should appear at a different location in the *r*–*K* phase. The lack of significant difference between Crique Sarco and Conejo is explained by the similar age of the villages, both having been inhabited for nearly 100 yrs; the mosaics around these villages are equally well developed and relatively stable, rates of exploitation

Table 1. Study villages, sampling, subsistence activity, and settlement dates.

Village	Surveyed households	Total No. households (Census)	Sampling percent	Year founded	Subsistence farmers
Lucky Strike	8	10	80%	2004	7 (88%)
Graham Creek 2009	16	16	100%	1998	-
Graham Creek 2008	17	17	100%	1998	17 (100%)
Machakilha	20	22	91%	1987	17 (85%)
Conejo	19	30	63%	1912	17 (89%)
Crique Sarco	47	56	84%	1910	26 (55%)

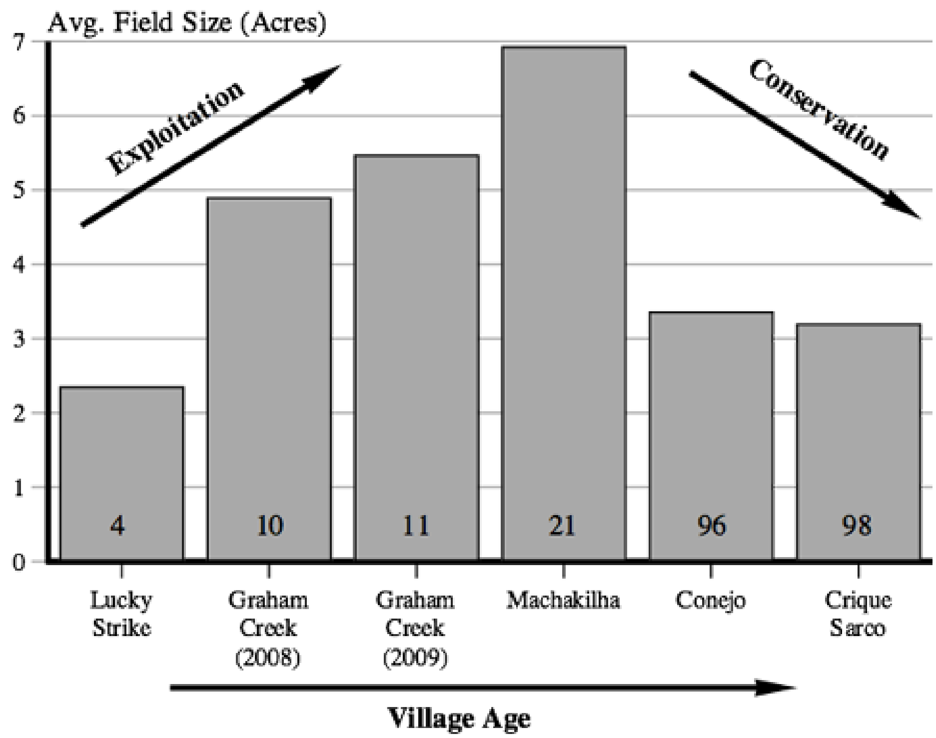
are similar, and, thus, they are better characterized by the *K* phase. Swidden is actively used in all villages, so these results appear to suggest that overall, Q'eqchi' swidden maintains its identity under a range of environmental conditions and therefore is resilient to changes in the state of the secondary forest mosaic. However, is this evidence of resilience, or does it simply support the notion that that Q'eqchi' villages overexploit the forest and quickly reach ecological carrying capacity?

Evaluating Ostrom's Framework for Analyzing Linked Social–Ecological Systems

Ostrom (2007) proposes one way to analyze effective management of natural resources such as the Belizean forests. Her framework calls for identifying a relevant set of social, economic, political, and ecological variables that can be used to analyze whether a particular social–ecological system effectively manages its natural resources. In an earlier book, *Governing the Commons,* Ostrom (1990) suggested that one way to maintain long-term sustainability of common-property resources was to provide a mechanism, often a social institution, to monitor and enforce against abuse. Sometimes regional or national governments undertake this but, in many cases, the participants themselves monitor and sanction abuses of local natural resources.

