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Does Collective Action Sequester Carbon? Evidence from the Nepal Community Forestry Program

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SUMMARY

This paper uses 620 forest plot measurements taken from a nationally representative sample of 130 Nepal community forests combined with information on forest collective action to estimate the effects of collective action on carbon per hectare and three additional measures of forest quality. We use three measures of forest user group collective action, including membership in the Nepal Community Forestry Programme (CFP). Collective action shows large, positive, and statistically significant carbon effects vis-à-vis communities exhibiting no evidence of forest collective action, which do not necessarily correspond with results for other measures of forest quality. We find that depending on the collective action definition and physiographic region, forests controlled by communities exhibiting no evidence of forest collective action may have as little as 34% of the carbon of forests governed under collective action. We do not, however, find evidence that CFP forests, our narrowest measure of collective action, store more carbon than forests outside the CFP. Our results therefore suggest that it is the collective action behavior and not the official CFP label that offers the largest gains. Carbon benefits from collective action are therefore not found to be conditional on CFP participation.

1. Importance of the issues and introduction

Lower income countries emit little of the carbon pollution that causes climate change. They are, however, responsible for the majority of net deforestation and forest degradation, which are also important sources of carbon emissions. Net deforestation and forest degradation account for between 12% and 20% of annual greenhouse gas (GHG) emissions, which is more than all transport combined (IPCC, 2007; Saatchi *et al.*, 2011), and net carbon emissions from tropical land use change are estimated to be 2.4 ± 0.4 Gt per year (Pan *et al.*, 2011). Total carbon stored in forests is 638 gigatons (UNFCCC, 2011) to 861 gigatons (Pan *et al.*, 2011), with over half above ground.

The United Nations Framework Convention on Climate Change (UNFCCC) Initiative on Reducing Emissions from Deforestation and Degradation (REDD+) is a program by which UNFCCC Annex 1 countries provide support to non-Annex 1 countries, such as Nepal, in exchange for measurable additional carbon sequestration. An important question is how to incorporate the approximately 25% of developing country forests that are managed by communities (World Bank, 2009) into REDD+. These community forests may contain significant carbon that could be protected under REDD+ and the collective action (CA) they are engaging in may even now be sequestering carbon.

Such carbon sequestration is costly, because community forests in low-income developing countries provide products that are essential to the daily lives of billions of people, including fuelwood, forest fruits and vegetables, building materials, and animal fodder (Cooke, Köhlin, & Hyde, 2008). More effective CA is believed to lead to better management of these ecosystem services (Yadav, Dev, Springate-Baginski, & Soussan, 2003), but it may also yield more carbon sequestration, because reduced pressures allow forests to regenerate.

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The Nepal Community Forestry Program (CFP) is one of the most important examples of forest CA in a low-income country and the most important forest devolution program in Nepal. It has almost 19,000 registered forest user groups representing over 35% of the population and as of 2015 in hill districts over 78% of households were community forest user group (CFUG) members.[1] For example, in the hill district of Salyan (population approximately 250,000) in 2014 there were 558 CFUGs[2] The existence of the CFP therefore makes Nepal an ideal setting for testing the hypothesis that forest CA sequesters carbon.

Building on preliminary analysis in Bluffstone *et al.* (2015), we test whether being part of the CFP has an effect on carbon. We utilize a nationally representative random sample of CFP communities and forests. The CFP subsample (i.e., the treatment) is then matched with an equal number of observationally equivalent forests and communities that are not part of the program. Because CFP status is defined at the forest level and likely non-random, we select non-CFP forests (i.e., NCFs) and associated communities to be observationally equivalent to community forests (CFs).

A total of 620 forest sample plots in 130 forests are analyzed using random effects panel data and OLS regressions with errors clustered at the forest level. We also aggregate our plot-level data to the forest level and test our hypothesis using nearest neighbor propensity score matching. We find that many forests that are not part of the CFP exhibit CA that is similar to CFs. We therefore expand our definition of CA to include two additional CA measures and examine whether forest CA in those forests and communities lead to more carbon per hectare. More carbon is not necessarily consistent with and can indeed be inversely related to other possible measures of forest stand health, such as greater tree density per hectare, additional canopy cover, and regeneration (Coomes, Hodaway, Kobe, Lines, & Allen, 2012; Enquist, West, & Brown, 2009; Stephenson *et al.*, 2014). We therefore separately evaluate the effects of the CFP and two broader CA definitions on these potential quality measures.

In Section 2 we provide very brief discussions of the Nepal community forestry experience and literature at the intersection of carbon sequestration and CA. Section 3 presents our methods and data. Section 4 overviews results followed by conclusions, policy implications and areas for research.

2. Key literature on carbon sequestration and collective action

Forests play a critical role in climate change, because they are a source of greenhouse gas emissions and offer sequestration opportunities (Chaturvedi, Tiwari, & Ravindranath, 2008). Carbon sequestration in forests may also be particularly cost-effective climate investments (Kindermann *et al.*, 2008; Stern, 2007; Strassburg, Turner, Fisher, Schaeffer, & Lovett, 2009). These combined observations provide important justifications for REDD+.

An estimated 15.5% of global forest area is under the formal control of communities, providing key subsistence products and community control has increased over time (RRI, 2014). Using worldwide forest data and CA elements, Chhatre and Agrawal (2009) demonstrate there are both tradeoffs and synergies between carbon sequestration and community livelihoods. They suggest detailed studies to better understand the implications when forests are controlled by communities. In this vein, Beyene, Bluffstone, and Mekonnen (2016) evaluate the effect of local community forestry collective action on carbon sequestration in Ethiopia, but find minor effects. Yadav *et al.* (2003), Gautam, Webb, Shivakoti, and Zoebisch (2003) and others claim that CFs in Nepal can help reduce forest degradation, which could imply less carbon emissions that should be credited under REDD+. Karky and Skutsch (2010) estimates that the opportunity cost of such carbon sequestration may be less than $1.00 per ton.

