Trade-offs and synergies between carbon storage and livelihood benefits from forest commons

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Edited by Elinor Ostrom, Indiana University, Bloomington, IN, and approved September 4, 2009 (received for review July 22, 2009)

Forests provide multiple benefits at local to global scales. These include the global public good of carbon sequestration and local and national level contributions to livelihoods for more than half a billion users. Forest commons are a particularly important class of forests generating these multiple benefits. Institutional arrangements to govern forest commons are believed to substantially influence carbon storage and livelihood contributions, especially when they incorporate local knowledge and decentralized decision making. However, hypothesized relationships between institutional factors and multiple benefits have never been tested on data from multiple countries. By using original data on 80 forest commons in 10 countries across Asia, Africa, and Latin America, we show that larger forest size and greater rule-making autonomy at the local level are associated with high carbon storage and livelihood benefits; differences in ownership of forest commons are associated with trade-offs between livelihood benefits and carbon storage. We argue that local communities restrict their consumption of forest products when they own forest commons, thereby increasing carbon storage. In showing rule-making autonomy and ownership as distinct and important institutional influences on forest outcomes, our results are directly relevant to international climate change mitigation initiatives such as Reduced Emissions from Deforestation and Forest Degradation (REDD) and avoided deforestation. Transfer of ownership over larger forest commons patches to local communities, coupled with payments for improved carbon storage can contribute to climate change mitigation without adversely affecting local livelihoods.

climate change | mitigation | decentralization | institutions | REDD

Tropical forests play a crucial role in global climate change (1–3) in addition to their widely recognized contributions to rural livelihoods in developing countries (4, 5). It remains unclear, however, whether forests that contribute more to livelihoods store more carbon or less, or if carbon storage and livelihood contributions of forests are unrelated (6). Indeed, there have been many calls for a better general understanding of the nature of trade-offs vs. win–win outcomes in the context of the multiple contributions of forests to human welfare (7, 8). The urgency of the global need to increase carbon storage in forests and local reliance on forests for continuing livelihood benefits through extraction of forest biomass make it especially important that scientists better understand the relationship between carbon storage in forests and their contributions to livelihoods.

This article focuses on forest commons, a particularly important class of forests used jointly by a relatively large number of often heterogeneous users, with defined boundaries for the forest and its user group, and legally enforceable property rights to streams of benefits from the forest (9–10). It is particularly important to understand the complex connections between carbon storage and livelihood contributions of forest commons. Community-owned and managed forests comprise >10% of forests globally (4), and the extent of forests used by local communities is close to 18% (10–11). Although individual forest commons are relatively small in area—typically <1,000 hectares—they are crucial to the livelihoods of the rural poor in the developing world: Development agencies have estimated that in the aggregate such forests provide livelihood benefits to more than half a billion poor people (12–13). In part because such forests are essential to rural livelihoods, governments in many developing countries have transferred management and use rights to rural users through decentralization policy reforms (14–15). Evidence is emerging that such a focus may be instrumental in reconciling multiple outcomes from forests in developing countries (16–18).

Existing studies of benefits from forest commons, and from forests more generally, have provided valuable insights into (*i*) how and under what conditions forests contribute sustainably to human welfare in different ways (19–20); (*ii*) the role of local-level property rights arrangements, economic and demographic forces, and national policy regimes in influencing forest conservation (11, 21–22); and (*iii*) how participation and decentralization of decision making affect specific forest-related outcomes (23–24). No one has yet undertaken a quantitative assessment of the trade-offs and synergies related to carbon storage and livelihood benefits using data from multiple countries.

We used data collected by the International Forestry Resources and Institutions (IFRI) research program (25–26). The IFRI research program and its database provide the most systematic and best available quantitative information on forest commons in the developing world (27). By using the IFRI database, we identified 80 forest commons in 10 tropical countries (22 in East Africa, 13 in Latin America, and 45 in South Asia). We excluded from our analysis extremely small forests and cases in temperate regions (Fig. 1, Fig. S1). The sample encompasses substantial variation in biophysical features and communities that depend on them for livelihoods. Cases range from very small (<100 Ha) to very large (>5,000 Ha) forests, vary greatly in their elevation above sea level and topography, and are characterized by a range of population densities (Fig. S2).

