Using Technology to Enable Community-Based Forest Monitoring:
From theory to implementation challenges and opportunities

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Introduction

Forests are precariously poised to exacerbate global warming or ameliorate it. They sequester nearly half of the world's terrestrial carbon and they hold 20-50 times more carbon than the ecosystems that replace them.[1] Yet, this sequestration potential is jeopardized by deforestation and forest degradation. In 2008, these activities resulted in 12% of total anthropogenic CO_2 emissions.[2]

While global efforts to tip forests toward greater carbon sequestration are prominent, it is important to consider other consequences of deforestation. Forests host around 90% of the biodiversity in the Earth's terrestrial biosphere.[3] Deforestation degrades habitat for fauna and flora and it impairs essential ecosystem services that humans rely upon. Forests serve as water catchment areas, provide habitat for pollinators, reduce soil erosion, and supply edible forest products, fuel wood and medicinal plants. Approximately 60 million people depend entirely on these services for their survival. This forest-dependent population is largely comprised of people living in extreme poverty, on less than $1 USD per day.[4]

Global concern regarding biodiversity loss and the degradation of essential ecosystem services has spurred multinational efforts to reduce deforestation over the past 40 years. As nations prepare a new strategy to reduce emissions from deforestation and degradation (REDD), it is important to consider past lessons and employ innovative tools to help REDD avoid pitfalls of earlier efforts.

This case study presents a new model that uses cutting-edge technology for measuring and monitoring forest carbon emissions. After a brief overview of REDD monitoring requirements, Helveta's interactive cartography application, CI Earth, is introduced. Drawing upon current and potential uses of this application in Nigeria's Afi Mountain Wildlife Sanctuary, this case study describes how technical and practical challenges of REDD may be overcome through community-based forest monitoring with CI Earth.

REDD monitoring: requirements and challenges

Community-based forest monitoring should be considered in the context of REDD policy objectives and technical capabilities. Compensating national or sub-national actors for reducing emissions from deforestation and degradation will require precise carbon accounting. A REDD monitoring system would need

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[1] Houghton, 2008.

[2] Van der Werf et al, 2009.

[3] Global Canopy Foundation, 2008.

[4] Eliasch, 2008.

to begin with a baseline assessment of the initial extent and condition of forest cover and an estimate of associated carbon stocks. Subsequent loss of forest cover would be measured regularly and resultant carbon emissions would be calculated in a manner consistent with baseline carbon stock estimates.[5]

Many national governments and non-governmental organizations have argued that a REDD monitoring system must be relevant, consistent, comprehensive, efficient and robust.

The relevance of the system would be demonstrated by its capacity to generate information directly pertinent to REDD policy requirements. Such requirements and the procedures used to fulfill them should be consistent with earlier UNFCCC definitions and protocols. The system should be comprehensive enough to be applied globally at national and sub-national levels. Cost-effectiveness would be essential for global application of the system, while efficiency would be a prerequisite for real-time carbon accounting in dynamic environments. An efficient system could also provide opportune information to aid management efforts. Lastly, the monitoring system should be scientifically robust and methodologically valid.[6]

There is broad consensus that a monitoring system centered around remote sensing would be most apt to meet REDD requirements. However, this consensus dissolves when devising schemes that work around the numerous technical limitations to working with satellite imagery. Most of these limitations pertain to the resolution of imagery.

As numerous scientists and government leaders have reiterated, satellite imagery with high spatial, temporal and spectral resolution can be a powerful tool for monitoring deforestation.[7] Forest loss can be detected at 80-95% accuracy with high spatial resolution satellite imagery. However, such imagery (e.g. Quickbird, Ikonos) is generally not freely available, globally comprehensive and frequent enough to be used as the basis of a global monitoring system. Medium spatial resolution imagery, such as Landsat is freely available at a higher temporal resolution and it is globally comprehensive, but with vast swaths of damaged data since 2003. Landsat imagery has been proposed as a viable option for REDD monitoring needs.[8]

Even the best passive remote sensors perform poorly in the tropics due to high amounts of atmospheric noise. Although the quality of satellite imagery can be vastly improved when corrected with data from active remote sensors such as lidar and radar, this type of advanced image processing is time-consuming, expensive and technically demanding.[9]

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[5] DeFries et al, 2007.

