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

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1. Importance of the Issues and Introduction

Evidence published in March 2013 suggests that the earth is now hotter than about ¾ of the last 11,000 years (Marcott et al., 2013) and IPCC (2014) evaluated with medium confidence that the period 1983-2012 was hotter than the last 1400 years. The United Nations Framework Convention on Climate Change (FCCC) of 1992 is the international agreement that governs efforts to mitigate this climate change. At least at present, developing countries do not have formal obligations, though many made pledges at the 2009 Conference of the Parties in Copenhagen. Developing countries generate a majority of global emissions, since 1992 have increased much faster than those from richer Annex 1 countries and are projected to reach 2/3 of greenhouse gas (GHG) emissions by 2030 (Stern, 2013).

Finding areas of cooperation is therefore critical and an important area is land use change. The UN Collaborative Programme on Reducing Emissions from Deforestation and Degradation (REDD+) is a program by which FCCC Annex 1 countries provide support to non-Annex 1 countries, such as Nepal, in exchange for measurable additional carbon sequestration. These reductions are potentially important, because net deforestation and forest degradation account for between 12% and 20% of annual GHG emissions, which is more than all transport combined IPCC, 2007; (Pan et al., 2011; Saatchi et al., 2011; van der Werf, 2009). Virtually all net deforestation occurs in developing countries, with an estimated net carbon source from tropical land use change of 2.4 $\pm$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.[2]

While REDD+ is being rolled out, an important question is how to incorporate the approximately 25% of developing country forests that are managed by communities (World Bank,

[2] For comparison, total carbon emissions by humans since 1750 are estimated to be approximately 375 gigatons (IPCC, 2014).

2009). These community forests may contain significant carbon that could be protected under REDD+ and the collective action (CA)[3] they are engaging in may, even now, be sequestering carbon. Low-income developing countries' community forests 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 et al., 2008). More effective CA leads to better management of these ecosystem services, reduced fuelwood, timber and fodder collections (Bluffstone et al, 2008). It may also yield more biomass and carbon sequestration, because reduced pressures allow forests to regenerate (Beyene et al., 2015; Chhatre and Agrawal, 2009.

We examine whether, using three different CA measures, forest CA in Nepal leads to larger carbon stocks per hectare. More carbon is not necessarily consistent with and can be inversely related to other potential measures of forest stand health, such as greater tree density per hectare, additional canopy cover and regeneration (Enquist et al., 2009; Stephenson et al., 2014; Coomes et al., 2012). We therefore separately evaluate the effects of CA on all four forest quality measures.

We test our hypotheses using a nationally representative random sample of forest dependent communities and forests, some of which are part of and others outside the Nepal Community Forestry Programme (CFP). The CFP is the most important forest devolution program in Nepal, with over 18,000 registered forest user groups representing over 35% of the population. The existence of the CFP makes Nepal an ideal setting for testing the hypothesis that forest CA sequesters carbon.

This treatment group is matched with an equal number of forests that are not part of the program. A total of 130 forests with 620 forest sample plots are analyzed and the effects of CA,

[3] The Merriam-Webster online dictionary defines collective action as "united action by an association (as of nations against an aggressor)."

including being part of a registered community forest (CF), are evaluated using panel data regression, OLS regression and nearest neighbor propensity score matching.

Our main findings are that within the existing institutional environment, CA has large positive effects on carbon stocks compared with open access, but these gains are not conditional on being formal CFs. Depending on our measure of CA, we are able to identify effects at both the forest and plot levels, especially when matched based on plot and forest characteristics. CF participation, which is our narrowest measure of CA, is found to have 14% more carbon compared with the mean when CF and non-CF (NCF) plots are explicitly matched, but we are unable to detect effects of CF program participation on carbon in our other three models. Broader measures of CA vis-à-vis open access show robust, positive carbon effects, which do not necessarily correspond with results for other measures of forest quality.

