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Carbon, biodiversity, and livelihoods in forest commons: synergies, trade-offs, and implications for REDD+

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Abstract

Understanding the relationships and tradeoffs among management outcomes in forest commons has assumed new weight in the context of parallels between the objectives of community forest management and those of reduced emissions for deforestation and forest degradation (REDD+) programs to reduce carbon emissions while supporting local livelihoods. We examine the association between biophysical, demographic, institutional and socio-economic variables and three distinct forest management outcomes of interest to both community forestry and REDD+ advocates—carbon storage, biodiversity conservation, and livelihood benefits—in 56 forest commons in Nepal. REDD+ programs aim foremost to increase forest carbon storage and sequestration, but also seek to improve forest biodiversity, and to contribute to local livelihood benefits. The success of REDD+ programs can therefore be defined by improvements in one or more of these dimensions, while satisfying the principle of 'do no harm' in the others. We find that each outcome is associated with a different set of independent variables. This suggests that there is a need for policy-makers to clearly define their desired outcomes and to target their interventions accordingly. Our research points to the complex ways in which different factors relate to forest outcomes and has implications for the large number of cases where REDD+ projects are being implemented in the context of community forestry.

Introduction

Community-managed forests are a widespread and growing governance arrangement, particularly in the developing world. Forest land owned by or designated for indigenous peoples and local communities represents approximately 15.5% of the global forest area (Rights and Resources Initiative 2014). However, approaches to community forestry differ across countries and community forestry practices vary across sites within countries, often reflecting a diversity of institutional arrangements for benefit- and power-sharing (Yadav *et al* 2003, Sunderlin 2006). These variations have proved a fertile field for research on communities and forests. They have enabled a large body of work to examine the multiple benefits, limitations, and constraints of community empowerment in the forest sector (Schreckenberg and Luttrell 2009). They have also made possible the investigation of the conditions associated with positive social and ecological outcomes (Poteete and Ostrom 2004, Chhatre and Agrawal 2009, Persha *et al* 2011).

Considerable research has described socio-ecological dynamics in forest commons systems. For example, recent quantitative analyses have examined the governance variables that affect synergies and

tradeoffs between carbon and livelihood benefits in community-managed forests (Chhatre and Agrawal 2009, Persha *et al* 2011). However, these analyses aggregated different social and ecological indicators into combined outcomes. There has been little explicit analysis of whether the factors most closely associated with these outcomes vary across different social and ecological dimensions, or how such variation might create trade-offs for policy-makers in structuring and targeting interventions that maximize outcomes of higher priority. Understanding these relationships and tradeoffs has assumed new weight in the context of climate-change mitigation in the forest sector and particularly with respect to the potential role of community-managed forests in reducing carbon emissions while supporting local livelihoods (Hayes and Persha 2010, Karky and Skutsch 2010, Newton *et al* 2015).

It is particularly important to assess how different factors may be associated with outcomes of interest in community forests where *reducing emissions from deforestation and forest degradation* (REDD+) programs are being implemented in conjunction with community forest management (Agrawal and Angelsen 2009, Hayes and Persha 2010, Karky and Skutsch 2010). The objectives of REDD+ programs correlate closely with those of community forest management: both governance interventions aim to conserve forests (resulting in greater carbon sequestration and biodiversity conservation) and to support local livelihoods (Newton *et al* 2015). Identifying the factors associated with improved outcomes in community managed forests is therefore a critical step in the design and implementation of REDD+ programs in these forests. It is necessary to understand the extent to which the existing institutional arrangements and contextual conditions around community-managed forests are already associated with sustainable forest management so that REDD+ programs can be designed and targeted to leverage and complement existing efforts rather than generating programmatic conflicts and tensions.

Potential synergies between community forest management and REDD+ activities have particular relevance for countries such as Nepal (Dahal and Banskota 2009, Dhital 2009). Three decades of community forestry in Nepal have helped generate sustainable benefit flows to the rural poor, particularly for forests in the Middle Himalaya belt, but high levels of poverty warrant continuing international support to enhance community forestry-based livelihoods (Acharya 2002, MFSC 2013). REDD+ pilot projects are being implemented across the country, with community forest management at the heart of Nepal's REDD+ strategy (Ojha *et al* 2013, Newton *et al* 2015).