Nepal introduced the CFP in the late 1980s, because centralized forest management appeared to be leading to serious deforestation and forest degradation (Carter & Gronow, 2005; Guthman, 1997; Hobley, 1996; Springate-Baginski & Blaikie, 2007). The introduction of the National Forestry Plan in 1976, Decentralization Act of 1982 and Master Plan for the Forestry Sector of 1989 were key policy steps leading to the present day CFP. The Master Plan was followed by the Forest Act of 1993, which provided a clear legal basis for CFs, enabling the government to "hand over" national forests to CFUGs. The handover rules were detailed in 1995 forest regulations and operational guidelines, which were revised in 2009 and in 2014. CFUGs are recognized as self-governing, autonomous, perpetual and corporate institutions that can acquire, possess, transfer, or otherwise manage property (HMGN/MoLJ, 1993: Article 43). They can sell and distribute forest products according to an operational plan approved by the government District Forest Officer (DFO).

The distinction between CF and NCF forests is a legal one and well-defined. Becoming a CF requires that communities document claims, organize into user groups, elect officers, commit to participatory governance and prepare operational plans, which must be approved by DFOs every 5 years. DFOs provide technical support and issue permits for timber harvests. The main driver of CF status is therefore local CA, with the state playing enabling and oversight roles.

The CFP includes about 19,000 CFUGs and over 2.4 million households managing 1.8 million hectares (DoF, 2017). Three-quarters of CFs are in the hills, 16% in the high mountains and only 9% are in the lowland *Terai* (MOFSC, 2013). Nepal's REDD+ activities are largely focused on the CFP (Oli & Shrestha, 2009) and it is therefore especially important to understand the linkages between CFs, CA, and carbon sequestration.

A variety of indicators are used to assess forest health and vitality, including tree and seedling density, crown cover and primary productivity measured as biomass and/or carbon stock, with higher levels indicating higher quality.[3] The relationships between these forest parameters have been extensively investigated and the main conclusion of this literature is that depending on individual tree and forest stand circumstances, these measures may not always be positively correlated. For example, higher carbon stocks may be associated with higher or lower levels of canopy cover, tree density, and seedling regeneration (Coomes *et al.*, 2012; Enquist *et al.*, 2009; Stephenson *et al.*, 2014; West, Enquist, & Brown, 2009). In assessing the effects of an outside force such as CFP participation on forests, these forest quality measures cannot be presumed to give similar results and are most appropriately evaluated independently.

Assessing biomass in forests over time is critical for calculating carbon increments and a range of remote sensing and ground-based methodologies are available to estimate baselines. One widely used and important metric is the Normalized Difference Vegetation Index (NDVI), which is a measure of vegetative cover based on remotely sensed data. The NDVI is directly related to

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[1] National information available from the Ministry of Forest and Soil Conservation (MoFSC) Department of Forestry (DoF) Community Forestry Division website http://dof.gov.np/dof_community_forest_division/community_forestry_dof. Hill district information based on author calculations and data from the Community Forests Database (August 2015) available at http://dof.gov.np/image/data/Community_Forestry/Summary.pdf and the 2013 Nepal Statistical Yearbook (most recent available), which is available at http://cbs.gov.np/publications/statisticalyearbook_2013. All accessed August 16, 2016.

[2] See http://www.dfosalyan.gov.np/eng/images/pdf/database/database_of_cfugs.pdf for details.

[3] Carbon constitutes approximately 50% of forest biomass (Gibbs, Brown, Niles, & Foley, 2007) and this is also the IPCC (2006) default value.

energy absorption by plant canopies (Myneni, Hall, Sellers, & Marshak, 1995; Sellers, 1985), which is linked to carbon sequestration. Though it cannot be used to estimate carbon *per se*, the NDVI provides a reliable and comparable measure of baseline land quality.

3. Data, carbon estimation method, and identification strategy

This paper relies on plot- and community-level data collected from an equal number of CFs and NCFs. NCFs are government forests used by communities, but we emphasize that they are typically weakly controlled by the Government of Nepal.[4] Forest inventory and community data were collected in spring 2013 from 620 plots in 130 forests in the middle hill (approximately 700–3000 m in altitude) and *Terai* (<700 m) areas of Nepal. The high mountains, which are less populated and have limited carbon sequestration potential, are excluded.

Table 1 presents descriptive statistics by CFP participation and physiographic region. As mentioned above, the population of CFs is concentrated in the middle hills and NCFs in the *Terai*, which is reflected in our sample. Larger forests in the hills and *Terai* on average tend to be CFs. Figure 1 shows the spatial distribution of communities and forests, which is based on the nationally representative CF sampling methodology of MoFSC (2013).

NCFs typically have not been mapped and because communities do not have legal rights to NCFs, official user group member lists do not exist. There is therefore no inventory of NCFs, which meant they needed to first be identified in the field. Furthermore, in an average hill district 78% of households are members of CFUGs. NCFs are therefore relatively rare in the hills and there was a danger that random sampling could yield highly dissimilar CFs and NCFs, which when compared could yield biased estimates.