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. 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 et al., 2008). Carbon sequestration in forests may also be particularly cost-effective climate investments (Strassburg et al., 2009; Kindermann et al., 2008). An estimated 15.5% of global forest is under the formal control of communities, providing key subsistence products and community control is increasing (RRI, 2014). Using worldwide forest data and highly aggregated 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 et al. (2015) evaluate the effect of local community forestry collective action on carbon sequestration in Ethiopia, but find minor effects. Yadav et al. (2003), Gautam et al. (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 (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 in the context of serious deforestation and forest degradation, because centralized forest management was not working (Guthman 1997; Hobley 1996, Springate-Baginski and Blaikie 2007; Carter and Gronow 2005). 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 forest to community forest user groups (CFUGs). The handover rules were detailed in 1995 forest regulations and operational guidelines, which were revised in 2009. 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 Forestry 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 negotiate operational plans with 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 18,000 CFUGs and over 1.6 million households managing 1.2 million hectares (MoFSC 2013). Three-quarters of CFs are in the hills, 16% in the high mountains and only 9% are in the lowland *Terai* (MOFSC 2013). Nepal officially joined REDD+ in 2010 and REDD+ activities have largely focused on the CFP (Oli and Shrestha 2009). The CFP is the most important REDD+ institution 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.[4] The relationships between these forest parameters have been extensively investigated. The main conclusion of this literature is that depending on individual tree and forest stand circumstances, these measures may not vary monotonically with each other. For example, depending on the situation higher carbon stocks may be associated with higher or lower levels of canopy cover, tree density and seedling regeneration (Stephenson et al., 2014; West et al., 2009; Enquist et al., 2009; Coomes et al., 2012). In assessing the effects of an outside force such as CA on forests, these forest quality measures are therefore not expected to give similar results and are most appropriately evaluated independently.

Assessing baseline carbon is critical for calculating carbon increments and a range of remote sensing and ground based methodologies are available. One widely used and important tool 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 energy absorption by plant canopies (Sellers 1985; Myneni et al., 1995), which is linked to carbon sequestration. Though it

[4] Carbon constitutes approximately 50% of forest biomass (Gibbs et al., 2007) and this is also the IPCC (2006) default value

cannot be used to estimate carbon *per se*, the NDVI provides an important measure of baseline land quality.

3. Methods

This paper relies on forest and plot level data in CFs and NCFs. NCFs are government forests used by communities, but we emphasize that government forests are typically weakly controlled by the Government of Nepal.[5] Forest inventory and community data were collected in spring 2013 from 130 forests in the middle hill (approximately 700 – 3000 meters 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 CF status and physiographic region. The population of CFs is concentrated in the hills and NCFs in the *Terai*, which is reflected in the sample. Larger forests in both the hills and *Terai* on average tend to be CFs. Figure 1 shows the spatial distribution, which is nationally representative.

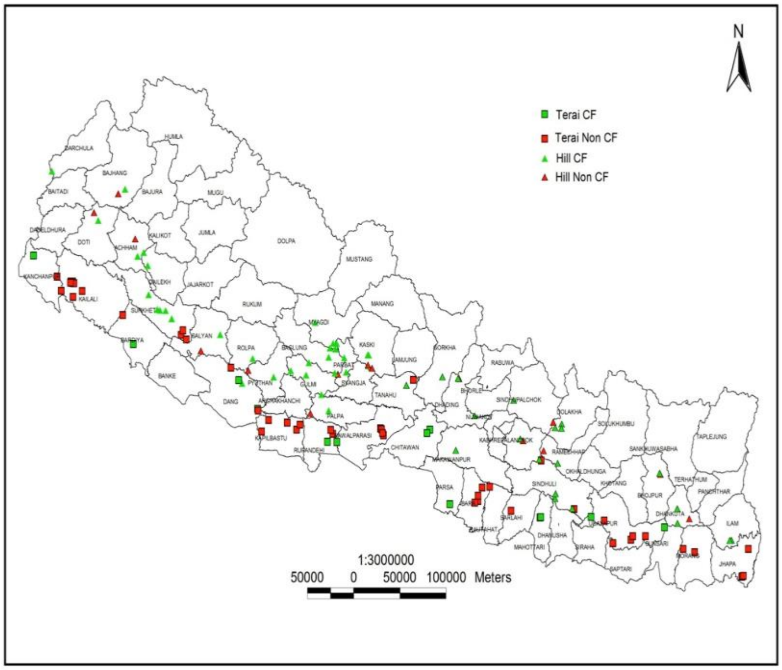
Table 1
Forest Size in Hectares by CF Status and Physiographic Region

