The Potential Role for Community Monitoring in MRV and in Benefit Sharing in REDD+

Edited by

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Table of Contents

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Preface

The Potential Role for Community Monitoring in MRV and in Benefit Sharing in REDD+

Abstract: Since the early design of activities to reduce emissions from deforestation and forest degradation in developing countries (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC), the need to engage local communities and indigenous groups in monitoring and reporting has been recognized. REDD+ has advanced under the UNFCCC negotiations, but most countries still need to define formally what the role of communities in their national monitoring systems will be. Previous research and experiences have shown that local communities can effectively contribute in the monitoring of natural resources. This editorial introduces a Special Issue of Forests which discusses the implications of and potential for including community based monitoring (CBM) in monitoring and benefit-sharing systems in REDD+. It outlines the main points of the nine contributions to the Special Issue which cover a wide geographical area and report on projects and research which engages more than 150 communities from eight different countries from Africa, Asia and Latin America. The editorial summarizes how the articles and reports build further understanding of the potential of CBM to contribute to the implementation, monitoring and distribution of benefits in REDD+. It also discusses the results of an on-going opinion survey on issues related to CBM and its relation to benefit sharing, which indicates that there is still disagreement on a number of key elements.

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1. Introduction

Developing countries interested in reducing emissions from deforestation and forest degradation (REDD+) under the United Nations Framework Convention on Climate Change (UNFCCC) have been requested to prepare a national forest monitoring system (NFMS) and a system to monitor, report and verify implementation (MRV). They have also been requested to engage local communities and indigenous groups as critical stakeholders in this process. The NFMS should be consistent with national inventories of emissions and removals of greenhouse gases that are based on methods and guidance published by the Intergovernmental Panel on Climate Change (IPCC). These inventories are usually prepared using national level information with low geographical resolution and without the participation of local communities or other forest owners/managers. However, it has been shown that members of rural forest communities can develop the skills to monitor and measure levels of carbon stocks in their forests and changes in these levels over time. Community monitoring has indeed been proposed as an option for REDD+ monitoring and reporting since international discussion on this policy first began in 2003. However, each country needs to define the role that community monitoring may play in the implementation and monitoring of REDD+. The objective of this Special Issue is to discuss and explore the social, technical and political implications and potential of including community-based monitoring (CBM) in MRV systems and benefit-sharing schemes in REDD+.

The idea for this Special Issue was born after the Side Event "Evolving Requirements and Solutions for REDD+ Monitoring with Community Focus" organized by the University of Twente and the Global Canopy Programme at the UNFCCC Nineteenth Conference of the Parties in Warsaw in November 2013 (COP 19). At this event it was argued that if information gathered by local actors could be included and tracked from the local to regional and national levels, this might help to design transparent mechanisms for the assessment of REDD+ implementation, to increase the level of resolution of data used by national monitoring systems and possibly even for benefit sharing. In the side event, a number of propositions about the potential for community monitoring on these issues were discussed with the audience using an "opinion poll format"; this was an interesting exercise. Among the participants there was general agreement that community monitored data could be sufficiently accurate for the purposes of REDD+ monitoring, and that new technologies offer promising options for this (*i.e.*, handheld computers or smartphones for entering and processing the data). However, there was disagreement about other issues, in particular whether CBM of carbon performance could be used as the basis for calculating financial rewards for local actors and whether the data could be integrated in some way into national forest databases and thus into national MRV systems [1]. It was clear that more research was needed on these issues, and this thus gave rise to the call for papers for this Special Issue in *Forests*.

We are proud to present here a range of responses to this call that include seven research articles and two reports from practical cases studies. The contributions cover a wide geographical range, engaging more than 150 communities and projects at local level from China, Ethiopia, Guyana, Indonesia, Laos, Mexico, Nepal and Vietnam. They address theoretical and practical aspects of the use of CBM in the context of national monitoring systems and benefit sharing schemes in REDD+.

2. The Special Issue

Departing from a the description of the technical architecture of REDD+ given the decisions adopted at the COPs of the UNFCCC, Balderas Torres [2] in the introductory article identifies four specific opportunities for communities to feed local information into national monitoring systems. First communities can be hired to set forest inventory plots as a means for increasing the sample size of national or sub-national programs; secondly, information on activity data and carbon stocks and changes can be derived from data produced as part of practices already being implemented by communities to obtain or to access specific benefits (*i.e.*, forest management plans); thirdly, activity and carbon related information from projects participating in carbon markets or other certification schemes could also be included in national monitoring systems; and finally, communities may contribute sources of information to demonstrate the implementation of social and environmental safeguards. The author concludes it will be necessary to consider the budgetary needs related to the costs of generating this information and the specific agreements for sharing local information with external stakeholders at national and international levels.

Many of the experiences describing the potential of communities to provide local information are focused in the generation of data on carbon stocks, which in the jargon of greenhouse gas inventories relates to information on emission factors. However there are fewer references exploring the potential of communities to produce activity data or information on forest area; this is one of the contributions of the work by Pratihast *et al.* [3]. In their article, Pratihast *et al.* [3] combine the use of high-resolution satellite imagery and professional measurements to assess the consistency of community monitoring of forest area and forest area changes in Ethiopia in terms of spatial, temporal and thematic accuracy. Community monitoring was used to describe changes associated with deforestation, forest degradation and also reforestation, in terms of their location, size, timing and causes within 10 local administrative units. The authors found a generally good correspondence of the data gathered by communities and observed that mobile devices worked better than paper-based recording systems; they also reported that issues related to accessibility to forest areas, size of forest patches to be mapped, capacity building, weather and motivation need to be addressed when engaging communities into MRV systems. Results show communities can offer complementary information to remotely sensed data particularly to define local land use and to assess forest degradation particularly over small areas.

A second contribution also exploring alternatives for producing information of forest areas at local level deals with the use of emerging new technologies; Paneque-Gálvez *et al.* [4] explore the possibility of using drones for community based surveys. They suggest that the technical potential for using drones to obtain local aerial imagery of forest areas and disturbances with very high resolution is excellent, and the costs are relatively low. Advantages include the possibility for gathering data with high frequency, the systematic coverage and good assessments of areas of degradation. However, there are also disadvantages such as airspace regulations. They conclude that drones should first be tested in areas where communities are already involved in monitoring, so that communities themselves could evaluate their use.

Another aspect that has been little researched are the capacities of communities to monitor carbon stocks over time since many of the earlier studies present results of measurements from a single point in time. Following up on this, Brofeldt *et al.* [5] present data from a multi-temporal monitoring project from six communities within four countries in South East Asia (Indonesia, China, Laos and Vietnam) to compare the accuracy and costs of community gathered data and professional brigades. Results presented indicate that accuracy of community carbon stock measurements improves over time, while confirming other studies that show costs of repeated community measurements decline and are less than those done by professional foresters. They stress that a key factor for successful monitoring is the use of simple measurement methods.

Two articles discuss the feasibility and sustainability of local participatory approaches as part of forest monitoring systems for REDD+. First, Boissière *et al.* [6] present a research framework analyzing the potential for participatory MRV in Indonesia. The authors present the criteria followed for the selection of seven pilot projects and the research questions and methods used to assess the feasibility of the schemes. To understand the implication of participatory schemes as regards the reporting of information in MRV systems, the existing Indonesian healthcare and forestry information systems will be analyzed to study the associated governance in the flow of information. Authors suggest that this type of study requires several types of analysis: social analysis to probe the enabling conditions for local participation; governance analysis to understand data flow; and remote sensing work to compare the gap between local (land use) and national (land cover) approaches. In all, this article provides a very rich and thoughtful design that hopefully will soon provide interesting results and can inspire similar efforts elsewhere. Continuing on the discussion of the enabling conditions for including communities into monitoring systems, Balderas Torres and colleagues [7] examine, based on a multi-criteria analysis, the potential implementation and sustainability of community monitoring in 11 projects under development in early action programs in Mexico. Projects are evaluated in terms of the prospects to produce carbon and activity data compatible with national systems, and in terms of the motivation for participation and the roles that members of local communities play in the implementation and monitoring of the projects. They note that each project has its own approach to monitoring (*i.e.*, practices and methods are not standardized), and that although all projects have the resources and capacities to carry out monitoring tasks, in most (though not all) cases, these skills reside in intermediary organizations (*i.e.*, NGOs and academia), not within the communities themselves; thus it will be necessary to create local capacities if communities are to do more autonomous monitoring on their own.

Any benefit distribution scheme in REDD+ will require using specific data from monitoring systems in a transparent way to define the magnitude and attribution of benefits associated to carbon performance at different geographical scales. The final article of this Special Issue discusses the data requirements of national monitoring systems for different benefit sharing schemes and potential role of CBM. Skutsch *et al.* [8] evaluate the technical, political and equity implications of two types of benefit sharing schemes: Firstly, output based systems focused on the evaluation of carbon performance; and secondly, input based schemes where financing and compensation relate to the costs of implementing specific activities. The authors indicate that output based systems imply higher transaction costs since they require more information and with smaller uncertainty, and they require the development of local reference levels and a strong verification system since incentives for actors depend on the data reported and thus there could be an incentive to overestimate the figures. The informational burden of input based schemes is lighter; moreover, in these schemes local actors can provide supplementary data to national systems regarding the success of the implementation of different activities and policies. Skutsch *et al.* [8] present a "dual" proposal where, firstly, reduced emissions could be assessed using data from national systems at regional level (*i.e.*, Tier 2, following IPCC methods) to evaluate the effect of activities promoted via input based schemes. The second component of the system could use output based approaches to promote forest management and conservation where compensation could be based on the carbon stocks and enhancements measured at local level; this data can later feed into national systems to improve the estimates to produce regional and national information with lower levels of uncertainty.

The Special Issue concludes with two case studies in countries which are already experimenting with community monitoring in REDD+ projects: Nepal and Guyana.

Shrestha *et al.* [9] present the information of a pilot REDD+ project involving 112 communities in Nepal that implemented an innovative approach for local forest governance and benefit sharing that included CBM comprehensively within a local MRV system. The rules for distributing the benefits involved combining payments based on carbon performance with payments linked to other socioeconomic criteria in order to produce an equitable and fair scheme (*i.e.*, criteria target poor groups, indigenous people and women aiming to prevent elite capture of benefits). Given the successful history of community forest management in Nepal, emissions from deforestation have been halted already in the area, thus in common with other articles in this Special Issue, benefits from reduced emissions were not considered and the carbon component of local payments was estimated using data on carbon stocks and enhancements. It is necessary to consider the costs of monitoring activities in order to set the right carbon prices. Benefits received at local level were used to co-finance social projects aiming to reduce poverty and took the form of both cash and in-kind payments (e.g., improved community infrastructure). While this case study describes how community monitoring can be included into MRV and benefit sharing in REDD+ in practice, the authors stress that it is necessary that governments define formally the role that CBM will play in national programs to create the necessary capacities and deploy the required governance systems [9].

Finally, Bellfield *et al.* [10] present information on a pilot project under implementation in 16 communities in Guyana and describe how CBM has been included in it. The project is piloting how to set up different elements of REDD+ related to MRV and capacity building. Communities contribute to the project's MRV system through participatory mapping and ground truthing of satellite imagery, the evaluation of local drivers of deforestation and forest degradation, through the implementation of forest inventories of aboveground biomass to measure carbon stocks and stock changes, and also through the provision of information to document the implementation of social and environmental safeguards and local co-benefits. CBM has been particularly useful in the project to understand the drivers of land use change, and the local dynamics of agricultural and farming practices; the article highlights the importance of keeping consistency within national systems and communities (*i.e.*, nomenclature of forest types). The report also describes how technological tools were used for the different monitoring components; it is clear that digital devices help to reduce time and costs to gather and register data, however more work is necessary to manage and analyze it. Processes to analyze and report this information need also to be adapted to the local contexts of communities, meanwhile as in the case described from Mexico, this specialized know-how resides on other/external actors (*i.e.* consultants). Authors stressed that in order to be sustainable in the long term these monitoring practices need to deliver local benefits and those participating in CBM should receive compensation for it. In order to harness the benefits that CBM can offer in the implementation of REDD+ it is necessary that governments take action to define the role of communities and reduce the uncertainty of policies as regards the contribution of communities to MRV systems and benefit sharing schemes.

3. Recent Developments

The articles and case studies in this Special Issue, as introduced above, go some way to answering the questions the Special Issue set out to resolve. However, there are still many issues unresolved. Among others the following questions remain:

- How to standardize methods and data for CBM so that it can be integrated into national systems? The article by Balderas Torres *et al.* [7] begins to examine this question but further work will be necessary. What variables in addition to carbon can be included to get the interest of communities? Should they be paid for the monitoring? The Guyana case study begins to address this but again further work needs to be done.
- How to distribute benefits to non-forest holders who implement REDD+ activities?
- How to (who should) design multi-scale performance-based equitable benefit-sharing schemes? Should rules for this be developed internationally? Nationally? At the local level?

With these questions in mind, a second opinion poll was put forward at the side event "REDD+ monitoring needs to support the distribution of benefits" this time at COP 20 in Lima, in December 2014. In this occasion an e-survey was set up prior to the event (overall 55 people provided inputs, 25 during the initial survey and a further 30 during the side event itself) (an overview of the results and interview with Veronique de Sy, who organized the survey, can be found on-line [11,12]). There was near unanimity on a number of issues, for example views indicated that standardized protocols for CBM would not diminish the interest of communities and that community data would indeed strengthen national data systems. There was also agreement on paying communities for monitoring, independently of carbon payments and on the needs to develop protocols to document inputs (e.g., days of labor) as well as outputs (i.e., carbon). There was a range of opinions on whether other actors (other than forest owners) should be eligible for REDD+ rewards, with the majority favoring inclusion of all major actors behind deforestation, if they reduce their pressure on the forests.

One issue however remains in considerable controversy: the basis on which REDD+ benefits should be distributed. There are various options, but the underlying question is whether payments should be made on the basis of carbon performance or on the basis of other indicators, such as opportunity costs, inputs or effort made for the REDD+ activities, or social needs (poverty). Those who agreed on carbon-performance systems claimed that REDD+ was always intended to be performance based (additional), and that this was determined by UNFCCC. Those who were against this felt that even though countries would be rewarded on the basis of performance, this model was not obligatory at the local level, indeed it would result in many problems, possibly leading to perverse incentives and possibly corruption. Moreover it was perceived to be too expensive, and would require too much capacity, to be implemented at the level of every community.

Despite this division of opinions, it seems logical that if communities will implement activities that mitigate climate change, they should be involved in the monitoring of such activities, and in particular in the measurement of the carbon savings. It has been proven that with some training and with suitable protocols, it would be feasible and cost-effective to involve communities in monitoring of REDD+ activities in their territories.

However this in no way implies that communities would then be free to sell their measured "carbon credits" in carbon markets or receive compensation based on carbon performance. Firstly, if they were measuring their own achievements against a local baseline there would have to be verification by independent third parties. Secondly, if the activities were part of a national strategy for REDD+, their achievements would have to be included with all other forest carbon losses and gains over the whole country, and assessed against a national reference emission level, before any performance based rewards could be attributed. How the distribution of benefits within national REDD+ programs is organized will be up to each government to decide. Most countries however have not yet clarified how they plan to distribute the benefits from reduced emissions and/or from carbon enhancements, and there is an on-going and active debate within civil society concerning the equity and efficiency of different options. Evidently, more debate will be required on the issue of benefit sharing, and possibly pilot projects using different reward systems are needed so that their relative merits can be tested. We look forward to another Special Issue in *Forests* devoted to this theme in a couple of years' time.

4. Final Remarks

We are satisfied that this Special Issue has been able to collect information from different geographies and contexts to build further understanding of how communities can contribute to the implementation and monitoring of REDD+. It has identified specific options by which local data can be incorporated into national monitoring systems. The articles and case studies show that CBM can provide data on carbon stocks, carbon stock changes, forest area and area changes, data to understand local drivers of emissions, and the implementation of safeguards according to local interests. They also show, in theory and in practice, how local data can be used to make operational different approaches for the distribution of benefits at the local level. While many issues need to be subjected to further research, the conclusions concur that there is a need to define the roles and rules for including formally CBM into the REDD+ activities implemented by each country. These are needed before plans for capacity building and phased implementation are drawn up. At this stage it will also be important to explore the implications of the different options for benefit-sharing schemes. The next step would involve not only building capacities, but also the institutional arrangements to formally incorporate CBM into monitoring and benefit sharing schemes.

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Guest Editors

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Potential for Integrating Community-Based Monitoring into REDD+

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Abstract: Countries at the United Nations Framework on the Convention on Climate Change (UNFCCC) have decided to engage local communities and indigenous groups into the activities for the monitoring, reporting and verification (MRV) of the program to reduce emissions from deforestation and forest degradation and increase carbon removals (REDD+). Previous research and projects have shown that communities can produce reliable data on forest area and carbon estimates through field measurements. The objective of this article is to describe the framework that is being created for REDD+ under the UNFCCC to identify the potential inclusion of local information produced through community-based monitoring (CBM) into monitoring systems for REDD+. National systems could use different sources of information from CBM: first, local information can be produced as part of public programs by increasing sample size of national or regional inventories; second, government can collect information to produce carbon estimates from on-going management practices implemented at local level driven by access to local direct benefits (e.g., forest management plans, watershed conservation); third, national data systems could include information from projects participating in carbon markets and other certification schemes; and finally information will be produced as part of the activities associated to the implementation of social and environmental safeguards. Locally generated data on carbon and areas under different forms of management can be dovetailed into national systems and be used to describe management practices, complement existing information or replace Tier 1/2 values with more detailed local data produced by CBM.

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1. Introduction

REDD+, the international policy to reduce emissions from deforestation and forest degradation and to promote the conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries is part of the efforts to mitigate climate change under the United Nations Framework Convention on Climate Change (UNFCCC). It is one of the activities developed in the Bali Action Plan for long-term cooperative action [1] and aims to provide incentives to developing countries to reduce emissions from deforestation and forest degradation and to enhance carbon stocks. In 2009, developing countries aiming to participate in REDD+ were requested to create a robust and transparent National Forest Monitoring System (NFMS) to estimate anthropogenic emissions and removals by sinks, forest carbon stocks and forest area changes [2]; however capacities required for this among many countries still need to be developed [3]. At the Conference of the Parties (COP) in Copenhagen (COP 15) the need to engage indigenous groups and local communities in monitoring and reporting activities in REDD+ was recognized and countries were encouraged to prepare appropriate guidance for it [2]. Ever since, countries have started to design and implement systems to monitor carbon in forests. The objective of this work is to review different elements of the design and implementation of national REDD+ programs in order to identify potential options for integrating community based monitoring (CBM) as means for generation of information at the local level to fulfil requirements of monitoring, reporting and verification (MRV).

The document discusses the potential for up-scaling and dovetailing local information as part of the national forest monitoring system (NFMS) and the associated MRV system of REDD+. The opportunities for CBM are identified by considering the general methods available for the estimation of carbon content and forest area [4]. This document presents first a description of the main decisions adopted by the COP of the UNFCCC related to REDD+; this is followed by the identification of the opportunities for CBM within the framework for national programs stemming from the UNFCCC; later the potential contribution of CBM to the different elements within REDD+ is described; then options for integrating CBM into national MRV and NFMS are discussed.

2. REDD+ and CBM

Rural communities can gather field data in the context of climate change mitigation instruments such as REDD+ via CBM (e.g., [5]). CBM can help to link remote sensing and national forest inventories of carbon stocks to local implementation and measuring carbon from forest degradation in REDD+ [6]. The design of MRV systems for REDD+ will depend on specific management objectives selected in national programs, the resources available and other factors as accessibility to the sites. With appropriate design and planning, local monitoring schemes can help reducing costs, increase accuracy and precision and facilitate the use of local data for national and international monitoring schemes [7].

REDD+ is a program that will be implemented in three general phases (*i.e.*, preparedness, implementation and full monitoring of results-based activities) [8]. It includes five activities to mitigate climate change (*i.e.*, reduced deforestation, reduced forest degradation, conservation of forest carbon stocks, sustainable management of forests and carbon enhancements); these activities should be implemented with the full participation of relevant stakeholders, particularly indigenous groups and local communities [9]; environmental and social safeguards need to be implemented in all the phases of REDD+ [9]. The assessment of results-based actions will require the establishment of national level reference emissions levels and forests reference levels measured in tCO_2e/yr (REL/RL) [9]. The information used to establish these baselines needs to be consistent with the information contained in the National Inventories of Greenhouse Gases Emissions and Removals by Sinks (NGHGI) and can be established following a step-wise approach (*i.e.*, this refers to the incorporation of better data and methods to transit from systems based on international default data -Tier 1- to national level –Tier 2- and locally produced data -Tier 3-) [9].

NGHGI are elaborated following the guidance and guidelines published by the Intergovernmental Panel on Climate Change [4,10–12]. For REDD+, developing countries were asked initially (in 2007) to use the most recent guidelines first for the estimation of emissions from deforestation and two years later to estimate carbon stocks and forest area changes [1,2]. In Cancun (COP 16), non-Annex I countries were instructed to use guidelines presented in IPCC, 2003 to estimate forest related emissions and removals by sinks as part of their NGHGI [8]; this signifies an improvement in the use of more recent methodologies and a more comprehensive approach since the other sections of the inventories of non-Annex I countries are based on the 1996 revised guidelines IPCC [10] where the Land-Use Change and Forestry section is methodologically limited [4].

In order to access results-based finance, results-based actions need to be subjected to full MRV [9]. Mitigation activities implemented by non-Annex I countries seeking international support would be subjected to international MRV [2]. During 2013 steps taken towards the implementation of REDD+ under UNFCCC included the discussions on the possible ways to pay for results-based actions and incentivize non-carbon co-benefits [13]; thus co-benefits would need to be quantified and monitored and appropriate baselines may need to be developed.

In REDD+ the aim is to develop a MRV system to evaluate results consistently with the NFMS and NGHGI to produce detailed data with high level of resolution and low levels of uncertainty based on IPCC guidelines. The step-wise implementation requires transiting from the use of data of Tiers 1 and 2 to Tier 3 for emissions factors and from general statistics on forest area (e.g., from FAO), to geographical and temporally explicit information with high levels of resolution and frequent updating for the representation of land. In practice a large effort will be required to produce detailed geographical information and data of the different carbon reservoirs and changes in stocks at local level. CBM offers an opportunity to advance in the step-wise monitoring process for REDD+ by including more measurements and carbon stocks, and also due to the fact that it can allow the mapping of the areas with different forest management practices (Management Units); this is essential to understand the effectiveness of activities implemented in REDD+.

3. Opportunities for CBM in REDD+

The decisions adopted by the COP have highlighted the pertinence of including CBM comprehensively as part of the MRV system of REDD+. However it is necessary to identify the specific opportunities and modalities for the inclusion of CBM into the MRV system for REDD+ considering different types of activities and policies that can be implemented. Figure 1 presents a schematic summary of the different steps for the implementation of REDD+ based on the rules and framework that are being built within the UNFCCC and the potential for including information generated through CBM into the NFMS.

In the international arena, REDD+ is based on the notion of results-based finance at country level. The assessment of results requires a strong and reliable NFMS that meets international standards as regards data requirements. The process described in Figure 1 starts from the NFMS, which is one of the first requirements for countries interested in REDD+ (1 in Figure 1). The NFMS, based on IPCC guidelines and consistent with NGHGI, is one of the inputs needed for the establishment of national baselines (REL/RL) (2), which will be based on historical trends of deforestation and degradation, but which may be adapted to take into consideration national circumstances. The REL/RL together with the understanding of the drivers of emissions, and barriers to adoption of sustainable practices, provide an important input for the design and preparation of REDD+ actions and policies (3). Once the activities are implemented (4) then results need to be subjected to MRV (5). Steps 3 to 5 represent roughly the phases for the implementation of REDD+ and might include different processes and activities within each of them. Depending on the evaluation of performance against the baselines it will be possible to evaluate whether or not there would be access to results-based finance; in which case the following step would be to identify mechanisms for benefit sharing (6). Each country should design its own schemes for internal sharing of the financial benefits that flow to the country as a result of its overall performance. The evaluation of performance is made by comparing the results against the reference levels (from 2 to 5); however results serve to update the baselines (from 5 to 2), to revise the REDD+ policies and strategies based on the observed effectiveness for the next period of implementation (from 5 to 3), and to update information in the NFMS (5 to 1). In all the stages safeguards need to be implemented (0); however, in order to keep the diagram simple, arrows are not included to link safeguards to the other stages. The process will be iterative during the transition from the preparedness and implementation stages until activities are fully implemented and subjected to full MRV. REDD+ will be the umbrella that brings together and consolidates different initiatives to manage forests sustainably; some of these are activities already in operation and others still need to be defined.

Figure 1. General Process for implementing REDD+ and opportunities for CBM; solid lines indicate the expected implementation process of REDD+; dotted lines refer to expected local benefits and options for community based monitoring (CBM).

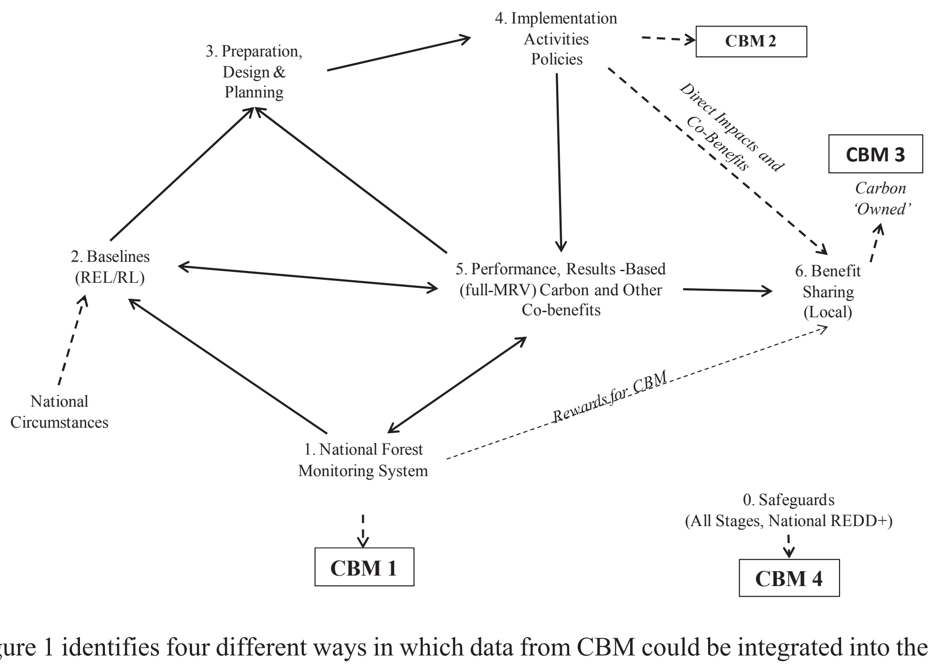

Figure 1 identifies four different ways in which data from CBM could be integrated into the MRV system: first, CBM can potentially provide information of carbon stocks and forest area to feed the NFMS which contributes in setting the REL/RL (CBM-1 in Figure 1); the second case refers to the information on activities which may be set up by communities primarily for non-carbon purposes (e.g., timber, water, biodiversity, farming improvements *etc.*), this information may not be expressed as carbon figures but could be used to derive these estimates (CBM-2); the third case is the information on changes in carbon stocks produced by independent carbon projects or by stakeholders participating in REDD+ activities promoted by national governments (CBM-3); and finally, CBM can provide feedback on the local implementation of safeguards (CBM-4). Table 1 presents a brief description of the potential challenges associated with these four CBM types that may contribute to national REDD+.