For each forest in the sample we used basal area of trees per hectare as a measure of above-ground carbon storage. The livelihoods index measures contributions from the forest common to basic subsistence needs of local users—a composite of proportions of firewood, fodder, green biomass used as fertilizer, and timber for domestic use supplied by the forest common (see *Materials and Methods* and *SI Materials and Methods* for details). The sample has substantial variation in the 2 outcomes, but there is no association between carbon storage and livelihood benefits from these forests (Spearman's $\rho = -0.017$, Prob > t = 0.8781, $n = 80$). The lack of association between carbon storage and

Author contributions: A.A. designed research; A.A. performed research; A.C. contributed new reagents/analytic tools; A.C. and A.A. analyzed data; and A.C. and A.A. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Data Deposition: The data is available for replication at the following website: http://sitemaker.umich.edu/ifri/referenced_datasets.

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This article contains supporting information online at www.pnas.org/cgi/content/full/0905308106/DCSupplemental.

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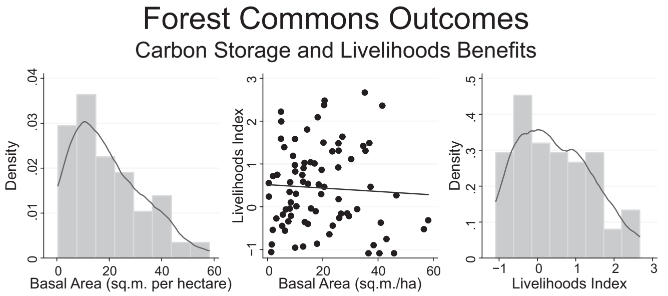

Fig. 1. Trade-offs and synergies in multiple outcomes from forest commons. Forest commons in our sample are spread across 10 tropical countries in Asia, Africa, and Latin America. The sample represents considerable variation in carbon stored as above-ground tree biomass and contributions to local livelihoods from forest commons, and very low association between the two outcomes.

livelihood benefits shows that both win–win and trade-off outcomes are possible in forest commons (Fig. 1). Indeed, this lack of association is itself an important finding because it suggests that the divergent assertions in existing studies about trade-offs or synergies in forest outcomes may be an artifact of the particular samples and single-country focus of many studies (16, 18, 28–30). Given the observed distribution of carbon storage and livelihood benefits, we suggest that for advancing a theoretical and policy-relevant understanding of trade-offs and synergies it is necessary to examine how the two outcomes are associated with social and institutional factors (Fig. S2, Fig. S3). Because both carbon storage and livelihood benefits are influenced by a variety of driving forces, an examination of the direct relationship between the two dimensions of forest commons outcomes is no more than a starting point. It is certainly inadequate to illuminate why in some cases these two outcomes seem to vary together in the same direction (synergies) and in others, have an inverse relationship (trade-offs).

Our analysis of trade-off/synergistic relationships between carbon storage and livelihood benefits focuses on 3 factors of special interest: Size of the forest commons, local autonomy, and ownership. These factors are central concerns in academic and policy debates on the institutional aspects of recent decentralization reforms (4, 10, 14–16, 23–24, 30). We compare the simultaneous effect of forest size, local autonomy, and government vs. community ownership on the joint outcomes of carbon storage and livelihood benefits. To simplify a complex relationship, we divided the sample into local communities with low vs. high levels of autonomy in making management decisions about the forest commons (Fig. S3). In addition, we also include in the analysis distance of users to the forest and distance of forest to the nearest administrative center (See *Materials and Methods* and *SI Materials and Methods* for a more detailed explanation of the choice of variables included in and omitted from the analysis).