	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	30.5	4.75	84
Terai (50 NCFs, 15 CFs)	240.41	1.10	1088.00	129.22	1.68	805
Overall	149.00	1.10	1088.00	106	1.68	805

Figure 1

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

Map of Research sites



The forest inventory was carried out in 130 forests, with 325 randomly selected plots in CFs and 295 in NCFs.[6] Forest data are collected at the plot level. Relying on our random sampling methodology, dependent variables, such as carbon, that are countable are converted to per hectare values. For the forest-level analysis, we average across plots.

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 and the largest 1088 hectares. Appendix 2 in the SI presents the distribution of plots across quintiles of the 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 a circle with a total area of 250 m^2 and radius of 8.92 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 on each plot (sample mean 14.3 trees)

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

and heights measured using clinometers. 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 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 biomass and the details on estimation are available in Appendix 2 in the SI.

+Environmental and community data were 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. 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 one used to collect subsistence products and for grazing. NCF identification presented other challenges, which are discussed in the SI Appendix 2.

Though our main interest is carbon sequestration and the possibility that CA and particularly the CFP sequesters carbon, we also analyze three other measures of forest health. Our first is number of trees per hectare, which allows for the possibility that carbon on a plot could consist of only a few trees. As discussed by Stephenson et al. (2014) even aged stands with large trees may grow more rapidly than other plots, but have fewer trees per plot. This could imply fewer trees with more carbon at the stand level.

The second 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] Lower canopy cover in Nepal typically indicates that branches have been lopped for fuelwood and fodder, but can also indicate plots with large trees (West et al., 2009; Enquist et al., 2009). Finally, the extent of regeneration, 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 in Nepal such near climax forests are unusual. Because regeneration can also indicate past disturbance events (Coomes et al., 2012), however, it may be negatively correlated with carbon stocks.

CF status is in reality a subset of broader forest CA and our data indicate that some NCFs engage in significant collective action. For example, even though they have no legal status, 37 of 65 NCF leaders 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, 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. The SI Appendix 2 provides household descriptive statistics that indicate NCF households perceive significant CA.

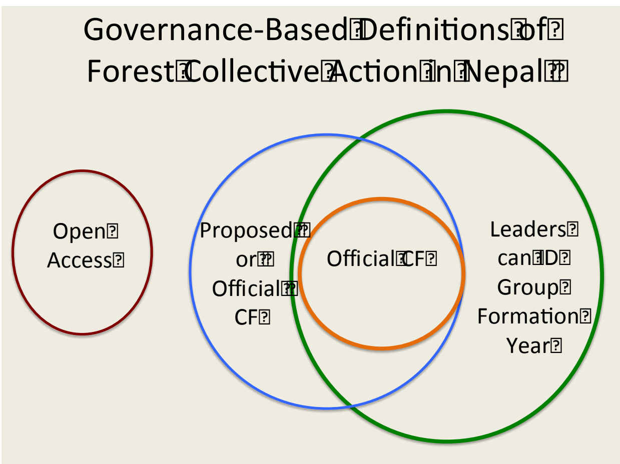
We interpret the ability to identify forest user group formation years to indicate the existence of well-defined groups. Forest user group formation year identification is therefore a

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

broad and objective if not comprehensive measure of CA[8]. Our three CA measures run from broad to narrow and are represented by the dummy variables below. Figure 2 presents the overlap between these CA measures.