This paper examines the associations of three important socio-ecological forest management outcomes with a common set of key biophysical, demographic, socio-economic, and institutional factors. Our analysis explores how variation in these key factors is related to carbon storage, biodiversity conservation, and livelihood benefits, each central to REDD+ programs. Within the context of Nepal's community-managed forests, we test the hypothesis that the same key factors are associated with the likelihood of improved forest management in terms of the three outcomes.

Methods

Our analysis draws on a unique and rich dataset comprising information on social, ecological, and governance variables on a wide range of representative forests in human-dominated tropical landscapes. The International Forestry Resources and Institutions (IFRI) research network has been collecting and compiling this data in 16 countries since 1992. In each case, including Nepal, the data are collected by in-country partners who currently have more than two decades worth of experience using the IFRI research instruments. The collected data include quantitative and qualitative biophysical, demographic, institutional and socio-economic variables collected using a combination of ecological field measurements and focus group and survey based interviews with forest-users. The variables used in this analysis are described below, and a full description of the survey methods is available from IFRI (2013).

We use original data for 56 community-managed forest sites in Nepal that were surveyed using IFRI research instruments. The majority of sites ($N = 42$) were formally, legally-designated community forests. The remainder ($N = 14$) were legally-designated as government, private, or protected area forests, but with *de facto* use and/or management by community forest user groups. We focused on a single country to reduce the significant effects of heterogeneity in biophysical, socio-economic, cultural, and political contexts inherent in multi-country analyses. Nepal constitutes an outstanding test case in which to study community forest outcomes over time, given its extensive history of community-forest management (>35 years) on a large-scale (~18 000 community forest user groups) (Pandit and Bevilacqua 2011, MFSC 2013).

Dependent variables: forest management outcomes

We used proxies for three key sustainable forest management outcomes—biodiversity conservation, carbon storage, and livelihoods benefits (variable names in *italics*; table 1). As a proxy for *carbon* storage, we used a measure of forest biomass (the aggregate basal area of all trees >10 cm DBH per hectare, Chhatre and Agrawal 2009). As a proxy for *biodiversity* conservation, we used a measure of tree species richness (calculated using the Chao-1 estimator of tree species diversity, for trees >10 cm DBH, Persha

Table 1. Model averaged coefficients for carbon, biodiversity, and livelihood outcomes for all models where Δ AIC < 1.

				1—Ethnic diversity		2—Legal designation: Yes		3—Collective action		4—Forest size		5—User-group size		6—Rulemaking autonomy: Yes	
Model	AIC	Weight	R^2	Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
Carbon															
1	179.60	0.410	0.149	−2.573	0.896										
1 + 2	180.10	0.320	0.181	−2.681	0.893	0.660	0.493								
1 + 2 + 3	180.41	0.270	0.217	−3.142	0.940	1.150	0.596	−0.092	0.065						
Model averaged coefficient				−2.762	0.938	0.523	0.631	−0.025	0.053						
Model averaged R^2			0.178	0.161		0.024		0.010							
Biodiversity															
4 + 5	192.23	0.340	0.113							0.003	0.002	−0.0002	0.0001		
2 + 4 + 5	193.04	0.230	0.143			−0.693	0.554			0.003	0.002	−0.0002	0.0001		
1 + 5	193.16	0.220	0.096	−1.615	1.041							−0.0002	0.0001		
1 + 4 + 5	193.21	0.210	0.140	−1.251	1.054					0.003	0.002				
Model averaged coefficient				−0.612	0.993	−0.159	0.394			0.002	0.002	−0.0002	0.0001		
Model averaged R^2			0.122	0.016		0.007				0.050		0.074			
Livelihoods			D^2												
2 + 3 + 5 + 6	−56.81	0.620	0.305			−0.106	0.035	0.007	0.004			−0.00002	0.00001	0.055	0.029
1 + 2 + 3 + 5 + 6	−55.87	0.380	0.330	0.094	0.059	−0.126	0.036	0.009	0.004			−0.00002	0.00001	0.067	0.030
Model averaged coefficient				0.036	0.058	−0.114	0.037	0.008	0.004			−0.00002	0.00001	0.060	0.030
Model averaged D^2			0.315	0.009		0.168		0.138				0.208		0.068	

et al 2011, using the R package {*vegan*}, Oksanen *et al* 2013). Finally, as a proxy for *livelihoods* benefits, we used a composite measure of the extent to which the forest provided subsistence and commercial livelihoods to the forest user (measured as the locally defined proportion of households in each user group that depends significantly on the forest for subsistence and commercial livelihoods, Chhatre and Agrawal 2009). To construct this measure we calculated the mean of the proportion of households depending on forest for subsistence and the proportion of those depending on forests for commercial livelihoods. Higher values of *carbon* and *biodiversity* are likely desirable from a conservation perspective. It is less clear whether higher values of *livelihoods* are desirable. On the one hand, greater dependency on the forest could indicate a forest in good condition that provides benefit flows to local communities. Alternatively, forest dependency could indicate higher levels of poverty. As such, in this paper we report the associations between the livelihoods outcome and our set of independent variables, but remain agnostic about the desirability of increasing or decreasing forest dependence.