Results

To examine how forest size, local autonomy in rule making, and community vs. government ownership are associated with trade-offs or win–win relationships between carbon storage and livelihood contributions, we use a 4-part classification of joint outcomes in sampled forest commons: (*a*) Those providing above average carbon storage and livelihood benefits, which we term "sustainable commons," (*b*) those providing below average carbon and livelihood benefits, labeled "overused commons," and (*c* and *d*) those providing above average benefits on 1 dimension but below average on the other—"deferred use commons" (for high carbon storage and low livelihood benefits) and "unsustainable commons" (for low carbon storage and high livelihood benefits). We predict membership in one of the four joint outcome categories using forest size, decision making autonomy, and forest land ownership as predictors through multinomial logistic regression analysis (Table 1, Table S1, Table S2). We find that the area of the forest commons and the degree of rule-making autonomy are both positively associated with win–win outcomes—high carbon storage and livelihood benefits and negatively with lose–lose outcomes. On the other hand, ownership of forest commons has a trade-off relationship with carbon storage vs. livelihood benefits.

Table 1. Multinomial logit regression results

Independent variables	Marg. effect	Std. error	*z*-value	Prob.> *z*
Overused forest commons: Low carbon and low livelihoods				
Forest size	**−0.125**	**0.0503**	**−2.48**	**0.013**
Ownership	−0.0323	0.1422	−0.23	0.820
Autonomy	**−0.2218**	**0.1134**	**−1.96**	**0.050**
Distance	−0.0751	0.1148	−0.65	0.513
Admin.	−0.0037	0.0039	−0.93	0.351
Unsustainable forest commons: Low carbon and high livelihoods				
Forest size	0.037	0.0562	0.66	0.510
Ownership	**0.4073**	**0.1203**	**3.39**	**0.001**
Autonomy	−0.0659	0.1347	−0.49	0.625
Distance	−0.1288	0.125	−1.03	0.303
Admin.	0.0002	0.0026	0.09	0.931
Deferred use forest commons: High carbon and low livelihoods				
Forest size	−0.0622	0.037	−1.68	0.093
Ownership	**−0.4577**	**0.1688**	**−2.71**	**0.007**
Autonomy	0.0706	0.0888	0.80	0.426
Distance	**0.3085**	**0.1017**	**3.03**	**0.002**
Admin.	**0.0034**	**0.0016**	**2.08**	**0.037**
Sustainable forest commons: High carbon and high livelihoods				
Forest size	**0.1501**	**0.0418**	**3.59**	**0.000**
Ownership	0.0827	0.0893	0.93	0.354
Autonomy	**0.217**	**0.1096**	**1.98**	**0.048**
Distance	−0.1045	0.0828	−1.26	0.207
Admin.	0.00006	0.0012	0.05	0.958

Dependent variable = forest commons outcomes. Number of observations = 80; likelihood ratio $\chi^2(15) = 56.74$; Prob. $> \chi^2 = 0.0000$; pseudo $R^2 = 0.2580$. "Forest size" = log of forest size (hectares); "ownership" = ownership of forest commons, community ownership = 0, government ownership = 1; autonomy, local autonomy in making rules, no = 0, yes = 1; distance, distance of local users to the forest commons, $<$5 km = 1, 5–10 km = 2, $>$10 km = 3; Admin., distance to nearest administrative center (in kilometers). Bold font indicates statistically significant associations ($P < 0.05$).

Specifically, larger forest commons are more likely to be classified as sustainable commons—the group of forests providing above average carbon storage and livelihood benefits ($P < 0.0001$, $n = 80$) (Fig. 2*B*) and less likely to be classified as overused commons (low carbon storage and livelihood benefits) ($P = 0.013$, $n = 80$) (Fig. 2*A*). Similarly, greater local autonomy in making rules about forest management is associated with a higher probability that the forest will be in the sustainable commons category ($P = 0.048$, $n = 80$), and a lower probability it will be classified as overused commons ($P = 0.050$, $n = 80$).