- Narrow definition: Forest and community are registered CFs (CF)
- Modest definition: Forest and community are registered *or* proposed CFs (CForPROPOSED)[9]
- Broad definition: NCF forests and communities where village leaders are able to report the year forest user groups were established (CanIDFUGyear)

Figure 2



In our models we adjust for environmental variables, such as total forest area, altitude, plot slope, ecosystem type (hill versus *Terai*) and soil quality. We also adjust for environmental features that may be outcomes of CA, such as plantation versus natural forest, evidence of erosion or fire, but in Appendix 4 we present models without these variables. We find that without these variables our estimated CA coefficients increase in magnitude without other changes.

In all models we adjust for 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

[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.

[9] 23 NCFs are proposed CFs. We do not know the quality of the proposals. 18 of these have identifiable start dates and 5 do not.

clouds.[10] This variable adjusts for historical baseline and helps avoid endogeneity bias. As shown in Appendix 4, we find that *plots in CFs on average have lower levels of 1990 NDVI (p=0.00)*. Plots in forests where FUG 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 and the second is the user group migration rate, defined as the fraction of household members that are reported to have migrated. This variable is included, because 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 (Loksin et al, 2010) and remittances made up 15% of GDP in 2004/2005 (Bohra and Massey, 2009).

Though CF and NCF community variables are not significantly different, there are statistically significant ecological differences between CFs and NCFs, because most CFs are in the hills and NCFs are in the *Terai*. As expected, there are also differences in forest management participation, structure and quality, with CFs on average reported as performing better than NCFs. Our hypothesis is that this better performance yields better forest quality, including carbon sequestration. Appendix 2 in the SI presents these results taken from our 1300 household survey, including Wilcoxen tests for mean differences and Appendix 4 presents tests at the plot level.

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

We analyze the effect of our three CA metrics on four measures of forest quality (carbon, trees/ha, canopy cover and regeneration at both the forest and plot-levels.[11] In Appendix 4 we present the forest-level OLS and plot-level random effects models, but mainly focus our discussion here on average treatment effects using propensity score matching. Though not addressing unobservable factors affecting the probability of treatment (e.g. existence of strong leaders), matching on observables is an appropriate way to construct a counterfactual using observational data (Rosenbaum and Rubin, 1983). Our independent variables and strategy for identifying the effects of CA on forest quality are presented in Appendix 3.

The treatments are CF, PROPOSEDorCF and CanIDFUGyear (for NCFs only to avoid conflating with CF status). All propensity scores are estimated using the full sample and are balanced, indicating that the treatments and constructed controls are comparable. Matching is only done within the region of common support of the propensity score, which assures we are analyzing comparable observations and are excluding unmatched observations. Propensity score details are discussed in section 4 and in SI Appendix 4.

4. Results

Average carbon is 92.4 tons, with 560 trees and just over 30,000 seedlings per hectare across our 130 forests. Table 2 breaks carbon down by CF/NCF and hill/*Terai*. Average carbon per hectare in CF and NCF forests are not statistically different, but the difference between hill and *Terai* forests is significant, with *Terai* forests having on average 42% more carbon than hill forests. This difference reflects the generally more productive ecosystems in the *Terai*.

Table 2
Average Forest Level Carbon per Hectare by CF Status and Physiographic Zone (kg)

	Hill	*Terai*	All CF/NCF
CF	76091.67	118327.4	89737.05

[11] At the forest level we estimate OLS regression models with dependent variables in logs and robust standard errors and at the plot level random effects with the panel over plots within forests. These results are in SI Appendix 4.