Unfortunately, there is little ethnohistorical evidence that 19th and 20th century Q'eqchi' institutions had features to facilitate robust management of the forest commons, but it may be that historical factors prevented their development. The heredity of the "alcalde" system, a Q'eqchi' institution that manages other community resources such as the village commons and roads between villages, dates to pre-Hispanic times when an "acalde col" was responsible for managing community lands (Farriss 1984). These duties were lost some time after the arrival of Europeans in Central America and, later in the mid-19th century, the British government adopted a policy from the Spanish that co-opted traditional Maya leaders as local government officials named "alcaldes." These local leaders were paid a small stipend to manage minor bureaucratic duties, but the real goal of the policy was to establish better control of remote Indian villages (Bolland 1987). During most of the colonial period up to present, agricultural monitoring has not been part of the alcalde's duties, except for the following: if a new family wishes to move into a village and farm, they must seek permission from the alcalde. When this happens, the alcalde consults the community, and if they agree, it is his duty to acquaint the new farmer with the location of fallow fields around the village that may still be in use. However, after this formal introduction to the village and forest, the new family is free to farm as they see fit. Thus, alcaldes can prevent access to the commons by limiting the

Fig. 2. Average field sizes.



Note: The number within each column represents the village's age at the time of the survey.

number of families in the village, but they do not monitor the commons on a day-to-day basis for overuse.

It seems that in manipulating indigenous-leadership norms, the British may have created a disincentive among the Q'eqchi' against forming their own political institutions or giving natural resource-management responsibilities to village leaders. One explanation for this is that doing so could have exposed them to additional colonial control. Thus, after migrating from the temperate highlands of Alta Verapaz, development of social norms to help manage lowland tropical forest commons probably occurred outside of the alcalde's legal domain and in counter-hegemonic fashion to discourage British exploitation.

Explaining Swidden's Resilience with a Graduated Sanction Model of Reciprocity

Q'eqchi' norms related to market-oriented agricultural production suggest a possible mechanism by which they could manage the forest commons without institutional support. Wage labor, not labor exchange, is normally used to cultivate rice or when clearing land for pasture. Why? This is because rice is only grown for the market, it requires large amounts of land, and it is labor-intensive to plant. The same holds when preparing land for pasture. Normally, a man asked to plant rice or clear forest for pasture would refuse unless he is paid for his labor. The pool of potential laborers is limited to men living in the village and few Q'eqchi' have cash reserves or access to credit; therefore, in refusing to help, a farmer can limit the requestor's

Table 2. ANOVA post hoc multiple-comparisons analysis of field sizes showing the significance of between-village differences.

	Lucky Strike	Graham Creek 2008	Graham Creek 2009	Machakilha	Crique Sarco
Lucky Strike					
Graham Creek 2008	*0.000				
Graham Creek 2009	*0.000	0.377			
Machakilha	*0.000	*0.000	*0.026		
Crique Sarco	**0.085	*0.000	*0.000	*0.000	
Conejo	**0.051	*0.000	*0.001	*0.000	0.620

* Significant at 0.05
** Significant at 0.10

productivity and market-oriented production can become constrained.

The only agricultural tasks for which labor exchange is used relate to maize production, which is primarily a subsistence crop. As long as a farmer is known to repay his labor obligations, he can organize large groups without any financial investment. Consequently, the Q'eqchi' should view market-oriented land uses such as rice plantations and cattle pastures in a qualitatively different manner than subsistence maize agriculture. This nonmarket category of land use embodies an ethos that defines acceptable uses of the forest, and only acceptable uses are suitable for reciprocal labor exchange. Nevertheless, use of the forest is open to all men in the village, who have autonomy to use it for either subsistence or market purposes.

Given these constraints, a violation of both the forest commons and of social norms could occur if someone tried to organize a large labor group to plant an inordinately large corn field known to be destined for the market. If this happened, those invited to the labor group could respond as if the farmer was engaged in overt market-oriented production by demanding payment or refusing to help, or by subtler methods such as failing to show up at the appropriate time, or, if they owed labor, sending a less efficient worker, for example, a young son. This kind of punishment would be very similar to the graduated sanctioning Ostrom thought could come from within groups of natural-resource users (Ostrom 1990). Whereas avoiding labor debts may impose social costs, these may be compensated by increased social status or access to advanced ritual knowledge. A single person avoiding a labor group might only decrease productivity by a small margin. However, Q'eqchi' labor-exchange networks are almost always limited to men within a single village, so if several of them avoided participating, productivity could be significantly reduced. This could serve as an effective sanction against abuse of the forest commons.