For CBM 1 it is clear that if the main purpose of carbon monitoring is solely to increase the sample size of the national forest inventory, communities would need to be compensated and paid accordingly (e.g., based on the time they invest in the monitoring); one feasible option is to include these practices as an obligatory activity within existing forest management public programs. For CBM 2, the burden of monitoring would be much less, but some incentive might have to be arranged to encourage reporting on these activities from the local level; not all communities may have capacities or the will to organize and commit to this kind of monitoring. The challenge would be first to create the appropriate levels of social capital to facilitate this process. For CBM 3, the monitoring of stock changes would be an integral part of the REDD+ activity on the ground, and the cost of monitoring would be considered a transaction costs to be covered by carbon markets or from a national benefit distribution system. It will be necessary to create the appropriate agreements for information and benefit sharing related to CBM 2 and 3 since the communities will own the information. For CBM 4 it is still not clear what type of activities could be done by communities to monitor the implementation of safeguards and hence it is not possible to assess the kinds of monitoring or costs involved. In all cases it is necessary to evaluate labor availability for CBM activities since agricultural practices have different demand for labor throughout the year.

Benefit Sharing

In Figure 1 it is shown that the implementation of REDD+ could produce at least three different flows of benefits to local communities in addition to climate change mitigation: compensation for collaboration for producing information for NFMS (e.g., wages for community forest inventory brigades) (CBM 1); benefits from the participation in carbon based market mechanisms (*i.e.*, carbon payments) (CBM 3); finally in CBM 4 benefits will relate to the possibility of maintaining presence and influence in the implementation process of REDD+ and possibly designing an agenda according to local interests. It will be at the third stage of implementation of REDD+ when the trade-offs between carbon and non-carbon benefits will be solidified [14], CBM can provide information in this context for benefit sharing. It is not clear what benefits communities might derive from sharing information produced through CBM 2 activities with the regional or national REDD+ programs; but given that such activities may have an impact on carbon stocks, the data they provide could form a basis for some non-performance related subsidy or incentive. These subsidies or incentives that could be part of the performance-based distribution of benefits will be additional to the strengthening of local capacities and direct benefits from the implementation of activities associated (e.g., timber, NTFP, water and other local environmental services).

Table 1. Description of general opportunities for CBM in REDD+ and main challenges.

Type	Description	Main Challenges
CBM 1	(1) Data gathered to increase sample size of national inventories usually made by professionals. (2) Information collected as part of other public programs.	(1) Methodological consistency across communities and quality assurance. (2) Training and capacity building. (3) Analysis and management of data with different geographical sampling intensity since not all communities will participate.
CBM 2	(1) Detailed information on activities implemented (for characterization of management units). (2) Information usually not expressed in terms of carbon (e.g., timber volume) but data could be used to estimate carbon stocks/changes.	(1) Very heterogeneous data generated depending on local context: activities implemented and co-benefits of interest. (2) Need to harmonize methodological approaches, including qualitative variables and proxies and need to integrate them into national MRV system. (3) There might not be information of all carbon reservoirs. (4) Communities own the information; it is necessary to explore potential integration onto national systems.
CBM 3	(1) Information produced as part of: - Participation in independent projects in the carbon markets - Certification schemes (e.g., FSC); or- Decentralized activities/programs promoting REDD+.	(1) Training/capacity building for advanced methods is required (e.g., Tier 3). (2) Some activities take place in non-forest lands (*i.e.*, afforestation/reforestation, pastureland management). (3) Need to harmonize methodologies from carbon markets and that from NFMS/MRV. (4) Challenge to harmonize baselines of project based approaches *versus* regional/national approach. (5) As in CBM 2 communities own the information, need to explore integration onto NFMS. (6) Risk of possible double counting, environmental integrity of estimates. (7) Implementation constrained by level of carbon prices; monitoring is a large part of transaction costs.
CBM 4	(1) Monitoring of safeguards; this will involve non-carbon variables.	(1) Still it is not clear how safeguards will be implemented in all stages of REDD+. (2) It is necessary to harmonize protocols and processes to monitor social and environmental (biodiversity) if they are to be integrated into the NFMS.

It is important to point out that CBM could be part of the activities to follow-up REDD+ implementation without necessarily being included formally in NFMS or NGHGI systems. However if local data is used to obtain carbon estimates this can help to define benefit sharing schemes in a more transparent way. In fact, a more transparent design and planning of REDD+ including participation of communities and other stakeholders might help to avoid conflict during implementation [15]. A common challenge in the four options identified will be the creation of the system within the NFMS to collect, analyze and share the information to be produced through CBM.

In REDD+ both determining the current level of carbon stocks and determining the prospects for further improvements are of interest. This second element is often neglected in discussions on monitoring and CBM. However, for communities, gaining a better understanding of what their opportunities could be under REDD+ is very important, *i.e.*, a kind of diagnostic process that would help them decide on a future management strategy. The following sections review the information required to characterize the different activities of REDD+ and how this could be generated via CBM.

4. CBM and the Different Elements within REDD+

4.1. Reduced Deforestation

In the context of the efforts to mitigate climate change from the Marrakesh Accords, forests are defined as those areas where the canopy of woody vegetation, capable to reach a height of at least 2–5 m at maturity, covers at least 10%–30% of a minimum area of 0.05 to 1 ha [16]; each country should define the appropriate parameters to define their forests. Deforestation is the process by which forest cover is completely and permanently removed beyond the threshold of the definition of forests, for other land uses/covers, typically cropland, grasslands for ranching, housing or the development of infrastructure due to direct human influence. The basic input to assess emissions from deforestation are the area where land-use changes take place and the difference in carbon stocks of the final and initial land uses.

An historical analysis of deforestation can be done to some extent by analyzing a series of satellite images and other remotely sensed data to get the trend in land use change; emission factors can be based initially on the information on carbon stocks from default data (Tier 1) or the national forest inventory (Tier 2). In general, deforestation can be monitored with considerable reliability based on remotely sensed data (contingent to the scale, resolution and frequency of the input data) (e.g., [17]); data on carbon stocks based on large inventories can also provide information with relatively low level of uncertainty. However this information cannot be applied to obtain estimates at local level for local forest management. Satellite imagery can be used to prepare an initial stratification of a study area [18], but it might not be able to identify local management practices and could have classification errors. CBM can help to overcome these issues.

CBM data is not available for earlier periods and therefore cannot be used directly to compare past deforestation rates with current ones. However, it can produce information that defines local management units to define the polygons changing land uses and the different activities undertaken by the community (e.g., forest stands, areas under cyclical timber management, or under shifting cultivation, the boundaries of which cannot be identified directly from remote sensing). Local inventories can also be used to update the data at a Tier 3 level or generate information of other carbon reservoirs if they have not been included in the NFMS (*i.e.*, soil, dead organic matter).

The variables of interest for carbon monitoring as regards deforestation are: forest area (distinguishing between different strata including management practices); estimated average carbon stock per hectare within each stratum; extent of area change (to non-forest) in each stratum between time 1 and time 2; and drivers. If possible it is important to describe the percentage of the area change that was the result of burning, as this allows the emissions of non-CO_2 GHG.

4.2. Reduced Degradation and Carbon Enhancements

Forest degradation and carbon enhancement refer to the changes in carbon stocks in areas of forest that remain as forest during a period of analysis. Forest degradation refers to the losses of carbon in areas that remain classified as forests under the definition of forest adopted by a country. Degradation is said to occur for instance if a forest with an initial canopy cover >90% is subjected to a process of logging which may reduce the canopy cover down to the lower threshold level (*i.e.*, 10% to 30%). It is important also to understand that carbon losses might occur not only in the arboreal stratum of the forest but also below the canopy, "invisible" to most remote sensing technology [19,20]. Degradation can also relate to the reduction in the rates of carbon uptake that in the long term would degrade the forest [19]. For instance, grazing might reduce the recruitment of new trees, thus after old trees die they would not be replaced by young ones.

The opposite of forest degradation is carbon enhancement. In this case, a forest that has been degraded in the past and is recovering, accumulating carbon and possibly even augmenting its canopy cover. Carbon enhancements could occur due to the natural growth of existing vegetation under an improved management regime, also by the natural and induced recruitment of young trees and other plants, and through the deposition of dead organic matter and assimilation into soils. Activities to promote carbon enhancement can include tree planting to restore the forest, soil restoration activities that might favor the establishment of vegetation and the control of activities degrading the forest (*i.e.*, cattle exclusion, limits on extraction of firewood and poles, forest fires, *etc.*).

Under improved forest management it is quite possible that degradation is brought to a halt and that after some time, net growth and enhancements are measured on the ground [19]. In this scenario it can be assumed that carbon gains include those from the enhancements measured plus the reduced degradation in comparison with a baseline (e.g., [21]). It would be necessary to ensure that any activities previously degrading stocks in the area have not been displaced elsewhere (*i.e.*, monitoring leakage).

The information required to monitor reduced degradation and enhancements refers to the rates of change in the loss and accumulation/assimilation of carbon per forest stratum and the management units where these take place (*i.e.*, processes listed in Table 2). Activities to control degradation and or facilitate enhancements could target a specific reservoir, they can be monitored when the activity is started (per event) and then on a periodical basis (e.g., yearly or even monthly once comprehensive protocols are in place to monitor variables such as survival in plantations, operability of protective fences, number of cattle, amount of timber/fuel-wood extracted per community/household, *etc.*). Usually rates of changes are obtained when carbon inventories are made periodically (*i.e.*, Stock Difference Method, IPCC 2003). However Gain-and-Loss methods can also been used to monitor specific degradation/enhancement processes and management activities. These methods rely on estimated off-take and regrowth rates. When Gain-and-Loss methods are used, periodical standard inventories can be put in place to "verify" the impact of the management activities on the forest by considering the initial and final levels of carbon.

Table 2. Processes and activities associated to carbon reductions and increments for different reservoirs.

Reservoir	Losses/Reductions	Gains/Increments
Trees	Timber Harvesting, Illegal Logging, Fuel-wood Collection, Grazing, Mortality and Disturbances (Pests, Fires, Meteorological).	Growth in standing trees, Natural recruitment of trees, Tree Planting, Forest Management Practices (Growth after Thinning, Cattle Exclusion, Fertilization/Watering); Carbon in Durable Wood Products
Shrubs	Harvests and Fuel-wood Collection, Grazing, Mortality, Disturbances, Harvest	Cattle Exclusion, Planting, Natural Growth, Natural Recruitment
Herbs	Grazing, Harvest (e.g., Fodder), Disturbances, Mortality, Erosion.	Cattle Exclusion, Soil Conservation, Planting, Natural Growth, Recruitment
Soil	Erosion, Soil Extraction, Fire, Cattle	Soil Conservation (Barriers-Thinning-Disturbances, Terraces, Dams), Assimilation (from deadwood, litter)
Deadwood	Fuel-wood Collection, Fire, Assimilation Rate (into soil), Erosion	Disturbances, Thinning, Mortality, Deposition Rate. Reduced Extraction (below mortality/ deposition rates)
Litter	Erosion, Fire, Assimilation Rate (into soil)	Disturbances, Thinning, deposition rate
Fire Occurrence	Factors that Increase Occurrence: Deadwood, dry herbs/shrubs; drought, wind, human presence, agricultural practices, roads, rubbish, limited access.	Factors that Reduce Occurrence/ Severity: Brigade and vigilance, firebreaks, black lines, prescribed fires, improved access, fast access for brigades.

CBM can produce information on the underlying strata within the forest as well as the geographical boundaries where activities to control degradation and enhance stocks take place, and on the changes in carbon stocks. In this case it could be possible to include in the CBM a number of metrics which would be additional to standard forest inventories, such as registries on resource use, description of changes in management activities (e.g., improved management) and inputs for or success of, new management practices (e.g., soil conservation, restoration through tree planting, *etc.*); this will depend upon the activities selected for implementation and the local arrangements agreed.

4.3. Sustainable Management of Forests and of Other Lands

Experiences have proven that participatory community forest management is a useful approach to improve forest management [22,23]. In the Marrakech Accords Forest Management was defined as "*practices for stewardship and use of forest land aimed at fulfilling relevant ecological (including biological diversity), economic and social functions of the forest in a sustainable manner*", referring to both natural forests and plantations (Marrakesh Accords, Forest Management, [16]). An equivalent or operative definition of sustainable management of forests (SMF) has not been adopted in the context of REDD+ at the UNFCCC. Forest management practices can refer to practical specific activities on the ground at stand level (e.g., thinning, tree-planting, fertilization, harvests, *etc.*), as well as to activities carried out at a regional level (e.g., fire prevention/combating system) [4]. Activities included as part of forest management will periodically modify carbon stocks and the gain and loss rates, and should be monitored and accounted as reduction of degradation and enhancement of stocks. Hence the comments made at the end of the previous section would apply equally to SMF. IPCC [12] provides specific guidance to account for carbon stored in durable harvested wood products, which can be identified as additional benefits of SMF.

In terms of the information needed for monitoring the performance of SMF and mitigation actions in other land uses IPCC [4] provides specific guidance for projects. The information to be gathered as part of a monitoring system includes the geographical boundaries of the areas under different management, the description of the management practices, statistics on the inputs and outputs from forest management (e.g., fertilizer, number of plants, survival; harvests, thinning, accumulation in dead organic matter and soil), information from growth models, and information from forest inventories. The value of CBM to the community in terms of providing diagnostics for sustainable management of forests is that SMF is one of the possible strategies that the community might use to tackle degradation or to encourage enhancement of stocks.

4.4. Conservation of Forest Carbon Stocks

The UNFCCC have not clearly defined what is implied by "conservation of forests carbon stocks" in the context of REDD+, and neither have they suggested how it could be rewarded in terms of performance; it is the only REDD+ activity that does not involve change in total carbon stock, and it cannot be rewarded on a per ton basis. Several situations could arise in which forests might be said to be "conserved". For example, if a neutral balance in carbon stocks is the product of direct human activity including intensive market-oriented timber extraction, this might be characterized as SMF (*i.e.*, when harvests equal growth) rather than as conservation. When the balance in carbon is the result of the "natural" rates of growth and mortality/decay through the use of total exclusion of activities, or possibly through "soft" management activities (e.g., an area devoted to conservation, scientific activity or ecotourism), then it is clearer that the REDD+ activity could be conservation. This division would enable the identification of different policies and incentives to achieve the different objectives. For instance, SMF could be promoted by providing capacity building for planning and certifying forest management practices, by providing appropriate financing options to buy the required equipment and develop markets for products made with certified timber. On the other hand, incentives for "carbon conservation" activities could be embedded with programs for the management of protected areas, and programs supporting the provision of other environmental services (e.g., water, biodiversity), for instance via programs of Payment for Environmental Services (PES).

Communities themselves could use CBM as a tool for analyzing the processes currently on-going in their forests to determine whether strict conservation is a viable and useful option for all or parts of their forests. CBM can also be used to provide information over management areas and carbon stocks as described in the previous sections.

4.5. Construction of Baselines

A critical difference between individual projects developed for carbon markets, and a national REDD+ program, is how the baselines are set. In markets, individual projects measure performance against a baseline that covers the territory of the project itself and usually a buffer zone around it. In REDD+, performance needs to be assessed at the national level (by the third stage of implementation). However, the activities contributing to this at the sub-national level will have to be assessed against corresponding baselines too. One option is to create nested baselines in REDD+ and aggregate them from the local to regional and national levels [24]. The national REL/RL describes the expected emissions based on national historical trends and national development expectations (expressed as development adjustment factors, DAFs). To some extent, the construction of local baselines could mirror this process. It is highly unlikely that each and every community or forest owner will be required to develop an individual baseline, given the costs and the difficulties involved in this [25]; however an approach including local data can be used to develop baselines for specific management units. Rather there are likely to be regional or provincial level baselines and possibly sub-provincial baselines. Local communities through CBM could contribute to the construction of this lowest level of baselines by providing historical information on land management and drivers, expectations and future developmental needs. Local land-use management plans at community and municipality level could also be used as sources of information; projects supported by international NGOs in the Biosphere Reserve of El Triunfo in Chiapas are developing local land use plans to analyze alternative development scenarios including the carbon dimension [26]. The analysis of alternative development scenarios can be developed in a participatory fashion to set the reference levels and also to determine local opportunity costs of REDD+ (e.g., [27]).

4.6. Understanding Drivers

In order to design adequate strategies it is necessary to understand the drivers of emissions and barriers for favoring carbon enhancements, conservation of carbon stocks and SMF. A large amount of information on the implementation of REDD+, including information related to drivers of emissions and non-carbon impacts of these activities, can be gathered by local actors through CBM. Monitoring schemes could be prepared for specific management practices and policies adapted for different contexts.

4.7. Safeguards

Social and environmental safeguards were included in REDD+ to ensure that this program will not harm the interest of local communities and developing countries and will have no negative effects on biodiversity and other environmental services. As included in the Cancun Agreements, social safeguards indicate REDD+ needs to be consistent with national forest plans and other related international conventions; governance schemes should be transparent, effective, participatory and respect the rights of local and indigenous communities. This might imply the recognition of customary rules (e.g., [28]). For the environmental safeguards, a major concern is the potential conversion of natural forests to plantations with the associated loss of biodiversity; conversely

REDD+ should promote the conservation and protection of natural forests and reduce reversals and leakage [8].

Information that can be produced locally for the implementation of safeguards includes the documentation of the processes for the design of REDD+ programs and specific plans for activities to be implemented in the field. In this context, CBM schemes where actions are driven by local interests and have a larger share of local participation will produce this information in a more transparent way [7]. The monitoring of social safeguards will follow different processes from those to monitor carbon stocks, stock changes and forest areas. The later system will focus on monitoring the results of implementation whereas that for social safeguards will focus on ensuring initially that REDD+ and its governance schemes are designed properly. Once REDD+ enters into operative stages it will be necessary to continue monitoring the way in which activities are implemented. For environmental safeguards, it will be important to show that relevant criteria have been included in the design of implementation strategies to protect natural forests. For the implementation stage, considerations of leakage and permanence can be included accordingly into the procedures for data analysis.

Table 3. Key information that can be produced for different REDD+ activities and elements through CBM.

REDD+ Activity/Element	Key Information that can be Produced through CBM
Reduced Deforestation	Forest area and management units; carbon stocks; changes in forest area with high geographical scale and frequency.
Reduced Degradation and Carbon Enhancements	Information of management units; registries for activities implemented for use of gain and loss methods (e.g., harvest, fuel collected, plantings reforestation); rates of change of degradation/enhancement (tCO_2e/ha-yr).
Sustainable Management of Forests	Information of management units; description of practices; information of inputs/outputs of SMF practices; carbon estimates based on information of growth models and local forest inventories
Conservation of Forest Carbon Stocks	Information of management units; information from other conservation programs (e.g., PES, ecotourism, including *ad hoc* forest inventories).
Construction of Baselines	Local land use plans including carbon inventories and local development needs can be used to set local reference levels in a nested system.
Information of Drivers	Historical information on land use and drivers of changes; local information of barriers for implementation of sustainable practices.
Safeguards	Documentation of implementation process of social safeguards; information of non-carbon impacts of REDD+ activities.

Table 3 presents a summary of the information that can be gathered through CBM. There is an extensive body of literature documenting cases of communities producing geographical data through participatory approaches, including climate change mitigation efforts (e.g., [29,30]). It is possible for communities to gather information to characterize management practices and carbon stocks and stock changes. It is important that national systems (NFMS/MRV) are able to integrate this information;

in fact it is expected that by simulating local participation communities might participate more effectively into REDD+ implementation [31]. The geographical information could be reported by the communities to the national systems if for instance countries create an Activity Reporting System as described in the IPCC guidelines [4]; this can help in integrating local data into the stratification system for the representation of lands. The next section presents potential options to integrate data on carbon stocks and stock changes into national systems.

5. Dovetailing Data from CBM into MRV Systems

This section presents potential options for the integration of local data into national NFMS. National forest inventories can provide information on the level of carbon stocks and after successive measurements have been taken they would also provide data on the average growth rate of standing trees, mortality and recruitment as observed in the plots. This data is useful to estimate emissions from deforestation once the changes in forest area are assessed via remote sensing. Moreover, since the inventories also collect information on local conditions e.g., on observed degradation and causes of this, the changes in stock may be related to drivers of deforestation and degradation in a generalized sense over large areas. However, given the sampling scale of the national inventory (e.g., one site per 5 km, working at scales of 1:250,000 as in the case of Mexico (e.g., [32]), it will not be possible to pick up changes in carbon stocks in forests at the management unit and parcel levels. For accurate assessment of changes in carbon stocks at the level of the management unit or parcel, there is no real alternative to local generation of data; CBM is one approach that would appear particularly useful in this context.

As mentioned above, the information that can be produced locally through CBM includes the delimitation of polygons of forest under different management, the description of such practices and the changes observed in carbon reservoirs at *ad hoc* frequencies. This information can contribute substantially to the assessment of emissions and removals; this local MRV could provide data for integration in the NFMS. Figure 2 shows different options to combine local and national level information.

The upper part in Figure 2 presents a hypothetical case of a forested area (Region A) in a country. Suppose that in the NFMS region A is classified as a coniferous forest and the inventory grid includes 16 plots. Since there are no more details on the management practices the carbon stock change factor for region A, presented in the lower part of Figure 2 is given by the results of the national inventory (Tier 2 data) (Scenario I). It is important to recall that the carbon estimate of A is obtained considering the information from all the inventory plots from the same strata in the country (coniferous forest), not only using the 16 plots within polygon A.

If communities in the region perform different management practices in polygons B and C, (e.g., sustainable forest management and forest restoration) they can map these using CBM (e.g., through participatory mapping). Local particularities and the effect of local management in B and C are not captured by the NFMS system since the NFMS does not recognize B and C as different management units. It would be necessary to increase the scale at which information is managed to allow the inclusion of smaller polygons corresponding to local management units.

Figure 2. Options to integrate local data produced through CBM with NFMS in REDD+.

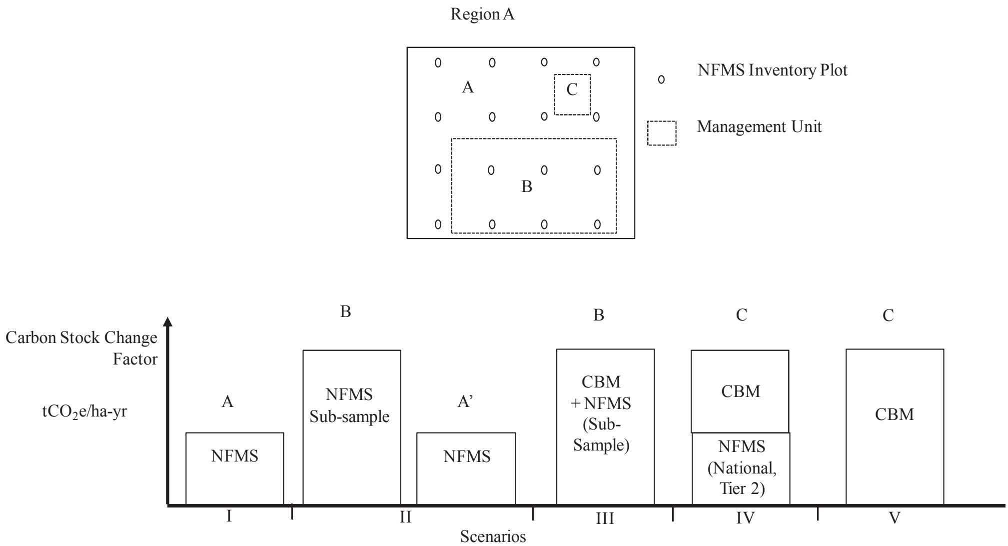

Figure 2 shows there would be at least four possible ways in which CBM could feed information to national systems in REDD+ to generate carbon estimates. The first option depicted in scenario II shows the case when there are measurement plots of the NFMS within B (6 in this case). If this sub-sample is large enough, it could be possible to compare information of B to that of A' (*i.e.*, original data in A once the information in B has been removed and treated independently); if statistical differences are detected, then B can be identified as a new stratum within the NFMS. An initial option to consider this approach is to include the geographical information of existing forest management programs (polygons) into the NFMS and check if independent new strata can be identified based on management practices (e.g., PES, Reforestation, Community Forestry, Forest Management Plans, Carbon Markets).

Scenario III in Figure 2 refers to a situation when the information from the NFMS in the polygon B is not sufficient to produce prove of statistical difference in the mean values in B and A'. CBM can be used to increase the sample size within B and to include information of other carbon reservoirs not included in the original sample. The information of the six sites of the NFMS in B can show the local variance and can be used to define the size required of the local inventory. In order to combine data from NFMS and CBM it is necessary to verify comparability of the information (*i.e.*, methodological and temporal consistency); estimates would produce Tier 3 data valid for B. As in the previous scenario it would be necessary to "remove" the subsample of the inventory plots from the original data for A.

Scenario IV shows the case when there are no NFMS plots within the management area C and practices to be implemented will affect specific carbon reservoirs. Carbon estimates for area C can use Tier 2 data from NFMS for carbon stocks not affected by local management. The information can be complemented through CBM for the reservoirs/activity of interest which will generate Tier 3 data; the Tier 2–3 results would be valid only for area C. Alternatively a complete local forest inventory could be implemented in C to produce Tier 3 data for all the carbon reservoirs (Scenario V), hence neglecting the use of previously developed Tier 2 data at national level (e.g., to participate in carbon markets or when various reservoirs will be affected).

It is important to point out that when additional data of new carbon reservoirs or processes is integrated into the NFMS an initial effect could be an increase in the level of estimated emissions; in order to produce consistent estimates of performance, the baselines should be recalculated accordingly.

When the geographic information from a locally managed forest unit is integrated into national systems, the corresponding "original" polygon in the NFMS should be partitioned. Then new carbon data could be associated to the area under specific management (carbon stocks, carbon stock change factors and associated uncertainties). Each forest polygon in each stratum would have an associated carbon stock/stock change factor, which could be disaggregated for each carbon reservoir (*i.e.*, biomass, soil, DOM, non-CO_2e GHG; the information would include the mean value and the associated uncertainty). If CBM is included into MRV then these individual pieces of information for each carbon reservoir and associated uncertainties could be integrated and updated in a participatory mode for each polygon; CBM can replace Tier 1 or Tier 2 values by local data and also complement information for specific reservoirs when these were not included originally. When the information of the "new" polygon is added, the national inventory and associated uncertainties could be re-estimated. It will be necessary to review the technical requirements to make the data compatible in terms of geographical and temporal scales and to consider adequate methods to analyze the propagation of uncertainties.

