Mitchell, S.R., M.E. Harmon, K.B. O'Connell, and F. Schnekenberger. In revised. The optimal role of forests in climate change mitigation: Bioenergy production or carbon sequestration? *Nature Clim. Change*

Mitchell, S., M.E. Harmon, and K.B. O'Connell. 2009. Forest fuel reduction reduces both fire severity and long-term carbon storage in three Pacific Northwest Ecosystems. *Ecol. Applic.* 19:643–655.

Murrary, B.C., B. Songen, and M.T. Ross. 2007. Economic consequences of consideration of permanence, leakage and additionality for soil carbon sequestration projects. *Clim. Change* 80:127–143.

Plantinga, A.J., and K.R. Richards. 2008. International forest carbon sequestration in a post-Kyoto agreement. The Harvard Project on International Climate Agreements. Discussion Paper 2008-11. Cambridge, MA. 27 p.

Ryan, M.G., M.E. Harmon, R.A. Birdsey, C.P. Giardina, L.S. Heath, R.A. Houghton, R.B. Jackson, D.C. McKinley, J.F. Morrison, B.C. Murray, D.E. Pataki, and K.E. Skog. 2010. A synthesis of the science on forests and carbon for U.S. forests. Issues in Ecology 13, Ecological Society of America, 16 p.

Skog, K.E., and G.A. Nicholson. 1998. Carbon cycling through wood products: The role of wood and paper products in carbon sequestration. *For. Prod. J.* 48(7/8):75- 83.

Smithwick, E.A.H., M.E. Harmon, and J.B. Domingo. 2007. Changing temporal patterns of forest carbon stores and net ecosystem carbon balance: The stand to landscape transformation. *Landsc. Ecol.* 22:77–94.

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Response

Measurement, Monitoring, and Verification: Make It Work!

Coeli M. Hoover

The capacity of forests to absorb and store carbon is certainly, as the authors note, an important tool in the greenhouse gas mitigation toolbox. Our understanding of what elements can make forest carbon offset projects successful has grown a great deal over time, as the global community has come to understand that forest degradation and conversion are the result of a number of drivers, and that successful forest-based climate mitigation programs must take into account the need for residents to earn a livelihood. This realization has lead to the REDD (Reducing Emissions through Deforestation and Forest Degradation) program of the United Nations, and more recently to REDD+, which broadens the scope to include sustainable forest management and enhancement of forest carbon stocks.

Forest carbon offset projects, both domestic and international, face a similar set of challenges. At the core of these challenges are the difficulties associated with measurement, monitoring, and verification. Forest measurements are not new; the first forest mensuration text was published in the United States in 1906 (Graves 1906), and although we now possess laser rangefinders, digital data recorders, and a greater understanding of the statistical methods behind sampling designs, the fundamentals remain the same. The measurements are not technically difficult to make. Challenges arise in the form of difficulty of access to remote and rugged terrain, lack of suitable volume or biomass equations, and, most critically, the expense of conducting an inventory that meets an acceptable error standard. Another inherent difficulty is the problem of scale: the number of plots required to meet a target error level is quite different for a project than a nationwide inventory, and so it is unlikely that one system can provide data to meet all users' needs.

The authors note that accurate estimates of forest area are often problematic in developing nations. In fact, conflicting estimates of forest area can also occur in developed nations with a long history of forest inventory. Part of the problem does stem from the definition of "forest," but disagreement in area estimates is also the result of the use of differing imagery and methodology, because various organizations have individual preferences and objectives. High-quality remote sensing data are available at a variety of resolutions from a number of platforms. What is lacking is international (and sometimes national) consensus on the base imagery and approach to estimation. Although there will always be uncertainty in estimates (of both area and biomass), consistently applied approaches can go a long way toward constraining that uncertainty. The barriers are more institutional than technical in this case.

The problems of monitoring and verification clearly require a large spatial scale. Leakage is extremely difficult to detect on a project-by-project basis, especially since leakage can easily cross political boundaries. In addition, monitoring for disturbance (either natural or anthropogenic) demands frequent reassessments to detect change. A strong remote sensing component is critical to successful and meaningful monitoring and verification. LiDAR (light detection and ranging) in particular offers great promise as a way of conducting large-scale repeated assessments of forest biomass, especially for remote and rugged areas. However, the use of LiDAR approaches is constrained by the need for field inventory data because mathematical equations that relate field data to LiDAR data need to be built for different forest types, much in the way that biomass equations need to be developed for different species. Recently established regeneration is not easily detected by satellite-based sensors, and it can be difficult to distinguish the nature of a disturbance without a site visit. Boots on the ground and eyes in the sky are equally key elements to a successful forest monitoring program (see Reams et al. 2010).

Of course, the costs involved are considerable; remote sensing and field data collection are expensive. Funds for field inventory are often difficult to obtain because the labor-intensive and low-tech nature of the work is unattractive to funding agencies. Governance is also a challenge; problems can arise in project management, land tenure, and other areas. Technical capacity and infrastructure varies widely, and mechanisms for dealing with the risk of reversals are still developing.

In the face of these obstacles, it is tempting to simply wait until the technical, policy, and organizational hurdles are overcome, rather to risk investing in a still-developing offset framework. Instead, forestry professionals should view this as the field's "Project Runway" moment: that point where the designer, working against a strict deadline, has hit a snag and is advised to "make it work!" If we wait for every wrinkle to be sorted out we risk missing the window of opportunity to reap the greatest benefit from offset projects, especially in locations where forest conversion is proceeding rapidly. Perhaps a rating system similar to bonds could be used, where programs with high quality measurements, low risk of reversals, and good governance structures would receive a top rating and command a higher price per ton while projects that met a less stringent set of criteria would receive lower prices. Such a mechanism would reward the effort required to meet a high standard, while not excluding projects where the capacity does not yet exist to meet rigorous criteria. Community members in the project areas can be trained to conduct forest inventories, providing income and building capacity at a low cost to the investor. Using the mitigation potential of forests effectively requires us to overcome obstacles in the areas of measurement, monitoring, and verification. I suggest that we view this as an opportunity to engage in adaptive management on a large scale. Only by experimenting with a variety of solutions to the policy, organizational, and technical challenges of creating verifiable forest carbon offsets while providing livelihoods can we learn which approaches are both feasible and effective. We may not have all of the answers, but it's time to make it work.

Literature Cited

Graves, H.S. 1906. Forest Mensuration. Wiley, New York.

Reams, G.A., C.K. Brewer, and R.W. Guldin. 2010. Remote sensing alone is insufficient for quantifying changes in forest cover. *PNAS* 107(38):E145.

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