This model of graduated sanctions can be expressed with the following set of causal relationships:

If a farmer's request for help is:

...judged an acceptable use of land ∴ labor is provided ∴ land use increases; or,

...judged an unacceptable use of land ∴ labor is not provided ∴ land use decreases.

Any perceived violation of the commons could trigger one's labor partners to avoid providing the requested labor, including symbolic acts such as failing to make the proper offerings to the Tzuultak'a. In this context, public ritual display would gain functional significance, but it is the network of labor relations among farmers that amplifies an individual's avoidance of a labor exchange into an effective collective sanction.

Labor-Group Functions and Dynamics

Anthropologist Richard Wilk notes that labor groups are about more than just work; they are important arenas of social interaction: "working in a group always leads to joking, laughter, gossip, verbal and physical play, and all kinds of learning. Men get to see each other's fields and check the progress of crops. The fun is balanced by the solemn quiet ritual of sharing a meal afterward, when religion brings the group together" (Wilk 1997). My own experiences participating in labor-exchange groups support this sentiment, but to better understand the functional role of labor groups, the survey asked if farmers talk with others when deciding where to plant their fields. Overall, 64% reported talking to others about where to locate their field, and 36% did not. As Wilk suspected, labor groups are about more than just work: they are important opportunities for environmental learning, and this information is used as a farmer plans his own agricultural activities.

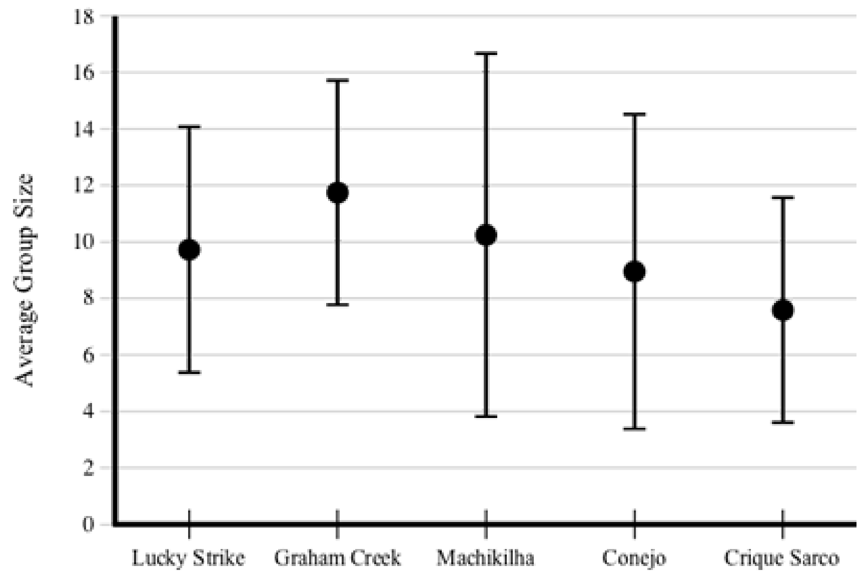
Could the organization of labor groups serve a functional role in the maintenance of resilience? To answer this, farmers were asked to recall the number of men they recruited for their most recent labor group (Fig. 3). Graham Creek and Machakilha, both young villages, have larger groups on average than either Conejo or Crique Sarco, which are much older villages. In the figure, larger standard deviation values occur when a wide distribution of labor-group sizes are reported, whereas small values occur when group sizes are more consistent. Given this, there are three particularly interesting features: (1) average group size in Machakilha is smaller than Graham Creek, (2) Machakilha has a larger standard deviation than Graham Creek, and (3) the size of the smaller groups used in Machakilha appear to be similar in size to Conejo and Crique Sarco. Intriguingly, Machakilha is just 11 yrs older than Graham Creek, yet it appears to be moving towards the distribution of smaller group sizes seen more commonly in the older *K*-phase villages.