[6] Herold and Johns, 2007.

[7] Mumby, 1999; DeFries et al, 2007; Herald and Johns, 2007; UNFCCC, 2007.

[8] DeFries et al, 2007; Olander, 2008.

[9] Lu and Weng, 2007.

The myriad of imperfections that plague remote sensing underscores the importance of diversification and verification.

Given the trade-offs entailed with using various types of remote sensing data, practitioners diversify the types of data they use. Many advocate for a hybrid monitoring approach for REDD that capitalizes on the strengths and weaknesses of different of satellite imagery. Globally comprehensive, medium-resolution imagery would form the foundation of a 'wall-to-wall' monitoring system. And higher quality remote sensing data would enhance monitoring in select 'hotspots'.[10] Higher quality data could be radar, lidar or satellite imagery with a finer spatial scale, more optical bands or greater temporal resolution.

Even when performing advanced image corrections, slight geometric inconsistencies between datasets can add new types of errors. Poor atmospheric conditions and radiometric noise can impair the quality of any satellite image and, more importantly, the accuracy of maps it is used to produce.

These challenges are aggravated when using satellite data to detect forest degradation. Degradation tends to be more expansive than deforestation, yet the extent of degradation is often undetermined because most types of degradation cannot be properly sensed remotely. Canopy fires, forest conversions to tree plantations, selective logging, fuel wood extraction and other types of understory thinning all result in emissions of carbon dioxide, but the latter activities are nearly impossible to detect with medium quality satellite imagery.[11]

To address the technical limitations of remote sensing, field surveys must be an integral component to REDD monitoring. Field surveys are essential for estimating initial carbon stocks in forest biomass. They are the backbone of accuracy assessments. Lastly, field surveys can provide other spatial data that can augment the overall effectiveness of REDD activities.

Bottom-up monitoring with Heleveta's CI Earth

REDD monitoring with remote sensing can be considered 'top-down', while field surveys are essentially 'bottom-up'. Merging these two approaches for REDD monitoring can result in a synergistic system that is more scientifically robust and substantively comprehensive.

Helveta's CI Earth technology is an interactive cartography application designed for 'bottom-up' monitoring in forest environments. It consists of a ruggedized touch-screen HHC (hand held computer) for field data gathering, a versatile data capture application and an online platform for map sharing.

The core goal of CI Earth is to provide stakeholders with accessible and accurate information gathered using state-of-the-art technology which generates high

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[10] DeFries, 2007; Herald and Johns, 2007; Olander et al, 2008.

[11] Peres, 2006.

quality spatial data on forest assets and uses. It is a forum for sharing different types of knowledge on forest resources to create a rich database of information, which can be mobilized for participatory spatial planning, conflict resolution and forest monitoring and management.

To broaden the group of stakeholders that can participate in CI Earth mapping, the data collection interface can be image- or text-based. CI Earth technology allows users to configure their own images and text and define the decision trees for capturing data. This facilitates the collation of forest information in a manner that is comprehensible to forest communities regardless of their native language and literacy level.

With CI Earth's user-defined interface, the tool can be modified to meet a wide variety of data needs.

The CI Earth online application enables users to share maps, and view and query maps produced by others. CI Earth data points and associated images can be exported to GIS products such as ArcView or Google™ Earth.

CI Earth technology has been deployed in Nigeria, Central African Republic, Republic of Congo and Cameroon.[12] Before going into more detail on current and potential uses of this technology in Afi Mountain Wildlife Sanctuary of Nigeria, some basic information on this protected area is provided.

Afi Mountain Wildlife Sanctuary

Afi Mountain Wildlife Sanctuary (AMWS) provides a rich case study because this protected area is distinctive in ways that heighten its importance. Yet, the sanctuary confronts a range of challenges that are common in other forest environments throughout the world.