6. Conclusions

It is essential to include CBM in MRV and NFMS in REDD+ to comply with the decisions adopted under the UNFCCC and favor the transit to systems with data of higher levels of detail (Tier 3 and high geographical scale). Given this, it is critical to define and enable options for integrating local information into national monitoring systems. This article has highlighted the potential contribution of CBM for producing information on carbon stocks and stock changes and for mapping geographical data for different REDD+ activities.

There are opportunities for integrating different sources of local information into MRV systems; this information can help in the step-wise implementation of the NFMS. Information sources include data produced by communities as part of their management practices motivated by the access to local benefits and environmental services (CBM 2) and information produced for REDD+ projects associated both with carbon markets and with national programs (CBM 3); additionally governments can include specific features in the monitoring of existing public forest management programs to produce information for NFMS or even design schemes based on CBM to increase the sampling intensity of existing inventories (CBM 1). Finally there will be a flow of information that will be generated as part of the implementation of social and environmental safeguards (CBM 4).

In order to create CBM schemes on a national or regional scale an initial investment is needed to build appropriate capacities and to provide the basic operative infrastructure. It is necessary to define the strategies necessary to work on the different possible CBM approaches; if systems need to make use of public programs or to hire local brigades as part of NFMS, appropriate budgets will be required for this (CBM 1). If activities driven by local interests are to be promoted (CBM 2), it is necessary to ensure methodological consistency and that the management activities will not compromise carbon performance of the program; for this, there are alternatives such as providing input-based incentives to activities that prove to have non-negative carbon effects. It will be necessary also to create appropriate linkages with projects participating in carbon markets and other certification schemes that could provide useful information to NFMS/MRV (CBM 3); this will help to define the systems for sharing of benefits while maintaining the environmental integrity.

Participatory options can be created via an *ad hoc* Activity Reporting System that could allow completing or replacing the information of carbon emissions/removals for specific management units. The Activity Reporting System could make use of information generated already available as part of local land use plans, and other programs (e.g., PES, NPAs, community forestry, forest management plans, *etc.*). New technologies are being used to create flexible and innovative systems to monitor natural resources. It will be necessary to create options to make the best use of these tools and include them into basic systems for the representation of lands and the system to generate carbon stock change factors as part of REDD+.

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Conflicts of Interest

The author declares no conflict of interest.

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Combining Satellite Data and Community-Based Observations for Forest Monitoring

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Abstract: Within the Reducing Emissions from Deforestation and Degradation (REDD+) framework, the involvement of local communities in national forest monitoring activities has the potential to enhance monitoring efficiency at lower costs while simultaneously promoting transparency and better forest management. We assessed the consistency of forest monitoring data (mostly activity data related to forest change) collected by local experts in the UNESCO Kafa Biosphere Reserve, Ethiopia. Professional ground measurements and high resolution satellite images were used as validation data to assess over 700 forest change observations collected by the local experts. Furthermore, we examined the complementary use of local datasets and remote sensing by assessing spatial, temporal and thematic data quality factors. Based on this complementarity, we propose a framework to integrate local expert monitoring data with satellite-based monitoring data into a National Forest Monitoring System (NFMS) in support of REDD+ Measuring, Reporting and Verifying (MRV) and near real-time forest change monitoring.

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1. Introduction

Forests cover approximately 30% of the Earth's land surface [1] and are of immense value to humankind, as they provide habitats for a wide variety of species and play an important role in the global carbon cycle. However, a loss of approximately 2101 square kilometers of tropical forests per year [1] has made a significant contribution to the increase of greenhouse gases (GHGs) in the atmosphere, resulting in accelerated global warming [2,3]. To mitigate this effect, the United Nations Framework Convention on Climate Change (UNFCCC) has proposed an international mechanism called Reducing Emissions from Deforestation and Degradation (REDD+) in developing countries [3,4]. The REDD+ mechanism includes reducing deforestation and forest degradation, forest enhancement, sustainable forest management and conservation [5]. Recently, the 19th Conference of Parties (COP) of the UNFCCC in Warsaw, November, 2013, agreed on a collection of seven decisions on REDD+ [6]. Together with the REDD+ decisions adopted at previous COPs, these decisions provide international policy guidance (the Rulebook on REDD+) on how countries should deal with REDD+ in the framework of the UNFCCC [6]. Besides reduction of carbon emissions, the REDD+ mechanism also includes establishment of national institutions, ensuring co-benefits and safeguards and, above all, creating performance-based financing mechanisms [2,7,8].

A country participating in REDD+ requires a reliable, transparent and credible national-level forest monitoring system (NFMS) for Measuring, Reporting and Verifying (MRV) activity data and emission factors [8–10]. Activity data is defined as the magnitude of human activity resulting in emissions or removals. In the case of forest-related emissions and removals, activity data refers to forest area change (generally measured in hectares), whereas the emission factor is related to the rate of emission of a given GHG from a given source, relative to units of activity (generally measured in tons of carbon per hectare) [2]. Given that forest change is a dynamic process, monitoring needs to be carried out on a regular basis to support national MRV requirements. Establishing such monitoring systems is presumed to be expensive for developing countries [8,11–13]. An activity monitoring system should be based on four broad monitoring objectives related to the location, area, time and drivers of forest change. These objectives should be properly integrated with monitoring and MRV systems at the national level. Current schemes for monitoring these activities are based on remote sensing and field measurements mainly from national forest inventories.

Remote sensing has proven to be very useful for deforestation monitoring at the global, national and subnational scale [1,14–16]. However, remote sensing based monitoring of forest degradation and regrowth still remains problematic [17–19], due to cloud cover, seasonality and the limited spatial and temporal resolution of remote sensing observations. Enhancing the interpretation of remote sensing analyses requires substantial ground verification and validation [20]. Accomplishing these tasks through national forest inventory data is expensive, time-consuming and difficult to implement across large spatial scales [21,22].

Community-based monitoring (CBM) is an emerging alternative method for forest change monitoring that promises to be cheaper than conventional monitoring methods [7,23–25]. CBM methodologies can be organized into two main categories: (i) forest carbon stock measurements for emission factors; and (ii) forest change monitoring for activity data. Results from well-designed forest carbon measurement studies [26–29] have demonstrated that local datasets are comparable to professional measurements, while being cheaper to obtain. Furthermore, CBM can be considered as a tool to empower the local communities and raise awareness towards better forest management [30,31].

While CBM-based forest carbon stock measurement has been shown to be feasible [26,27], monitoring of forest change through CBM has not been thoroughly investigated yet. Forest change monitoring is a continuous process, which requires continuous data acquisition, and local communities may act as active *in situ* sensors [32]. Their local knowledge could be especially valuable in signaling forest change activities (deforestation, forest degradation or reforestation) and providing valuable information, such as location, time, size, type and proximate drivers of the change events on a near real-time basis [24]. The impacts of these activities are rarely captured comprehensively in national forest inventories or from remote sensing [7,8,25]. The recent development of hand-held technologies continues to improve and has significantly enhanced the local capacity in data collection procedures [29]. Data acquired by communities can therefore play an essential role in enhancing the efficiency and lowering the cost of monitoring activities, while simultaneously promoting transparency and better management of forests. Thus, local participation within monitoring programs holds promise for national REDD+ MRV implementation.

Despite the potentials of CBM, the main challenge of using locally collected data lies in the lack of confidence in data collection procedures [30]. The accuracy and reliability of such datasets are often questionable due to inconsistencies arising from the fact that local participants collect data independently of each other. This can further result in incomplete data collection and a biased representation of changes in a study area [33]. Therefore, data credibility and trustworthiness are major obstacles to the integration of CBM data in NFMS [34,35]. This fact has triggered us to rectify the current shortcomings and expand the current state of knowledge in community-based forest monitoring and its utility in NFMS. Specifically, we aim to check the consistency of local datasets and investigate their complementary use to remote sensing.

The purpose of this research is to discover new perspectives and insights into community-based observations. The aims of this paper are to: (i) present the details of a local expert-based forest monitoring system; (ii) assess the spatial, temporal and thematic accuracy of local expert data against independent field-based measurements and high resolution SPOT and RapidEye satellite imagery; and (iii) explore the complementarity of local expert data with remote sensing data. While the UNESCO Kafa Biosphere Reserve in Southwestern Ethiopia is shown here as a case study, the concepts presented in this study are applicable to a broader geographic scope and can be scaled up to the national level in support of NFMS and REDD+ MRV.

2. Materials and Methods

2.1. Study Area Description

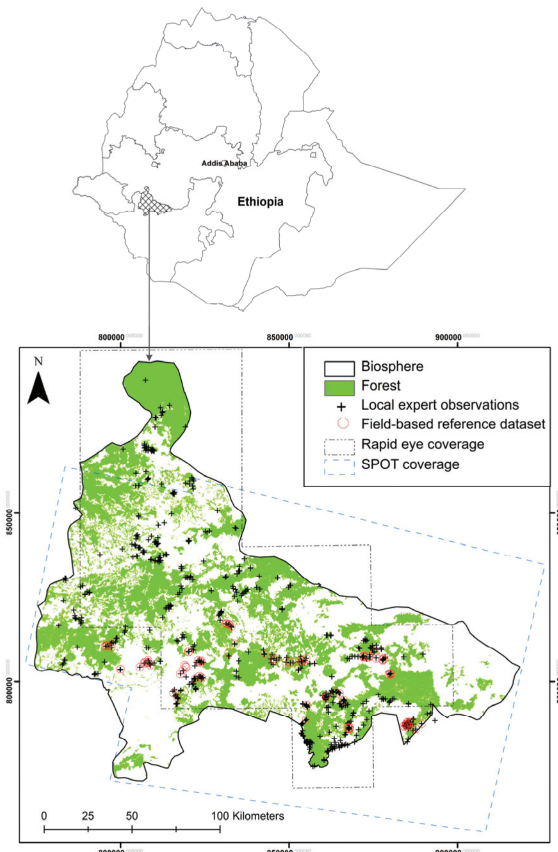
The study area is situated in the Kafa Zone, Southern Nations Nationalities and People's Region (SNNPR), in Southwestern Ethiopia (Figure 1). The Kafa Zone is over 700,000 ha in size and was recognized as a Biosphere Reserve by UNESCO's Man and the Biosphere (MaB) program in March, 2011. This region is characterized by Afromontane cloud forest, with approximately 50% of the land cover still forested. Average annual precipitation in the area is approximately 1700 mm, and average annual air temperature is approximately 19 °C [36]. The topography of the Kafa Biosphere consists of mountains and undulating hills, with elevations ranging between 400 to 3100 m. The forest ecosystem provides an important contribution to the livelihoods of the people in the area, including wild coffee, valuable spices and honey from wild bees. It also represents a significant store of forest carbon as above-ground biomass.

2.2. Description of the Forest Monitoring System in the Kafa Biosphere Reserve

According to REDD+ monitoring and implementation guidelines, it is important to involve local community groups and indigenous societies to carry out forest monitoring, in particular if there is any prospect of payment and credits for environmental services [6,31,37]. A variety of practical experiences from developing countries, such as Nepal, Tanzania, Cameroon, India, Mexico, Indonesia, China, Laos, Cambodia and Vietnam, have demonstrated that local communities can play an essential role in forest monitoring and management programs [7,26–29,38]. However, most of these experiences are limited to carbon stock measurements in support of REDD+ MRV, with few prescribed field methods for establishing activity monitoring (forest change) on the ground [24,29].

In this study, we present a ground-based system to monitor activity data because of their increasing importance in the context of REDD+. The following setup was designed to contribute an efficient and continuous forest monitoring system for the Kafa Biosphere Reserve.

Figure 1. Study area in the UNESCO Kafa Biosphere Reserve, Southwestern Ethiopia; local expert observations (black crosses) were compared with a field-based reference dataset (red circles) and high resolution remote sensing data from the SPOT (footprint shown as a blue dotted line) and RapidEye (footprint shown as a black dotted line) sensors.



Selection of local experts: Selection and recruitment of local experts acts as the backbone for a forest monitoring system, as the success of these CBM systems largely depends on the knowledge, commitment, feeling of ownership and competencies of these individuals [39]. The selection process featured in this study is based on a scheme of collaborative design of monitoring with external interpretation of the data, one of five schemes of local involvement in monitoring proposed by Danielson *et al.* [40]. A total of 30 local experts were recruited within the frame of the project called "Climate Protection and Primary Forest Preservation—A Management Model using the Wild Coffee Forests in Ethiopia as an Example" under the Nature and Biodiversity Conservation Union (NABU).

The recruitment was done through the Kafa Zone Bureau of Agriculture and Rural Development (BoARD). The selection was done in such a way that it represents on average three experts from each of the 10 woredas (administrative units in Ethiopia). All chosen local experts had at least a secondary level of education and some fundamental understanding of forest management. This selection procedure was seen as a step towards greater community involvement in monitoring activities with the representatives involved from all woredas, assuring the potential for significant enhancement of the monitoring capacity of the project. Apart from monitoring, these experts also bear responsibilities for other project activities, such as the development of ecotourism, reforestation, community plantations, the distribution of energy saving stoves and awareness raising for the sustainable use of forest resources (e.g., honey and wild coffee).

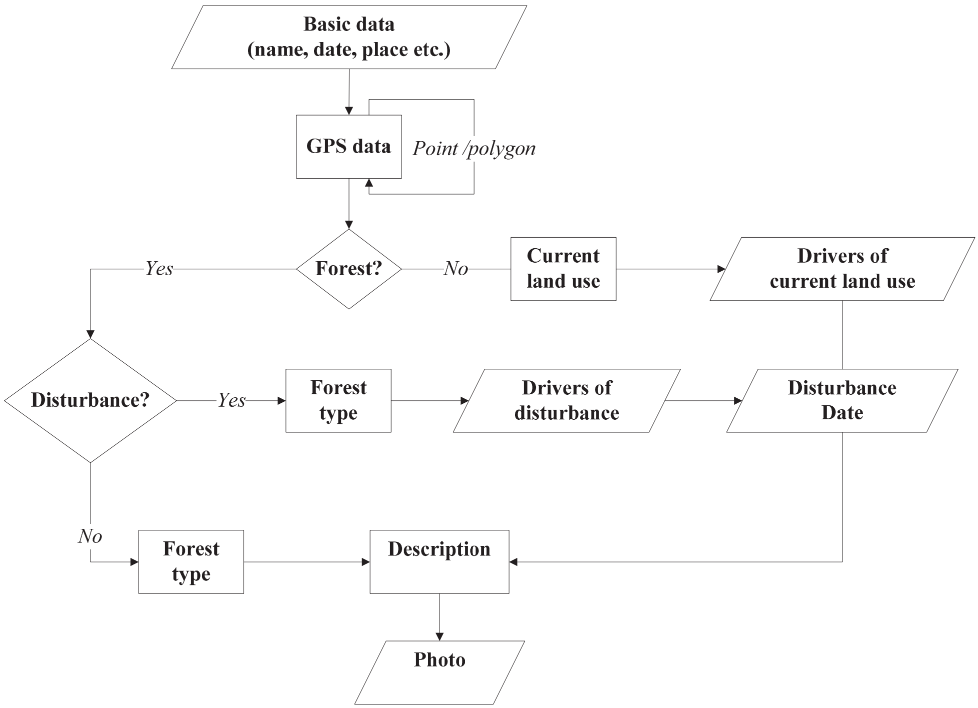
Data acquisition: Two methods of data acquisition were implemented and tested in this study. In the first method, paper-based forest disturbance forms with GPS devices were used by local experts to acquire forest monitoring data. The data collection forms were designed primarily with project monitoring objectives in mind, but also were compliant with REDD+ MRV requirements. This form focused on capturing forest changes, including small-scale forest degradation, deforestation and reforestation. In the second method, mobile devices with integrated GPS and camera functionality were used to increase the ease and simplicity in collection, entering and managing locally acquired data. For this purpose, a decision-based data collection form (Figure 2) was designed in XML and was deployed on mobile devices using the Open Data Kit (ODK) Collect application [41]. This form contains optional input constraints, flows that depend on previous input, icon-based user-friendly graphics and local language support. Mobile devices stored the data asynchronously and transferred data to data servers over GPRS, Wi-Fi or USB, as connectivity was available. An online database management system based on ODK Aggregate, postgreSQL and PhP was designed for the proper storage, analysis and visualization of the acquired data. Further details of the adopted proposed data acquisition method can be found in Pratihast *et al.* [29]. A paper-based data acquisition system was used in 2012, whereas mobile devices were used to collect the data in 2013. Even though the tools used to acquire data were different, the overall form of the design was consistent, with a few key differences in terms of multimedia features.

Training and capacity building program: user friendly training materials were produced for the developed technology and data collection methodology. A series of training events was conducted before and during the implementation of the monitoring activities. The main purpose of training was to enhance the capacity of local experts and to develop approaches and strategies for program implementation.

2.3. Reference Datasets

Local experts are capable of reporting forest change process at a high temporal frequency. Finding suitable reference data that can thoroughly assess the spatial, temporal and thematic accuracy of these data is difficult, however. In this study, two types of accurate reference datasets were acquired to evaluate the accuracy of these local expert data: field-based reference dataset (FRD) and remote sensing (RS).

Figure 2. Decision-based data acquisition form for local experts; the questions that are posed in the forms depend on answers given to preceding questions; such a design ensures that the questions are relevant to the land cover change being described.



Field-based reference dataset (FRD): we conducted a field visit in order to validate the ground data collected by local experts. Due to cost constraints, it was not possible to visit all locations reported by local experts. We selected six accessible woredas owing to practical considerations. These woredas contain more than 65% of the local expert data. Within these woredas, 140 locations (Figure 1) were randomly selected and were revisited during November–December, 2013, by a team of professionals. The decision-based data acquisition form on the mobile devices (Figure 2) was used by the team of professionals to measure location, size, time, drivers and photographs of change events.

Remote sensing (RS): a time series of high resolution remote sensing images acquired between 2005 and 2013 (including pan-sharpened SPOT and RapidEye images) were available for the analysis of reference data (Table 1) in the study area (Figure 1, Appendix Table A1). The SPOT 4 and SPOT 5 imagery have a ground resolution of 10 m and 2.5 m, respectively, whereas RapidEye has a ground resolution of 6.5 m. Locally-reported forest monitoring locations were visually interpreted based on an approach described by Pohl and Van Genderen [42]. Following this approach, images were systematically examined and pixels representing forest change areas were manually digitized as polygons. The forest change areas were estimated by calculating the polygon area.

Table 1. Summary of the SPOT and RapidEye scenes used in this study.

Sensor	Ground resolution	Year of acquisition	Number of scenes
SPOT 4	10 m	2005–2006	6
SPOT 5	2.5 m (Pan sharpened image)	2007–2011	8
RapidEye	6.5 m	2012–2013	27

2.4. Accuracy Assessment

Several metrics have been proposed by researchers to describe the quality of geographic data [43–45]. However, no specific list of elements with a consistent definition has yet been agreed upon. The latest attempt to standardize data quality elements is ISO 19113 in 2002 [46], which proposes the following five elements: completeness, logical consistency, positional accuracy, temporal accuracy and thematic accuracy. In this study, we limited the quality assessment to three of these major categories, namely spatial, temporal and thematic accuracy, since these are essential aspects of forest monitoring datasets [8]. The details of the accuracy measures employed in this study are listed in Table 2.

Table 2. Specific approaches used to assess the spatial, temporal and thematic accuracy of local expert data.

Category	Measured variable local expert data	Reference data	Measures of accuracy
Spatial Accuracy	Location variables (Qualitative) GPS accuracy Size of forest change	Field based	Confidence interval (95%)
Temporal Accuracy	Time of change	Remote sensing	Time lag
Thematic Accuracy	Presence of forest Forest change type Driver of forest change	Field based	Error matrix

2.4.1. Spatial Accuracy

In this study, three aspects of the spatial accuracy of the local experts' data were assessed, including categorical location information, GPS location information and the estimated size of forest change. The categorical location information included categories for representing the administrative units, like woreda, kebele (administrative sub-unit of a woreda) and a spatial category representing distance to core forest, nearest village and roads (*i.e.*, less than 1 km, 1–2 km, 2–3 km and more than 3 km). To estimate the accuracy of these responses, comparisons were made between the local expert data and the FRD. From this sample, the fraction of correct observations in the total population of local expert reports was estimated using the hypergeometric distribution [47], a discrete probability distribution that describes the probability of obtaining a correct response from a finite population size without replacement. The 95% confidence interval was calculated by using the 0.025 and 0.975 quantiles of this distribution.

In addition to the categorical location descriptors, local experts provided GPS readings for each report. Each reading was associated with a measurement error reported by the GPS receiver. The GPS measurement errors in the local expert dataset were compared with measurement errors in the FRD using a *t*-distribution [47]. Using this distribution, the mean bias (with 95% confidence interval) and the standard deviation between the local expert and FRD GPS errors were calculated.

Finally, the size of forest change polygons mapped by local experts were compared with change polygons digitized from visually interpreted high resolution SPOT and orthorectified RapidEye time series imagery. Forty deforestation polygons falling within the spatial extent of the SPOT and RapidEye time series were selected. The relationship between the size of field-delineated change areas and polygons digitized from high-resolution imagery was evaluated using a *t*-distribution.

2.4.2. Temporal Accuracy

Recording the timing of forest change is essential for the implementation of a robust forest monitoring system. Assessing the temporal accuracy of local monitoring data remains a challenge due to a lack of reference time series imagery of sufficient temporal density and spatial resolution that can describe disturbances in near real-time [48,49]. To overcome this limitation, only the area for which time series images of SPOT and RapidEye were available (Table 1) was used for this analysis. Here, a visual interpretation of the time series of satellite images for each local data set was carried out, and the time of forest disturbance was estimated for each data set. Furthermore, a temporal lag between the reference satellite datasets and local expert datasets was calculated to determine the average time delay or temporal lag of deforestation (Equation 1):

$$\text{Temporal lag} = \text{Year of detection by remote sensing} - \text{Year of detection by local experts} \quad (1)$$

2.4.3. Thematic Accuracy

Attributes, such as the presence or absence of forest, forest change type and drivers of forest change were included in the assessment of thematic accuracy. The accuracy of these variables was assessed by comparing local expert dataset with the field-based reference dataset. An error matrix was produced for each category and used to derive producer's accuracy, user's accuracy and the overall accuracy [50].

3. Results

3.1. Characteristics of Local Monitoring Data

3.1.1. Attributes of the Local Expert Monitoring Data

Local experts are capable of systematically monitoring forest change. In this study, we focused on deforestation and forest degradation processes to illustrate the major attributes of the data collected by local people (Figure 3, Table 3). The results show that local experts have documented forest change processes, which include spatial (location and size), temporal (time of change events) and thematic (type of change, driver of change and photograph from the North, East, West and South directions) information. Furthermore, deforestation, the conversion from forest to non-forest land [8], and forest degradation, negative changes in forest biomass without conversion to another land cover type, could be mapped separately using data provided by local experts (Figure 3). In this case, local experts tried to delineate exact deforestation areas from the ground by recording multiple GPS location around the boundary (Figure 3a). On the other hand, forest degradation is a gradual process without a fixed boundary [8] and could therefore not be mapped with such precision. In such cases, local experts provided the central location and approximate area affected rather than an exact change polygon (Figure 3b).

3.1.2. Monitoring Frequency

During the period of January, 2012, to December, 2013, a total of 755 locations were observed (Figure 4). Of these, 46% were labelled as forest degradation, 25% as deforestation and 30% as reforestation. All data in 2012 were acquired using paper forms with hand-held GPS devices, whereas in 2013, data were acquired using mobile devices. In general, local observations were spread equally over the whole Biosphere Reserve (Figure 1). However, monitoring efforts were not consistent throughout the year (Figure 4). Irregularities in monitoring activities were influenced by a wide range of factors, including the timing of training and capacity building programs and adverse weather conditions. The number of received monitoring forms (in 2012) and digital observations (in 2013) increased during training and capacity building program (January to March), while it decreased during the rainy season (July to September).

3.1.3. Drivers of Forest Change

Drivers of forest change were mostly associated with agriculture expansion and settlement expansion, followed by charcoal and firewood extraction, intensive coffee cultivation, timber harvesting and natural disasters, which mainly included landslides erosion and windfall. Many of the drivers were found to co-occur at a single location (Table 4). In the case of agricultural expansion, 34 of the events were attributed to agriculture expansion alone, whereas 185 events were attributed to agriculture expansion together with charcoal and fire wood collection, and 61 of those changes were found to be due to the co-occurrence of agriculture expansion and timber harvesting. This observation is logical considering that agriculture expansion in Kafa Biosphere Reserves is in fact a gradual process coupled with forest degradation. After demarcation of a portion of forest area for agricultural development, a farmer commonly keeps much of the forest for the first couple of years to harvest coffee, spices, fuel wood, charcoal and timber, before the forest is fully cleared to make way for agricultural activities.

Figure 3. Examples of (**a**) deforestation monitoring and (**b**) forest degradation monitoring by local experts; observations were mapped either as polygons (**a**) or point (**b**) features, depending on the process being described; each form was accompanied by four photos representing the north, east, south and west perspectives; the attribute tables associated with these observations are shown in Table 3.

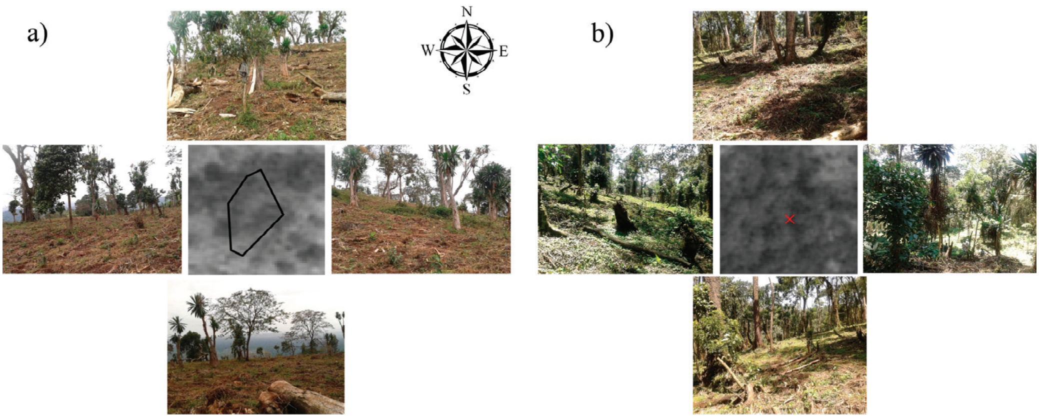


Table 3. Attribute tables derived from local expert observations of deforestation and forest degradation (shown in Figure 3a,b, respectively).