This labor-group analysis appears to capture Machakilha transitioning from *r* to *K*, providing insight into "how" labor-exchange networks adapt to the development of a secondary forest mosaic: they use smaller labor groups and cultivate smaller fields. Counterintuitively, this contradicts the logic of carrying capacity. As villages age, agricultural activities convert primary forest into less productive secondary forest. Under the assumptions of carrying capacity, one would expect to see either migration or the use of larger labor groups and larger fields to compensate for declining productivity. Instead, we see decreasing field sizes and smaller labor groups. What would explain these changes?

Ecologists have suggested that there is an evolutionary tradeoff between fitness and resource quality (Levins 1962). Perhaps labor-exchange networks provide flexibility to adjust group size and help the Q'eqchi' avoid some of the reduced fitness effects that might otherwise result from farming in degraded secondary forests. One problem they might encounter is difficulty finding fertile areas, because farming in secondary forest is more dependent on underlying soil quality. Primary forest tends to be more productive, because burning large old-growth trees releases large nutrient pulses that sustain plant growth while compensating for local deficiencies in geologic parent materials or topography. When burning secondary forest, nutrient pulses are limited and, therefore, it is more important to find high-quality soils to cultivate. These pockets of soil occur at a smaller spatial scale, i.e., in small patches, and may account for the smaller size of labor groups used in older villages. If so, it may be because many small labor groups are more efficient than a few large groups when searching a degraded and patchy secondary forest mosaic for the highest quality soils.

Farmers' perceptions of differences in resource quality may help substantiate the importance of this primary or secondary-forest dichotomy and the ongoing importance of secondary forest to subsistence. Farmers were asked: "Which is more important: primary forest, secondary forest, or are they equally important?" Their responses were surprising: 74% of those who reported farming as their most important form of subsistence thought secondary forest was as important as primary forest. Of those who relied on other livelihoods such as woodcarving, a pension, or a salary, 68% thought primary forest was a more important resource. This pattern clearly illustrates that subsistence farmers

Fig. 3. Average reported labor-group sizes and standard deviations.



highly value secondary forest even though its agricultural productivity is diminished.

As Wilk notes, Q'eqchi' labor-exchange groups are important sites of social interaction and learning, but they may also enable adaptation to a dynamic and coupled human–natural system. This is important because alcaldes do not appear to actively defend the forest commons. So far, it has been shown that historical land-use patterns among the Q'eqchi' ostensibly fit the adaptive-cycle model, and may help maintain resilience. Analysis of historical changes in labor-group size suggests that adaptation is taking place, and that smaller labor groups correlate with older secondary forest mosaics. A candidate hypothesis has been proposed that could explain this correlation: smaller labor groups are more effective at searching the secondary-forest mosaic for the best field locations. The dichotomy between the perceived agricultural potential of primary and secondary forest has been tested with survey data, and it appears that secondary forest is as important an agricultural resource as primary forest to subsistence farmers. Survey results also show that environmental knowledge is learned and shared as Q'eqchi' farmers consult each other about suitable field locations. Thus, Q'eqchi' swidden appears to encourage learning, diffusion of agriculturally important information, and adaptation to changes in the local environment. These features help the Q'eqchi' monitor the forest's response to farming activity and respond accordingly to these changes.

Network Reciprocity

Although Q'eqchi' swidden agriculture appears to maintain resilience by encouraging learning and adaptation, it remains unclear as of yet how network properties substitute for institutional monitoring of the forest commons. To explore this question, labor-exchange networks from each village were analyzed for indications of reciprocity and hierarchy. Several specific social-network statistics have been suggested for analyzing resilience in coupled human–natural systems (Bodin et al. 2006, Janssen et al. 2006). Here, I take a different approach and focus on network reciprocity and hierarchy statistics because they form a quantitative continuum for measuring social organization that should encompass Q'eqchi' labor exchange. Q'eqchi' labor reciprocity, as with similar forms worldwide, is presumed to be nonhierarchical, and presupposes

Table 3. Measurements of reciprocity and social hierarchy in Q'eqchi' labor-exchange networks. All statistics are measured on a 0–1 scale.