Independent variables: biophysical, institutional, demographic, and socio-economic factors

We selected independent variables identified in several key earlier studies as being associated with variations in socio-ecological outcomes in community forests (e.g. Chhatre and Agrawal 2009, Persha *et al* 2011, table 1). These variables include features of forest and communities in terms of their (a) biophysical characteristics (*forest size*, in hectares); (b) institutional arrangements (*legal designation* as community forest (yes) or as government, private, or protected area forest (no), and the degree of forest-user *rule-making autonomy*, defined as yes if 'about right' and no otherwise); and (c) demographic and socioeconomic characteristics of forest user-groups (*user-group size*, measured as the number of individuals; *ethnic diversity*, calculated using the Simpson's Index; and *collective action*, calculated as an index of the extent of cooperation between forest users, and their investment in forest commons (table 1) (see supporting information).

Models

We used an information theoretic and model averaging approach to statistical model building, to avoid the pitfalls of conventional stepwise regression analyses (which can inflate Type I error rates) and potential model selection uncertainty associated with the use of single statistical models (Burnham and Anderson 2004, Whittingham *et al* 2006). We constructed a series of multiple linear regression models in the R statistical environment using R version 3.1.3 (R core development team 2014), modeling *carbon*, *biodiversity*, and *livelihoods* as a function of our independent variables. Non-normally distributed residuals for the *carbon* and *biodiversity* models were corrected using a square root transformation of the dependent variables. We were not able to correct the heavy-tailed distribution of our residuals for the *livelihoods* model with a transformation, so we instead used a robust linear regression model, which accounts for the effect of outliers, using the 'rlm' function in the {MASS} package (Ripley *et al* 2015). For each of our dependent variables, we first ran all possible model combinations of independent variables using the 'dredge' function in the {MuMIn} package (Bartón 2015). We then used the 'model.avg' function in the {MuMIn} package to calculate model-averaged regression coefficients for all models with Δ AIC < 1. Finally, we calculated the model-averaged partial R^2 (for the linear regressions) and D^2 (for the robust linear regressions) to obtain relative estimates of the explanatory power of each variable (Guisan and Zimmermann 2000).

Results

Carbon

Ethnic diversity, *legal designation*, and *collective action* were all retained as predictors in our best fitting models (model averaged $R^2 = 0.178$, table 1). Of these, ethnic diversity had the strongest association with carbon (model averaged partial $R^2 = 0.161$). Forest user groups with lower ethnic diversity and collective action, and forests that were legally designated as community forests, were associated with higher carbon (figure 1(A), table 1).

Biodiversity

User group size, forest size, *ethnic diversity,* and *legal designation* were all retained as predictors in our best fitting models (model averaged partial $R^2 = 0.122$, table 1). Of these, user group size had the strongest association with biodiversity (model averaged partial $R^2 = 0.074$). Forest user groups that were smaller and that had lower ethnic diversity, and forests that were larger and not legally designated as community forests, were associated with higher biodiversity (figure 1(B), table 1).

Livelihoods

User group size, *collective action, legal designation*, *rule-making autonomy, and ethnic diversity* were all retained as predictors in our best fitting models (model averaged partial $D^2 = 0.315$, table 1). Of these, user group size had the strongest association with livelihoods (model averaged partial $D^2 = 0.208$). Forest user groups that were smaller, and which had higher collective action, greater ethnic diversity, and greater rule-making autonomy, and forests that were not legally designated as community forests, were associated with higher livelihood outcomes.