	(71102.69)	(102999.5)	(84310.32)
NCF	72068.45	101988.1	95083.6
	(70414.55)	(65616.93)	(67397.78)
All Hill/*Terai*	75068.82	106820.9	
	(70342.33)	(78111.61)	

Standard deviations in parentheses

Table 3 presents descriptive statistics by whether NCF village leaders can identify the formation years of their groups, which we take to imply CA rather than open access. As discussed in SI Appendix 4, for this CA measure we analyze only NCFs to avoid conflating with CF status and to better balance our samples. We also analyze the effects of vintage, which suggest that by some measures older forest user groups have better forest quality.

Table 3
Average Forest Carbon per Hectare (kg) by Whether Forest User Group is Well-Defined (<u>NCFs</u>)

	Hill	*Terai*	All
NCF Leader Can Identify Group Formation Year	122056.4 (74800.52) n=7	116354.2 (61143.91) n=30	117433 (62843.28) n=37
NCF Leader Cannot Identify Group Formation Year	28329 (20865.43) n=8	80439.07 (67697.46) n=20	65550.48 (62550.86) n=28
All Hill/*Terai*	72068.45 (70414.55) N=15	101988.1 (65616.93) n=50	

Standard deviations in parentheses

We see in Table 3 that NCFs with well-defined groups average more carbon per hectare than forests without an identifiable formation year. Whether forests are located in the hills, *Terai* or in total, average carbon per hectare is greater if formation year is identified. In the *Terai*, for example, forests without a clear group have only 70% of the carbon of those with an identifiable year. As shown in Appendix 4, open access plots are also more likely to have evidence of fire and erosion (with less average slope).

Table 4
Forest-Level Average Treatment Effects Using Nearest-Neighbor Propensity Score Matching

	Narrow ← Collective Action Treatment → Broad

Forest Quality Metric	ATT CF Groups			ATT ProposedorCF			ATT CanIDFUGyear (NCFs only)		
	Treated/ Control	ATT	t-stat	Treated/ Control	ATT	t-stat	Treated/ Control	ATT	t-stat
Carbon/ha. (kg)	65 / 25	12905	0.66	88/ 28	31125	1.890*	37 / 15	73627	3.812***
Trees/ha.	65 / 25	14.12	0.116	88/ 28	77.9	0.824	37 / 15	-9.56	0.053
Canopy Cover (%)	65 / 25	2.563	0.418	88/ 28	1.56	0.257	37 / 15	3.028	0.292
Seedlings/ha.	65 / 25	2605	0.319	88/ 28	11537	2.163 **	37 / 15	18302	1.772*
Region of Common Support		0.095 – 0.992			0.305 – 0.999			0.404 – 0.999	
Post Matching Ave. Prop. Score Difference		0.0139			0.007			0.017	

* *p*<0.1; ** *p*<0.05; *** *p*<0.01. All treated forests were matched with control forests.

Table 4 indicates that at the forest level the two broader CA measures have statistically significant positive effects on forests. Forests with CanIDFUGyear have an estimated 74 tons (p<0.05) more carbon per hectare than open access forests, which is equivalent to 80% of mean carbon. CForProposed forests also have more carbon, with a marginal effect of about 31 tons (p<0.10). Forests governed under these broader measures of CA also have more regeneration and CanIDFUGyear has the largest effect at 60% of the mean. The CF (i.e. narrowest CA measure) coefficient estimates are positive, but not statistically significant.