Category	Measured Variables	Value of Deforestation (Figure 3a)	Value of Forest Degradation (Figure 3b)
Spatial	Woreda	Gawata	Gawata
	Kebele	Ganty	Ona
	Distance to road	More than 3 km	1–2 km
	Distance to nearest village	1–2 km	1–2 km
	Distance to core forest	More than 3 km	More than 3 km
	GPS coordinates (latitude, longitude)	7.53, 35.84	7.54, 35.81
Temporal	Disturbance date	03-18-2013	03-18-2005
Thematic	Disturbance type	Deforestation	Forest degradation
	Driver of disturbance	Agriculture expansion, timber harvesting and firewood	Coffee cultivation, timber harvesting and firewood
	Size of disturbance	2 ha	4 ha

Figure 4. Number of observations collected by local experts in 2012 and 2013; all observations in 2012 were acquired using an analogue (paper-based) system, whereas observations acquired in 2013 were collected using either analogue or digital (smart phone-based) methods.

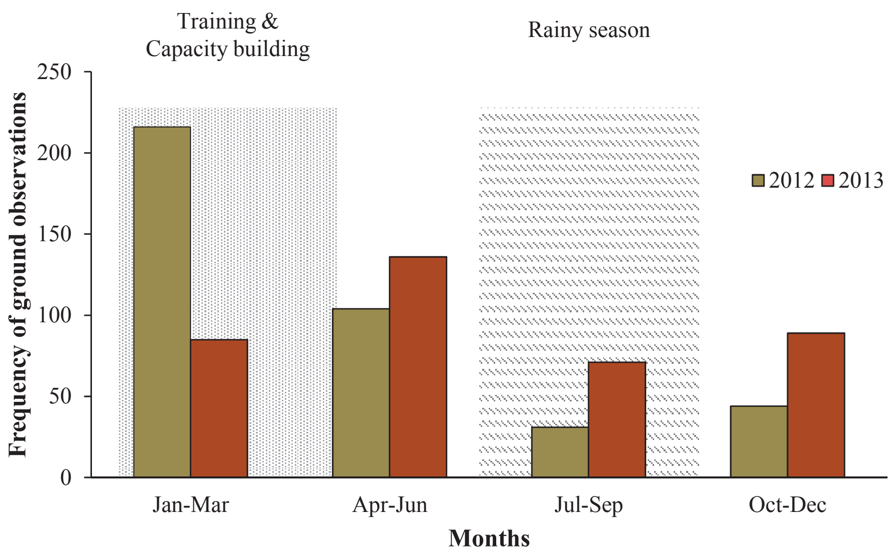


Table 4. Number of instances of the co-occurrence of forest change drivers. Numbers along the diagonal indicate the number of instances that a particular driver was reported alone.

Number of occurrences	Forest change drivers					
	Agriculture expansion	**Settlement expansion**	**Charcoal and fire wood**	**Intensive coffee cultivation**	**Timber harvesting**	**Natural disaster**
Agriculture expansion	34					
Settlement expansion	48	42				
Charcoal and fire wood	112	75	57			
Intensive coffee cultivation	0	55	76	19		
Timber harvesting	61	70	44	10	15	
Natural disaster	13	17	2	1	2	2
Total	268	259	179	30	17	2

3.2. Results on Accuracy Assessment

3.2.1. Spatial Accuracy

A breakdown of the estimated fraction correct of assigned spatial categories with a 95% confidence interval is shown in Table 5. The spatial accuracy varied considerably across the various spatial categories included in the monitoring forms. The woreda was recorded with the highest mean fraction correct of 0.92, whereas the estimated distance to core forest was found to have the lowest mean fraction correct of 0.71.

Table 5. Fraction correct of local data assignment to spatial categories.

Spatial category	Fraction correct	
	Mean	**Confidence interval (95%)**
Woreda	0.92	0.88 to 0.96
Kebele	0.78	0.72 to 0.84
Distance nearest village	0.77	0.71 to 0.83
Distance nearest road	0.75	0.68 to 0.81
Distance to core forest	0.71	0.64 to 0.77

A comparison of GPS errors reported by local experts with those reported in the FRD showed a slight systematic error of 0.65 m between the two datasets (Table 6). A similarly slight bias was found between forest change areas as reported by the local experts and forest change areas derived from high resolution remote sensing imagery, in cases where these areas did not exceed 2 ha (Table 6). In larger change areas (exceeding 2 ha), however, the absolute bias increased to 1.06, implying that local experts had systematically underestimated the area of large change polygons.

Table 6. Positional accuracy of local expert data.

Measure	Mean bias	Standard deviation	Confidence interval for mean bias (95%)
GPS error (m)	0.65	1.79	0.62 to 0.68
Size of forest change (ha); polygons <2 ha	0.16	0.29	0.13 to 0.20
Size of forest change (ha); polygons >2 ha	−1.06	1.26	−1.28 to −0.85

3.2.2. Temporal Accuracy

Each forest change event was recorded by local experts with a time stamp that represents the time at which the process of change took place. In total, 40 deforestation and 60 degradation locations were visually assessed from high resolution remote sensing (SPOT and RapidEye) imagery. An example of the visual interpretation of high resolution time series of SPOT5 (2008–2010) and RapidEye imagery (2012–2013) is shown in Figure 5. The locally mapped polygon is displayed at the center of each subset of image. The interpretation shows that the forest cover was significantly reduced after 2012.

The histogram of the temporal accuracy of locally determined change dates compared to high resolution imagery for deforestation and forest degradation is shown in Figure 6. Here, a positive temporal lag indicates that local experts indicated a change date earlier than that determined using remote sensing data, and a negative time lag indicates the reverse situation. The results reveal that 33% of deforestation events reported by local experts corresponded accurately to the dates observed in the remote sensing data. In other cases, 25% and 20% of total deforestation events as observed from remote sensing were detected one and two years earlier than the local reported time, respectively (Figure 6). On the other hand, the comparison of dates associated with forest degradation as reported by local experts shows that the majority of these signals were recorded one (32%) to two (22%) years earlier than dates detected by remote sensing.

Figure 5. Example of visual interpretation to assess the temporal accuracy of the local expert dataset; the image subset is based on SPOT5 data from 2008 to 2011 (red = Band 3, green = Band 1, blue = Band 2) and two RapidEye images from 2012 and 2013 (red = Band 3, green = Band 2, blue = Band 1); a ground photograph taken by a local expert in 2013 is also shown; the red polygon is the forest change mapped by a local expert; the forest change occurred between 2012 and 2013.

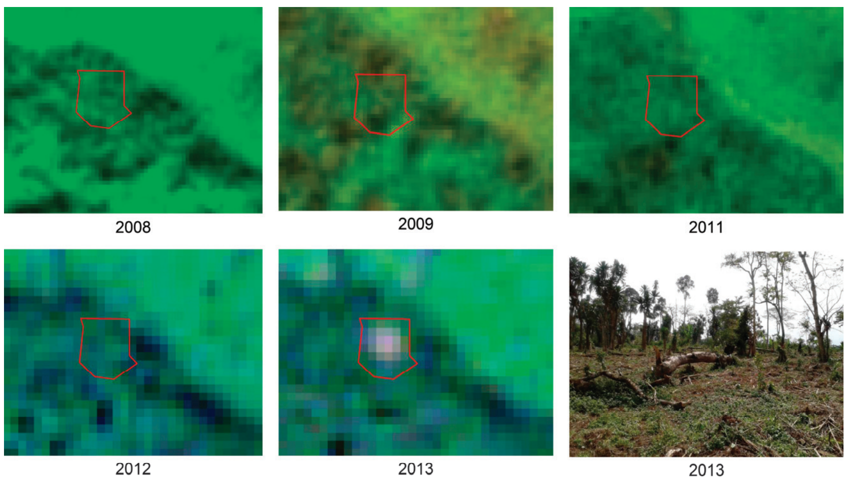
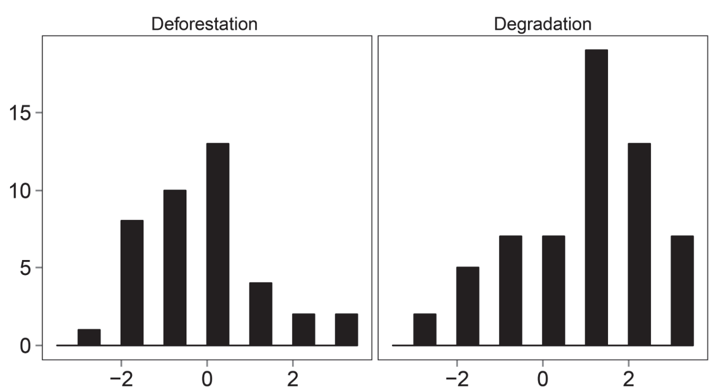


Figure 6. Histogram of time lags in capturing deforestation (**left**) and forest degradation by remote sensing (SPOT and RapidEye) imagery (**right**); a time lag is defined as the difference between change dates observed from remote sensing image interpretation and those dates recorded by local experts.



3.2.3. Thematic Accuracy

Thematic information is one of the added values of the local expert dataset compared to remote sensing. Summaries of the accuracy assessment of three thematic elements (the presence of forest, forest change type and drivers of forest change) are shown in Table 7.

Table 7. Accuracy assessment of local expert data compared to field-based reference dataset in the thematic domain.

Elements	User accuracy	Producer accuracy	Overall accuracy
Presence of forest	93%	92%	94%
Forest change type	83%	84%	83%
Driver of forest change	71%	68%	69%

The results show an overall accuracy of 82% for thematic elements compared to the field-based reference dataset. The presence of forest was found to have a producer's accuracy of 92%, a user's accuracy of 93% and an overall accuracy of 94%. The drivers of forest change had a comparatively lower producer's accuracy of 71%, a user's accuracy of 68% and an overall accuracy of 69%.

4. Discussion

4.1. Local Expert-Based Forest Monitoring System

The establishment of robust and reliable NFMS in developing countries is an expensive and challenging task. Several studies have shown that CBM has the potential to increase the saliency, credibility and legitimacy of such forest monitoring systems [7,26–28,30,51]. However, current studies do not clearly describe the following aspects of forest change monitoring (related to activity data): (1) the long-term operational procedures of community involvement; (2) technology selection; (3) consistency of local datasets; and (4) complementarity with remote sensing data. In this regard, we demonstrate an operational forest monitoring system that includes local expert activity monitoring data in the UNESCO Kafa Biosphere Reserve, Southern Nations, Nationalities and People's Region (SNNPR), Ethiopia. In general, our monitoring setup allows local experts to collect forest change variables, such as geo-location, size of forest change, time of forest change and proximate drivers behind the change, in more detail. Similar to previous studies [29,52], we also found that the use of mobile devices has a clear advantage over a paper-based system in capturing photographs and multimedia information from the ground and improves the local capacity in data collection, transmission and visualization procedures (Figure 3 and Table 3). Furthermore, our results show that these datasets are fully structured in terms of spatial, temporal and thematic detail and capable of describing the forest change process well. While our results are based on a local case study, these monitoring activities have the potential to be scaled up to the national level and integrated with an NFMS.

The local expert-based forest monitoring system in this study faced some critical barriers, such as systematic coverage and consistency in monitoring frequency. Our results show that 53% of the local data were collected within 1 km of the local road network, hindering systematic coverage of the study area. This restriction is a result of poor road infrastructure or a lack of transportation means. A recent study in Southwestern Ethiopia has shown that most forest change occurs in remote locations far from urban areas [53], suggesting that much of these changes could not be fully captured by local experts alone. This mobility barrier could be overcome by engaging local communities who live near the forest areas of interest.

We also observed that the frequency of local data collection depends largely on weather conditions and motivations towards monitoring activities. A decrease in data acquisition was seen during the rainy season, indicating that weather has a significant impact on the mobility of local people. This reduction in data frequency may also be due to a decrease in disturbance activities by farmers during this time. The motivation can be triggered by providing local experts with adequate incentives for conducting monitoring activities even during adverse weather conditions and also providing them with the necessary accessories and travel means. Regular training and capacity building programs should also be conducted to keep the local experts updated. While such initiatives in motivating the local experts towards efficient monitoring may not fill the data gap completely, they could help to substantially increase the commitment and long-term engagement of local people towards monitoring.

4.2. Critical Review on the Accuracy of Local Datasets

In this study, we assessed the spatial, temporal and thematic accuracy of the local expert dataset. Identifying the factors influencing these accuracies is important to understanding the role that this dataset can play in a forest monitoring system. The main influencing factors are explained in detail below.

4.2.1. Spatial Accuracy

Spatial accuracy was influenced by three main factors: interpretation of administrative boundaries, GPS errors and failure to map full polygons. First, the administrative boundaries are not always visible on the ground. Local experts may incorrectly interpret these boundaries when they are away from their own villages. This error might be solved by providing base maps prepared by an Ethiopian mapping agency and regional governments during field work, which may contain the updated information regarding these administrative layers.

Second, GPS location error arises due to the weak signal caused by dense forests and high slopes. Mobile devices used in this study achieve maximum GPS accuracy by taking the average measurement from all available satellites reached in a given time. GPS accuracy could be improved by using averaging positional measurements over a longer period of time [54].

Third, the area of change estimated by local experts was found to be biased due to difficulties in mapping large change polygons in the field. When an insufficient number of polygon vertices was mapped by the local experts, resulting polygons were smaller than those delineated by visual interpretation from remote sensing imagery, giving rise to a negative bias in field-based area estimations. These errors could be avoided by implementing a visualization feature in the mobile device-based forms, whereby local experts can see the polygon they have mapped while in the field. Based on observed errors that arise in the mapping process, these can be corrected by the local experts.

4.2.2. Temporal Accuracy

To assess temporal accuracy of the local dataset, temporal lag was calculated based on forest disturbance dates determined using remote sensing time series data. The temporal lag in detecting deforestation and degradation (Figure 7) is not necessarily a direct result of inaccuracies in the local dataset, but rather highlights differences in the interpretation of change between ground-based and satellite-based methods in the case of deforestation and forest degradation.

Evidence from our study indicates that deforestation is detected earlier using higher resolution SPOT and RapidEye imagery compared to local expert observations. This time lag in deforestation detection is likely due to differences in the interpretation of change events. Since optical remote sensing observes changes in the canopy cover of forests, changes delineated by visual interpretation of remote sensing time series were directly related to land cover changes. Local experts, on the other hand, reported changes in land use (e.g., the conversion of forest land to agricultural land) [55]. The difference between the land cover and land use-based definition of deforestation is important in this case, because actual land use change typically follows several years of gradual canopy cover change. Whereas deforestation was understood by local experts to mean the conversion of forest land to cropland, changes in the canopy cover in the years preceding this change were often interpreted as land cover change (deforestation) by the remote sensing analyst, thus giving rise to the temporal lag observed in this study (Figure 6).

Interestingly, a reverse temporal lag was found in the case of forest degradation reported by local experts. Optical remote sensing data are known to have limitations with regards to the detection of low-level degradation, especially when driven by fuelwood collection [24], as was found in this study (Table 4). This low level degradation generally takes place underneath the forest canopy and is thus not detectable using remote sensing data until degradation rates are such that canopy openings begin to appear. For this reason, a delay in degradation detection by remote sensing was found in this study. In many cases, low-level degradation is not at all detectable with optical remote sensing data when degradation fails to result in canopy openings. In this case, local datasets convey a clear advantage when combined with remote sensing data to achieve a comprehensive description of the degradation processes.

4.2.3. Thematic Accuracy

While analysis of the thematic accuracy of the local experts' dataset showed a high overall accuracy (82%), the drivers of forest change were reported with a relatively lower accuracy (69%). One possible explanation for this lower accuracy could be due to differences in perceiving the proximal drivers of forest change by local experts and the team of professionals who were involved in collecting FRD. Another explanation for this lower accuracy could be the complexity of multiple drivers and dynamic nature of land use changes, which make categorization of forest change drivers difficult. In the case of Ethiopia, multiple drivers, such as fuelwood extraction, grazing, timber harvesting and agriculture expansion, operate together, and choosing the most prominent driver for such a situation is difficult (Table 4). The reporting of drivers could be improved through improved form design (e.g., using simplified classes and iconography).

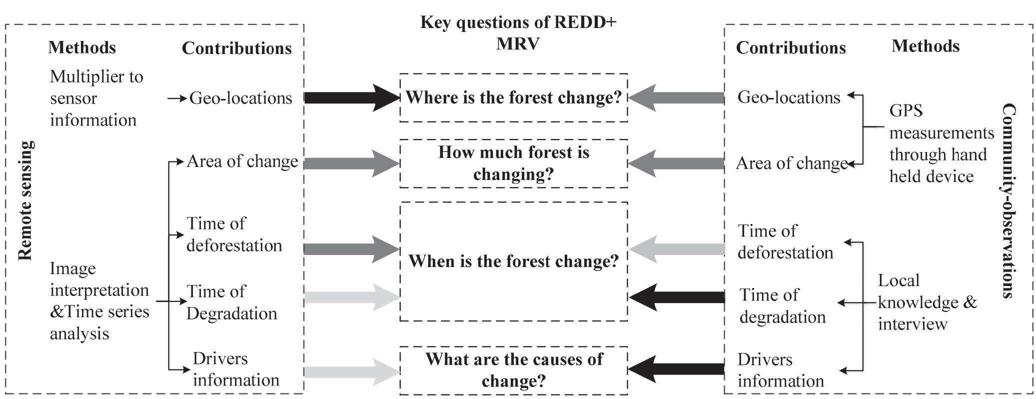
4.3. Potential Role of Local Datasets in an Integrated Monitoring System

4.3.1. Complementarity with Remote Sensing Analysis

The local data stream presented in this paper is not an investigation to replace or compete with remote sensing-based monitoring data, which is conventionally used in forest area change analyses, but is rather envisioned to be complementary to these data. The complementarity between remote sensing and community-observations is described below in the context of several key REDD+ MRV questions (Figure 7).

The first question for REDD+ MRV is the location of change. Remote sensing approaches are highly suitable for answering this question. The value of remote sensing data and their successful implementation to monitor forest change on various scales (global, regional, national, *etc.*) and at various resolutions is well established [1,15]. The advantages of these methods include consistent data acquisitions, automated data processing and large area coverage [14,56,57]. A main shortcoming is the need for spatially-explicit ground (*in situ*) data to enhance the reliability of these remote sensing products [58]. There is always a lack of spatially-explicit and statistically representative ground data, because this information is expensive and time consuming to acquire. To address this deficiency, local data streams proposed in this study may provide a useful way to complement remote sensing data. The spatial accuracy results of the local expert data (Tables 5 and 6) show that local datasets can be used to better understand information related to local administration (e.g., the name of the district and village) or geographical characteristics (distance to roads, nearest village and core forest). Similarly, remote sensing may help to add value to local data streams by providing wall-to-wall coverage, which can be used to validate local data streams. The synergies of both methods may lead to a more efficient monitoring system for data acquisition and to rendering reliable information.

Figure 7. Contributions of remote sensing and community-observation for REDD+ MRV monitoring objectives related to location, size, timing and drivers of forest change; black arrows indicate a very strong contribution; dark grey arrows indicate a reasonably strong contribution; and light grey arrows indicate a limited contribution to these monitoring objectives.



The second REDD+ MRV question is the area of forest change. Both remote sensing and local datasets have their own difficulties when used to map the area of forest change. In general, remote sensing plays a promising role for mapping larger areas, because of its ability to map wall-to-wall changes [15]. However, the trade-offs between the spatial and temporal capabilities of remote sensing limits their use to monitoring small-scale forest change [14]. Since we have shown that local datasets are sufficiently accurate to track small forest changes, the overall mapping of forest change area can be enhanced by exploiting the synergy between these datasets.

The third REDD+ MRV question is related to the timing of forest change. Historical archives of remote sensing imagery and the prospect of a continuous data stream based on new satellites, such as Landsat 8 and Sentinel-2, offer a possibility to analyze the temporal patterns of forest change and the impact of human activities [57,59]. However, the temporal accuracy of detected changes based on this imagery depends on: (1) the availability of cloud-free observations; (2) the seasonality and climate trends; and (3) the spatial scales of land cover change phenomena. In areas with high persistent cloud cover, the detection of actual changes can be delayed due to missing observations, and the seasonality of vegetation can obscure actual changes. Climate events, such as major droughts, can result in temporal signals that resemble actual change, thus contributing to errors. Finally, the scale of change can influence the time at which a change is detected from space. Specifically, we have seen in this study that higher resolution SPOT and RapidEye imagery detect deforestation earlier than local experts, whereas the detection of forest degradation using remote sensing data is delayed compared to that of local experts. Reports of small-scale deforestation and forest degradation from local experts can therefore contribute to an improved understanding of change processes, and the integration of both methods should lead to a more efficient system to signal new changes in near real-time.

The final REDD+ MRV question is related to the driver of forest change. NFMS for REDD+ needs to be designed to track and completely document the drivers of forest change processes [6]. Drivers vary across regions [60], leading to different dominant forest change processes and different approaches needed to tackle these drivers [24]. In general, remote sensing has limited capabilities to track forest change drivers, whereas community-observations are very accurate in reporting these drivers. These drivers of change can be better understood with an intimate knowledge of forest change processes, and this information has the potential to enhance the pertinence of the remote sensing data analysis. Information on drivers collected by local experts thus presents new opportunities for monitoring forest change events.

4.3.2. Link to the National Forest Monitoring System ("Up-Scaling")

The UNFCCC encourages developing countries to establish an NFMS in support of REDD+ MRV [6]. The NFMS needs to monitor forest carbon and changes in compliance with the five IPCC principles: consistency, transparency, comparability, completeness and accuracy [2]. However, most developing countries have a low monitoring capacity, and the development of these capacities will take considerable time and resources [11]. In this research, we found that local communities can monitor forest changes in a cost-effective way. By scaling up CBM activities to the national level, these capacity gaps can be addressed in an efficient and cost-effective way. Developing countries should therefore give priority to CBM in developing their NFMS and MRV systems.

The UNFCCC REDD+ also offers an opportunity for safeguards, biodiversity conservation and other ecosystem services beyond carbon sequestration [61–63]. Monitoring all of these elements within REDD+ is a challenge. Our proposed local monitoring system is based on well-established monitoring principles and experiences. The main advantage of the system is the flexibility in design. The data acquisition side of the system can be easily modified, and it can incorporate other types of environmental monitoring variables. Thus, the integration of other environmental monitoring variables may lead to long-term benefits [18] and shape the future of REDD+ monitoring and implementation efforts [12].

4.4. Future Research Directions

Although our study is founded on the argument that considerable progress can be made towards community-based forest monitoring in REDD+, there is a clear need for improvements to the monitoring set-up. The first area of improvement is the engagement of local communities that have an impact on the success of the proposed monitoring setup. In our study, local experts were employed and the acquaintance of the local people with their local area was a clear advantage in monitoring local changes. Moreover, the feeling of ownership that local people have for their locale has a strong influence on the motivation to participate. Local capacities should therefore be developed through extensive training. The second area of improvement is related to data entry errors. Advancements in hand-held devices, such as smart phones and PDA devices, will improve local participation within monitoring programs. The application of mobile devices can improve the local participation and reduce data entry error within monitoring programs [29]. However, further improvement is needed in terms of user-friendly form design. Specifically, drop-down selection options and multimedia (photos, video and audio) are preferable to manual text entry, which is prone to entry errors. Finally, there is a need to integrate near real-time data streams from both satellites and CBM. Recently, efforts have been made towards improving near real-time forest monitoring using remote sensing data [15,64]. However, the efficacy of near real-time monitoring from ground-based sources, such as CBM, has not yet been investigated. Addressing these gaps in CBM is an important next step in the arena of REDD+ MRV and NFMS.

5. Conclusions

Community-based monitoring is gaining popularity, and large volumes of ground observations that can potentially enhance forest monitoring are being generated. To tap into this potential, we need a better understanding of local data contributions, in particular their consistency and complementarity with remote sensing.

In this article, we present a novel approach to monitor forest change through local experts and evaluate the accuracy and complementarity of local datasets over field-based reference measurements and high resolution satellite imagery from SPOT and RapidEye. We demonstrate the application of the approach by implementing a CBM case study with 30 local experts in the Kafa

Biosphere Reserve in Ethiopia. The proposed approach helps us to understand the characteristics and competencies of local datasets. The results show that the local experts are accurate compared to field-based observations and high resolution remote sensing in providing the spatial, temporal and thematic details of the forest change process. Local monitoring data also offer a way to complement and enhance remote sensing-based forest change analysis. In future research, we foresee new ways to integrate local expert monitoring data with satellite-based monitoring data into NFMS in support of REDD+ MRV and near real-time forest change monitoring.

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Author Contributions

Arun Kumar Pratihast, Ben DeVries, Lammert Kooistra and Martin Herold conceived and designed the study. Arun Kumar Pratihast carried out field work, data analysis and prepared the manuscript. Arun Kumar Pratihast, Ben DeVries and Valerio Avitabile designed the tools for ground data acquisition. Mesfin Tekle coordinated the work of the local experts. Sytze de Bruin contributed to the statistical analysis. All authors contributed to the preparation of the manuscript.

Appendix

Table A1. The details of SPOT and RapidEye scenes used in this study; the tile IDs of SPOT images are based on the SPOT K-J reference grid.

Sensor	Tile ID	Date of acquisition
SPOT4	133–336	2-03-2005
	133–335	2-03-2005
	132–335	12-22-2005
	134–336	12-11-2006
	134–335	12-11-2006
	133–336	6-07-2006
SPOT5	133–335	11-02-2007
	133–335	12-28-2008
	133–335	1-12-2009
	133–335	1-01-2010
	133–335	24-3-2011
	134–336	2-06-2011
	134–335	2-06-2011
	134–335	2-06-2011
	133–336	2-15-2011
	133–336	1-26-2011
	133–335	3-24-2011
	133–335	3-24-2011
	133–335	3-24-2011
	132–335	2-05-2011
RapidEye	3642428	12-12-2012
	3642528	12-12-2012
	3642528	2-24-2013
	3642627	12-12-2012
	3642628	2-24-2013
	3642727	2-24-2013
	3642728	2-24-2013
	3742302	10-17-2012
	3742401	1-02-2013
	3742402	10-17-2012
	3742501	2-24-2013
	3742502	1-05-2012
	3642428	1-02-2013
	3642527	12-12-2012
	3642827	2-24-2013
	3642828	2-24-2013
	3742302	1-01-2012
	3742302	2-25-2013

Table A1. *Cont.*

Sensor	Tile ID	Date of acquisition
	3742402	1-01-2012
	3742402	2-25-2013
	3742403	1-01-2012
	3742403	10-17-2012
	3742403	2-25-2013
	3742501	1-02-2013
	3742502	10-17-2012
	3742502	1-02-2013
	3742502	2-25-2013

Conflicts of Interest

The authors declare no conflict of interest.