	a) Hybrid reciprocity	b) Hierarchy	c) Efficiency	d) Connectedness
Lucky Strike	0.4231	0.0000	0.0952	1
Graham Creek 2008	0.2179	0.6897	0.4833	1
Graham Creek 2009	0.3804	0.5000	0.2667	1
Machakilha	0.1733	0.6333	0.6275	1
Conejo	0.2647	0.6757	0.8190	1
Crique Sarco	0.2466	0.2081	0.8202	1

an equal exchange of labor. Based on this, one would expect high levels of reciprocity and low levels of hierarchy. Evidence either of differences in reciprocity between villages or of embedded hierarchies might suggest that Q'eqchi' labor-exchange networks are more complex than previously thought; systematic differences might suggest that they have regulatory properties. A possible function, hypothesized earlier, is that increasing levels of unreciprocated labor debts could limit the productivity of farmers perceived as violating the forest commons. Combined with embedded hierarchies and connectedness, these network properties might provide an effective alternative to institutional management of the forest commons.

Hybrid reciprocity is the most basic network statistic calculated, and it most closely represents the expectation of Q'eqchi' labor-exchange relations. It simply measures whether each observed labor relationship is reciprocated and expresses the result as the proportion of reciprocated ties in each village (Table 3*a*). A clear interpretation of these measurements is not as straightforward as the simplicity of the statistic might suggest: the youngest village, Lucky Strike, has the highest rate of reciprocity, but decreasing rates do not appear to correlate with time since settlement. Indeed, the lowest labor reciprocity rate is in Machakilha, a village only slightly older than the two youngest villages. Rates in Crique Sarco, the oldest village, are higher than the second-youngest village. The clearest pattern that can be deduced is that high reciprocity rates can be sustained only for a very short period of time over the course of the village life cycle; or alternatively, that there are special circumstances operating in Lucky Strike and in Graham Creek in 2009 that help maintain high reciprocity rates.

Network Hierarchy

Avoiding oppression from British colonial authorities may have discouraged the Q'eqchi' from vesting alcaldes, their normative "hierarchical" institution, with responsibility for monitoring the forest commons. However, is it possible that hierarchical properties could also be embedded in the structure of Q'eqchi' labor-exchange networks? Guetzkow and Simon (1955) proposed that primordial hierarchies exist within social systems without being formalized or socially indexed. Forty yrs later an idealized model of social hierarchy for directed social networks was proposed (Krackhardt 1994). This model is shown in Fig. 4*a* where all individuals except for the leader (node A) receive a single connection. This represents the ideal that each worker in a prototypical hierarchy should report to a single boss. Figure 4*b* illustrates how an idealized hierarchy can be preserved even when individuals supervise multiple subordinates. Using this simple model, the "network-hierarchy" statistic assesses how well networks are structured with regard to these asymmetric, directed relationships.

In idealized hierarchies, subordinates should always work through their immediate superior to access high-level individuals and not make connections across the hierarchy. “Network efficiency” measures this property and it is inversely related to the presence of superfluous connections beyond the minimum necessary to maintain the hierarchy’s structure. Social connections are costly to maintain and, therefore, any connection in excess of the minimum is considered in a strict sense, inefficient. In Fig. 4*b*, for example, it would be unnecessary for (E) to be connected to both (B) and (C). The presence of both connections would not violate the command structure of the hierarchy, but both connections are not necessary to maintain the hierarchy. On the other hand, individual (B) must be connected to (A), so a perfect hierarchy will always have one less connection than the total number of individuals; any fewer and the network would decompose into discrete components. This final concept, “network decomposition,” is represented by the “connectedness” statistic that indicates the number of components in each network.

There are many ways other than hierarchy to maintain network connectedness, but the utility of this approach is that Q’eqchi’ labor networks may build upon other hierarchical social structures such as kinship and age cohorts to help keep their labor networks connected. One alternative is the concept of a “cut-point”; nonredundant nodes that connect separate groups of highly connected nodes and which, if removed, would separate the network into two or more discrete components. As such, cut-points share similarities with the hierarchy statistics considered in this analysis. However, the difference is that cut-points are abstract properties of social networks needing explanation in their own right. The hierarchy statistics used here relate intuitively to the differential access to power and prestige provided by kinship and seniority, which are important aspects of Q’eqchi’ social organization (Wilk 1997). So, whereas Krackhardt’s network-hierarchy model is an abstraction of the stratification of power commonly seen in Western-style organizations, a general form of social hierarchy remains a likely structuring mechanisms for maintaining connectedness in Q’eqchi’ labor-exchange networks.