To address these realities, researchers at ForestAction Nepal, which is one of the premier forest research organizations in Nepal, based on their field knowledge, in consultation with district forestry officials, chose 65 NCF sites in areas close to CFs, which were randomly selected from the nationally representative sample of MoFSC (2013). NCF sites were selected so they resemble the CF sites to the extent possible in terms of ecological zone, forest type, ethnic composition, caste distribution, proximity to roads, farming system, socio-economic characteristics, etc. in all senses except the forests had not been handed over as CFs. Therefore, the intent is that sample CF and NCF forests should be fully comparable, which is essential for unbiased treatment effect estimates. Selected NCFs were also proximate to comparator CFs (e.g., certainly in the same district), but not adjacent to them. This was avoided in case forest users simultaneously used both forest types. Comparable NCFs are abundant in the Terai and so when many comparable NCF sites were available, NCF sites were chosen randomly at the district level. A complete list of matched CF and NCF communities are provided in Appendix 1 in the SI.

We find that based on 15 observables (well-being class, caste, house materials, and sanitation) presented in Appendix 2, average CFs and NCFs are not statistically different, which suggests they are indeed comparable. There are statistically significant ecological differences between CFs and NCFs, because as is true for the population, most sampled CFs are in the hills and NCFs are in the *Terai*. CF members are more likely to be food insufficient, likely for the same reason. As expected, there are also differences in respondent-perceived forest management participation, structure, and quality, with CF households on average reporting better performance than NCFs. Our hypothesis is that this better performance yields better forest quality, including more carbon.[5]

Environmental and community data are collected that are expected to affect biomass and carbon. Community data are directly collected for NCFs and equivalent CF data are taken from MoFSC (2013). Both sources use interviews with user group executive committee members or village leaders, as well as forest user group members. Pairing communities with CF forests is straightforward, because forests and CFUGs are legally approved. For NCFs we analyze the forests identified by users and/or leaders as the most important ones used to collect subsistence products and for grazing. As communities have no legal rights to NCFs, identification presented challenges. For example, NCFs have generally not been officially mapped. Forest mapping was therefore done based on periphery identification by user group leaders. User households may also be less well defined than in CFs. Numbers of households in NCFs were therefore calculated on-site after developing user group lists in consultation with user group leaders.

The plot-level forest inventory was carried out in 130 forests, with 325 randomly selected plots in CFs and 295 in NCFs.[6] Relying on our random sampling of plots within forests, all variables such as carbon, which are countable are converted to per hectare values and for our forest-level analysis, we average plot-level results by forest. The number of plots was calculated for a 10% error and 95% level of confidence using Saxena and Singh (1987). The sampled forests are of different sizes, with the smallest forest 1.1 hectare and the largest 1088 hectares and the number of plots per forest therefore varies by forest size. Appendix 2 in the SI presents the distribution of plots across quintiles of the forest size distribution.

After forest boundaries were identified, sample plots were chosen using randomly generated GPS points. If a point proved inaccessible (e.g., on a very steep slope) or inappropriate (e.g., in a stream), additional points were generated. The GPS point served as the center of three concentric circles, the largest of which had a total area of 250 m^2 and radius of 892 m. This 250-m^2 area was the sample area for estimation of tree biomass, where trees are defined as plants larger than 5-cm diameter at breast height (DBH) at 1.3 m above ground. Trees were counted within each plot (sample mean 14.3 trees) and heights measured using clinometers. Counted and measured trees were marked with enamel or chalk to avoid double counting.

Forest carbon is comprised of tree and sapling biomass, leaf litter, dead wood, and soil organic carbon (IPCC, 2006). In this paper only above ground tree and sapling biomass are estimated. Allometric equations from Chave *et al.* (2005) allow us to take account of DBH, tree height and species density in biomass estimates. Biomass is converted to carbon using the IPCC (2006) default conversion factor of 0.50. On average, sapling biomass is 3% of total above ground biomass and is estimated based on a 100-m^2 area with radius of 5.64 m. Details on carbon estimation procedures are available in Appendix 2 in the SI.

Though our main interest is carbon sequestration and the possibility that CA and particularly the CFP sequesters carbon, because biomass and carbon are at best partial measures of forest quality, we analyze three other measures of forest health. Our first is number of trees per hectare. A few trees on a plot could indicate forest maturity or climax vegetation. Such climax forests are relatively unusual in Nepal and few trees on a plot may also mean the plot has experienced significant harvesting. As discussed by Stephenson *et al.* (2014), even aged stands with large trees may

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[4] Forest names and sampling details are given in Appendix 1 in the Supplementary Information (SI).

[5] Results from 1300-household survey conducted in our 130 forest communities, including tests for mean differences. Appendix 4 presents Wilcoxon rank-sum tests for ecological differences at the plot level.

[6] 30 NCF plots were omitted because of data quality concerns.

Table 1
Forest size in hectares by CF status and physiographic region

	CF (50 hills, 15 Terai)			NCF (15 hills, 50 Terai)		
	Mean	Min.	Max.	Mean	Min.	Max.
Hill (50 CF, 15 NCFs)	105.31	1.12	526.00	30.50	4.75	84.00
Terai (50 NCFs, 15 CFs)	240.41	1.10	1088.00	129.22	1.68	805.00
Overall	149.00	1.10	1088.00	106.00	1.68	805.00