The ~100km^2 sanctuary is located in southeastern Nigeria and it is mostly comprised of lowland and hill tropical forest.[13] The sanctuary's high level of biodiversity is distinctive even among other protected areas. Afi Mountain hosts a large number of endemic amphibian, butterfly, fish, bird and small mammal populations. Africa's most threatened primate, Cross River gorilla, enhabit the sanctuary as well as other endemic and endangered species including Nigeria-Cameroon chimpanzee (Pan troglodytes vellerosus), drill (Mandrillus leucophaeus) and Preuss's guenon (Cercopithecus preussi).[14]

High species richness among primates is the primary reason why Afi's status was heightened from a multi-use forest reserve (Category VI) to a strict wilderness

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[12] Helveta Ltd, 2009a.

[13] Oates et al, 2006.

[14] Nuesiri, 2003.

protection area (Category I) in 2000. Constituting less 9% of all protected areas worldwide, this type of refuge is rare.[15]

Despite the sanctuary's ambitious protection status, large portions are still used for prohibited activities, including farming and hunting. A recent AMWS report cited 98 illegal farms inside the sanctuary, several incidences of uncontrolled forest fires and ample evidence of hunting.[16] In forests near the sanctuary, these activities are practiced along with the extraction of timber, fuel wood and edible forest products.[17]

AMWS is similar to countless other protected areas that are referred to as paper parks. Paper parks have a documented protection status that is more rigorous than the level of protection achieved on the ground. Deforestation and degradation within and beyond the sanctuary release carbon dioxide into the atmosphere, impair ecosystem services, isolate protected areas and reduce the landscape's capacity to conserve fauna and flora.

Many of the practical challenges of managing forests also apply to measuring and monitoring them. Cross River State Forestry Commission, Fauna and Flora International, Wildlife Conservation Society, Nigerian Conservation Foundation and Pandrillus Foundation have formed a conservation partnership to tackle these challenges in Afi Mountain Wildlife Sanctuary and the surrounding 16 villages.

Mapping forest degradation on Afi Mountain with CI Earth

Helveta Ltd. began collaborating with Fauna and Flora International (FFI) on behalf of the Afi Conservation Partnership in 2006. The initial objective was the provision of a technology-based system for mapping forest boundaries, forest access routes, biodiversity indicators and evidence of illegal poaching and forest clearing that could be used by rangers and indigenous communities in Afi. Helveta conducted a workshop with representatives of the Afi Conservation Partnership and local communities to explore data collection needs and preferences. By early 2007, an Afi-specific CI Earth platform was launched to engage government foresters and local communities in the monitoring process.[18]

Afi's CI Earth system is currently focused on assessing illegal activities and biodiversity indicators within and around the sanctuary. The CI Earth interface

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[15] The World Conservation Union (IUCN) divides protected areas into six categories: (I) strict nature reserve, wilderness protection area, or wilderness area managed mainly for science or wilderness protection, (II) national park managed mainly for ecosystem protection and recreation, (III) national monument, managed mainly for conservation of specific natural features, (IV) habitat/species management area, managed mainly for conservation through management intervention, (V) protected landscape/seascape, managed mainly for conservation or recreation, and (VI) resource protected area, managed mainly for sustainable use of natural resources. Naughton-Treves, 2005.

[16] Ubi, 2007.

[17] Oates et al, 2006.

[18] Helveta Ltd, 2009b.

for Afi features images of common threats and endemic species. Data collected with CI Earth units are compiled by the sanctuary's conservation coordinator. Over time, these datasets reveal how key species utilize natural resources in the sanctuary, which areas are prone to illegal exploitation, and where gaps may exist on forest patrols.

CI Earth roadmap for REDD monitoring

The section delves into more detail on specific REDD-related data needs and explains outlines how CI Earth technology can be used by forest communities for baseline measurements, long term monitoring and maximizing co-benefits of REDD activities. Regardless of the 'top-down' approach used for measuring initial forest cover, 'bottom-up' field survey data will be essential. The versatility of CI Earth positions it well to meet these data needs.

Establishing a baseline of initial forest cover and carbon stocks begins with a land cover classification. After defining the area of interest, and selecting an appropriate type of satellite data, the land cover classification will include six main steps: (1) determination of a suitable classification system, (2) selection of training samples, (3) image pre-processing, (4) classification, (5) post-classification image processing, and (6) accuracy assessment.[19] CI Earth data can be integrated into many of these steps to improve the quality of the land cover classification.