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Small Drones for Community-Based Forest Monitoring: An Assessment of Their Feasibility and Potential in Tropical Areas

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Abstract: Data gathered through community-based forest monitoring (CBFM) programs may be as accurate as those gathered by professional scientists, but acquired at a much lower cost and capable of providing more detailed data about the occurrence, extent and drivers of forest loss, degradation and regrowth at the community scale. In addition, CBFM enables greater survey repeatability. Therefore, CBFM should be a fundamental component of national forest monitoring systems and programs to measure, report and verify (MRV) REDD+ activities. To contribute to the development of more effective approaches to CBFM, in this paper we assess: (1) the feasibility of using small, low-cost drones (*i.e.*, remotely piloted aerial vehicles) in CBFM programs; (2) their potential advantages and disadvantages for communities, partner organizations and forest data end-users; and (3) to what extent their utilization, coupled with ground surveys and local ecological knowledge, would improve tropical forest monitoring. To do so, we reviewed the existing literature regarding environmental applications of drones, including forest monitoring, and drew on our own firsthand experience flying small drones to map and monitor tropical forests and training people to operate them. We believe that the utilization of small drones can enhance CBFM and that this approach is feasible in many locations throughout the tropics if some degree of external assistance and funding is provided to communities. We suggest that the use of small drones can help tropical communities to better manage and conserve their forests whilst benefiting partner organizations, governments and forest data end-users, particularly those engaged in forestry, biodiversity conservation and climate change mitigation projects such as REDD+.

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1. Introduction

Tropical forests play a critical role in the global carbon cycle [1] and harbor around two-thirds of all known species [2]. Large tracts of tropical forests have long been inhabited by humans, thus leading to a significant overlap between linguistic, cultural and biological diversities [3]. Presently, tropical forests are also home to a significant proportion of the world's poor [4], and therefore synergies between poverty alleviation and forest conservation strategies are essential for successful conservation [5]. In tropical regions, it is claimed that community-based forest management has the potential to both alleviate poverty [6] and be more effective for forest conservation than protected areas [7,8]. Though such claims are not clearly supported by quantitative evidence [9], community-based forestry continues to be central to many development and conservation projects worldwide. In such efforts, sound community-based forest management strategies have to be developed in combination with community-based forest monitoring (CBFM) [10] strategies so that a range of assessments can be made over time and management can be adaptive.

Likewise, CBFM will be essential to the successful implementation of the Reduced Emissions from Deforestation and Forest Degradation (REDD+) program [11] across tropical communities because CBFM has significant advantages over governments and other organizations working in community forests [12–14], and because local participation is essential to improving forest governance [15–17] and constitutes a fundamental safeguard under REDD+ [18,19]. Thus, for instance, forest data gathered by trained community members have been shown to be as accurate as those gathered by professional scientists, but at a much cheaper cost, and can provide greater survey repeatability and more detailed data about the occurrence, extent and drivers of forest loss, degradation and regrowth at the community scale [12,13,20–24]. CBFM can also supplement [25] existing national forest inventories in tropical countries [20,26] and should therefore be a fundamental component in national forest monitoring systems and in systems to measure, report and verify (MRV) REDD+ activities, which to date are inadequate in most REDD+ project sites [27]. Furthermore, CBFM could facilitate the transition from centralized forest monitoring approaches to more transparent, independent and widespread models, which should deliver substantial benefits [28]. In addition, CBFM can help communities deter people (whether locals or abutters) from carrying out illegal activities in their territories, hence contributing to improved forest governance [29]. CBFM may also lead to the social and institutional strengthening of communities, empowered by the use of technologies and greater knowledge and awareness of policies, which in turn may enhance their ability to negotiate claims in REDD+ and to help achieve equitable, efficient and effective REDD+ outcomes [12,20,22,23]. For all these reasons, CBFM can improve forest monitoring in tropical countries, with potential co-benefits for biodiversity conservation, climate change mitigation and livelihood support [12,30].

CBFM is usually carried out through conventional ground surveys to gather forest data inventories by measuring variables in permanent plots such as diameter at breast height (dbh), tree height, percentage of canopy cover, number of trees and tree species. Such surveys cover a very small area and are usually costly, time-consuming, tedious, and plagued with logistical difficulties in the tropics (e.g., safety, access to remote sampling sites). In order to develop more effective approaches to CBFM, in this paper we assess: (1) the feasibility of using small, low-cost drones (remotely controlled aerial vehicles) in CBFM programs; (2) their key advantages and disadvantages for communities, partner organizations and forest data end-users; and (3) to what extent their utilization, coupled with ground surveys and local ecological knowledge, would improve tropical forest monitoring, particularly in light of the needs of REDD+ MRV systems, as compared to using only ground surveys or ground surveys coupled with other remote sensing approaches. Our assessments are timely and necessary because although drones are being increasingly used for a range of environmental monitoring tasks with reasonable success, we do not know of any programs now being developed to use small drones for CBFM. To our knowledge, this is the first paper that evaluates the prospects, challenges and opportunities of using small drones for CBFM in tropical areas as a way to improve forest monitoring, which is central to effective REDD+ implementation. The subject is very topical and relevant as reducing and preventing tropical deforestation and forest degradation is a vital global climate mitigation strategy [31,32], and key to sustain global biodiversity [2].

We reviewed both academic and non-academic literature dealing with the use of small drones [33] for environmental applications, including forestry. We first provide a brief overview of such uses, including the types of drones that could be employed specifically for CBFM. We then outline and briefly discuss the key advantages and disadvantages that we expect from the use of small drones for CBFM, according to how we envisage the whole process in the short-term, which includes some external training, assistance and funding from organizations working alongside communities (e.g., in REDD+ projects) so that drones can be operated by communities; we evaluate the pros and cons from the standpoint of communities, partner organizations and forest data end-users. In addition, we provide a brief assessment regarding the improvements we expect in forest monitoring by means of implementing this drone-assisted CBFM approach, particularly in relation to REDD+ MRV systems needs, and discuss the main prospects, challenges and opportunities for implementing this approach at present and in the near future. We ground our assessments on the authors' own experiences in community forest management and monitoring in several tropical contexts as well as our expertise in the remote sensing of forests, a literature review of drone applications in environmental monitoring, and firsthand experience flying small drones for mapping and monitoring tropical forests and training people to operate them.

2. The Use of Small Drones for Environmental Mapping and Monitoring

As with technologies such as GPS, small drones were initially developed for military use, but are increasingly being deployed in civilian applications [34], including mapping, monitoring and managing habitats and natural resources. Although small drones are not used widely in environmental applications yet, their use is likely to increase rapidly as their prices decrease and the technology becomes easier to use [35,36].

The earliest scientific publications of environmental data gathered with small drones were studies carried out by Tomlins, Lee and Manore using a hobby-grade model aircraft, and later a custom-designed small drone [37–39]. In his pioneer research, Tomlins identified as many as 46 environmental applications in which small drones could be useful [37]; yet this technology remains unexplored for most such applications [40]. Although some initial attempts were made to employ small drones in environmental research in the 1990s and early 2000s (e.g., [41,42]), researchers have only begun seriously investigating the use of drones over the last seven to eight years. Recent papers discuss the potential benefits of small drones for specific environmental applications (e.g., [43–46]), including a recent special issue on the topic published in 2011 in *GIScience and Remote Sensing* (see [47]).

Although the development of environmental remote sensing technologies and methods has been closely related to the study of forests (e.g., [48–52]), the bulk of the academic literature published about the development and use of small drones for environmental applications is not concerned with forests. Instead, the focus is on the use of small drones in precision agriculture (e.g., [46,53,54]) and vegetation monitoring in rangelands (e.g., [44,55–59]). Other environmental research applications found in the literature include biodiversity monitoring [60–64], habitat monitoring [65–67], and soil properties [68,69]. Another application that can assist in environmental monitoring is the generation of high spatial resolution digital surface/elevation models from drone imagery [70,71].

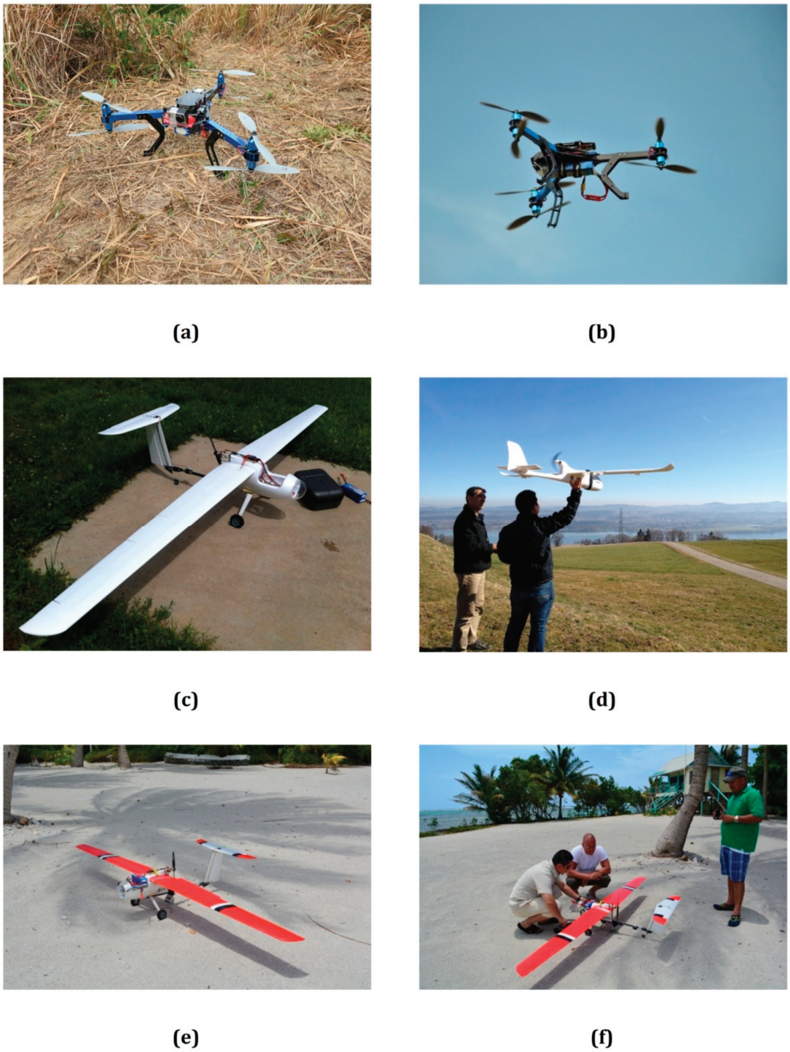
Most drone research on forests has focused on mapping and monitoring fires [72–75], but some studies have aimed to monitor forest stands with small drones [60,76–84]. A pioneer study by Horcher and Visser [85] emphasized the potential use of small drones for forestry applications , and Koh and Wich recently published a paper that outlined some tasks geared toward tropical forest conservation that can be accomplished by "conservation drones" [86]. Our review of non-academic literature [87] suggests that small drones are increasingly being used by timber companies and government forestry agencies for applications such as tree crown/gap mapping, forest stand mapping, volume estimation, wind blow assessment, pest monitoring, and harvest planning. Additionally, conservation NGOs and staff of protected areas worldwide are becoming interested in using small drones for conservation-related tasks (e.g., surveillance of wildlife, monitoring of land-use change and illegal activities within reserves such as poaching and illegal game hunting) [88].

3. Small Drones Suitable for Community-Based Forest Monitoring

Existing drone types can be classified according to a range of criteria, including size and payload [89], control systems, flight range, altitude and endurance. A very simple classification based on flying altitude is provided by Everaerts [90], another based on flying altitude and range can be found in [40], and a more comprehensive classification following military-standard criteria (though focused on environmental applications) is provided by Watts *et al.* [45]. Most environmental applications use small drones that have light payloads, can cover relatively short distances, and are only able to fly missions over short periods of time and at low altitudes [91]. Within the category of small drones, we distinguish three main types according to their design and flight mode: (1) various balloons, blimps, kites and paragliders; (2) rotary-wing aircraft; and (3) fixed-wing aircraft (Figure 1 shows rotary- and fixed-wing aircraft that we have used).

For the purposes of CBFM, balloons, blimps, kites and paragliders are not suitable because it would be very difficult to cover large areas with these systems and therefore they are best utilized for very local monitoring needs (e.g., permanent monitoring at key areas for fire/smoke detection). Rotary-wing aircraft such as helicopters and multicopters (e.g., quadracopters, octocopters) may not be well suited for CBFM in large community forests because these drones can only cover short distances [92] for short durations (typically up to 30 or even 40 min) owing to their high power demand relative to their limited battery size. However, they may be more useful than fixed-wing drones in instances where canopy gaps are large enough for vertical ascent [93] and descent, but no landing strip is available. In contrast, fixed-wing aircraft have gliding capabilities that enables greater flight endurance than rotary-wing aircraft, which allows them to operate over the longer distances (up to 15–20 km) that CBFM frequently requires in tropical forests. In addition, many fixed-wing drones can be built from hobby-class model aircraft, which may significantly reduce their cost and provide greater payload flexibility [40,86]. Both rotary- and fixed-wing drones can either be flown fully manually by a ground operator with the assistance of live telemetry systems or be easily pre-programmed to fly fully autonomously when an autopilot system is fitted into the drone's body (though partial ground control is recommended for safer landing and take-off).

Figure 1. Examples of rotary-wing (**a**,**b**) and fixed-wing drones (**c**–**f**) used by *ConservationDrones*.



Given these advantages, we recommend the use of small fixed-wing aircraft for CBFM and our assessment here is primarily concerned with such drones [94], although many of the advantages and disadvantages we discuss in this paper apply to rotary-wing aircraft as well. We prioritize full or semi-automation of drone flights because a higher degree of autonomy implies that a community could begin monitoring with less training than that required by fully manual operation. However, some degree of manual operation will most likely be necessary in certain situations (e.g., to interrupt a mission if required). In such cases, a telemetry system would allow for active manipulation of the flight from a laptop, tablet, or special goggles, and such manipulation is relatively straightforward after training. If manual operation of a drone is necessary, the telemetry system can stabilize the flight altitude, thus avoiding significant geometric problems in the imagery acquired.

4. Key Advantages of a Drone-Assisted Community-Based Forest Monitoring Approach

In this section we outline and briefly discuss key advantages we have identified for communities, partner organizations and forest data end-users [95] to using small drones for CBFM to complement community ground surveys. In the subsequent section we examine the main disadvantages. In addition, we provide a qualitative assessment of the relative importance of every advantage to communities, partner organizations, and forest data users.

The lists of advantages and disadvantages in this section and the next refer to the benefits and limitations we foresee for communities, partner organizations and forest data end-users wishing to implement a drone-assisted CBFM approach. This serves as a first assessment of the feasibility and desirability of this approach to CBFM in comparison with what could be achieved by ground surveys alone, or by ground surveys coupled with other remote sensing options (*i.e.*, satellite or piloted aircraft imagery). Our lists are based on how we envision the entire CBFM process to proceed over the next few years. Specifically, we suggest that community members would be able to autonomously plan and acquire drone imagery to monitor their forests after receiving adequate training from a partner organization, and would be able to mosaic and visually inspect the imagery to detect forest change and other information important to the community. We would, however, expect partner organizations to undertake more complex geospatial analyses. This approach would also entail external assistance for drone maintenance and repair [96], as well as continued funding to secure drone operation by community members.

The key advantages identified are presented and discussed according to technical issues (e.g., sensing capabilities, drone operation and maintenance skills, image analysis, monitoring capabilities, potential to enhance and ease CBFM), social issues (implications for people in communities), and environmental issues (implications for the local environment). See Table 1a for a synopsis of all the advantages and their relative importance to communities, organizations and end-users. Although we are addressing CBFM in a broad sense, we discuss some specific issues with special reference to the needs of REDD+ MRV programs because we expect this drone-assisted CBFM approach to be particularly attractive to national and international organizations involved in REDD+ who will have the capacity to provide the necessary training, assistance and funding that communities would require.

- *Extremely high spatial resolution*. The operational flying altitude of small drones, usually in the range of 50–300 m, permits the acquisition of extremely high spatial-resolution imagery, with pixels on the order of a few centimeters (rather than a few meters). This feature greatly enhances the visual analysis of imagery and thus can significantly improve CBFM. For instance, at this spatial resolution, specific trees and canopy gaps can be identified and easily monitored (see Figure 2). Furthermore, forest loss, degradation and regrowth processes could be accurately detected and monitored at this level of detail [97] by trained community members. Such data would not just be relevant for partner organizations and end-users, but also for communities themselves. For the former, the hyperspatial resolution of drone imagery would enable monitoring of many forest traits that currently are unachievable (at least accurately) through other remote sensing datasets. These include the identification of individual tree species by coupling imagery with botanical expertise, the detection of invasive plant species and pests, the estimation of aboveground biomass (where allometric equations exist for specific tree species), and the identification of different stages of forest regeneration or degradation, all of which are fundamental to assessing forest health condition, carbon storage and biodiversity levels, and hence to conservation and climate change mitigation policies. Although the retrieval of such information can be potentially accomplished by ground surveys alone, the use of small drones would also allow detailed mapping over much larger areas than ground surveys, and imagery at this spatial resolution should be much more meaningful to communities than ground survey data at the plot level.

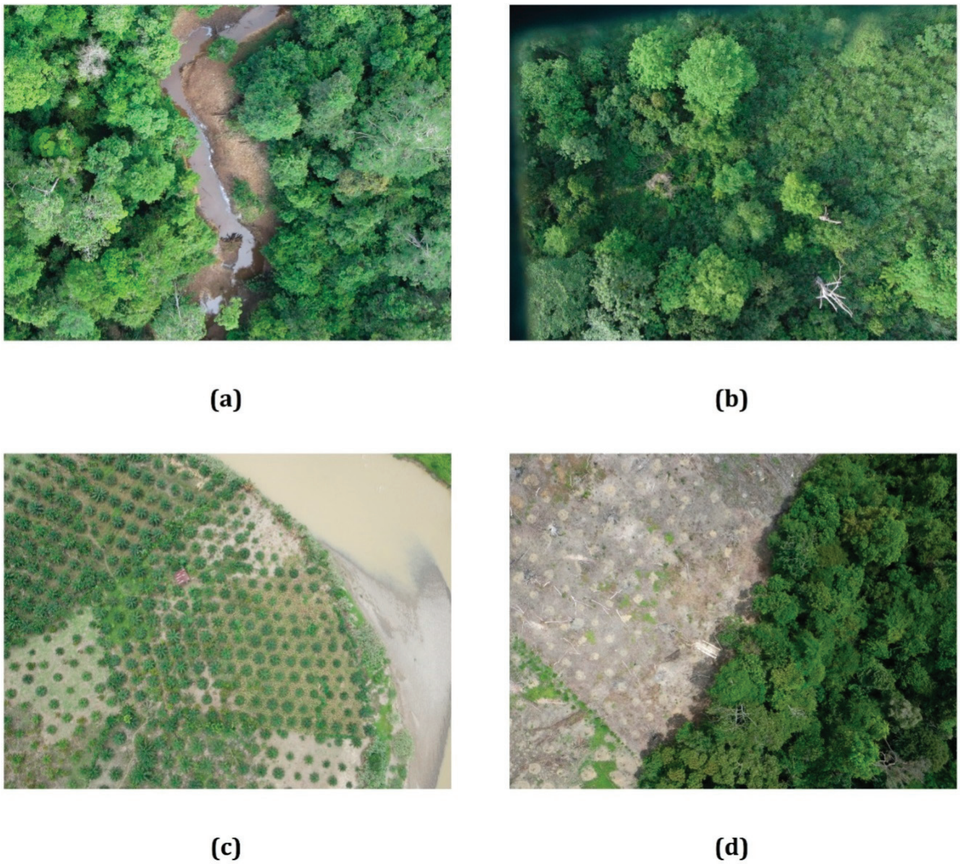
- *Potential for high temporal resolution*. The comparatively lower cost of operation and maintenance of small drones allows users to acquire imagery far more frequently than with conventional remote sensing technologies such as satellite and piloted aircraft imagery. This means that community drone users would have the potential to update their imagery and compile high-resolution time-series imagery that would allow thorough assessments of local forest condition at much shorter intervals. Survey frequency could be decided according to organizations' and end-users' needs (so long as there is agreement with communities beforehand). This key feature would enable year-round monitoring of tropical forests, which is critical to improving tropical deforestation and degradation monitoring [98] because seasonal differences in canopy structure may be significant and therefore difficult to detect with single-date imagery. Tropical dry forests, for instance, exhibit a seasonal phenology associated with a long and severe dry season [99] and, therefore, require frequent observations to capture such phenological variations.
- *Insensitivity to cloud cover*. Small drones typically fly below cloud level (e.g., 50–100 m), which gives them a significant advantage over conventional remote sensing platforms, particularly in habitats with frequent dense cloud cover such as lowland rainforests and montane tropical cloud forests. Data provided by CBFM with small drones could greatly improve digital imagery of these cloud-covered regions, which would also benefit forest agencies and data end-users.
- *Potential for three-dimensional drone image generation*. Small drones are increasingly used for digital surface/elevation model generation [70,71]. The potential to apply 3-D imagery would seriously improve some tasks required to enhance forest monitoring strategies (e.g., the detection and quantification of forest degradation and regrowth stages). Also, the possibility of producing very accurate 3-D forest models with small drones would assist in the retrieval of forest structural parameters such as height, basal area, and tree density. In turn, this would improve the estimation of above-ground biomass, something urgently needed for improved carbon storage assessments in tropical forests [100]. Though the generation of 3-D products would be undertaken by data end-users and be particularly useful to them, 3-D maps might also represent a meaningful way for communities to better understand different features of their territories, including their forest resources.

Table 1. Qualitative assessment of the main advantages (**a**) and disadvantages (**b**) expected in the adoption of a drone-assisted community-based forest monitoring program, from the perspective of communities, partner organizations, and end-users.

(**a**) **Advantages**	**c**	**o**	**u**
Extremely high spatial resolution	1	1	1
Potential for high temporal resolution	1–2	1	1
Insensitivity to cloud cover	2–3	1	1
Potential for three-dimensional drone image generation	3	1–2	1
Potential to ease CBFM and make it more attractive to communities	1	1–2	3
Shallow learning curve of drone users	1	1	3
Relatively low price of drone imagery	2–3	1	1
High cost-effectiveness within the context of CBFM	2–3	1	2–3
Data acquisition decentralization	1	1–2	2–3
Enhanced monitoring of illegal activities	1	1–2	2–3
Access to otherwise inaccessible areas	1	2–3	3
Potential environmental benefits	1–2	2–3	2–3
Potential social and institutional strengthening of communities	1	2–3	2–3
Control of data acquisition and ownership would lie in community members' hands	1	1–2	3
(**b**) **Disadvantages**	**c**	**o**	**u**
Small payload	3	2–3	1–2
Low spectral resolution	3	2–3	1
Poor geometric and radiometric performance	3	2–3	1
Low software automation	3	2–3	1
Sensitivity to atmospheric conditions	2–3	1–2	1–2
Short flight endurance	1–2	1	1
Possibility of collisions	1	1	3
Potential problems for repairs and maintenance	1	1	3
Dependence on external assistance and funding	1	1	2–3
Ambiguous or cumbersome regulatory environments for flying small drones	1	1	1
Safety & security issues	1	1	1–2
Debatable relevance for community conservation and socio-economic development	1–3	1	3
Potential social impacts	1	1	2–3
Ethical issues	1	1	1–2

Notation: c = community, o = partner organization, u = end-user. Values refer to importance scores as follows: 1 = high, 2 = medium, 3 = low. More than one value (*i.e.*, 1–2, 2–3, or 1–3) is also allowed and indicates that the importance of a particular advantage/disadvantage for c/o/u will be case-specific. For instance, the potential for high temporal resolution will be very important (value = 1) for communities with territorial problems because high re-survey frequency would allow for improved territorial surveillance, but not so important for other communities (value = 2).

Figure 2. Examples of imagery gathered by small drones that show the extremely high spatial resolution that can be achieved. (**a**) Danau Girang (Sabah, Malaysia); (**b**) Chitwan National Park (Nepal); (**c**) Palm oil plantation by river (Indonesia); (**d**) Recently logged forest (Indonesia). Imagery provided by *ConservationDrones*.



- *Potential to facilitate CBFM and make it more attractive to communities*. Owing to the hyperspatial resolution of drone imagery and the potential for high survey frequency, a drone-assisted CBFM approach has the potential to ease CBFM in comparison with a conventional approach. For instance, forest strata within communities could be far more accurately delineated into homogenous units using small drones, which in turn could reduce the number of permanent ground plots needed per strata, and the number of attributes to be measured on the ground (e.g., canopy cover). In addition, the ability to survey the entire community territory with a few flights suggests that small drones could lead to significant time savings in monitoring and community data analysis, particularly in the case of medium- and large-sized community territories (*i.e.*, hundreds to several thousand hectares). Moreover, the acquisition of high spatial and temporal resolution drone imagery would be far more meaningful to communities than the mere retrieval of plot-level forest data and, consequently, the utilization of drones would make CBFM more attractive to forest communities.

- *Fast learning curve of drone users*. Small drones can be programmed to operate either fully or semi-autonomously by users with relatively little training and geomatic knowledge. The commercial drone market is increasingly targeting people with little experience flying small drones and the smallest ones are particularly easy to fly by individuals with little training, so they would be appropriate for forest community members after receiving specific hands-on training from partner organizations. For instance, besides pre-programming flight paths and manual drone operation (flying, landing and take-off), setting up necessary components (e.g. GPS, photo/video camera) and downloading the acquired imagery onto a computer are all relatively straightforward tasks. Also, the geotagged drone images acquired could be mosaicked or overlaid onto Google Earth by community members after training so that they could carry out visual analyses of their forests [101]. Overall, training is relatively straightforward and varies from 1–5 days (in cases where trainees are familiar with computers) to 14 days (in cases where trainees have no prior experience with computers). In practice, the skills, innate ability and motivation for these technical activities are more likely to be found amongst younger community members.
- *Relatively low price of drone imagery*. The outlay required for purchasing, operating and maintaining a small drone is rather low when compared with the cost of commissioning piloted aircraft missions or acquiring imagery from any of the high spatial-resolution satellites available (e.g., IKONOS, QuickBird, RapidEye) on a regular basis. Cheap drones already exist for uses such as those discussed here. Koh and Wich [86], for instance, used a self-made *conservation drone* for tropical forest monitoring at an estimated cost of US$2,000, and are currently developing and testing cheaper models [102]. Small drone prices are expected to diminish swiftly, whilst simultaneously technical capabilities are improving (as is the case for most technology developments). Off-the-shelf solutions are available for anywhere up from US$3,000. Furthermore, there is a potential future in 3-D printed drones of sufficient specifications and capacity as the costs rapidly decrease; these are still in research and development status but progressing fast [103–105]. Organizations would not need to purchase expensive software to allow communities to program the missions and download the data, nor to process the imagery, as open-source solutions are already available and could be used along with their in-house software capabilities. Alternatively, organizations could outsource at a relatively low cost the pre- and post-processing of drone imagery gathered by communities. Many of the companies that manufacture and sell small drones also offer low-fee services that include imagery uploading, processing, ortho-mosaicking, and other analyses that may be needed (e.g., digital elevation models).
- *High cost-effectiveness within the context of CBFM*. The ability to survey all the community territory with a few flights would make the coupling of small drones with ground surveys more cost-effective than ground surveys alone. This is particularly pertinent if payments for monitoring are involved, because significantly less time would need to be devoted to surveys (at least for medium- and large-sized community territories, *i.e.*, hundreds to several thousand hectares), and the approach remains cost effective when the costs of training community members in drone operation are factored in. If many communities in a region wish to employ

small drones, however, it may be more effective to have a single small drone owned and operated by a consortium of communities (if they exist), a regional-scale NGO that participates with the communities, or, in some circumstances, a local authority that has sound relationships with the communities involved.