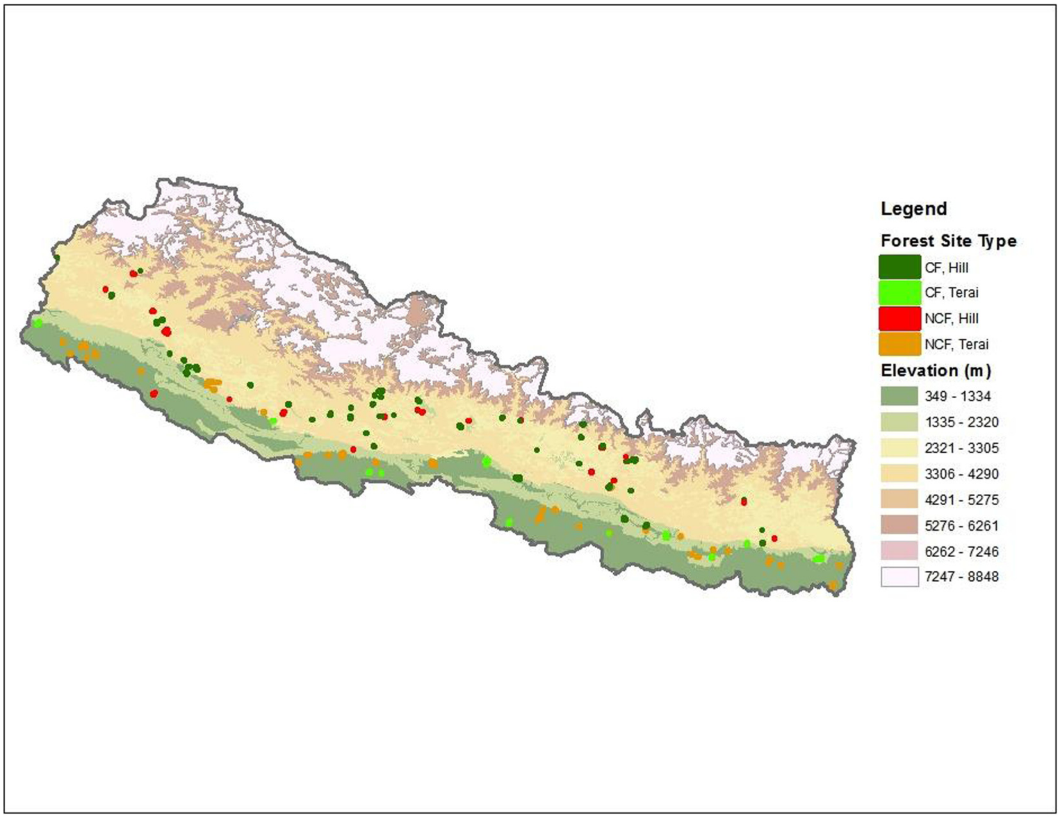

Figure 1. Map of research sites.

grow more rapidly than other plots, but have fewer trees per plot. This could imply more carbon, but fewer trees.

The second additional measure is percent canopy cover from the center of each sample plot as estimated by field enumerators, which evaluates the extent of side branches in sample plots.[7] Low canopy cover in Nepal typically indicates that branches have been lopped for fuelwood and fodder, but can also indicate plots with large trees (Enquist *et al.*, 2009; West *et al.*, 2009). Finally, the extent of regeneration in a circle of 3.14 m^2 (1 m radius), measured as number of seedlings per hectare, can indicate the degree to which farm animals like goats, cattle, sheep, and water buffalo have grazed in forest areas. Of course, mature forests have little regeneration, but because of mixed uses, in Nepal such near climax forests are unusual. Because regeneration can indicate past disturbance events (Coomes *et al.*, 2012), it may be negatively correlated with carbon stocks. Figure 2 shows the plot-level sampling methodology for estimating tree carbon, sapling carbon and number of seedlings per plot and per hectare.

As was already mentioned, our data indicate that some NCFs engage in significant collective action. For example, even though they have no legal rights, 37 of 65 NCF leaders (55%) are able to identify the year their forest user group was formed. The first group started in 1991 and the most recent was established in 2012. Many NCFs not only identify their formation year, which is a potential measure of the existence of a clearly defined group, but also claim collective action behaviors. For example, 74% of NCF leaders agreed or strongly agreed with the statement "*the community forest has clear boundaries between legitimate users and nonusers and nonusers are effectively excluded.*" Furthermore, 68% of NCF leaders report they have "*... formal, informal or customary rules and regulations that govern the access, use (harvesting) and maintenance (management) of the forest*" and 22 say these rules are in writing. Appendix 2 provides household descriptive statistics that indicate NCF households also perceive significant forest CA, which suggests that the group-level assessments are reasonable.

We interpret the ability to identify a forest user group formation year to indicate the existence of a well-defined group, which is one of the key CA criteria identified by Agrawal (2007) and Ostrom (1990, 2000). Forest user group formation year identification is therefore an objective if not comprehensive measure of CA[8]. Our three CA measures run from narrow to comprehensive

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[7] This is a key measure of forest quality used in Agarwal (2010).

[8] As discussed by Ostrom (1990, 2000, 2009), Agrawal (2007) and many others, group clarity is a critical component of CA. All CFs can, of course, identify such years, because they are legal entities.

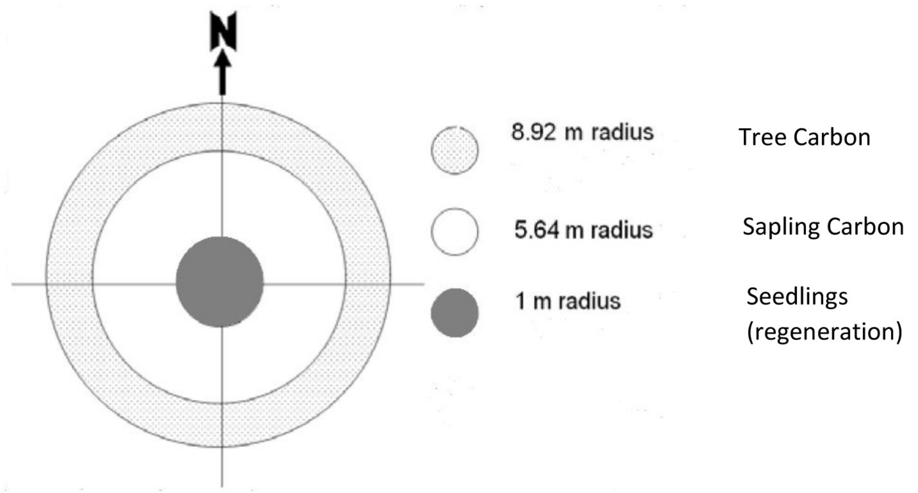

Figure 2. Forest plot sampling methodology.