Classification systems can be 'supervised', 'unsupervised' or a hybrid of the two. Supervised classifications use samples of different land covers to 'train' image processing modules to identify similar objects in a satellite image. Training samples, GPS-referenced notes indicating exactly where different types of land cover occur, can be gathered using CI Earth. Unsupervised classification systems distinguish landmasses by drawing upon their varied spectral responses to solar radiation.[20] Such systems do not require sampling sites. Supervised and unsupervised classifications are generally preferable because they minimize the amount of human bias that may be introduced when solely relying upon visual interpretation to classify land cover.[21]

Before performing the classification, satellite imagery must be pre-processed to remove errors such as radiometric noise, poor atmospheric conditions and geometric inconsistencies. To correct for the latter type of errors, CI Earth can be used to record the locations of conspicuous features in the landscape that can be recognized in satellite imagery. This spatial information forms a consistent foundation to accurately position and geometrically correct satellite data.

After classifying a satellite image and correcting the land cover map to remove subsequent noise, the accuracy of the land cover map should be assessed to determine its limitations. No classification map will be 100% accurate for all purposes. Consequently, detecting different type of errors and weighing their

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[19] Lu and Weng, 2007.

[20] Eastman, 2006.

[21] GOLF-GOLD, 2008.

specific magnitude is a fundamental component of map production. Although accuracies can be assessed with very high spatial resolution imagery, a field-based survey is more scientifically robust.[22]

There is no universal method of accuracy assessment. The methodological approach should recognize case-specific data limitations, as well as map-user accuracy requirements. For REDD monitoring, it is important to note that the accuracy of land cover maps will most likely differ by class and vary spatially. For example, a classification system might identify settlement areas more successfully than forest areas. Furthermore, the classification of forest on flat lands may be more accurate than the forest classification in montane areas.[23]

Class and spatial variation in map accuracy highlight the importance of sub-national image validation. Though ‘wall-to-wall’ land cover mapping on a national level is advisable to monitor leakage, accuracy assessments should be conducted in numerous regions and localities within a given nation.[24] Certain areas, such as biodiversity hotspots, may be of greater interest and therefore necessitate a higher level of classification precision. Other localities may be selected for in depth validation because their topographical features render them difficult to classify. Regardless of the site selection criteria, a more pervasive survey that gathers data on multiple tiers (e.g. national, regional/biome and local) can be expected to produce better metrics of accuracy.[25]

Accuracy assessment field surveys can be conducted jointly with carbon stock inventories, which should also be measured at multiple tiers.[26] Depending upon the initial biomass of various land covers, deforestation and degradation activities will release different amounts of carbon dioxide. Again, nation- and biome-wide biomass estimates may be used for the wall-to-wall carbon accounting. However, more spatially explicit biomass measurements will increase the accuracy of emission estimates.[27]

To meet this rigorous set of field data needs, CI Earth technology provides a multifaceted, user-friendly platform. Land cover samples used during image pre-processing, classification training, accuracy assessment, and biomass estimates can all be gathered at the community-level by a diverse group of stakeholders with CI Earth technology.

Given the intensity of data needs, engaging a wide variety and a large number of stakeholders will be advantageous for practical reason. There are also several important social and economic reasons to meaningfully engage forest users in REDD monitoring.

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[22] DeFries, 2007.

[23] Strahler et al, 2006.

[24] DeFries, 2007.

[25] GOFC-GOLD, 2008.

[26] Olander et al, 2008.

[27] Houghton, 2008; GOLC-GOLD, 2008.

Maximizing REDD co-benefits with CI Earth

Improved management of forest resources to reduce emissions from deforestation and forest degradation can simultaneously provide multiple co-benefits such as conserving biodiversity, maintaining essential ecosystem services and empowering forest-dependent communities. CI Earth's versatility provides a platform to maximize these co-benefits.

All hectares of forest are not equally endowed with forest assets or beleaguered with threats. For example, wildlife habitat is not generically dispersed across a landscape. Water catchment capacity is not equally distributed throughout swaths of forest and forests on steep mountainsides may be difficult to access and less likely to be converted to agricultural land. Spatially explicit monitoring of biodiversity indicators, ecosystem services and trends in anthropogenic disturbances can be used to identify priority areas for REDD interventions.