- *Data acquisition decentralization*. This has substantial advantages not just for communities but also for partner organizations and forest data end-users, including government agencies [28]. For instance, gathering forest data through a drone-assisted CBFM approach would permit the creation or enhancement of national forest inventories in tropical countries, thus potentially improving the management of community forest resources and their participation in REDD+ projects [26]. We propose that prior to setting up a CBFM system supported by small drones, communities would agree with partner organizations on the frequency of image acquisition, spatial resolution and delivery format, and the accompanying information which communities would pass on to organizations (e.g., other data from complementary ground surveys, qualitative data on forest change drivers).
- *Enhanced monitoring of illegal activities*. Illegal timber extraction could be monitored with these systems, not only by monitoring forest cover change with time-series photography, but also by locating extraction trails and regular monitoring of the boundaries in real-time with videography [85]. Fire and illegal land-use change that alter forest cover (e.g., cropping, pasture expansion) could also be monitored timely, as could illegal exploitation of forest resources and wildlife poaching [86]. The enhanced ability of small drones to monitor illegal activities could be of great significance for communities whose land or other resources are being stolen by abutters, as is often the case in many tropical forests [106].
- *Access to inaccessible or remote areas*. Areas difficult to access within a community territory (e.g., steep slopes, rocky terrain, swamps, mangroves) could be surveyed with small drones [85]. In addition, remote territorial areas could be more easily reached by small drones. This would be particularly useful in forest communities with low population densities and large territories, which are common in many tropical countries.
- *Potential environmental benefits*. The use of small drones can substitute for the need for community members to open forest trails to reach and survey dense forest patches, thus reducing forest degradation and the risk of affecting rare or sensitive species. Additionally, the relatively quiet operation of small drones does not seem likely to disturb or distress wildlife and people [85].
- *Potential social and institutional strengthening of communities*. Similar to other mapping technologies (e.g., GPS, participatory GIS), the use of drone technology has the potential to empower forest communities. Such empowerment might lead to their social and institutional strengthening and communities might then be in a much better position, for instance, to negotiate payments under REDD+ or other PES programs (e.g., [12,22,23]). Thus, capacity-building in this arena may help forest communities access new financial assets.
- *Control of data acquisition and ownership would lie in community members' hands*. Based upon an appropriate agreement with partner organizations, community members could acquire imagery as often as desired [107] in order to gather relevant information for

themselves (e.g., for monitoring illegal activity in specific conflict zones) and that required by outside organizations (e.g., related to REDD+). Thus, communities would not need to adapt to a strict monitoring operations calendar independently set up by government agencies or companies in charge of satellites or piloted aircraft. Community drone users should have no legal restrictions regarding data acquisition as long as they do not violate flying regulations specific to small drones, whether safety, nuisance, or privacy. Moreover, data should be owned by the community so that it can become a relevant actor in any negotiation regarding their forests, particularly in connection with REDD+ projects.

5. Key Disadvantages of a Drone-Assisted Community-Based Forest Monitoring Approach

In this section we discuss the key disadvantages of using small drones in CBFM (see Table 1b for a list of all the disadvantages and their relative importance for communities, organizations and end-users). As before, we discuss disadvantages in a broad sense while considering the specific needs of REDD+ MRV systems.

- *Small payload*. Small drones are greatly constrained by the amount of equipment they can carry onboard owing to their small size and low weight. This limits the quality of the imaging sensors that can be fitted into a small drone, which together with the high price of professional small imaging sensors, hampers the acquisition of certain types of data and, therefore, of certain types of analyses that organizations and end-users might want to undertake.
- *Low spectral resolution*. Although small drones can be outfitted with a variety of sensors (e.g., multispectral, hyperspectral, lidar, radar) tailored to the specific needs of users, the high costs of such high spectral-resolution sensors makes their utilization unlikely in the case of CBFM, particularly if many communities wish to participate in the CBFM approach presented here for programs such as REDD+. However, the conventional RGB digital cameras frequently used in small drones might not suffice for certain tasks associated with scientific forest monitoring (e.g., leaf physiological properties), which need greater spectral resolution.
- *Poor geometric and radiometric performance*. First, because small drones are so much lighter than spaceborne and airborne sensing platforms, they are far more susceptible to pitch, roll and yaw distortions, which in turn affect the possibility of accurately georeferencing the imagery acquired. This problem is further aggravated by typically insufficient state-data recorded by low-cost small drones. Therefore, geometric distortions may be difficult to resolve even for remote sensing experts. In addition, accurate ground control points may be needed for image registration and ortho-rectification, which might be difficult for community members to gather due to the absence of evident landmarks over forested regions. Second, because cheap digital cameras are frequently used instead of professional imaging sensors, poor radiometry in image mosaics may lead to inaccuracies in the products derived. These geometric and radiometric problems may only be a problem for end-users when very accurate products are needed, however, and improvements in small drone technology are expected to overcome these issues within the next few years.

- *Low software automation*. Most common image pre-processing and processing tasks still require improvements in automation so that complex analyses can be done faster by organizations and end-users. This includes stitching imagery over densely forested areas and geometric and radiometric corrections if a great level of accuracy is needed, particularly in the case of time-series analyses. But again this issue is being rapidly improved by remote sensing software developers.
- *Sensitivity to atmospheric conditions*. Although small drones can usually fly sufficiently low so as not to be affected by cloud cover, other atmospheric conditions such as fog, heavy rain, and strong and variable winds can hinder their operation. For best imaging accuracies, wind speed should be as low as possible and, depending upon the specific drone model, typically they should not be higher than 15–25 km/h.
- *Short flight endurance*. This is potentially a very significant constraint because the low weight capacity severely restricts the size of the batteries a drone can carry. Nonetheless, this should not be a major constraint for CBFM unless a community's territory is very large. Flight times of around 50–60 min are currently feasible and can image up to 500 ha for a flight at 250 m altitude, which results in an extremely high spatial resolution of less than 10 cm per pixel side [108]. Several such missions could potentially be flown during one day from different locations within the community and thus map a relatively large area.
- *Possibility of collisions*. Small drones are not usually equipped with warning or evasion systems, and collisions can occur if flight input coordinates are entered incorrectly or if something enters their flight path [85]. There are dangers of collisions with power lines, cell phone masts, *etc.*, especially with inexperienced operators. Due to their airframe fragility, collisions pose a significant risk to small drones and warrant the need for training and acquiring expertise on flight path setting and manual maneuvering when needed. Yet, as drone operators would be community members who know the area well, this is not expected to be a major issue after adequate training. The availability of reliable digital terrain models might help better set up the flight altitude in mountainous areas, thus alleviating the possibility of collisions.
- *Potential problems for repairs and maintenance*. Drone repair is difficult for non-experts. This may pose a significant problem if crashes occur, the drone or any component breaks down, or something is lost or stolen. Hiring a mechanic or sending the drone for repair to the partner organization may significantly increase the operating cost and loss of flying time. Though such problems are rapidly decreasing due to technological improvements, without securing funds and trained personnel to perform repairs and maintenance as necessary, we would expect the utilization of drones in CBFM to be severely hampered in the short-term. A well-prepared operational plan for how to deal with these contingencies is essential.
- *Dependence on external assistance and funding*. Along with the need for assistance whenever a community-operated drone breaks down or needs maintenance, communities would be very dependent on initial training and continued funding from partner organizations or government agencies. However, determining the amount of external assistance needed for community training and how much external funding is necessary requires further investigation.

Nevertheless, we expect this disadvantage to diminish rapidly as technology is fast improving in terms of cost, quality and ease of use.

- *Ambiguous or cumbersome regulations for flying small drones*. The laws of many countries regarding the use of small drones are ambiguous. For example, in the USA, strict regulations and a cumbersome permit process impede their use, particularly in the case of non-commercial models. Strict regulations are repeatedly highlighted as a major impediment to the widespread adoption of small drones in research and civil applications [40,45,109]. In most tropical countries, however, clear regulations do not exist yet, and we do not expect very strict regulations for environmental applications such as CBFM. Actually, flying permits may not be needed for CBFM in communities with secure land tenure arrangements as long as flights are kept at low altitudes within community property.
- *Safety and security issues.* The operation of small drones in dangerous territories, such as community forests where illegal logging and farming, poaching, illegal drug production, land encroachment, or military activities might be taking place, may pose significant threats to the security of the drone operators, other community members, and even the partner organizations' personnel involved in the CBFM program. Although this is not a specific problem of drones, illegal actors might feel more intimidated by small drones than by people on the ground if they know of their surveillance capabilities (e.g., video recording).
- *Debatable relevance for community conservation and socio-economic development*. Communities must have a clear interest and commitment toward monitoring their forest resources in a "scientific" manner, particularly if they wish to participate in REDD+ or other PES programs. This approach to CBFM would not be relevant and could be antagonistic for communities that do not want to engage in externally-driven conservation programs and development projects on ideological grounds. Indeed, a reliance on drone technology usage could be felt as reinforcing trends toward "modernization" and provoking radical changes in the wants and aspirations of community members. Worryingly, such changes might lead to social conflicts within and among communities.
- *Potential social impacts*. The use of small drones for monitoring raises a series of social, cultural and political issues. Thus, for instance, drone technology usage might lead to community segmentation by widening the knowledge gap amongst technology users and other community members (younger/older, male/female) and by altering the existing internal power dynamics. Engaging in drone-assisted CBFM for REDD+ or other PES projects might cause communities to lose their material and perceived autonomy as regards their socio-economic and cultural traditions (e.g., decrease of time devoted to traditional activities in farming, hunting and foraging as a result of more time spent in forest measurement and monitoring, which may be detrimental for traditional knowledge conservation [110]). Employing small drones for CBFM should thus be subject to social approval and consensus from community members prior to implementation in order to avoid or reduce potential conflicts [111].
- *Ethical issues*. The most immediate ethical concern is the possibility of privacy violations and the requirements for free, prior and informed consent (FPIC). These issues are pertinent in all instances of the surveillance of people, their properties, resources and activities [35], but are

especially salient in the case of small drones because people may feel that a flyover is even further outside their control than are ground surveys. The misuse of drone technology for surveillance without acceptable transparency and communally-agreed rules of engagement could provoke severe conflicts amongst community members (e.g., accusations of privacy violations and spying). Partner organizations could be ultimately blamed for whatever problems that might arise amongst community members as a result of the introduction of drone technology (e.g., conflicts resulting from surveillance of private properties, whether as purposeful espionage or an unintended outcome of forest monitoring). Ethical issues would therefore be a particular concern for organizations introducing small drones to forest communities.

6. Expected Improvements in Forest Monitoring by Means of Small Drones to Support CBFM Programs

Given the substantial potential benefits of drone imagery outlined above, we suggest that outstanding improvements in CBFM could be achieved through the utilization of small drones, in addition to limited ground surveys in permanent plots. Aside from the benefits to tropical forest communities, these improvements might be of enormous interest to governments, NGOs and scientists, particularly in the context of REDD+ and other similar PES programs. Specifically, we expect the drone-assisted CBFM approach proposed and evaluated here could deliver improvements in four broad areas:

(1) Improvements in gathering spatially-explicit forest data at the community-wide scale, which is the first stage of data needs for sound CBFM [23]. Drone aerial surveys could be combined with participatory mapping approaches to better identify and map areas of particular interest (e.g., where deforestation, degradation or regrowth processes occur, community boundaries and conflict zones, forest areas under different land tenure arrangements, management types and rules, forest areas sensitive to natural hazards and illegal activities).

(2) Improvements in gathering spatially-explicit forest data at the plot level, which is the second stage of data needs for sound CBFM [23], even though less permanent plots might need to be surveyed and fewer forest variables might need to be measured in them. Plots would be accurately mapped rather than just surveyed on the ground, thus leading to the retrieval of more meaningful forest data.

(3) Achievements in (1) and (2) would lead to improvements in characterizing, at the community scale and for each forest type: (a) forest condition (*i.e.*, level of conservation, degradation or recovery); (b) carbon stocks and biodiversity levels; and (c) drivers of deforestation, degradation and regrowth. We posit that the data quality obtained from communities who engage in a well-designed drone-assisted CBFM approach would far exceed what is feasible without community participation using conventional forest monitoring approaches. In the context of REDD+, such data would be much more detailed than the requirements of the highest reporting level of the IPCC (*i.e.*, tier 3). The ability of small drones to map and quantify forest degradation and regrowth, and therefore to improve the estimates of carbon

emissions and sequestration related to both processes, would be particularly significant in the context of REDD+ MRV systems. In practice, the second "D" and the "+" of REDD+ are neglected to date, owing to the inability of conventional remote sensing imagery to accurately map degradation and regrowth [112,113], a problem further aggravated in the complex landscape mosaics often found across tropical forests [113].

(4) Improvements in the previous three areas could significantly enhance the modeling of carbon stocks and biodiversity levels at local scales according to different scenarios, as well as validate existing models. More accurate models at local scales would lead to more accurate scaling up to regional/national/international forest modeling efforts such as those commonly undertaken with remote sensing imagery of coarser spatial resolution (e.g., Landsat, MODIS, AVHRR). For instance, at present there is a significant mismatch between above-ground biomass field measurements and estimates from conventional remote sensing data [114]. We believe that a drone-assisted CBFM approach could help bridge this gap and thus improve scaling up above-ground biomass models from which to enhance the estimates of carbon stocks.

Although improvements in these four broad areas would be particularly significant for scientists and other data end-users (e.g., government officials), the improvements in (1) and, to a lesser extent in (2), would be relevant also to those communities that wished to engage in a drone-assisted CBFM approach under REDD+ (or under any project that required community members to monitor their forest resources on a regular basis).

7. Opportunities and Constraints for Designing and Launching Drone-Assisted Community-Based Forest Monitoring Programs in Tropical Forests

In this section we discuss further some of the main advantages and disadvantages identified in the previous two sections with the aim of flagging key opportunities and constraints for deploying drone-assisted CBFM programs in tropical countries. We also explain how we envisage a feasible drone-assisted CBFM program in the short-term and give some recommendations about its implementation in tropical contexts, placing emphasis on the needs of REDD+ MRV systems.

On the one hand, the ability to acquire extremely high spatial resolution imagery and at high survey frequencies suggests that the utilization of small drones in CBFM programs would substantially improve what can be "seen" from the air in tropical forests, which would be extremely important for forest data end-users as discussed above. Moreover, having frequent imagery with this level of detail should make it more attractive for communities to engage in CBFM programs because, in addition to potential payments from REDD+ or similar PES programs, communities would be able to better monitor their own territory to spot illegal activities such as logging, mining or land encroachment, as well as support any territorial claims they might have. Forest communities might also be empowered by using drone technology if they retained the control of data acquisition and ownership, which could lead to their social and institutional strengthening, thus potentially improving community forest governance and opportunities to negotiate claims regarding their forest resources under REDD+ or similar programs. Drone-assisted CBFM programs should significantly contribute to the decentralization of forest data acquisition and forest management. This would be advantageous for partner organizations and governments in terms of their budget and time constraints insofar as communities retrieved forest data and adhered to the sustainable management strategies deemed necessary to support national and international forest conservation efforts such as REDD+ [18,28,115]. Furthermore, a well-designed drone-assisted CBFM program should be cost-effective for partner organizations and governments for at least three reasons. First, the costs related to purchasing small drones, training communities to acquire imagery, and performing drone repairs and maintenance would be low compared to acquiring other remote sensing imagery of very high spatial resolution at short time intervals. Second, a drone could be used by several different communities if necessary. And third, the involvement of communities in forest monitoring enables the incorporation of their local knowledge of forests, which should be invaluable as regards the spatio-temporal distribution and direct drivers of forest loss, degradation and regrowth.

On the other hand, several constraints still exist that may cast doubts on the feasibility of launching a successful drone-assisted CBFM program in tropical areas. For example, it is uncertain if country-specific airspace regulations will restrict the use of small drones in communities, although it is unlikely that flying at low altitude within the territorial limits of communities will be prohibited. Also, it is uncertain if the most tropical forest-dependent, traditional societies (*i.e.*, the least acculturated and integrated into the market economy) will be interested in engaging in drone-assisted CBFM in the short-term. Even in communities potentially interested in participating, such as those wanting to engage in REDD+ or similar PES projects, there might be community members opposed to such engagement. We acknowledge that, as happens with the introduction of any technology in rural communities, the introduction of drones can pose a real risk of creating tension and conflicts between community members, and among different communities within the same society. Ethical issues should always be taken into account by researchers, partner organizations, and community leaders. Safety and security issues where illegal activities take place in the forest and violence may be exerted against drone operators and assistance personnel should also be carefully considered.

In addition, for the case of communities whose members are willing to participate in a drone-assisted CBFM program, it is not clear how the communities could approach partner organizations or government agencies to engage in such a program, and what criteria the latter would use to select eligible communities. At this point, we think that attempts to introduce this CBFM approach will have to come from partner organizations and government agencies rather than from communities, though this situation is likely to change in the near future as civil drones' popularity is rapidly increasing [116]. We suggest that small drones could already be used to support ongoing CBFM programs, particularly those related to REDD+ pilot projects, as a way to test their potential to improve monitoring tasks. At the same time, such pilot studies should make their potential negative social impacts visible, as well as the constraints set by the continued need for external assistance and funding for drone repairs and maintenance. To pursue a drone-assisted CBFM, we suggest that forest communities would first need to select at least two or three community members who ideally would be computer-literate, have previous experience in managing their forest, and have good communication skills to liaise with partner organizations' personnel and other stakeholders. The participation of women should be encouraged because they usually have specific knowledge of their forests owing to gendered management tasks and therefore women can enrich CBFM programs and should benefit from them [117,118]. Such people would have to receive specific training for as long as necessary [119] so that afterward they would be able to acquire drone imagery of their community forests and visually inspect them to detect areas and types of forest change. Such imagery should then be handed over to partner organizations in a specific format and at specific time intervals, together with the ancillary information previously agreed upon (e.g., a georeferenced image mosaic covering the entire or a specific part of community forests, with information about the direct causes of deforestation, degradation and regrowth). After data delivery, remote sensing analysts and other scientists from partner organizations and/or government agencies would analyze the drone imagery and ancillary data to ensure that the scientific requirements of the funding program (e.g. the MRV system of a REDD+ project) were met. Critically, communities should be timely informed of project results by partner organizations and should retain data rights to use data according to their own convenience and interests. Finally, communities should be allowed to use drones for non-scientific purposes too, most notably for territorial surveillance.

8. Conclusions

In this paper we have evaluated the prospects, challenges and opportunities of using small drones for CBFM in tropical areas as a way to improve forest monitoring, which is central to effective REDD+ implementation and other conservation efforts. The subject is very topical and relevant because the reduction and prevention of tropical deforestation and forest degradation is a climate mitigation option with a large and immediate carbon impact globally [31,32], and is essential to global biodiversity conservation [2]. Given the rapid drone technology developments, we argue that the drone-assisted approach to CBFM suggested and evaluated in this paper has a great potential to enhance CBFM. We suggest that this approach is feasible in many tropical locations as long as some degree of community forestry already exists or communities have expressed sincere interest in implementing these new technologies. We expect that most of the current constraints and challenges identified in our assessment will be surmounted relatively soon as technology is rapidly improving in terms of cost, quality and ease of use by non-experts.

In addition, we posit that the utilization of small drones for CBFM in tropical forests has potential benefits for livelihood support despite the potential social problems we have discussed. This CBFM approach could represent an excellent opportunity for communities wishing to enhance their institutional capacities for natural resource governance and thereby the management and conservation of their forest resources, regardless of whether they wish to engage in REDD+ or other similar PES programs as a way to diversify their income sources. The utilization of small drones by communities in CBFM programs should also bring substantial benefits to partner organizations and forest data end-users, who need to respond to current international forest policy data requirements, particularly those of REDD+. Nevertheless, before attempting to implement a drone-assisted forest monitoring program based on communities, the potential advantages and disadvantages should be assessed on a case-by-case basis in accordance with the development pathways communities want to pursue, as well as the specific project needs of the partner organizations and end-users.

Overall, the utilization of small drones in CBFM programs has significant potential co-benefits for carbon and biodiversity conservation as a result of improvements in forest monitoring and the capacity to create or enhance national forest inventories in tropical countries, which is key in REDD+ MRV systems. Therefore, organizations engaged in REDD+ and government agencies working on REDD+ preparedness should explore and test the most appropriate CBFM approaches that can be integrated into their forest monitoring and safeguard information systems. The drone-assisted CBFM approach put forward and evaluated in this paper could be a good candidate in such efforts because, despite its great potential, empirical research is needed to test it. In our view, the primary issues that need to be carefully examined are the socio-cultural, political and ethical impacts of introducing this monitoring approach in communities, their relevance for community development, and the degree to which communities would need external training, assistance and funding for drone operation.

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Author Contributions

Jaime Paneque-Gálvez and Michael K. McCall designed research. Jaime Paneque-Gálvez performed research. Jaime Paneque-Gálvez wrote two drafts that were reviewed and improved by Michael K. McCall, Brian M. Napoletano, Serge A. Wich and Lian Pin Koh. Jaime Paneque-Gálvez revised the manuscript and the rest of authors read and approved its contents.

Conflict of Interest

The authors declare no conflict of interest.

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88. Further information can be found in the Internet on websites such as http://conservationdrones.org/, http://rhino-uav.org/, http://www.iapf.org/en/campaigns/iapfdrone, http://wwf.panda.org/?206154/nepal-tests-new-unmanned-aerial-vehicle-technology-to-stop-wildlife-crime.
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91. It is important to note that while most environmental applications presently use small drones, there is a trade-off between the size of the drone and the accuracy of the data that it can collect.
92. However, we are aware of instances where such drones have covered up to 50 ha, so they may serve in small forest communities.
93. Vertical landing is also advantageous because the lower speed inherent to this type of landing reduces the likelihood of the equipment suffering impact damages.

94. Note, however, that many of the publications cited in this paper have not used small, fixed-wing aircraft.
95. Most probably the partner organizations and forest data end-users would be government agencies, environmental or development NGOs, and research teams. Note that partner organizations would not necessarily be data end-users and also that community members might also, in certain instances, become data end-users.
96. We believe that the approach which we envisage for the entire process of implementing CBFM assisted by small drones is the most feasible and desirable in the short-term, particularly given current constraints. However, we expect that as technology becomes easier to use and forest monitoring decentralization advances, forest communities could undertake all the necessary processing tasks without the assistance of partner organizations. This premise might also be valid for drone repairs and maintenance in certain cases, but this technological diffusion will be likely be slower and more problematic.
97. Importantly, partner organizations and governments could use this spatial information to produce highly accurate maps of forest cover change. Moreover, coupled with community local knowledge of the main drivers of such forest change, the quality of data obtained from communities would far exceed what is feasible to achieve without their participation, and would be much more detailed than the requirements of the highest reporting level of the IPCC (*i.e.* tier 3).
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108. Note that at equal camera sensor size and focal length, the lower the flight altitude, the higher the spatial resolution of the imagery acquired (*i.e.* the smaller the pixel size). Currently, small drones can acquire imagery at a spatial resolution of even 1–2 cm per pixel side (e.g., 2.2 cm flying at 100 m above the ground using a camera with a sensor size of 6.17 × 4.55 mm and a focal length of 6.9 cm; see for instance [80]).
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119. We do not think more than two weeks would be needed, even for community members failing to meet the two main criteria for selection (computer-literacy and experience in forest management), particularly if drones are to be used with an autopilot system (*i.e.*, in automatic or semi-automatic flight mode). This issue, however, requires further investigation.

Community Monitoring of Carbon Stocks for REDD+: Does Accuracy and Cost Change over Time?

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Abstract: Reducing emissions from deforestation and forest degradation in developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries (REDD+) is a potentially powerful international policy mechanism that many tropical countries are working towards implementing. Thus far, limited practical consideration has been paid to local rights to forests and forest resources in REDD+ readiness programs, beyond noting the importance of these issues. Previous studies have shown that community members can reliably and cost-effectively monitor forest biomass. At the same time, this can improve local ownership and forge important links between monitoring activities and local decision-making. Existing studies have, however, been static assessments of biomass at one point in time. REDD+ programs will require repeated surveys of biomass over extended time frames. Here, we examine trends in accuracy and costs of local forest monitoring over time. We analyse repeated measurements by community members and professional foresters of 289 plots over two years in four countries in Southeast Asia. This shows, for the first time, that with repeated measurements community members' biomass measurements become increasingly accurate and costs decline. These findings provide additional support to available evidence that community members can play a strong role in monitoring forest biomass in the local implementation of REDD+.

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1. Introduction

The UN Framework Convention on Climate Change (UNFCCC) introduced reducing emissions from deforestation and forest degradation (REDD) as an international fund- or credit-based mechanism for reducing carbon emissions and protecting forest ecosystems. Since the launch of the idea, REDD and its development into REDD+, has received enormous interest from developing countries as a potential source of international funding for an ailing forestry sector. To date, more than 40 developing countries have developed REDD readiness plans and initiated REDD+ 'readiness' activities [1].

The UNFCCC decision FCCC/CP/2010/7/Add.1. [2] at the Convention of Parties meeting 16 (COP16) in Cancún encouraged developing country Parties to contribute to climate mitigation actions in the forest sector, through the REDD+ mechanism [3]. The following activities were proposed for implementation as deemed appropriate by each Party and in accordance with their respective capabilities and national circumstances: (a) Reducing emissions from deforestation; (b) Reducing emissions from forest degradation; (c) Conserving forest carbon stocks; (d) Sustainably managing forests; and (e) Enhancing forest carbon stocks.

Thus far, most countries that have developed REDD+ readiness programs have not undertaken many of the above activities. Instead, our review of 10 REDD+ Readiness Preparation Proposals (R-PPs) shows that countries and their development assistance partners have focused on solving challenges related to quantifying forest cover changes and carbon stocks, and calculating reference emission levels within the "business as usual" scenario, or the changed scenario related to the implementation of activities under REDD+. Very few have paid attention to how REDD+ could be implemented in ways that involve local communities and to ensure their active participation [1,4,5].

Hence, despite the enormous potential of REDD+ for conservation of tropical forest ecosystems and the improvement of livelihoods for forest-dependant people [6], various concerns have been raised regarding possible negative outcomes of REDD+ activities [7–12]. One of the specific questions that have arisen in many tropical countries is how the rights of indigenous peoples and local communities over forest lands and resources will be dealt with as REDD+ programs are implemented [13–15]. These rights include the sharing of benefits arising from the REDD+ programs, participation in the decision-making related to the programs, and the respect for indigenous and local knowledge on forest resources [16]. Without adequate protection of these rights, there are concerns that indigenous peoples' and local communities' livelihoods and access to resources and culturally important areas, will be disrupted in the name of broader efforts to substantially reduce or halt deforestation [16].