Table 5
Plot-Level Average Treatment Effects Using Nearest Neighbor Propensity Score Matching

	Narrow ← Collective Action Treatment → Broad								
Forest Quality Metric	ATT CF Groups			ATT ProposedorCF			ATT CanIDFUGyear (NCFs only)		
	Treated/ Control	ATT	t-stat	Treated/ Control	ATT	t-stat	Treated/ Control	ATT	t-stat
Carbon/ha (kg)	325 / 295	16327	1.365*	433 / 128	50796	5.190 ***	169 / 83	42728	3.007 ***
Trees/ha.	325 / 295	-48.27	-0.815	433 / 128	2.747	0.055	169 / 83	-94.61	-1.65**
Canopy Cover (%)	325 / 295	-5.311	-1.59*	433 / 128	-0.901	-0.28	169 / 83	-6.863	-1.60 *
Seedlings/ ha.	325 / 295	1052.4	0.308	433 / 128	12100	3.795 ***	169 / 83	1479	0.292
Region of Common Support		0.256 – 0.857			0.461 – 0.899			0.682 – 0.911	

Post Matching Ave. Prop. Score Difference	0.0019		0.0067		0.0020

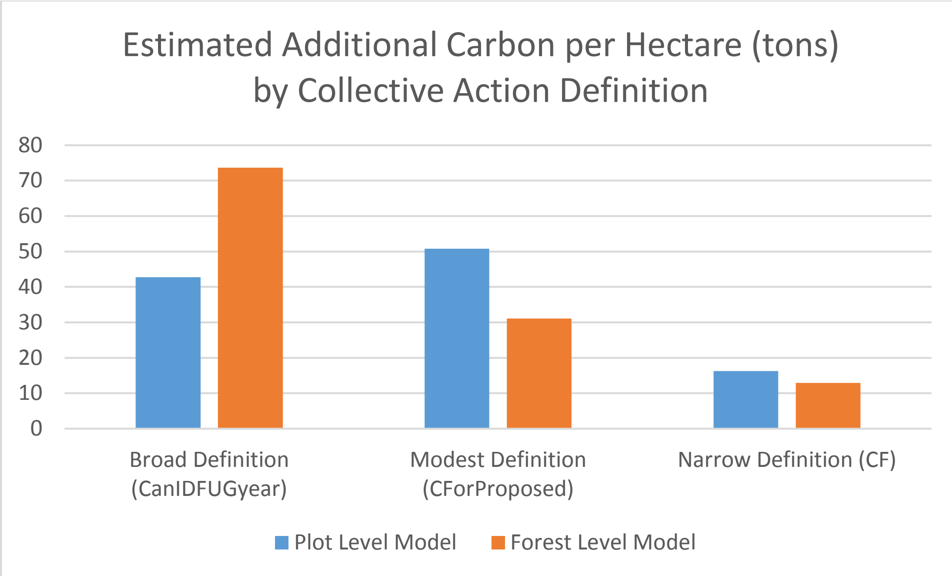
* *p*<0.1; ** *p*<0.05; *** *p*<0.01. All treated plots were matched with control plots.

The plot level models offer more precise estimates due to more observations.[12] CF status is positively and significantly ($p < 0.10$) associated with carbon per hectare at the plot level. We estimate that compared with matched NCF plots, those in CFs have approximately 14% more carbon.

Plots experiencing broader forest-level CA treatments vis-à-vis counterfactuals show positive effects on carbon that are larger than the CF treatment. CanIDFUGyear plots are estimated to have 42 tons more carbon or about 45% of average plots ($p < 0.01$). They also have substantially more seedlings per hectare, but a lower percentage of canopy cover, which is not unexpected based on the literature. CForProposed has the strongest plot-level effects, with about 50 tons more carbon (54% of mean, $p < 0.01$) and better regeneration ($p<0.01$) than other plots. The average treatment effects of CA on sequestered carbon by CA definition are summarized in Figure 2. In general, the broader measures of CA sequester more carbon vis-à-vis counterfactuals and the effects are 30% to 80% of mean carbon stocks.

Figure 2 Carbon Sequestered due to Collective Action (Tons). Propensity Score Matching Model Average Treatment Effects

[12] 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*.. As discussed in SI Appendix 4, NCFs were chosen to match with CFs sampled by MoFSC (2013). There was therefore no trouble balancing all blocks. Plots within forests, where much more heterogeneity exists and which were sampled randomly, were more difficult to match. While at the forest levels all exogenous variables in Appendix 3 could be used to estimate propensity scores, to obtain balance for CFs and CanIDFUGyear only the following variables ware used in plot level propensity score estimations: NDVI_1990; hill dummy; Sal forest and clay/loam soil dummies. To estimate the ProposedorCF Probit only NDVI_1990 and the hill dummy were included.