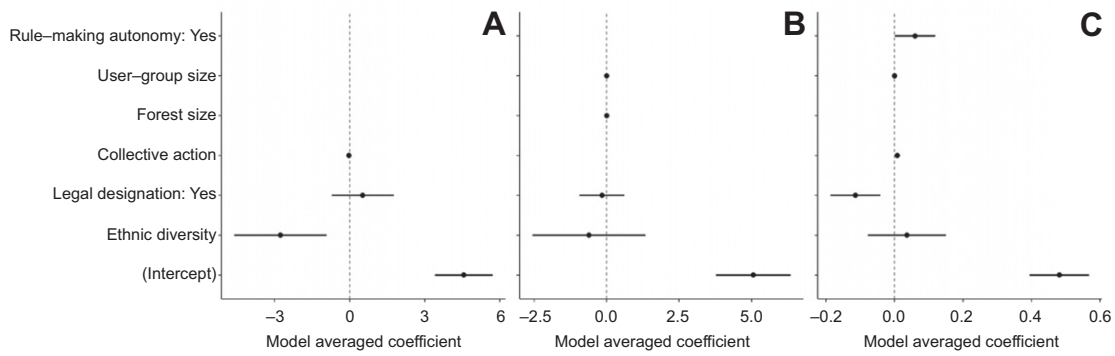

Figure 1. Model averaged regression coefficients (points) and 95% confidence intervals (bars) for independent variables (*y* axis) associated with (A) carbon, (B) biodiversity, and (C) livelihood outcomes for models where Δ AIC < 1.

Carbon, biodiversity, and livelihoods

Carbon was positively and significantly associated with *biodiversity* ($r = 0.317$, $P = 0.026$). Neither *carbon* ($r = -0.15$, $P = 0.301$) nor *biodiversity* ($r = 0.06$, $P = 0.680$) were significantly associated with *livelihoods*.

Discussion

REDD+ programs aim foremost to increase forest carbon storage and sequestration, but also seek to improve forest biodiversity, and to contribute to local livelihood benefits (Angelsen 2009). The success of REDD+ programs can therefore be defined by improvements in one or more of these dimensions, while satisfying the principle of 'do no harm' in the others. Two of the management outcomes (carbon and biodiversity) were more closely related to each other than either was to the livelihoods outcome. This may suggest greater potential for achieving win–win synergies between these two biophysical outcomes than between either of these outcomes and livelihood outcomes, within these sites in Nepal.

Trade-offs between multiple outcomes

Each of the three sustainable forest management outcomes was associated with three to five of the independent variables used in our analyses (table 1; figure 1). Greater tree biomass (our proxy for carbon) was positively associated with legally-designated community forests, but was negatively associated with higher collective action and higher ethnic diversity. Greater tree species richness (our proxy for biodiversity) was positively associated with larger forests and higher ethnic diversity, and negatively associated with larger user-groups and legally-designated community forests. Higher subsistence and commercial benefit flows from forests to forest communities (our proxy for livelihoods) were positively associated with larger user-groups, higher collective action, higher ethnic diversity, and greater rule-making autonomy, and negatively associated with legally-designated community forests. Many of these variables have been shown to be important by previous studies of community forest management outcomes, including studies using IFRI data (e.g. Agrawal and Angelsen 2009, Persha *et al* 2011). A novel contribution of this study is to examine the relationships between a common set of independent variables and multiple separate forest management outcomes. Many previous studies either examine only a single outcome (e.g. Nagendra 2002) or combine multiple outcomes into a single categorical variable (e.g. Chhatre and Agrawal 2009).

Each outcome was associated with a different set of independent variables. If this is also the case elsewhere, this suggests that there is a need for policy-makers to clearly define their desired outcomes, and to design and target interventions accordingly. Forest size was significantly associated with biodiversity, but not with carbon or livelihoods. Similarly, rule-making autonomy was only associated with the livelihoods outcome. Such variation has evident implications for REDD+ management and policy. For example, community forest management might be used as a mechanism to achieve positive REDD+ objectives, either by building on the natural, human and institutional capital associated with existing community forest sites, or by expanding the network of community forests into sites where REDD+ objectives are a priority, such as in high carbon-stock biomes (Balooni and Lund 2014, Newton *et al* 2015). In Nepal, such high-carbon areas include the Terai, though there has historically been political resistance to the establishment of community forest sites in this region (Bampton *et al* 2007). Site selection for such initiatives might be guided in part by the associations between the selected variables and forest management outcomes. However, variation in these associations implies that, depending on the priority accorded by different decision makers to particular outcomes, the criteria applied in different sites are likely to vary. Factors that are consistently associated with improved outcomes in more than one

dimension may be more attractive as a screening or selection tool: for example, smaller forest user-groups in our analysis were associated with both higher biodiversity and higher livelihood outcomes and thus could, in these sites, serve as a basis for seeking improved outcomes in both dimensions (if higher livelihood outcomes are deemed to be desirable) (table 1).