Another key debate surrounding the development of REDD+ relates to costs [17–19]. Opportunity costs are generally considered to be the largest cost component of REDD+ and have been estimated globally and regionally [20,21]. Although opportunity costs are critical in the assessment of REDD+, the set-up, implementation, and monitoring costs of REDD+ projects may also form a significant portion of the total project costs [18,22–24]. Thompson *et al.* (2010) [19] found that on average about 20% of the total transaction costs were due to monitoring.

One of the main tools which REDD+ may employ to assess compensation and benefits to be distributed to participating communities is the monitoring of carbon stocks and identification of foregone benefits in relation to the five types of REDD+ activities. To date, REDD+ monitoring has focused on remote sensing and generally involves foreign experts and national consultants [18]. However, reliance on outside experts to set up and even run forest carbon monitoring is not only expensive [25], but may also offer an excuse for recentralization of forest governance and the exclusion of local people [13,26].

Where the aim of monitoring is to obtain forest biomass data for management decisions at the local scale, alternative monitoring approaches that involve local people are emerging [27–31]. It has been suggested that such approaches have considerable potential to complement professional monitoring in developing countries because they may be relatively cheap. Furthermore, community based monitoring has been shown to have positive effects on safeguarding local forest rights and forest access and to promote local involvement in decision-making [32,33]. Another benefit of forest carbon measurements by community members is that it may reduce transaction costs of the monitoring so that it is economically viable for poorer communities to become involved in carbon finance projects [34].

Locally based monitoring approaches are susceptible to various sources of bias. Problems include a risk, in the absence of careful documentation, of methods drifting over time, differences in scale, or of results reflecting long-term perceptions more than current trends [30,35]. Quantitative assessments of the accuracy of carbon stock assessments by local communities are scarce [18,36,37]. Available studies have focused on a comparison of static findings—*i.e.*, above ground woody biomass (AGB) at a single point in time. Trends in the accuracy of forest biomass community monitoring over time has not been examined, and temporal trends in costs have been briefly investigated by one case study only [18].

The present study aims to help fill our gap in knowledge on: (i) the development in accuracy of community based monitoring of carbon stocks over consecutive years and costs of community monitoring of above-ground forest biomass over time; and (ii) the start-up costs and trend(s) in costs for community based monitoring of carbon stocks, compared to monitoring carried out by professional foresters. We hypothesized that community members involved with monitoring would learn from experience and hence the accuracy of measurements would increase over time and, simultaneously, that the costs of community monitoring would decrease over time as community monitors became more self-sufficient and would need less training.

2. Methods

2.1. Study Sites and Data Collectors

We collected new data from permanent vegetation plots in nine forest types of Indonesia, China, Laos, and Vietnam. Study sites were opportunistically chosen in the four countries. Among the selection criteria were the usage by local communities of the candidate forest sites and the potential for reduction in forest degradation.

In East Kalimantan, Indonesia, plots were established in Batu Majang Village, Kutai Barat District, in the Province of East Kalimantan, in lowland dipterocarp forest (40–500 m.a.s.l.; 400 ha). On forest margins, a few large trees were harvested by the local community, but most of this forest has remained unmanaged over the last decades [38]. The study site in China was in Manlin village in Xiangming township of Xishuangbanna Autonomous Prefecture, Yunnan Province. It comprises tropical mountain forest at 900–1200 m.a.s.l. In total, 761 ha in two forest types were surveyed; slightly disturbed forest (470 ha) and moderately disturbed forest (291 ha), including overgrown swidden fields and areas with ancient tea trees mixed with natural forest vegetation. In Laos, a site was established in Ban Sakok village, Viengthong District, Hauphan Province. It comprises hilly evergreen monsoon forest at 600–1600 m.a.s.l. In total, 162 ha in two forest types (100 ha and 62 ha) were surveyed; primary closed forest and disturbed open forest surrounded by old and new swidden fields. In Vietnam, the study sites were in Diem and Moi villages in Con Cuong District, Nghe An Province, within lowland evergreen monsoon forest between 160 and

460 m.a.s.l. In total, 314 ha in four forest types (125 ha, 104 ha, 67 ha and 18 ha) were surveyed. The degree of disturbance varied from undisturbed forest to secondary forest, severely degraded forest, and forest regrowth in former swidden fields. The study sites are described in detail in Danielsen *et al.* (2013a) [37].

Plots were measured independently by both community-members and professional foresters between September 2011 and May 2012 [37] and re-measured by the same teams between January and July 2013 for the present study. Representatives of the local communities helped select community participants for the monitoring based on their interest and experience with forest resources; hence, these community members are probably more skilled than the average villager. All community monitors had attended primary school, and all received 1–2 days training in methods and approaches from intermediate organizations (research organizations and non-governmental organizations (NGOs)) in the first year of measurements and a one day refresher training before second years' measurements. In addition, the intermediate organizations supervised the community monitors in mapping forest areas and locating plots with GPS devices for 3–5 days in each study site during the first year and for 1–2 days during the second year after refresher training. The professional monitors all had academic degrees in natural sciences, and on average four years of experience in practical forest assessment.

All communities were in rural areas. The community in Kalimantan was connected to other communities only by river and relied mainly on subsistence agriculture, while the sites in China, Laos and Vietnam were connected by road. Villagers in Laos and Vietnam sold part of their agricultural produce at markets, whereas villagers in China were involved in rubber tapping in plantations and were relatively wealthier.

The forest types monitored encompassed a wide range of land tenure and usufruct rights, *i.e.*, communal forest (Indonesia), collective forest (China), State forest (China), and State forest with user rights allocated to villagers (Laos and Vietnam).

2.2. Methods for Measurements of Forest Carbon

To measure forest biomass, we used a simplified version of the radial nested sampling methods described by Verplanke and Zahabu (2009) [39] and Hairah *et al.* (2011) [40] (for details see Danielsen *et al.*, 2013 [37] Appendix S2). This method was chosen because it was considered important to keep the measuring technique as simple as possible, to reduce the potential bias due to technical error (*i.e.*, incorrect estimation of tree-heights, incorrect demarcation of more complex plot-designs, *etc.*) [41]. Community members first identified the total forest area to be monitored on printed maps with the assistance of an intermediate organisation (IO). Based on available knowledge of forest history (*i.e.*, previous logging or swidden agriculture), the community members and the staff of the IO then stratified the forest into homogenous areas (hereafter termed "stratum") that were treated as independent entities in the monitoring.

In each stratum, the community members and IO's staff randomly selected 15 pilot plots, where biomass stock variability was assessed. Based on this, the total number of sample plots required to estimate the average biomass stock per stratum with an error <20% was computed following Wagner *et al.* (2010) [42].

Based on this pre-analysis, IO's staff randomly picked up the appropriate number of permanent sample plots (PSP) on the map. The community members, supervised by one IO staff, and the professional foresters carried out independent forest inventories at each PSP with a maximum time lag of four months. PSP were re-measured by both community members and foresters about 1.5 years after initial measurements. To optimize comparison among both measurements, the same monitoring method and materials were used. As not all community members involved in the first census were available, each team in the 2nd survey included at least two veterans from year 1. Professional foresters were in most case the same, or if not, had similar monitoring experience and education level.

The girths of all trees with girth ≥30 cm (as a proxy for diameter breast height (DBH) ≥ 10 cm) and with girth ≥100 cm (DBH ≥ 30 cm) were measured at 130 cm height from tree base within a radius of 9 m and 15 m from plot centre, respectively. In Vietnam and Laos (year 1), and all countries (year 2), each measured tree was furthermore numbered to allow a tree-to-tree comparison of girth measurement between observers. IOs entered the data into Excel and estimated the total tree AGB using Pearson's allometric equation [43]. This allometric equation model has been widely used, notably in the context of REDD+, and is recommended by the Intergovernmental Panel on Climate Change (IPCC) guidelines [44] for estimating carbon stocks in tropical forests.

Analysis of the forest monitoring data and their costs was done in MS Excel. We used Student's *t*-test on log transformed data for estimating the accuracy of the identified AGB, and Wilcoxon's signed rank test on non-log transformed data for estimating the accuracy of plot demarcation and measurement of DBH across plots, strata and sites at a significance level of 0.05. We assumed that the forester values were more accurate than those from communities, and thus the foresters' measurements were used as a benchmark and community monitors results were compared against this.

2.3. Methods for Calculating Costs

Costs of community-based and professionally-executed measurements were calculated using the actual costs incurred for local transport, salaries, and materials during the training, re-fresher training, and fieldwork at each study site in year 2. To eliminate the additional costs incurred for extra staff and transportation for research purposes, the costs have been calculated including one day of refreshment training and a further 2 days of supervision in all sites. To this has been added the costs for community monitoring for all days that community monitoring activities occurred. This is consistent with the methodology used for cost calculation for year 1 as presented in Danielsen *et al.* (2013) [37] Appendix S3. The only changes from this methodology are, (i) because of new agreements with community monitors, "food for data gatherer" has been included in the "community members salaries"; and (ii) "training and supervision" has been split up into "Transport", "Foresters salaries" and "Accommodation" as these are the three main components of the work covered by the "Training and supervision" category in Danielsen *et al.* (2013) [37] Appendix S3. None of these changes impact the compatibility of the two cost calculations, and so comparison of costs across the two years is considered viable.

3. Results

3.1. Does Accuracy of Community Measurement of Biomass Increase with Greater Experience?

We compared community and foresters estimates of biomass. The above ground woody biomass (log-transformed) at all sites was normally distributed (Shapiro-Wilk skewness > −0.8/0.8 and visual confirmation of bell curve). We found that the biomass estimates obtained by community members differed only slightly from the estimates of professional foresters (Figure 1, Table 1). Whereas this difference was statistically significant in one-third of the sites (three sites out of nine) in year 1, the following year, the difference was significant in only one site out of nine (*t*-test, $p < 0.05$, Table 1). At this site, the community and forester biomass estimates differed with <3 ton/ha suggesting a small but systematic difference in measurements at this site (Moi stratum 2).

Figure 1. The identified above-ground woody biomass as measured by community monitors (blue) and professional foresters (red) in the two separate monitoring rounds done from September 2011 to May 2012 (Dark) and again from January 2013 to July 2013 (Light); error bars represent 95% confidence limits.

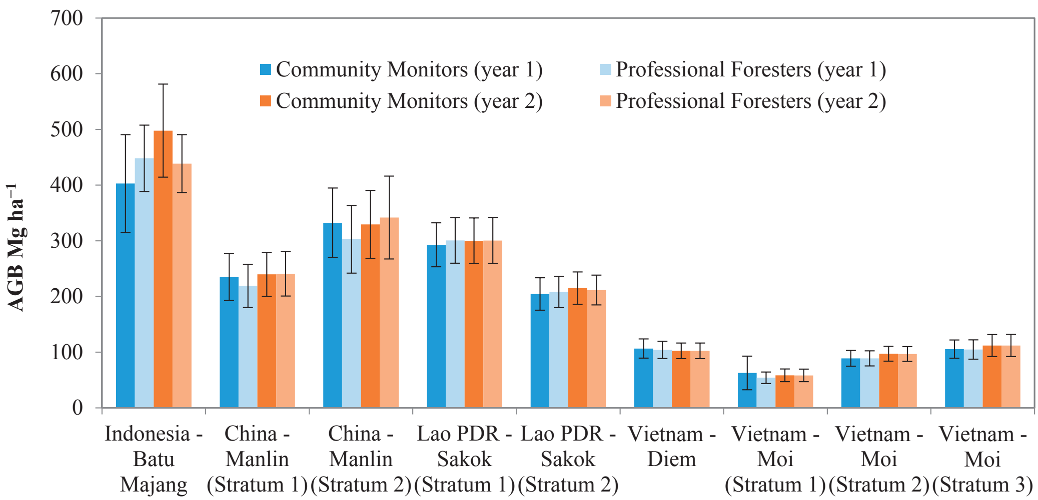


Table 1. Measurements of aboveground biomass by community members and professional foresters in four Southeast Asian countries, with p values for total AGB estimates (matched pair t test), tree DBH measurement (Wilcoxon signed rank test), and plot demarcation (Wilcoxon signed rank test) (n = 289 permanent plots); percentages equals proportion of plots (inclusion and exclusion of trees) and trees (tree girth) where community members' and professional foresters' measurements matched perfectly; n.a.—not available or too few degrees of freedom for analysis.

Study Site	No. of plots	Biomass Mean AGB in Mg ha^{-1} Year 1		Biomass Mean AGB in Mg ha^{-1} Year 2		Biomass estimates p		Tree girth (cm) p		Plot demarcation (Tree inclusion and exclusion) p	
		Community	Forester	Community	Forester	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Batu Majang	64	402.9	448.1	497.8	438.5	**<0.01**	0.19	n.a.	0.22 (4%)	<**0.01** (20%)	**<0.01** (48%)
Manlin 1	30	234.9	219.0	239.7	240.8	0.46	0.96	n.a.	0.54 (42%)	0.16 (0%)	0.49 (66%)
Manlin 2	30	332.3	302.7	329.5	341.7	**0.02**	0.69	n.a.	0.72 (26%)	0.25 (23%)	>0.9 (73%)
Sakok 1	32	292.8	300.6	299.9	300.5	0.19	0.82	**<0.01** (38%)	0.31 (38%)	n.a. (97%)	0.52 (69%)
Sakok 2	30	204.5	208.1	215.0	211.6	**0.03**	0.74	**<0.01** (52%)	0.27 (63%)	n.a. (88%)	n.a. (90%)
Diem 1	30	106.5	104.1	102.3	102.4	0.49	0.51	0.59 (47%)	0.78 (77%)	0.02 (60%)	n.a. (100%)
Moi 1	27	62.6	54.0	58.5	58.3	0.90	0.47	**0.01** (47%)	0.28 (66%)	0.38 (56%)	n.a. (100%)
Moi 2	28	89.0	88.9	97.2	96.7	0.91	**0.03**	0.36 (53%)	**0.02** (72%)	0.05 (50%)	n.a. (100%)
Moi 3	18	105.5	104.7	111.9	112.0	0.41	0.90	0.051 (54%)	0.81 (78%)	0.67 (22%)	n.a. (100%)

Biomass calculation requires the demarcation of the right trees, *i.e.*, only those trees inside the plot, and the measurements of tree girth. We first compared community and forester inclusion or omission of trees in plots. We found that from year 1 to year 2 the plot demarcation by community monitors improved in five out of six sites (Figure 2, Table 1). For Diem and Moi (Vietnam), community members and professional foresters included exactly the same number of trees in each plot in year 2 (from 11 to 36 trees/plot). For one site (Sakok 1), the correspondence between community members and foresters in terms of trees included per plot decreased from year 1 to year 2. For one site (Batu Majang), there was a significant difference in plot demarcation between community members and foresters both in the first and the second year. To further understand the accuracy of the community monitors estimation of AGB, we then compared community and foresters estimates of tree girth. In two countries, Laos and Vietnam, trees in plots were numbered in the first year allowing for a 1:1 comparison of tree girth measurements in two consecutive years. In these two countries, we found that from the first to the second year the accuracy in girth measurements improved substantially for five of six sites (Figure 3, Table 1). For one site (Moi stratum 2), a higher proportion of the trees were measured accurately (44% to 72%), yet we found a decreased *p*-value (0.36 to 0.02) at this site from the first to the second year. In the other two countries, Indonesia and China, the individual trees were not marked before the second year. Tree girth measurements can, therefore, only be compared for the second year. Here, we found no statistically significant difference in tree girth measurements between community monitors and foresters (*p*-value range from 0.22 to 0.72) (Table 1).

3.2. Do Costs of Community Measurement of Biomass Decrease with Greater Experience?

Our results show that transportation and salaries constitute the major element of the monitoring costs across all countries and sites, both for community members and professional foresters (62% to 90% of total costs). The cost of wages depends both on the time spent monitoring, and the pay-grade of the involved monitors. On the other hand, costs of accommodation and equipment were consistently low (10% to 38% of total costs) (Table 2).

In the first year, community measurements were more expensive than those carried out by foresters across all sites. However, we found that the cost of community monitoring decreased for all sites from year 1 to year 2 by between 6 and 46 percent. In contrast, the cost of professional foresters decreased in two sites but increased for three sites from year 1 to year 2. Overall, we found that community monitoring was consistently cheaper than professional foresters' for 4 of 5 sites in year 2 (Table 2 and Figure 4). We also found a marked decrease in the monitoring cost per hectare with increasing site areas for both community and professional foresters (Figure 4).

Figure 2. Relationship between the number of trees in each plot (*n* trees/plot) recorded by community members and foresters (with same units on *y*-axes as on *x*-axis and *y* = *x* lines; *n* = 289 permanent plots) over the two separate rounds of monitoring year 1 (blue square) and year 2 (red triangle); each point in the graphs represents one census of the number of trees in the plot by foresters (*x*-axis) and community members (*y*-axis).

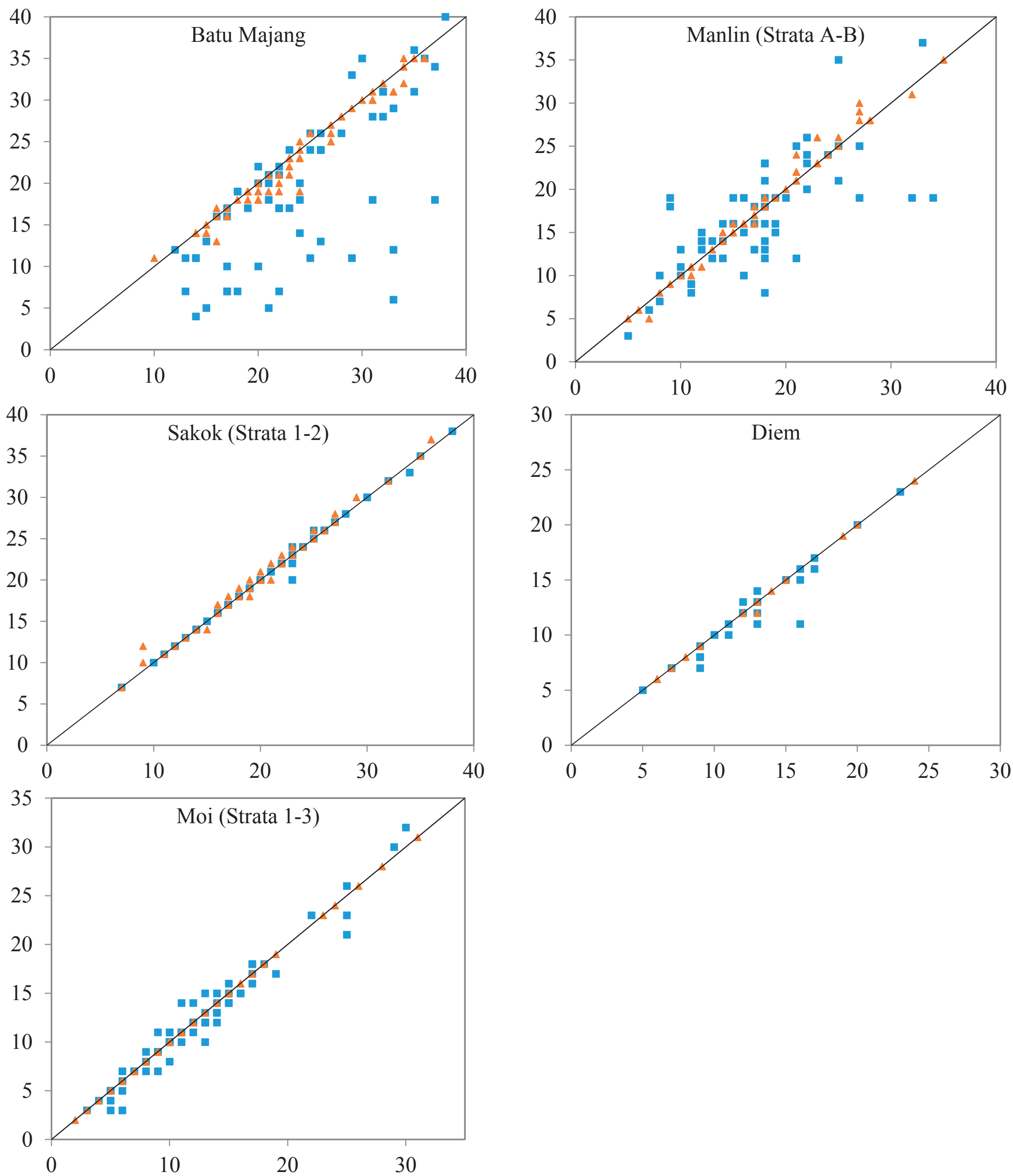


Figure 3. Relationship between the DBH of individual trees recorded by community members and foresters in year 1 (blue square) and year 2 (red triangle) (with same units on *y*-axis as on *x*-axis and *y* = *x* lines; *n* = 289 permanent plots); each point in the graphs represents one census of a single tree DBH as measured by foresters (*x*-axis) and community members (*y*-axis); Batu Majang and Manlin Strata 1–2 does not have any measurements from the first round of monitoring (blue square) as trees were not marked individually in year 1.

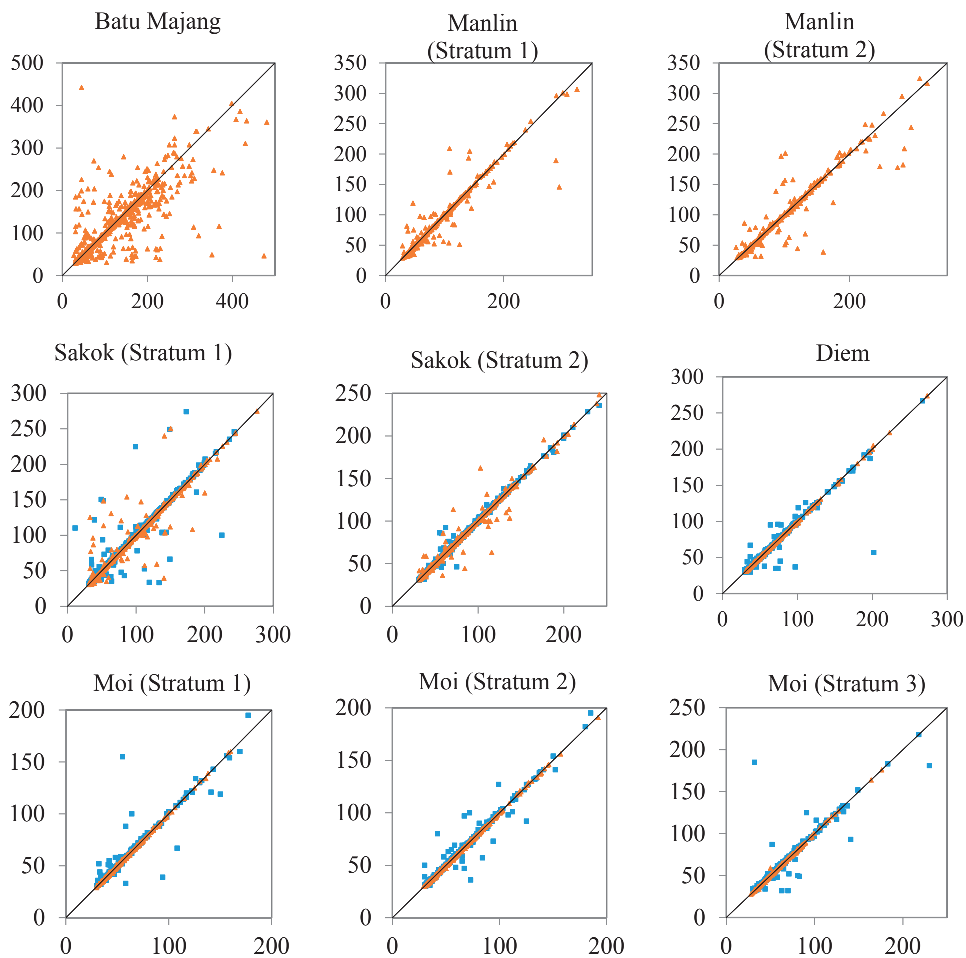
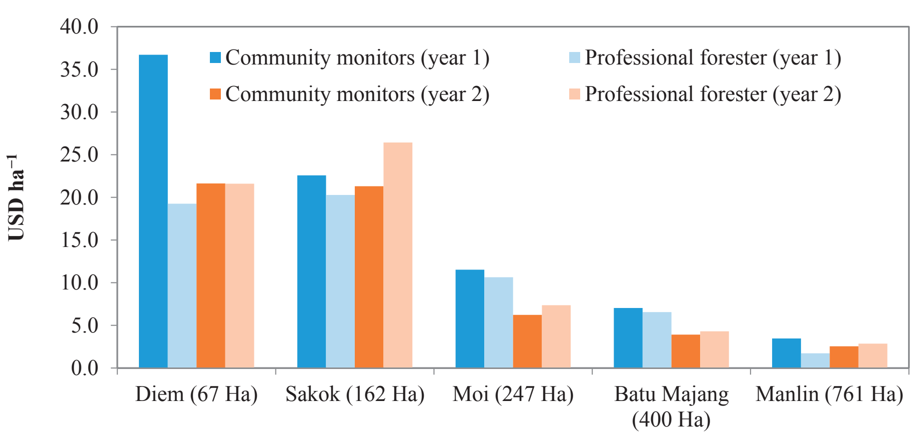


Table 2. Cost of community (white) and professional forester (grey) surveys of biomass (AGB) in the five sites; breakdown of costs is provided for measurements year 2; the cost per plot is provided for year 1 (found in Danielsen *et al.* (2013) [37]) and year 2; all costs are in US$/year.

Name of site	Area (ha)	Transport USD/year	Community members salaries	Forester salaries	Accommodation	Equipment	Total cost (year 2)	Cost/ha (year 1)	Cost/ha (year 2)
Batu Majang	400	307 (20%)	540 (34%)	130 (8%)	195 (12%)	395 (25%)	1567	7.0	3.9
Batu Majang	400	307 (18%)	462 (27%)	416 (24%)	144 (8%)	395 (23%)	1724	6.6	4.3
Manlin 1 + 2	761	533 (27%)	870 (45%)	336 (17%)	144 (8%)	56 (3%)	1939	3.5	2.5
Manlin 1 + 2	761	533 (25%)	528 (24%)	720 (33%)	336 (15%)	56 (3%)	2173	1.7	2.9
Sakok 1 + 2	162	2550 (74%)	360 (10%)	490 (14%)	0 (0%)	52 (2%)	3452	22.6	21.3
Sakok 1 + 2	162	2550 (60%)	140 (3%)	1540 (36%)	0 (0%)	52 (1%)	4282	20.3	26.4
Diem	67	1000 (69%)	180 (12%)	88 (6%)	83 (6%)	100 (7%)	1451	36.7	21.6
Diem	67	1000 (69%)	90 (6%)	175 (12%)	83 (6%)	100 (7%)	1448	19.3	21.6
Moi 1–3	247	1000 (65%)	270 (18%)	88 (6%)	83 (5%)	100 (6%)	1541	11.5	6.2
Moi 1–3	247	1000 (55%)	210 (12%)	315 (17%)	193 (11%)	100 (6%)	1818	10.6	7.4

Figure 4. Cost USD ha^{-1} for community monitors and trained foresters in the monitoring year 1 and 2.