Table 2
Collective action definitions and counterfactual against which effects are identified

Treatments/CA measures	Counterfactual
Narrow definition: Forest and community are registered CFs (CF)	All NCFs, including 57% with evidence of CA and 43% without
Modest definition: All communities (CF or NCF) in which village leaders are able to report the year forest user groups were established (CanIDFUGyear)	NCF communities where village leaders cannot identify the year of forest group establishment
Comprehensive definition: All communities that can identify the year of group formation (CanIDFUGyear), including CFs, and all those that have proposed forests to be CFs, but are not yet part of the CFP regardless of whether they can identify their group formation years.[1] (COMPREHENSIVE)	NCF communities that do not exhibit evidence of CA (presumed open access)

[1] 23 NCFs (35% of total NCFs) are proposed CFs. We do not know the quality of the proposals. 18 of these have identified establishment dates and 5 do not.

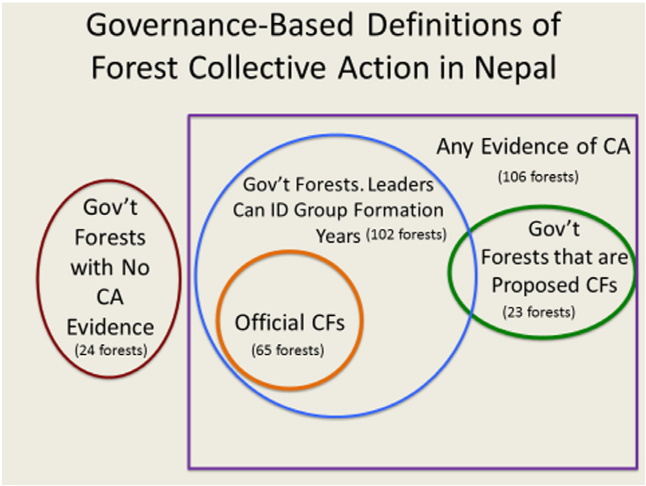

Figure 3. Forest collective action in Nepal.

and are represented by dummy variables. Table 2 presents our CA definitions and the counterfactuals against which we identify effects. Figure 3 shows the overlap between these CA measures.

In all models we adjust for a variety environmental variables, such as total forest area, altitude, slope, ecosystem type (hill versus *Terai*), soil color (black or other) and type (clay/loam or other) and aspect (to include moisture retention). Over 90% of forests are natural forests rather than plantations. As plantation establishment could in principle be a function of CA and therefore endogenous, we do not include this distinction in our models. In all plot-level models errors are clustered at the community level to incorporate unobserved community factors like total cattle in the community, ethnic group, religion, etc. for which we do not have data.

We adjust for forest-level baseline vegetation using the 1990 NDVI calculated from Landsat data images collected in November/December 1990. These dates are before any of the group formation years in our dataset and three years before the Forest Act of 1993 that established CFs. During these months the sky is typically very clear in Nepal and images are unimpeded by clouds.[9] This variable adjusts for historical baseline and helps avoid endogeneity bias. As shown in Table 6 in the following section, we find that plots located in CFs on average have lower levels of 1990 NDVI ($p < 0.001$). Forests where forest user group formation year can be identified and that are CFs or Proposed CFs have average 1990 NDVI levels equal to areas without collective action. These findings suggest that if anything current areas with collective action started out with less vegetation than current open access areas.

Our last two independent variables are at the community level and capture extraction pressures. The first is the number of households in forest user groups, which along with forest area provides a measure of average forest endowment. The second extraction pressure variable is the user group out-migration rate, defined as the fraction of household members that are reported to have migrated out of the village. This variable is included, because higher migration rates may reduce pressure on forests. Migration is significant in Nepali villages and in our sample several groups had over 20% out-migration rates. More than a million Nepalis work outside Nepal (Lokshin, Bontch-Osmolovski, & Glinskaya, 2010), predominantly from the hills, and remittances made up 15% of GDP in 2004/2005 (Bohra & Massey, 2009).

We analyze the effect of our three levels of CA (CF, CanIDFUGyear and COMPREHENSIVE) on our four measures of forest quality (carbon/ha, trees/ha, canopy cover and seedlings/ha) at the plot-level and averaged at the forest level. As our data are observational, sample selection, and endogeneity are potential problems. A spe-

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[9] We thank Charles Maxwell for assuring clear imagery and estimating the NDVI.

cial concern is that communities could engage in CA to assert property rights over high-quality forests, implying reverse causality. We see such a possibility as unlikely, however. First, in contrast to biomass and carbon, canopy cover and regeneration are forest quality measures with few incentives to assert property rights. With regard to biomass, as was already discussed, on average communities who in 2013 were engaging in CA started out with at best the same quality forests (measured as 1990 NDVI) as communities without CA. The details are discussed in Appendix 3. CA therefore does not appear to have been used to secure property rights to better quality forests.

Establishing a CF requires paperwork, time and negotiation outside the community that can be very costly, creating potential barriers. For example, using a survey of 309 households belonging to eight different forest user groups in the middle hills of Nepal, Adhikari and Lovett (2006) find that transaction costs for CF management as a percentage of resource appropriation costs are as high as 26%.[10]

It may be the case that there are unobserved characteristics that lead some communities to undertake CA, and these could account for carbon sequestration. However, such sequestration must occur through forest use decisions and CA is the most likely mechanism by which these decisions are influenced.