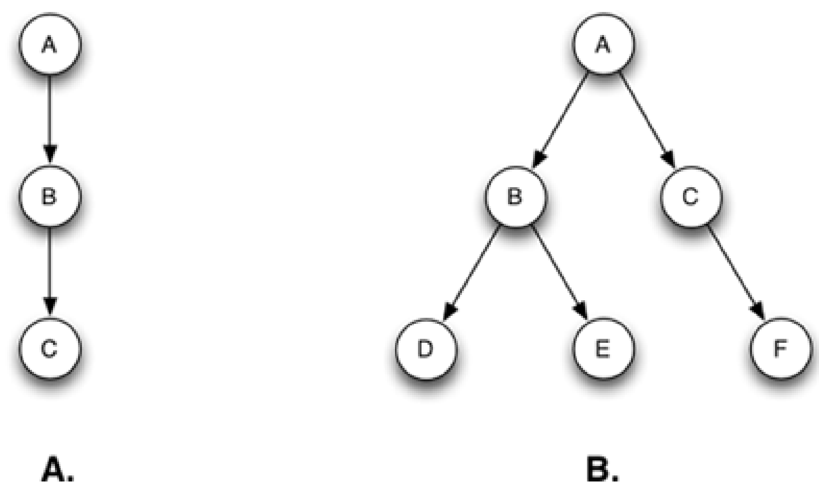
Each labor-exchange network was compared to Krackhardt’s hierarchy model, and deviations were measured using Krackhardt’s GTD method in Ucinet 6 (Krackhardt 1994; Table 3*b–d*). Leaving the Graham Creek follow-up survey aside for the moment, Machakilha, Graham Creek (during the initial visit), and Conejo exhibit high levels of hierarchy. The lack of hierarchy in Lucky Strike is undoubtedly related to the high levels of reciprocity in that village. Hierarchy is low in Crique Sarco because the network has fragmented into multiple cliques, although it retains connectivity. Overall, these results indicate that Q’eqchi’ labor-exchange networks can exhibit embedded hierarchical properties.

One question that arises is what purpose hierarchical labor relations might serve for the Q’eqchi’. I encountered an example during fieldwork when I observed a farmer ask his son to organize several men, including myself, for a labor exchange to plant his cornfield. Using Fig. 4*b* as a template of this interaction, the farmer (A) asked his son (B) to organize a labor group. His son (B) then asked me (D) and another man (E) to help plant his father’s field (A). Although the father and son constitute a single kin group, the son asked nonkin to participate, so Krackhardt’s network-hierarchy model can be generalized beyond the immediate kinship group. This example also illustrates how embedded labor hierarchies can operate in tandem with more common social hierarchies.

I have proposed that within labor-exchange networks, reciprocity’s antipode, that is, refusing to help, is a form of graduated sanction that protects the forest commons. The presence of hierarchical properties can be explained as a way to maintain connectedness: every network contains a single component and the highest possible connectedness score (Table 3*d*). In the model, embedded hierarchies provide a framework that constrains the entropic effects of a network based solely on dyadic ties. They do this by reaching through and binding together networks of reciprocated and unreciprocated relationships to provide the amplifying effects of collective action needed for natural-resource conservation.

Ethnographic evidence suggests that there is incentive for efficient labor-exchange networks to evolve because of a tension that exists between minimizing one’s material investment in holding a labor group and maintaining the capacity to access a larger labor network. Q’eqchi’ farmers have incentive to minimize labor-group size because a labor group requires a significant material

Fig. 4. A network model of social hierarchy (adapted with permission from Krackhardt 1994, Fig. 5.2).



investment in the proscribed meal before and after work, and for the ritually required incense and offerings. It is also a substantial time commitment into the future, when the farmer will have to fulfill his labor debt to each man who helped him. Yet, remaining connected to the labor network also helps buffer against risk: maintaining good labor relations with important farmers provides access to a larger pool of potential labor partners, enabling more flexibility in agricultural decision making. As farmers negotiate these competing incentives, networks will remove redundancy to become more efficient and, because of this, the network efficiency statistic should apply (Table 3*c*). The results show a clear pattern where networks begin with many redundant connections but become more efficient through time. Lucky Strike's labor network is technically inefficient because of multiple overlapping connections among farmers, whereas networks in the older villages, Crique Sarco and Conejo, are more efficient than those in Graham Creek and Machakilha.