Further, the positive effect of local autonomy on the predicted probability of sustainable commons increases with forest size (Fig. 2*C*). Forest size and local autonomy do not have a statistically significant relationship with deferred use commons and unsustainable commons (Table 1). We conclude that increasing forest size and greater local autonomy in matching rules to resource characteristics exist in a win–win relationship with carbon storage and livelihood benefits from forest commons.

In contrast, government ownership of forest commons has a positive association with forests in the unsustainable commons

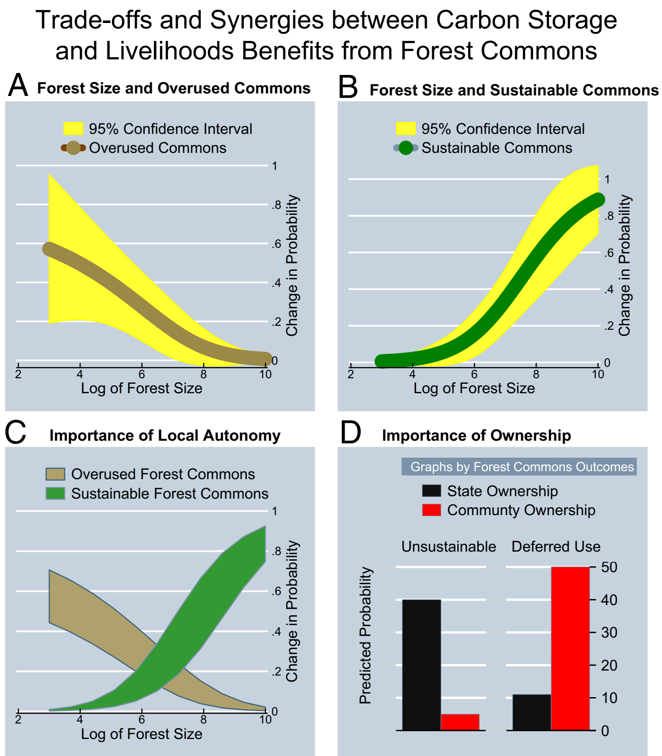

Fig. 2. Forest size, rule-making autonomy, and ownership of forest commons. (*A* and *B*) The impact of increase in forest size on the predicted probability of being overused and sustainable commons. Low benefits on both carbon storage and livelihoods (overused commons, *A*) are less likely for larger forests. Conversely, larger forests are more likely to provide high levels of carbon storage and livelihood benefits (sustainable commons, *B*). Together, *A* and *B* suggest that size of the forest is an important factor in determining joint outcomes from forest commons. (*C*) The impact of ''local autonomy'' on joint outcomes. The area shaded green in *C* represents the increase in the probability of a forest being classified as sustainable commons when the community managing it has high rule-making autonomy; the area shaded brown represents the decline in the probability of a forest being overused commons when the community managing it has high rule-making autonomy. The effects of local autonomy vary with the size of the forest common. (*D*) How ownership of forest commons affects the likelihood of the forest being in the category of deferred use or unsustainable commons. Government ownership is associated with a higher probability of overuse (low carbon storage and high livelihood benefits), and community ownership is associated with low livelihood benefits but high carbon storage as communities defer use.

category (high livelihood benefits but low carbon storage) ($P < 0.001$, $n = 80$), and community ownership is associated with a greater probability that a forest will be a deferred use common (high carbon storage but low livelihood benefits) ($P = 0.007$, $n = 80$) (Fig. 2*D*). This finding may appear counterintuitive. However, closer examination suggests that when local users perceive insecurity in their rights (because the central government owns the forest land), they extract high levels of livelihood benefits from them, and when their tenure rights are safe, they conserve the biomass and carbon in such forests.

Discussion

This article makes two contributions to ongoing conversations about trade-offs and synergies between carbon storage and livelihood benefits associated with social-ecological systems. Many such systems simultaneously generate multiple outcomes—forests, for example, make contributions to carbon storage and livelihoods; irrigation systems affect soil erosion and crop productivity; rangelands store carbon and provide livelihood contributions; and inshore fisheries are characterized by varying levels of productivity and sustainability. A deeper understanding of the performance of these systems requires simultaneous consideration of such multiple outcomes and the factors that drive the joint outcomes. Our analysis operationalizes this conceptual insight through a statistical approach that respects the simultaneity of the outcomes and shows how associations can be established between multiple outcomes and the factors that may be at play in their joint production.