At the plot level we present random effects models with groups defined by forest/community.[11] As a robustness check, in Appendix 4 we provide pooled OLS results with standard errors clustered at the forest/community level,[12] which yield results that are virtually identical to those from the random effects models. We use regression rather than semi-parametric propensity score matching, because our quasi-experimental sampling strategy is defined at the forest level. As a result, there is much more heterogeneity within CF and NCF classes at the plot level and we were unable to identify high quality matches.

At the forest level we estimate average treatment effects on the treated (ATT) using nearest neighbor propensity score matching and as already discussed our quasi-experimental sampling strategy was specifically designed for this purpose. All observables included in Table 6 are used to estimate a probit model, which defines the propensity scores on which matching is based. Balance in the propensity scores is achieved in all models and matching is only done within the region of common support of the propensity score, which helps assure we only analyze comparable observations and exclude unmatched control observations[13].

Propensity score matching assumes that treatment assignment (CF, CanIDFUGyear and COMPREHENSIVE) is wholly determined by the observable variables included in the probit equation. Though not addressing unobservable factors affecting the probability of treatment (e.g., existence of strong leaders), matching on observables makes it more likely that the counterfactual thus constructed is appropriate when using observational data (Rosenbaum & Rubin, 1983). Additional details on our propensity score matching identification strategy are provided in Appendix 3 and in Appendix 4 we provide the results of the probit models we use to estimate propensity scores.

Table 3
Plot-averaged forest carbon per hectare (kg) by whether CF = 1

	Hill	*Terai*	All CF/NCF
CF	76092	118327	89737
	(71103)	(102999)	(84310)
NCF	72068	101988	95084
	(70415)	(65617)	(67397.78)
All Hill/*Terai*	75069	106821	92410
	(70342)	(78112)	(76075)

Standard deviations in parentheses. Two-sample, two-tailed *t* tests for differences in means by CF status (rows) and geographic region (columns). Carbon per hectare is significantly different in hill and *Terai* region forests for CFs ($p \leq 0.10$) and across all forests ($p \leq 0.05$).

Table 4
Plot-averaged forest carbon per hectare (kg) by whether CanIDFUGyear = 1

	Hill	*Terai*	All
CanIDFUGyear = 1	82401	117167	99784
	(72625)	(80081)	(78045)
CanIDFUGyear = 0	28329	80439	65550
	(20865)	(67697	(62551)

Standard deviations in parentheses. Two-sample, two-tailed *t* tests for differences in means by CanIDFUGyear status (rows) and geographic region (column). Carbon per hectare is significantly different for communities where CanIDFUGyear = 1 compared with CanIDFUGyear = 0 in the hills ($p \leq 0.05$), *Terai* ($p \leq 0.10$) and across all forests ($p \leq 0.05$).

Table 5
Plot-averaged forest carbon per hectare (kg) by whether COMPREHENSIVE = 1

	Hill	*Terai*	All
COMPREHENSIVE = 1	82401	117530	100628
	(72625)	(77844)	(77065)
COMPREHENSIVE = 0	28329	70010	56116
	(20865)	(69230)	(60507)

Standard deviations in parentheses. Two-sample, two-tailed *t* tests for differences in means by COMPREHENSIVE status (rows) and geographic region (columns). Carbon per hectare is significantly different for communities where COMPREHENSIVE = 1 compared with COMPREHENSIVE = 0 in the hills ($p \leq 0.05$), *Terai* ($p \leq 0.05$) and across all forests ($p \leq 0.01$).

4. Results

Average carbon by forest is 92.4 tons per hectare, with 560 trees and just over 30,000 seedlings per hectare across our 620 plots. Table 3 evaluates the forest-averaged carbon broken down by CF/NCF and hill/*Terai* forests. Average carbon per hectare in CF and NCF forests are not statistically different, but the overall difference between hill and *Terai* forests is significant, with *Terai* forests having on average 42% more carbon than hill forests ($p \leq 0.05$). This difference reflects the generally more productive ecosystems in the *Terai*. It could also potentially reflect more carbon in NCFs as most NCFs are in the *Terai*.

Tables 4 and 5 present average carbon for our two broad measures of CA vis-à-vis counterfactuals, where COMPREHENSIVE forests are compared to presumed *de facto* open access. We see that communities with well-defined groups average more carbon per hectare than forests without an identifiable formation year. Whether forests are located in the hills ($p \leq 0.05$), *Terai* ($p \leq 0.10$) or in total ($p \leq 0.05$), average carbon per hectare is greater if formation year is identifiable (CanIDFUGyear = 1). In the *Terai*, for example, forests without a clear group have only 68% of the carbon of those with an identifiable year. User groups that do not meet either of our broad definitions of CA average only 56% of the carbon

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[10] Author discussions with Kaski District forestry officers suggest that CF formation may cost upwards of $4000. Viewing forest CA as exogenous to current forest quality seems particularly appropriate in the hills of Nepal where communities are stable and have traditionally controlled forests using customary methods. Indeed, having a core of households that were able to cooperate, settle in an area and several generations later their descendants formalize collective action as a CF could reasonably be considered an exogenous treatment.

[11] The model assumes that forest and plot-level error terms are uncorrelated with the control variables. Our matching strategy for sample selection makes this assumption more likely to hold than would random sampling of NCFs.

[12] As our treatments (CF, CanIDFUGyear and COMPREHENSIVE) are time-invariant, we cannot estimate fixed effects.

[13] In the modest CA definition model with CanIDFUGyear as the CA variable of interest, number of households in the forest user group had to be dropped to achieve balance.