* Forest-level model narrow collective action treatment effect not significantly different from zero. All other estimates significant at 10% or better levels.

The plot-level random effects models presented in the SI Appendix 4 reinforce the conclusion that CA is an important factor in carbon sequestration, but statistically significant effects come from broader CA vis-à-vis open access rather than formal CF certification. CForProposed plots are again estimated to have better forest quality, including 26 tons more carbon ($p < 0.10$), 128 more trees (22% of the mean at $p < 0.05$) and 9900 more seedlings ($p < 0.05$). Plots that are part of forests with clearly identifiable groups have over 30 tons more carbon per hectare than plots under presumed open access ($p < 0.01$) or about one-third of the mean, but about 17% less canopy cover. CF status is not estimated to improve forest quality in any panel data model.

The panel data models allow us to call out other factors affecting 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. Sal forests have more carbon as would be expected, because sal trees are dense and can be large. 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*. Plots governed by larger forest user groups have more canopy cover and trees per hectare. The local migration rate is not significant, which indicates that out-migration does not affect forest quality.

5. Discussion and Conclusions

In this paper we use a random sample of CFs matched with NCFs that local experts specifically identified as best possible matches. Forest level propensity score estimates indicate a high degree of balance, suggesting treatment and control communities are comparable. We use forest quality measurement methods that are labor intensive, but also allow us to carefully estimate carbon for trees and saplings, 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. Forests with measured CA in 2013 had lower or similar 1990 NDVI levels, suggesting that relatively worse forests and plots were subject to CA.

We find that within the existing environment collective action has important and generally positive effects on forest quality. Indeed, *in all models, user groups with a well-defined establishment year sequester more carbon compared with NCFs that are open access*. We believe this measure is an indicator of group clarity and therefore CA. It requires a group decision, which is important, but is not subject to sample selection because there is no formal opt-in decision.

We do not, however, find robust evidence that CFs sequester more carbon than NCFs or have better forest quality using our three other measures. As we have strong reason to believe and evidence that CA *per se* improves forest management and quality, it appears that some NCFs exhibit sufficient CA so that the CF program on balance adds little to forest quality. Indeed, NCFs in our sample report a variety of sophisticated CA behaviors, including written rules, clearly defined boundaries, etc.

It is not surprising that carbon is not higher in CFs than in NCFs, because operational plans do not include carbon values. It is, however, surprising that CA *per se* is so important for carbon sequestration when it is completely uncompensated. We would like to suggest that this result is really about savings. Carbon sequestration is a linear function of biomass, which can to a first approximation be referred to as "fuelwood" and "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. Under current arrangements carbon sequestration is therefore impermanent. REDD+ could potentially secure more permanent carbon sequestration.

Our findings suggest that FCCC Annex 1 funders and non-Annex 1 governments would do well to support community CA. Such support may be important if to credit CA under REDD+ CF groups must be formed. CF formation can be costly[13] and there may also be a need for group facilitation and training. Our data do not allow us to track forest quality across time. This is a limitation that we have tried to minimize through careful random sampling and matching. It leaves unanalyzed, though, the social relationship between CA in CFs and NCFs. For example, the Nepal CFP could have engendered norms of behavior and disseminated methods (e.g. related to group formation, operation and management) that were adopted in some NCFs. Certainly, many of the observed CA behaviors are the same. We just do not know where non-open access NCFs got those behaviors. We conjecture that over time NCF communities have adopted practices from the CF system.

[13] Author discussions with Kaski District forestry officers suggest that CF formation may cost upwards of $4000.

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