Understanding forest management outcomes

Our analyses describe the associations between multiple independent variables and three forest management outcomes of interest. The strength of these relationships was pronounced in some cases—for example, between user-group size and livelihoods (model averaged $R^2 = 0.208$). In other cases, the relationships were relatively weak—for example, between ethnic diversity and livelihoods (model averaged $R^2 = 0.009$). Here, we discuss ways in which the importance of these relationships can be understood and could be further explored, both in this context and elsewhere.

First, our analysis points to potential causal pathways that connect the independent variables and forest management outcomes. We selected the variables used in our analyses because they have proved to be relevant to community forest management in other contexts (Agrawal and Angelson 2009, Chhatre and Agrawal 2009, Persha *et al* 2011), and it is possible to conceive of logical mechanistic pathways through which these variables and outcomes are connected. For example, smaller forest patches are typically associated with lower biodiversity because of greater human disturbance, reduced population sizes, greater edge effects, and changes in community structure (Turner 1996). Similarly, higher biodiversity may be linked to smaller groups of forest-users because such groups are likely to exert a lower harvesting pressure and are less likely to overexploit species to the point of local extinction. As a second example, forests that are legally designated for community management often have rules that are locally created, contextually relevant, and which are respected and observed by forest-users (Larson and Soto 2008). Legally designated community forests may generate higher carbon benefits as a consequence of greater adherence to such locally generated rules. The ways in which these relationships variously play out in Nepal are additionally reported in many empirical case-studies and multi-site analyses (e.g. Nagendra 2002, Adhikari *et al* 2004), as well as comprehensive reviews that draw on more than multiple decades of community forestry experiences in the country (e.g. Acharya 2002, MFSC 2013).

Some of our results also appear contrary to previous evidence and assumptions. For example, forests that were not legally designated as community forests were associated with higher livelihood outcomes (defined as greater dependence on forest resources for livelihoods), whereas one might expect legally designated community forests to facilitate greater access to forest resources. Similarly, the association between lower levels of collective action and higher carbon outcomes might not have been predicted from the existing literature. More broadly, it is difficult to disentangle causality from association using observational studies, and while these data and our analyses enable us to describe *associative* links between our independent variables and these outcomes, they do not allow us to attribute a *causal* link. There remains a need to *explain* the associations. A quasi-experimental (e.g. matching-based) research design or longitudinal analysis using repeat-visit data would help to control for potential biases and facilitate more assured statements about causality (Ho *et al* 2007).

Second, the reported variations also need careful interpretation because the same independent variable may have contrasting directions of association with two different forest management outcomes. In our analysis, ethnic diversity, collective action, and the legal designation of forests as community- or state-owned all had negative associations with one outcome but a positive association with another. Although a deeper understanding of the causal linkages between these variables and the three outcomes is necessary to enable policy action, the results suggest complexity in the interactions between these variables and forest management outcomes and do not support a policy emphasis on win–win outcomes.

One means to further explore these relationships would be to collect data in a more targeted manner to test a specific hypothesis about the relationship between a specific independent variable and one or more forest management outcomes. Data could be collected on a larger number of communities with high levels of a variable of interest that are matched with other communities that are similar in terms of their basic demographic and socio-economic characteristics as well as in terms of their reliance on forests, but that have lower levels of the variable of interest. Such *a priori* research designs for data collection, coupled with matching based estimations post data collection, can permit more robust causal inference about the role of particular variables in enhancing multiple forest management outcomes.

Conclusions

Community forest management contributes to REDD + climate change mitigation objectives by serving as an anchor for the design and implementation of many REDD+ project-based interventions. Our analysis suggests that factors commonly used to explain community forest outcomes do have an association with multiple outcomes, and that the strength and

directionality of these associations vary depending on the outcomes in question, at least within our study sites. Ethnic diversity, collective action, and the legal designation as community forests are examples of this variation in directionality of association. The mechanisms driving these associations are complex, and do not support the common policy rhetoric arguing for win–win outcomes. Although such outcomes are feasible in selected cases, careful research designs are necessary to tease out the causal complexity of the drivers of the different outcomes of community forest management. Our research identifies some of the directions to develop such research efforts.

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