Table 6
Independent variables

Independent variables of primary interest		CF mean	NCF mean	*P* value
Variable name	*Variable description and coding*			
	1 = CF; 0 = NCF	1.00	0.00	0.00
CanIDFUGyear _	1 = Can identify year of forest user group formation; 0 = Cannot identify	1.00	0.57	0.00
COMPREHENSIVE	1 = COMPREHENSIVE criteria fulfilled 0 = COMPREHENSIVE criteria not fulfilled	1.00	0.63	0.00
Environmental variables (plot or average across plots by forest)[1]				
NDVI_1990	1990 average NDVI by forest	0.41	0.44	0.02
Altitude	Altitude in meters	1037.23	509.83	0.00
Slope	Percent (flat = 0)	21.26	10.31	0.00
Hill	1 = hill; 0 = *Terai*	0.67	0.23	0.00
Total forest area	Forest area in hectares	149.0	106.44	0.11
Soil color	1 = black; 0 = gray/red/white/yellow/other	0.69	0.6	0.02
Clay loam	1 = clay/loam soil; 0 = sandy/rocky soil	0.52	0.66	0.00
Sal[2]	1 = Sal forest, 0 = other forest	0.37	0.63	0.00
Aspect	N = 1;NE/NW = 0.75;E/W/flat = 0.50;SE/SW = 0.25;S = 0	0.53	0.50	0.03
Community variables				
HHsinfug	Total number of households in forest user group	295.80	296.63	0.70
Migration rate	Fraction of forest user group members that have migrated from the village	0.09	0.08	0.09

[1] Statistically significant differences largely reflect key ecological differences between the hills and *Terai*. Migration rates are higher in the hills than the *Terai*.

[2] Sal (*Shorea robusta*) is a member of the Dipterocarpaceae family. It is a particularly valuable timber species found in Nepal at lower elevations. 308 of 620 plots are primarily sal. Other species include broadleaf, pine, *bel* and *chilaune*.

Table 7
Random effects models of carbon and number of trees per hectare by CA measure (panel by plot)

	Coefficient estimates					
	Carbon per hectare (kg)			Number of trees per hectare		
CF	4105.40			-13.23		
	(15223)			(66.30)		
CanIDFUGyear		30046.			-71.27	
		(13409)**			(74.42)	
COMPREHENSIVE			37507			-4.15
			(13475)***			(75.68)
Environmental Controls including 1990 NDVI?	Yes	Yes	Yes	Yes	Yes	Yes
Community Controls?	Yes	Yes	Yes	Yes	Yes	Yes
R^2 within group	0.02	0.02	0.02	0.04	0.04	0.04
R^2 between groups	0.32	0.34	0.35	0.17	0.18	0.17
R^2 overall	0.21	0.22	0.23	0.13	0.13	0.13
Wald X^2	91.52	103.4	107.9	56.63	58.60	55.96
Prob > X^2	0.00	0.00	0.00	0.00	0.00	0.00

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$; robust standard errors in parentheses. $n = 620$ with 130 groups.
Bold Indicates statistically significant at the 10% level or better.

of groups exhibiting CA ($p \leq 0.01$) and in the hills only 34% ($p \leq 0.05$). As shown in Appendix 4, presumed open access plots (i.e., those that do not fulfill the criteria for COMPREHENSIVE) are also more likely to show evidence of fire and erosion (with less average slope).[14]

The plot-level random effects regression models are presented in Tables 7 and 8. Detailed results that include the effects of the control variables on forest quality are provided in Appendix 4 as are OLS models with errors clustered at the forest level. The OLS results are basically identical to those from the random effects models.

We find no effect of CF status on carbon, which suggests that under current institutional arrangements CFs do not contain more carbon than NCFs. We do find positive effects of CanIDFUGyear and COMPREHENSIVE. Plots located in forests where group leaders are able to identify the year of group formation are estimated to have 30 tons more carbon per hectare (about 1/3 of the sample mean) than those without a well-defined formation year ($p < 0.05$). COMPREHENSIVE, which is our broadest definition of CA and adds in proposed CFs that cannot identify group formation year, is estimated to have even larger effects vis-à-vis open access. Fulfilling this broad criterion for CA is estimated to increase carbon by 37 tons, which is 40% of the mean ($p < 0.01$). These findings suggest that basic CA offers large carbon gains vis-à-vis communities exhibiting limited or no evidence of collective action, but within the current institutional environment (e.g., no REDD+), being part of the CFP *per se* does not increase carbon.

Other forest quality results are limited. CFs are estimated to have fewer seedlings per hectare ($p < 0.10$) and plots in forests identified as CanIDFUGyear are estimated to have less canopy cover ($p < 0.05$), which may be the result of more dense, but younger forest stands.

As shown in Appendix 4, a number of control variables affect forest quality. History matters for all measures of forest quality, with plots having more vegetation in 1990 (measured by NDVI) also being of higher quality in 2013. Plots in larger forests tend to have more seedlings and carbon per hectare ($p < 0.05$), though carbon effects are small. Forests with sal trees have more carbon as would be expected, because sal trees are dense and can be large ($p < 0.01$). They also have more trees and seedlings per hectare. Hill plots have more trees, canopy cover, and seedlings per hectare all else equal than in the *Terai* ($p < 0.05$). Plots governed by larger

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[14] Appendix 4 also presents our analysis of the effects of forest user group vintage on forest quality, which suggests that by some measures older forest user groups have better quality forests.

Table 8
Random effects models of crown cover percentage and seedlings per hectare by CA measure (panel by plot)

	Coefficient estimates					
	Crown cover percentage			Seedlings per hectare		
CF	−3.54 (3.76)			−6949.00 **(3933.8)***		
CanIDFUGyear		−9.81 **(4.46)****			1896.70 (4174.30)	
COMPREHENSIVE			−7.29 (4.75)			5530.80 (4077.40)
Environmental Controls including 1990 NDVI?	Yes	Yes	Yes	Yes	Yes	Yes
Community Controls?	Yes	Yes	Yes	Yes	Yes	Yes
R^2 within group	0.01	0.01	0.12	0.02	0.02	0.02
R^2 between groups	0.17	0.20	0.18	0.27	0.26	0.26
R^2 overall	0.11	0.14	0.13	0.19	0.18	0.19
Wald X^2	44.58	50.37	46.63	63.29	58.03	57.38
Prob > X^2	0.000	0.000	0.000	0.000	0.000	0.000

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$; robust standard errors in parentheses. $n = 620$ with 130 groups.
Bold Indicates statistically significant at the 10% level or better.