The analysis presented in the article also has practical implications, particularly for securing livelihood and carbon storage benefits from forests used and managed as commons. The past two decades have already witnessed the transfer of use and management rights over >200 million hectares of forests to local users and communities across >60 countries (4). It is evident that the decentralization of management authority over public forests to local communities is not only about forest governance—it is equally about development and climate policies. Our findings have three important implications for decentralization reforms. One, if governments wish to improve livelihoods and carbon storage benefits from decentralization of forest governance, they may be able to secure important win–win outcomes by ensuring that the individual patches of forests that communities are beginning to manage are on the larger rather than smaller side. Two, improvements in both livelihood benefits and carbon storage can also potentially be secured if communities gain greater rights locally to make rules about how to govern forests.

The policy implications of the third finding of the study—related to the overharvesting of livelihood benefits from forest commons where governments retain ownership of the land—are particularly relevant for ongoing debates about payments for ecosystem services and the implementation of REDD (Reduced Emissions from Deforestation and Forest Degradation) initiatives (17, 31–33). Transfer of land ownership of forest commons likely advances carbon storage benefits because local communities have the incentive to defer present livelihood benefits (16). Such incentives can also be strengthened by providing compensation to local communities in exchange for deferring present livelihood benefits from forest commons (31–32). Existing REDD action plans under two major global initiatives—United Nations Framework Convention on Climate Change REDD and Forest Carbon Partnership Facility of the World Bank—do not yet identify communities or forest commons as relevant agents for managing forests to sequester carbon or derive livelihood benefits from forests (33). Instead, they focus on national governments, replicating long histories of centralized control over forests. Institutional mechanisms to channel REDD funds to local communities that take into account lessons from decentralized natural resource management will help in improving carbon sequestration without adversely affecting local livelihoods.

We should sound a cautionary note, however. Our statistical treatment of local autonomy in making rules and community vs. central government ownership has required that we greatly simplify the complexity of these concepts and the local practices they denote. There are many nuances within community and government ownership of resources as also in the ways local autonomy in rule making is practiced. Collection of better data in the future and using this data to further nuance the treatment of ownership and autonomy will help deepen and further enrich our findings.

Materials and Methods

Our data were collected as part of the larger data collection effort undertaken by the IFRI program (www.umich.edu/~ifri). The research program was founded in 1992 and currently works with 11 collaborating research centers in 10 countries as research partners. All IFRI data are collected through 10 research instruments that focus on different aspects of forests, user groups,

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and institutions in a given location. The objective of the data collection is to identify the connections between social and ecological processes in diverse forested landscapes. Over the past decade and a half, IFRI researchers have collected data in >200 settlements in 12 different countries. IFRI researchers gain a common understanding of the basic concepts and data collection strategies through a research and training seminar required of researchers interested in collecting data using IFRI instruments.

The collected data has been computerized in a database that can be used to analyze a variety of forest–people–institutional relationships. The dataset used for the analysis in this article has been drawn from the larger IFRI database and covers all cases for which information is available on all of the factors included in the analysis. The dataset can be accessed at http://sitemaker.umich.edu/ifri/referenced_datasets. The selected cases of forest commons are distributed across forest type and topographic variations and provide multiple benefits to their users.