When a village grows, the number of possible connections among farmers grows exponentially and, because of the costs associated with labor exchange, it should become increasingly difficult for farmers to maintain connections with all farmers in the village's labor network. To test whether increasing network efficiency could be a way to cope with these changes, a logarithmic model was fitted to a plot of the number of households and network efficiency. A good fit would support the proposition that farmers are negotiating the tension between the costs of participating in labor exchange and the risks of reducing the number of potential labor-exchange partners by increasing network efficiency. A strong degree of agreement was found (R^2=.84, p=0.028). The logarithmic curve indicates that a large number of redundant connections can be quickly removed from the labor network, with diminishing returns as farmers are faced with removing more important, better-connected labor partners. Thus, the efficiency statistic appears to be a good mechanistic model for explaining how embedded hierarchies maintain connectedness throughout growing Q'eqchi' labor-exchange networks.

One final observation should be noted: the network-efficiency analysis suggests that one way labor networks maintain connectedness is when farmers remove excess labor connections while retaining the most important ones. This means that the topology of any given Q'eqchi' labor network is actually an emergent property of dyadic relationships among farmers, as determined by each individual farmer's maintenance of his labor relationships. Thus, the high level of connectedness observed in each village may be the emergent property of each farmer increasing the efficiency of his own labor network.

Graham Creek Village: A Case-Study of the Omega–Alpha Phase

The preceding analysis suggests that reciprocity and hierarchy are adaptive properties in the evolution of Q'eqchi' labor-exchange networks, but it does not show whether network structures actually increase resilience. One way to test resilience is by examining how a system responds to an unexpected perturbation or shock. The adaptive-cycle model predicts that systems become more vulnerable to collapse as they move from exploitation to conservation because structural relationships, networks, and hierarchies become rigid and unresponsive. If collapse occurs the system reorganizes and renews itself during the omega–alpha phase. In 2008, Graham Greek village received a shock that could have triggered a structural collapse and an omega–alpha phase.

Early that year, the village's residents decided that they needed a diesel-powered corn mill. They agreed to acquire one and operate it as a low-cost cooperative. Acting on their behalf, a man from the village acquired one, and without telling anyone, he brought it to a safe location near the village. He called a community meeting and proposed to run the mill as a private enterprise, rather than a cooperative. When the village collectively denied his request, instead of acquiescing, he took the mill to another village where he began to run it privately. His entire extended family moved with him to take advantage of the economic opportunity it provided. The exodus nearly halved the village's population, and the leader of the village quickly set about recruiting new families. Within a year from the exodus, the village's population had returned to its previous level.

This incident provided an opportunity to examine how a demographic shock affected the village's land-use patterns and labor-exchange network. There is no significant difference in field size before or after the exodus from Graham Greek (Table 2). At both points in time, the forest was in largely the same state, was equally productive, and could be farmed in a similar manner, i.e., as would be appropriate during an *r* phase. After emigration, there was speculation that the village might not be viable, given its diminished population and remote location. However, quick repopulation enabled the village to exceed the average reported field size before the exodus (Fig. 2). This was perhaps because of the enthusiasm of the new farmers but, in any case, indicates that the village ultimately continued to use the forest at a high rate as compared to the older villages in the study. Network statistics indicate that overall levels of reciprocity increased, whereas hierarchy and efficiency decreased after the families left and the village was subsequently repopulated (Table 3).

When I first learned that Graham Creek had suffered this exodus and reorganization, I considered it an opportunity to learn about the poorly understood omega–alpha phase of the adaptive cycle. The haste with which the leader recruited new families, and the rumors of its possible abandonment, suggested that this village could either have collapsed altogether into an uninhabited state, or performed some kind of back loop in the adaptive-cycle model. Historically, village abandonment was not unusual in the Toledo District (Wilk 1997), but Graham Creek did not collapse and, in fact, quickly exceeded pre-emigration production levels. In part, this was facilitated by the leader's quick recruitment efforts. However, I believe that the social norms related to Q'eqchi' labor-exchange networks, which do not require formal institutions to operate efficiently, were also important. The new families already knew the rules and obligations required to participate in these networks, and the village was able to quickly incorporate the new farmers. The concomitant changes in network structure show how this happened: farmers increased rates of reciprocity and decreased hierarchy and efficiency.