Table 9
Forest-level average treatment effects on the treated (ATT) using nearest-neighbor propensity score matching

Forest quality metric	Narrow			←Collective action treatment→			Broad		
	ATT CF			ATT CanIDFUGyear			ATT COMPREHENSIVE		
	Matched treated/control	ATT	*t*-stat	Matched treated/control	ATT	*t*-stat	Matched treated/control	ATT	*t*-stat
Carbon/ha. (kg)	65/21	31540	1.20	102/21	37506	1.26	106/22	40022	1.36
Trees/ha.	65/21	173.40	1.01	102/21	−237.3	−1.37	106/22	−216.40	−1.36
Canopy cover (%)	65/21	6.71	0.78	102/21	−14.16	−1.30	106/22	−9.65	0.88
Seedlings/ha.	65/21	8787.00	0.90	102/21	5190	0.75	106/22	9389	1.10
Region of common support		0.030–0.999			0.37–0.999			0.3700–0.999	
Post matching ave. prop. score difference		0.029			0.027			0.023	

$^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. All treated forests were matched with control forests.

forest user groups have more canopy cover and trees per hectare. The local migration rate is not significant in any model, which suggests that higher average out-migration does not affect forest quality.

Table 9 analyzes the effect of our three measures of CA on forest quality at the forest level based on plot-level averages using nearest neighbor propensity score matching. We find no statistically significant effects in these models, though the estimated magnitudes of the CanIDFUGyear and COMPREHENSIVE carbon effects are very similar to the estimates from the plot-level models, suggesting that our sample sizes may be too small to detect effects. Echoing our plot-level analysis, though, we find that if the sample is restricted to NCFs only, communities with clearly defined group formation years have 73 tons more carbon per hectare than NCFs without well-defined group formation years. These results are provided in Appendix 4. As a robustness check, we re-run all models where the counterfactual is fixed as presumed open access (i.e., communities that do not fulfill the criteria associated with COMPREHENSIVE). We find virtually no change in results.

5. Discussion and conclusions

In this paper we use a random sample of CFs matched with NCFs that local forestry professionals specifically identified as best possible matches. Ten to eleven key community and environmental variables, including the 1990 NDVI, are used to estimate balanced propensity scores, suggesting that the randomly chosen treatment and the selected-based-on observables control communities are highly comparable. We use forest quality measurement methods that are labor intensive, but also allow us to carefully estimate tree and sapling carbon, count trees, evaluate canopy cover and examine regeneration. Because on-the-ground estimation methods are used, we are also able to gather detailed plot-level data that are shown to be important determinants of forest quality. Not surprisingly, we find that 1990 baseline vegetation matters for contemporary forest quality. Communities with measured CA in 2013 had forests with 1990 NDVI levels that were similar or lower than communities that in 2013 were not engaging in CA, suggesting that 2013 CA forests started out in no better condition than current open access forests.

We find that within the existing environment, at the plot level, which is the basic unit of our outcome variable data, collective action has positive effects on forest carbon. Indeed, we find that plots in forests controlled by user groups with well-defined establishment years or which are proposed as CFs have substantially more carbon than open access NCFs.

We do not, however, find evidence that CFs sequester more carbon than NCFs as a whole. These findings suggest that it is the CA—i.e., the group behavior—that increases biomass and not the formalization. Keeping in mind our counterfactuals and noting that based on the literature we have reason to believe that CA improves forest management, it appears that some NCFs exhibit sufficient CA so that the CF program on balance adds little to forest carbon. About 55% of NCFs in our sample can identify the year their groups were formed and 1/3 are proposed to be CFs. They also exhibit a variety of sophisticated CA behaviors, including written rules, clearly defined boundaries, etc.

It is perhaps not surprising that more carbon is not sequestered in CFs than in NCFs, because operational plans do not include carbon values. It is notable, though, that CA *per se* is so important for carbon sequestration, but we would like to suggest that this finding is really about savings. Carbon sequestration is approximated as a linear function of biomass, which to a first approximation can be called "fuelwood" or "timber." In our view communities that engage in CA are not sequestering carbon, but are allowing forests to grow so later they can perhaps be harvested.

Our findings suggest that FCCC funders and governments would do well to support community CA, because it is so much more effective than no collective action. In Nepal, CFUGs are a particularly important manifestation of CA. To the extent appropriate, streamlining government recognition of communities as CFUGs could therefore be an important avenue to support CA in Nepal. Such policy reform may be particularly important if, as expected, it will be necessary to form registered CF groups to credit CA under REDD+. Technical support could also be critical as there may be a need for group facilitation and training. Financial support for establishing CFUGs may also be important as forming CFUGs can be costly.

Our data do not allow us to track forest quality over time. This is a limitation that we have tried to minimize through randomly sampled CFs matched with hand-picked NCFs and detailed plot-level analysis. This approach leaves unanalyzed, though, the social relationship between CA in CFs and NCFs. For example, the Nepal CFP may have engendered norms of behavior (e.g., related to group formation, operation, and management) that were adopted in some NCFs. We are unable to document conclusively where non-open access NCFs got those behaviors, but we conjecture that over time NCF communities adopted practices from the CF system. NCF collective action norm formation is certainly an important area for additional research.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.worlddev.2017.07.030.

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