Data were analyzed using STATA version 9.2. The dependent variable is categorical with four values, formed by a combination of high and low levels along two dimensions of forest commons outcomes: (*i*) Above-ground carbon storage in woody biomass measured as basal area and (*ii*) contributions to subsistence needs of local residents measured by a livelihoods index. We calculated the basal area for every forest by averaging across all trees >10 cm DBH (diameter at breast height) in >30 randomly selected 10-m radius plots. We measure livelihood contributions by an index extracted through factor analysis of the proportions of (*i*) firewood, (*ii*) fodder, (*iii*) green biomass for fertilizer, and (*iv*) timber for domestic use that each forest provides to local users. All four constituent variables load on a single factor (LR test: independent vs. saturated: χ^2 (6) = 218.18; Prob > χ^2 = 0.0000, all factor loadings >50%; see Table S3 for more details). We also used the Cronbach's α to test the reliability and internal consistency of the livelihoods index (average inter-item covariance: 456.519; scale reliability coefficient: 0.7089; a coefficient >0.7 is considered acceptable). The analysis was implemented using multinomial logit regression. Given the small sample, we tested for a number of violations of the assumptions of the model. The final model was resilient to a series of postestimation tests. Likelihood ratio tests for independent variables (Ho: B = 0) and Wald tests for simple and composite linear hypotheses about individual parameters with a Bonferroni adjustment were not significant for any variable. The Small-Hsiao test for violation of the IIA assumption was not significant. Standard errors calculated using the Huber-White sandwich estimator did not produce significantly different results. Regression diagnostics do not indicate that any observations are unduly influencing the results.

Graphs were produced in STATA 9.2. Model parameters were used to predict probabilities for outcomes by specifying different values for the independent variables. All other variables, except for those being displayed in the graph, were held at their median value in the sample so as to ensure that the predicted probabilities would not be affected by skewness in the distribution of any of the variables included in the model. More details describing the data, the likelihood of omitted variable bias and selection bias in the sample, the issue of endogeneity, and the construction of the dependent variable are provided in the accompanying online *SI Materials and Methods*.

ACKNOWLEDGMENTS. We thank Catherine Benson, Eric Coleman, Anne Larson, Elinor Ostrom, Amy Poteete, Lauren Persha, Kent Redford, and Jesse Ribot for their comments on an earlier draft of this article. Rachel Kornak, Robin Humphrey, and Julie England provided valuable assistance with data cleaning. We thank all of the International Forestry Resources and Institutions (IFRI) researchers and national research teams including IFRI's collaborating research centers for their contributions to the IFRI network and data over the past 15 years. This work was funded by the Ford Foundation, the MacArthur Foundation, and National Science Foundation Grants HSD-0527138 and CNH-0709545. The data used in the analysis is available for download at http://sitemaker.umich.edu/ifri/referenced_datasets.