How do these results compare to the predictions of the adaptive cycle model? A precise interpretation is difficult because of ambiguities in the model itself, but it appears that the village may have executed a complete and rapid omega–alpha back loop without transforming the functional structure of the village. In this case, Graham Creek's labor network was adaptive precisely because it did not collapse: the flexibility inherent in it prevented the village from being abandoned. From this perspective, labor networks appear very resilient, perhaps so much so that the local forest now suffers from increased exploitation. However, the significance of this study is in illustrating that swidden's resilience can only understood as a property of network chronosequence, made apparent using social network analysis, and from this perspective, I would predict that Graham Creek will eventually settle into more limited use of a secondary-forest mosaic using the same set of labor norms, and after subtle reconfiguration of its labor-exchange network.

CONCLUSION

Swidden agriculture has been the subject of much debate, yet questions remain about the extent to which it is constrained by demographic growth, and if it adapts to environmental limits. It is frequently argued that swidden is prone to causing widespread deforestation when population growth triggers increased exploitation. The analysis presented here demonstrates the need for a more nuanced analysis.

Discussions of labor exchange, a key factor in swidden production, typically implicate reciprocity as a key social process. However, quantitative social-network analysis shows that reciprocity cuts two ways: increasing reciprocity rates can increase production, whereas decreasing it can help protect shared resources from overuse. I have proposed a novel graduated-sanction model of reciprocity in which farmers avoid labor obligations to marginally reduce the productivity of those perceived as violating the forest commons. A network context amplifies a single farmer's subtle avoidance of his own labor obligations into a collective action that may serve as an effective corporate sanction of commons violations. However, this can only occur if the village's labor-exchange network remains connected, so embedded hierarchies develop in tandem with other kinds of social hierarchies within the village such as kinship and age cohorts. This mechanism is proposed as an alternative to institutional management of common property resources, and explains why Q'eqchi' alcaldes do not actively monitor the commons. In this new model, labor exchange is at the center of Q'eqchi' swidden agriculture not only because it can help farmers organize a large labor force, as many would argue, but because it increases socioecological resilience.

The study described a case study of Graham Creek village in which forest exploitation increased linearly with population growth, supporting the idea that Q'eqchi' swidden quickly exploits its local natural resources during a highly productive growth phase. However, when compared to older villages, the levels of reciprocity that support exploitation eventually decrease: labor networks in older villages exhibit higher levels of hierarchy and efficiency, and fields and labor groups are smaller. This may be explained by the role of labor networks in shaping awareness of the commons. Labor networks not only increase a farmer's ability to coordinate large labor groups during exploitation; they also enhance learning and adaptation to an ecologically complex secondary-forest mosaic. In particular, a large number of smaller labor groups may be more effective at searching in the secondary-forest mosaic for high-quality but patchy soil resources, than a small number of large groups would be.

From the perspective of panarchy theory, the evidence suggests that Q'eqchi' swidden is a resilient system that can operate under a variety of different configurations. Productivity can be maintained at a high level when resources are plentiful, and continue at this level even when the system is shocked, as seen during the Graham Creek corn-mill incident. Further, the same social relations that sustain swidden agriculture can also reconfigure when farming in less productive secondary forest. Resilience is increased not by developing fragile institutional hierarchies, but rather, by using the connective properties of networks to protect common resources. Social-network analysis has helped quantify structural differences in labor networks, and illustrated how these properties evolve between the exploitation and conservation phases to help maintain swidden's resilience.

When swidden agriculture is viewed as a resilient system, incentive increases for farmers to remain in established villages and connected to labor networks. These networks help farmers by cushioning demographic shocks and maintaining agricultural productivity when forest fertility decreases. Without this adaptive capacity, they would be left with no other choice but to migrate to a less risky or more productive location. In cases where new swidden settlements can be formed, the implication of this on deforestation rates is significant: when farmers have incentive to remain at older settlements, overall migration rates will decrease. The adaptive capacity of Q'eqchi' labor-exchange networks provides these incentives, ultimately limiting the expansion of pioneer settlements into pristine areas and slowing overall rates of deforestation due to swidden agriculture.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol15/iss4/art15/responses/

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