Maximizing REDD co-benefits from forest management activities by first investing in priority areas will require spatial information that goes beyond the scope of carbon accounting. Data from long-term monitoring of endangered primates in Afi Mountain Wildlife Sanctuary is one example of auxiliary spatial information that can be used to select REDD priority areas. Strengthening forest conservation in the sanctuary would not only reduce carbon emissions from deforestation and degradation, but also safeguard crucial habitat.

Another hotspot approach may be geared toward maximizing reductions of greenhouse gases and returns on investment. Under this approach, forest areas that contain the highest carbon stocks with the greatest deforestation threat would be selected as priority areas for REDD interventions.[28]

A third hotspot approach places greater emphasis on conserving ecosystem services. Coarse analysis of ecosystem services globally has indicated that the sustainability of these essential services is jeopardized by unsustainable anthropogenic activities.[29] A finer analysis has demonstrated that regional conservation efforts geared toward safeguarding biodiversity have no greater impact on ecosystem services than regions selected randomly.[30] Thus, a hotspot approach geared toward conserving forest ecosystem services would result in a different set of REDD priority areas.

Although spatially evaluating forest ecosystem services is a highly technical exercise, it is another process that is best performed in close collaboration with local forest users.

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[28] Harris et al, 2008.

[29] Millenium Ecosystem Assessment, 2005.

[30] Naidoo et al, 2008.

CI Earth technology enables forest users to mobilize their indigenous knowledge in a manner that can be easily comprehended by external experts and decision-makers. Indigenous knowledge differs from scientific knowledge in that it is derived from close and long relationships between people and a specific land area.[31] This vast knowledge base can place forest-dependent people on a more equal footing with outsider practitioners because indigenous knowledge is advantageous in REDD-related monitoring.

Perhaps the most important co-benefit REDD can achieve is empowering forest-dependent communities socio-economically. Over 90% of the 1.2 billion people living in extreme poverty rely upon, and often unsustainably exploit, forest resources.[32] REDD is intended to be a financing mechanism to compensate countries that are willing and able to reduce emissions from deforestation and forest degradation. Herein lies a hotly contested facet of proposed REDD mechanisms: how will marginalized forest-dependent populations be incorporated into national REDD schemes.

Most of the world's forest area, approximately 84%, is publicly owned or managed. This complicates efforts to compensate forest users, who are most likely not forest owners.[33]

Furthermore, the viability of a REDD mechanism that compensates the public for *not* doing something – especially an activity that may already be illegal or contrary to the public interest – is controversial. In other words, paying people not to deforest land in protected areas, or forests that their community depends upon, could create a perverse incentive that jeopardizes the potential effectiveness of REDD financing.[34]

A positive incentive structure that pays people to carryout out tasks that increase carbon sequestration could be more effective. Successful participatory forest management schemes that enable communities to derive benefits from forest management initiatives provide concrete examples of the effectiveness of positive incentive structures in the forestry sector.[35]

CI Earth technology can form the basis of another positive incentive structure that compensates forest users for participation in baseline assessments and continuous field validation of remote sensing-based REDD monitoring. The importance of engaging local stakeholders in such essential REDD implementation activities cannot be overstated. CI Earth provides a framework for forest-dependent people to capitalize on their indigenous knowledge, which is sometimes the only resource forest-dependant population's control.

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[31] McCall, 2003.

[32] Global Canopy Foundation, 2008.

[33] Martin, 2008 citing FAO, 2006.

[34] Martin 2008

[35] Blomley et al, 2008; Nagendra et al, 2004.

Conclusion

The problem-solving arena for REDD has been dominated by large-scale national and international strategies. However, there is a substantial canon of literature on remote sensing, landscape ecology and forest management that justifies intensive measuring and monitoring of forest environmental on a sub-national and community-level. These approaches are not mutually exclusive. Indeed, given the magnitude of deforestation, only a synergistic combination of global and local efforts could adequately assess forest resources and ultimately harness them for carbon sequestration.

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