1. Lewis S, et al. (2009) Increasing carbon storage in intact African tropical forests. *Nature* 457:1003–1006.
2. Canadell JG, Raupach MR (2008) Managing forests for climate change mitigation. *Science* 320:1456–1457.
3. Miles L, Kapos V (2008) Reducing greenhouse gas emissions from deforestation and forest degradation: Global land-use implications. *Science* 320:1454–1455.
4. SunderlinW, Hatcher J, Liddle M (2008) *From Exclusion to Ownership: Challenges and Opportunities in Advancing Forest Tenure Reform.* (Rights and Resources Initiative, Washington, DC).
5. Wunder S (2001) Poverty alleviation and tropical forests: What scope for synergies? *World Dev* 29:1817–1833.
6. Smith J, Scherr SJ (2003) Capturing the value of forest carbon for local livelihoods. *World Dev* 31:2143.
7. Kareiva P, Watts S, McDonald R, Boucher T (2007) Domesticated nature: Shaping landscapes and ecosystems for human welfare. *Science* 316:1866–1869.
8. van Noordwijk M, Suyamto DA, Lusiana B, Ekadinata A, Hairiah K (2008) Facilitating agroforestation of landscapes for sustainable benefits: Tradeoffs between carbon stocks and local development benefits in Indonesia according to the FALLOW model. *Agric Ecosyst Environ* 126:98–112.
9. Schlager E, Ostrom E (1992) Property-rights regimes and natural resources: A conceptual analysis. *Land Econ* 68:249–262.
10. Chhatre A, Agrawal A (2008) Forest commons and local enforcement. *Proc Natl Acad Sci USA* 105:13186–13191.
11. White A, Martin A (2002) *Who Owns the World's Forests?* (Forest Trends, Washington, DC).
12. World Bank (2004) *Sustaining Forests: A Development Strategy* (World Bank, Washington, DC).
13. Eliasch J (2008) *Climate Change: Financing Global Forests* (Office of Climate Change, London).
14. Charnley S, Poe M (2007) Community forestry in theory and practice: Where are we now? *Annu Rev Anthropol* 32:301–336.
15. Larson AM, Soto F (2008) Decentralization of natural resource governance regimes. *Annu Rev Environ Res* 33:213–239.
16. Nepstad D, et al. (2006) Inhibition of Amazon deforestation and fire by parks and indigenous lands. *Conserv Biol* 20:65–73.
17. Chazdon R (2008) Beyond deforestation: Restoring forests and ecosystem services on degraded lands. *Science* 320:1458–1459.
18. Ranganathan J, Daniels R, Chandran MDS, Ehrlich PR, Daily GC (2008) Sustaining biodiversity in ancient tropical countryside. *Proc Natl Acad Sci USA* 105:17852–17854.
19. Takasaki Y, Barham BL, Coomes OT (2001) Amazonian peasants, rain forest use, and income generation: The role of wealth and geographical factors. *Soc Nat Res* 14:291–308.
20. Vosti SA, Braz EM, Carpentier CL, D'Oliveira MVN, Witcover J (2003) Rights to forest products, deforestation and smallholder income: Evidence from the western Brazilian Amazon. *World Dev* 31:1889–1901.
21. Angelsen A, Kaimowitz D (1999) Rethinking the causes of deforestation: Lessons from economic models. *World Bank Res Obs* 14:73–98.
22. Ostrom E (2007) A diagnostic approach for going beyond panaceas. *Proc Natl Acad Sci USA* 104:15181–15187.
23. Benjamin CE (2008) Legal pluralism and decentralization: Natural resource management in Mali. *World Dev* 36:2255–2276.
24. Ribot J, Chhatre A, Lankina T (2008) Institutional choice and recognition in the formation and consolidation of local democracy. *Conserv Soc* 6:1–11.
25. Wollenberg E, Merino L, Agrawal A, Ostrom E (2007) Fourteen years of monitoring community-managed forests: Learning from IFRI's experience. *Int Forest Rev* 9: 670–684.
26. Poteete A, Ostrom E (2008) Fifteen years of empirical research on collective action in natural resource management: Struggling to build large-N databases based on qualitative research. *World Dev* 36:176–195.
27. Dietz T, Henry AD (2008) Context and the commons. *Proc Natl Acad Sci USA* 105:13189–13190.
28. Brown K, Corbera E (2003) Exploring equity and sustainable development in the new carbon economy. *Climate Policy* 3S1:S41–56.
29. Nelson KC, de Jong BHJ (2003) Making global initiatives local realities: Carbon mitigation projects in Chiapas, Mexico. *Glob Environ Change* 13:19–30.
30. Sunderlin WD, et al. (2005) Livelihoods, forests, and conservation in developing countries: An overview. *World Dev* 33:1383–1402.
31. Nepstad D, Merry F, Rodrigues HO, Schwartzman S, Almeida O (2007) *The Costs and Benefits of Reducing Carbon Emissions from Deforestation and Forest Degradation in the Brazilian Amazon* (Woods Hole Research Center, Falmouth, MA).
32. Jack K, Kousky C, Sims KRE (2008) Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proc Natl Acad Sci USA* 105:9465–9470.
33. Pagiola S, Bosquet B (2009) *Estimating the Costs of REDD at the Country Level* (Forest Carbon Partnership Facility, 9 April, 2009). Available at http://www.forestcarbonpartnership.org/fcp/sites/forestcarbonpartnership.org/files/The%20Costs%20of%20REDD%2004–09-09. Accessed July 22, 2009.