4. Discussion

4.1. Trends in Accuracy of Biomass Measurements

We find that the correspondence in biomass data between community monitors and trained foresters generally improved from the first to the second round of measurements. Hence, accuracy in community biomass estimates increased in seven of the nine forest strata. For example, the *p*-value, indicating the level of agreement between the separate measurements for the identified biomass in Manlin stratum 1 and 2, has increased from 0.46 to 0.96 and 0.02 to 0.69, while Sakok Stratum 2 has increased from 0.03 to 0.74 (Table 1). The improved overall correspondence between community monitors' and professional foresters' measurements of biomass suggests that community members capacity to monitor biomass increases with repeated measurements and added experience although discrepancies still occur.

The accuracy in community plot demarcation (inclusion and exclusion of trees) increased for 8 of 9 strata in the second year (Table 1). The decreased accuracy in tree inclusion and exclusion by community monitors in Sakok stratum 1 in the second year of measurements is believed to result from trees that were <10 cm DBH in year 1 but which should have been included in year 2 (DBH > 10 cm). The large differences between community and forester measurements in some plots in Manlin and Batu Majang (Figure 2), could have a similar explanation, or be a result of difficult terrain, dense undergrowth leading to trees being overlooked by community monitors (or foresters) and the overall extremely diverse makeup of these forests, evident in the large confidence limits shown in Figure 1. The accuracy in community measurements of tree girth increased for five of the six strata where trees were marked (Table 1).

Inaccuracies that are observed may be the result of a number of introduced biases ranging from different criteria for tree mortality, accidental omission of trees caused by thick undergrowth, steep slopes or fatigue or misunderstood or ineffective instructions. The decreased accuracy of community monitors DBH measurement in Moi stratum 2 and plot demarcation in Sakok stratum 1 in the second year (Table 1) underlines the importance of continued attention to technical errors in refreshment training, and the importance of using simple data collection approaches. A solution for identifying and mitigating this in future REDD+ activities could be to have the plot establishment and baseline monitoring done by a joint team of trained foresters and community monitors, enabling thorough training of community monitors in a supervised environment and a good baseline to compare future community based monitoring against.

4.2. Trends in Cost

The total cost of wages depends on the time and number of people involved, both influenced by the skill of the measurers, the difficulty of the task and the distances and ease of moving around in the terrain. All three of these are dynamic; the skill of the measurers is increasing (at least for community monitors); the difficulty of the task decreases as the plot network is known; and the ease of moving increases as paths are established. However, the difficulty of moving around also partially depends on the weather, which can affect the time required.

In year 2, community monitors were cheaper than trained foresters across four out of five sites. As the skill of community monitors increase, monitoring becomes faster and the requirement for supporting staff decreases, and community monitoring becomes a cost effective alternative to professional forest monitoring. Cost could decrease even further if the trained forester undertaking refresher training could be provided by the district forest office instead of, as in this study, the provincial forest office.

The monitoring cost/ha also decreases as the size of the forest area being monitored increases (Figure 4). This is in agreement with the findings of Skutch *et al.* (2011) [18], Danielsen *et al.* (2011) [36], and Böttcher *et al.* (2009) [45] who found that monitoring costs will depend on desired level of accuracy and size of the project area.

4.3. Relevance to REDD+ Implementation

A number of countries have already selected community forest management as part of their national REDD+ plans as reflected in many national REDD+ readiness strategies [34,46]. Moreover, text in the Subsidiary Body for Scientific and Technological Advice (SBSTA) on REDD+ methodology [2] supports "full and effective" engagement of indigenous peoples and local communities, and the contribution of their knowledge, to monitoring and reporting activities, which is recommended in the GOFC-GOLD sourcebook [47].

Considering concerns about the cost of monitoring for REDD+ [19,22,24], our findings provide support for considering community monitoring in local scale and national carbon monitoring. Our findings also underline both the feasibility of using community monitors to cost-effectively and accurately monitor forest estates, but also the importance of training and attention to limiting the number of potential technical errors when developing manuals and undertaking training.

Within community-based options for implementing REDD+, there is a need to develop community MRV protocols that maximize the involvement of local people, while also meeting REDD+ forest monitoring requirements [17]. Although a number of manuals have been developed, these vary greatly in length and scope (Table 3), reflecting a lack of agreement on methods for community monitoring of carbon. Our experience suggests that manuals should be short and need to focus on (a) effective sampling design; (b) careful establishment of sample plots; and (c) accuracy in measurements. For all these issues simplicity is important, as a simple method is easier to remember and apply consistently. However, our results and experience from the field also suggests that training remains important and re-fresher training and supervision for a day or two helps improve accuracy.

Considering firstly how important monitoring is for all five of the key activities for REDD+ proposed by the UNFCCC (2010) [3], and secondly the concerns raised over safeguarding local and indigenous communities rights over land in the REDD+ implementation process [13–15], it seems that the potential for community monitoring to deliver accurate and cost effective monitoring should be considered seriously when planning future national REDD+ activities as well as local REDD+ projects. This study adds to the growing consensus that local people, using participatory methods, can produce data sets that are just as accurate as those that are derived professionally [30,31]. If community monitoring is to have impacts on forest management beyond the local scale, then the community monitoring must be embedded within - or linked to - a national (or international) scheme that feeds the data up to the levels at which governments and international agencies operate [37]. We suggest that the REDD Readiness work by the UN-REDD program and the World Bank's Forest Carbon Partnership Facility should pay more attention to the development of appropriate community based monitoring systems, and promote policies and build capacity to allow the input of locally generated data.

Table 3. Manuals for involvement of local or indigenous communities in the measurement of forest carbon stocks in developing countries ordered according to year of publishing (newest on top); the manual by Poulsen *et al.* 2013 [48] was used in the present study.

Title	Focus and Use	Pages	Reference
Manual for participatory mapping and monitoring of forest biomass.	Field manual. A practical manual to plot design, tree measurement, and data collection. Based on the Rapid Carbon Stock Appraisal (RaCSA) by ICRAF (2009). Part I of the Manual describes how to do participatory mapping. Part II describes how to establish participatory monitoring of forest biomass. Part III covers the annually repeated monitoring.	23	Poulsen, M. *et al.*, 2013. Theoretical framework for community-based forest monitoring. Impacts of reducing emissions from deforestation and forest degradation and enhancement of forest carbon stocks (I-REDD). FP7-ENV-2010–2014 [48].
Participatory Carbon Monitoring: Manual for Local People.	Forest level field data collection by local households for REDD+. A practical guide to plot design, tree measurement, and data collection. Data analysis is described in a separate manual for supporting staff.	31	Bao Huy B, Nguyen, T.H.; Sharma, B.; Nguyen, V.Q., 2013. Participatory Carbon Monitoring: Manual for Local People. SNV Holland - MBREDD+ [49].
Understanding Communty-Based REDD+ A manual for indigenous communities.	A general guide to participatory approaches relevant for REDD+, including forest level monitoring. Focus on REDD+ community based REDD+ projects on the voluntary carbon market.	207	Erni C *et al.* Understanding Communty-Based REDD+ A manual for indigenous communities. 2011. International Work Group for Indigenous Affairs (IWGIA) and Asia Indigenous Peoples Pact (AIPP) [50].
Technical Manual for Participatory Carbon Monitoring.	National level field data collection by local communities including data analysis and reporting. Includes guidelines for both local monitoring and supporting staff. Aimed at national carbon stock monitoring for Vietnam.	21	UN-REDD Vietnam Program. Technical Manual for Participatory Carbon Monitoring. 2011. United Nations Program for Reduced Emission from Deforestation and Degradation [51].

Table 3. *Cont.*

Title	Focus and Use	Pages	Reference
Field Guide for Forest Biomass and Carbon Estimation.	Forest and landscape level field guide for plot network establishment, data collection and data analysis. - Not directly aimed at community monitoring, but is very detailed and suitable for training of trainers of community monitors.	53	Walker, W.; A. Baccini., M.; Nepstad, N.; Horning, D.; Knight, E.; Braun, and A. Bausch., 2011. Field Guide for Forest Biomass and Carbon Estimation. Version 1.0. Woods Hole Research Center, Falmouth, Massachusetts, USA [52].
Forest Carbon Stock Measurement: Guidelines for measuring carbon stocks in community-managed forests.	Forest level field guide to community monitoring of carbon in Community Forests. Aimed at both community monitors and supporting staff. Specifically aimed to meet IPCC and VCS standards and includes field data collection, data analysis, leakage analysis and quality assurance.	69	Subedi, B.; Pandey, S.; Pandey, A.; Rana, E.; Bhattarai, S.; Banskota, T.; Charmakar, S.; Tamrakar, R. 2010. Forest Carbon Stock Measurement: Guidelines for measuring carbon stocks in community-managed forests. Asia Network for Sustainable Agriculture and Bioresources (ANSAB), Kathmandu, Nepal [53].
Measuring Carbon Stocks Across Land use Systems: A Manual.	Landscape level carbon monitoring by community monitors. Proposes "Rapid Carbon Stock Assessment" (RaCSA) following 6 steps. Local stakeholder input (land use, mapping, *etc.*) Compiling existing information under one zoning system. Stratificaton, sample design and GT planning Field measuring, allometric modelling. Ground truthing, satellite interpretation, change monitoring.	129	Hairiah, K.; Dewi, S.; Agus, F.; van Noordwijk, M and Rahayu, S. 2009. Measuring Carbon Stocks Across Land Use Systems: A Manual. Bogor, Indonesia. World Agroforestry Centre (ICRAF), SEA Regional Office, Brawijaya University and ICALRRD (Indonesian Center for Agricultural Land Resources Research and Development) [40].
A Field Guide for Assessing and Monitoring Reduced Forest Degradation and Carbon Sequestration by Local Communities.	Manual in forest level carbon monitoring including plot network establishment and field data collection. Specifically aimed at community monitors. Additional manuals available for supporting staff.	87	Verplanke, J.J. and Zahabu, E., Eds. 2009: A Field Guide for Assessing and Monitoring Reduced Forest Degradation and Carbon Sequestration by Local Communities. 93 p. Project team KYOTO: Think Global, Act Local (K:TGAL). Enschede, Holland [39].

5. Conclusions

Our study of locally based monitoring activities in four countries in South East Asia shows that the ability of local communities to monitor the AGB in their forest increases with repetition of monitoring activities to an extent where, for eight out of nine sites, the difference between the monitoring done by professional foresters and the community monitors was statistically insignificant. Furthermore, we found that over the two separate rounds of monitoring, community monitoring became cheaper from year 1 to year 2 to the extent that in year 2 community monitoring was more cost effective than professional monitoring for four out of five sites.

In our experience much of this success was based on the focus on simple methods that community monitors were able to apply correctly and consistently with a very limited amount of training and supervision.

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Author Contributions

Søren Brofeldt, Ida Theilade, Finn Danielsen, Michael K. Poulsen and Meine van Noordwijk designed research; Søren Brofeldt, Ida Theilade, Michael K. Poulsen, Tran Nguyen Bang, Arif Budiman, Jan Jensen, Arne E. Jensen, Yuyun Kurniawan, Simon B.L. Lægaard, Zhao Mingxu, Subekti Rahayu, Ervan Rutishauser, Dietrich Schmidt-Vogt, Zulfira Warta and Atiek Widayati facilitated or performed field research; Søren Brofeldt, Finn Danielsen, Teis Adrian and Meine van Noordwijk analysed data and commented on data analysis; and Søren Brofeldt, Ida Theilade, Finn Danielsen, Neil D. Burgess, Michael K. Poulsen and Teis Adrian wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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Participating in REDD+ Measurement, Reporting, and Verification (PMRV): Opportunities for Local People?

Manuel Boissière, Guillaume Beaudoin, Carola Hofstee and Serge Rafanoharana

Abstract: Assessing forest changes is the baseline requirement for successful forest management. Measurement, Reporting, and Verification (MRV) are three essential components for achieving such assessments. Community participation in resource monitoring and management is increasingly seen as a scientifically efficient, cost-effective, and equitable way to employ such practices, particularly in the context of REDD+. We developed a multidisciplinary approach to study the feasibility of Participatory MRV (PMRV) across three sites along a forest degradation gradient in Indonesia. We looked at both the local and national level needs of MRV. Our approach combines: (1) social research focusing on the enabling conditions for local participation in MRV; (2) governance analyses of existing MRV systems in forestry and health; and (3) remote sensing work comparing overlaps and gaps between satellite imagery and local assessments of forest changes. We considered in our approach the possible multiple benefits of PMRV (carbon mitigation, biodiversity conservation, livelihood security). Our study helped to identify the multiple stakeholders (communities, NGOs and governments) and what the levels of governance should be to make PMRV design and implementation feasible and sustainable.

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1. Introduction

Carbon emissions from tropical forests represent between 6 and 17% of global carbon emissions [1]. The Reduction of Emissions from Deforestation and forest Degradation, including conservation, sustainable management of forests and enhancement of forest carbon stocks (REDD+) is a mechanism for mitigating climate change with opportunities for payments associated with emissions reductions and maintenance of forest carbon stocks [2]. The need to measure emissions reductions with accuracy is therefore vital to REDD+ implementation and success [3]. However, measurements are still hampered by the complexity of national and subnational situations (e.g., lack of capacity and organizations to conduct measurements at local levels, risk of corruption regarding the distribution of incentives, lack of clarity about the international standards to be applied) [4].

Building knowledge for an efficient and equitable Measurement, Reporting, and Verification (MRV) system for carbon and non-carbon data, across different levels of governance, is crucial for accurate and trustworthy information on which to base decisions for climate change mitigation [5]. ‘Measurement’ in MRV refers to the monitoring and quantification of carbon stocks and their change over time. ‘Reporting’ is the information provided by governments on emission levels, and government policies and measures. ‘Verification’ refers to the “process of independently checking the accuracy and reliability of reported information or the procedures used to generate information” [6].

The United Nations Framework Convention on Climate Change (UNFCCC) recognizes the need for local community participation in carbon stock estimations [7], in order to improve social safeguards, benefit sharing [8–10], and to promote sustainable forest management. However, few methods have been developed and no *de facto* method accepted by those implementing community participation in MRV. Recent studies [11–13] have built on experience from participatory biodiversity monitoring to compare cost efficiency and quality of the data collected by local communities. Some have even compared community-collected data with carbon stock estimations made by scientists [14]. Although it is generally recognized that local people can (with training) estimate aboveground carbon, there is a lack of information about how to sustain such a system in the long-term.

There is little to no information on local people's participation in reporting data on forest inventories to national and international levels, and the role they could have in validation and verification. Danielsen *et al.* [14] and Phelps *et al.* [15] consider local communities for their possible role in data collection and as key stakeholders in approving (or not) REDD+ projects. However, according to Phelps *et al.* [15], central governments should manage carbon accounting. How the data flows from local communities to these national databases is still to be determined. Lotsch and Skutsch [9] mentioned the role of governments at the national level in clarifying the reporting structure between local communities and organizations responsible for managing national databases, including what their benefits would be.

We propose an approach that considers local people's participation in MRV at the measurement, reporting and verification stages, as a whole. In this research, we do not focus solely on one of these components independent of the other two. According to Danielsen *et al.* [14,16], it is possible for local people to learn how to estimate carbon stocks or carbon emissions in the context of REDD+. MRV also includes the measurement and monitoring of non-carbon data, such as the multiple benefits from the forest (e.g., from biodiversity, water and non timber forest products), the identification of drivers of change in forest cover and in local livelihoods [17]. However, it is more challenging to include non-carbon data measurements in a standardized data flow, and to consider how it affects decisions on land use. More challenges come from considering local people's contributions to the reporting and verification parts of MRV and any subsequent benefits. Visseren-Hamakers *et al*. [18] emphasize the necessity to use interdisciplinary research to address the multiple and complex challenges related to REDD+, including MRV.

In our research, we asked what is the feasibility and sustainability of local community participation in MRV for carbon and non-carbon data in Indonesia. To answer this question, we used a multidisciplinary approach that integrates social and spatial data, something that has been done before [19–21], but has never been applied to MRV. We analyzed the local communities' capacity to participate in MRV, their time, willingness, and experience in participating in communal activities. We examined existing structures in the health and forestry sectors and compared them to understand the local communities' contribution to information flows and reporting systems. Last, we studied the overlaps and gaps between changes in forest cover from local and scientific perspectives.

The research started in 2013. This methodological article presents the approach we used, as a first step; the results of the analysis will be reported in subsequent articles. The paper is organized as follows: we first describe how we developed our approach, including the research design and site selection; then we present and discuss the methods used in this feasibility study.

2. Developing a Multidisciplinary Approach

A team of researchers, including specialists in forestry and health governance, social scientists, and remote sensing experts, developed an approach to study the feasibility and sustainability of PMRV. This was used to compare different village conditions across Indonesia.

2.1. Pilot Sites

A few countries have developed a UN-REDD national program, which includes the creation of an MRV institution to manage a national carbon database for use in international negotiations on climate change mitigation. We decided to conduct our study in Indonesia because it was one of the nine pilot countries initially supported by a UN-REDD program [22]. The REDD+ Agency in Indonesia was officially created in late 2013 (Presidential Decree No 62/2013, signed on 2 September 2013) [23]. Our study could be particularly relevant to this new agency for the development of its programs.

We selected pilot sites that represent different conditions (different levels of forest degradation along a gradient in forest transition; population density; and socio-economic context) in three provinces of Indonesia (Figure 1), based on the criteria presented in Table 1: Papua, West Kalimantan, and Central Java. We intentionally chose research sites outside of REDD+ demonstration activities, to avoid the local communities (and their answers) being influenced by their relationships with the proponents.

We chose the criteria in Table 1 as they best show how situations in the three sites are contrasted along a forest transition curve. The criteria cover the environment (presence of natural forest), human capital (demographic pressure), site accessibility (difficulty to communicate), economic pressure (presence of the private sector), and presence of local schemes for environmental management (community forests). Activities included not only the village level, but also research at the district, provincial, and national levels. A multivariate cluster analysis was conducted for each site using secondary data from the Indonesian Central Statistics Agency [24], based on the criteria presented in Table 1, and combined with our knowledge of each local condition to select the sites.

Table 1 illustrates the gradient of natural forest cover in Indonesia from high in Papua to low in Java. Our site in Papua, with the most natural forest cover, has a low population density, low accessibility, medium economic pressure and community forestry is absent. Our site in West Kalimantan, with a medium population density, follows a transition from natural forest cover to agro-forests and smallholder plantations. Economic pressure is increasing, and access is easier than in Papua, with an important network of roads. Our site in Central Java has lost most of its natural forests due to high demographic and economic pressure, but community forestry is well developed.

To understand the forest cover changes in the different research sites, we created maps of land cover for years 1991, 2000, 2001, 2005, and 2011, using multi-spectral and multi-temporal optical data from different sensors, Landsat Thematic Mapper 5 and Spot 5. Before classification, pre-processing of satellite imagery was conducted to correct atmospheric disturbance and terrain effects.

A combination of spectral data and spatial information was used to assess anthropogenic disturbance of forest cover and to assess the performance of spectral reflectance, vegetation indices (*i.e.* the Normalized Difference Vegetation Index and Enhanced Vegetation Index), common band ratios, and spatial information from co-occurrence texture matrices to improve the accuracy of land cover analysis.

Figure 1. Map of the research sites in Papua, West Kalimantan, and Central Java.

2.2. Defining Research Questions

Projects using participatory approaches are, in general, limited in time [25]. Looking at long-term engagement of local communities in MRV is essential when developing a participatory approach. The local communities' capacity to contribute to MRV depends not only on their skills and education, but also on a set of indicators such as knowledge of and dependency on forest resources, previous participation in similar activities and land security. We combined these requirements to propose the following research question: What do we need to know if PMRV is to be feasible and sustainable?

Based on this main question, each group of researchers prepared sub research questions described in Table 2. A group of social scientists worked on the local conditions for PMRV to be successful in the three pilot sites, based on assets as defined in the Sustainable Livelihoods Approach [26]: social, human, natural, physical and financial capitals. Reporting is about how information flows, or how data is communicated from one level to a higher one, about the feedback each level gets and the efficiency of the system. The group of governance specialists compared how information flows from local to national levels in the forestry and health sectors. It was useful to learn, from existing experience, about reporting in these two sectors. We chose to study the health sector in Indonesia because it shows clear and functioning information flows, with local community participation, in contrast to the forestry sector. The last group, remote sensing experts, worked on the potential role of remote sensing in the validation of information provided by local communities and in the selection of sites for future measurements. They focused on characterizing forest degradation in each site, looking at overlaps and gaps with maps developed together with villagers.

Table 1. Criteria for selecting research sites in Indonesia.

Sites	Natural forest cover	Demography	Accessibility	Economic pressure	Importance of community forestry
Papua (Mamberamo Raya)	++	−	−	+	−
West Kalimantan (Kapuas Hulu)	+	+	+	++	+
Central Java (Wonosobo)	−	++	++	++	++

Note: ++ high, + medium, − low.

2.3. Developing a Research Design (Indicators and Methods) Based on the Research Questions

Based on the research questions we developed a set of indicators that helped us develop research methods. These indicators aided collaboration between the different research groups (the indicators are described in Tables 3, 4 and 5). Despite their different backgrounds, the researchers had to collaborate to make the approach integrative. Social scientists and remote sensing specialists worked together on improving the accuracy of satellite imagery interpretations based on the forest conditions according to local communities and ground checks. They also designed common methods, such as participatory maps. Both teams considered the potential role of local people in verification. The social science team collaborated with the governance team to look at the reporting systems and how information flows at the village level.

Some of these methods were adapted from multidisciplinary studies, in particular Sheil *et al.* [27] and Chambers [28] for participatory mapping, focus group discussions and household surveys; Mercado [29] and Geilfus [30] for Venn Diagrams and sociograms, and seasonal calendar; and Larson [31] and Liswanti *et al.* [32] for research related to land tenure. The different methods are explained in detail in Table 6.

The research objectives and the methods were presented in each village, during several community meetings. Occasionally this process required several additional sessions of explanations and discussion, initiated by the local communities, before they would agree to our methods and give their approval for the research to start.

Table 2. Main research question and its subset of research questions by theme and their links to MRV.

Main research question	Components of MRV	Social science study	Governance study	Remote sensing study
What do we need to know if PMRV is to be feasible and sustainable?	M, R, V	x	x	x
Subset of research questions				
What conditions make it possible for local people to conduct PMRV?	M	x		
What is needed for people to be willing to participate in PMRV?	M	x		
What existing organizations can support PMRV and what can PMRV learn from current and past organizations?	M, R	x	x	
How can existing systems in Indonesia that include MRV be used for PMRV in the context of REDD+?	R		x	
What is the existing approach to verify or validate the credibility of MRV data?	R		x	
How can we use various actors' perceptions to provide information about the robustness of the current MRV system?	R		x	
What scale of deforestation and forest degradation can be measured using spatial data and remote sensing analysis?	V			x
How to use remote sensing (RS) and geographical information systems (GIS) to select relevant sites for local communities to estimate carbon and drivers of forest changes?	M, V			x
How can RS/GIS be used in the development of PMRV?	V			*x*

3. An Integrated Approach to Study the Feasibility of PMRV

In this section, we first describe the three studies (social science, governance, and remote sensing (RS) and geographical information systems (GIS)). These three studies were developed together in an integrated way, in the same locations, to answer the main research questions. We present the links between research questions, sets of indicators and methods.

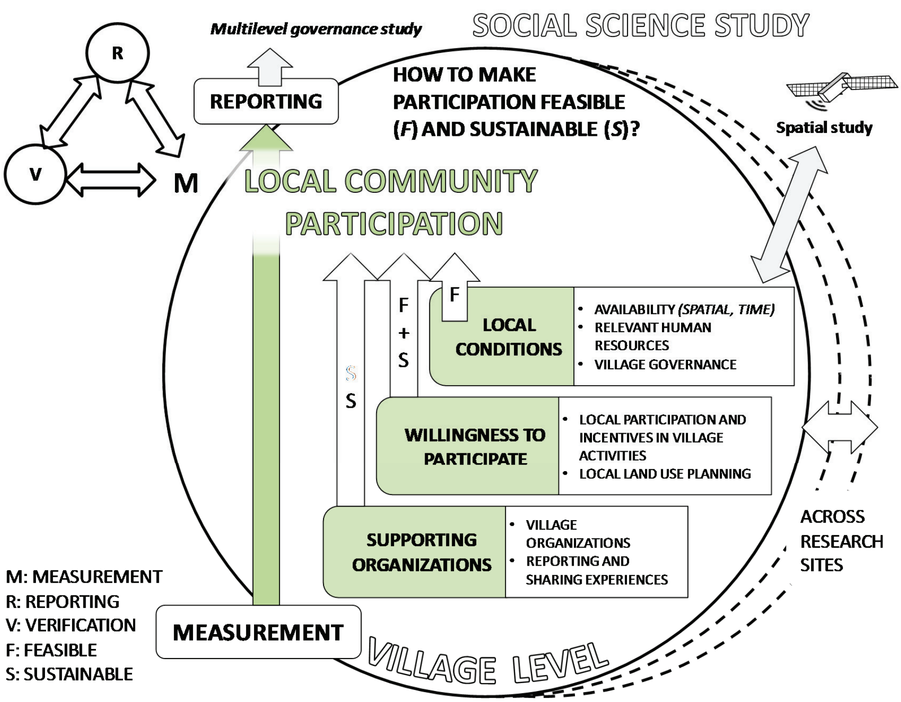
3.1. Measurements: a Social Science Study

The social science study focused on measurement (M—of MRV) at the village level and the other two components to a lesser extent. We learned from past and existing local reporting (R) experience within and between villages, government institutions, as well as from the private sector. The verification (V) part of the study was in collaboration with the GIS/RS team for participatory mapping and ground checks.

Figure 2 illustrates how the social science team conducted its investigations in each local context. The same set of questions, indicators, variables, and methods were used in each of the study sites.

From the main research question (Table 2) we recognized the importance of considering both sustainability and feasibility for PMRV and developed the methods described in Table 3. One method could be used to follow more than one indicator. Sustainability and feasibility were addressed by considering the local conditions, the willingness of villagers to participate and what supporting organizations could be used in developing PMRV, especially for reporting.

Figure 2. The social science research design.



We studied the enabling local conditions for PMRV, by analyzing the village demography, governance, and villagers' availability to take measurements.

Local people's willingness to participate depends largely on the kind of incentive they can expect. We looked at past and present experiences the villagers have had of participating in activities related to environmental issues and the kind of benefits they have received. Land tenure and land use were also important aspects to consider for future MRV, especially the site selection for the measurements, and the villagers who would be involved. Learning from local village organizations and their experience in data reporting and sharing helped us to identify the necessary conditions for sustainable measuring and reporting at the local level.

Table 3. Social science research design and the conditions for local participation in MRV.

Research questions	Indicators	Factors	Methods used
1-What conditions make it possible for local people to participate in MRV?	Availability	- Demography: age, gender, and occupation distribution	HH survey; KII general information; FGD forest management; FGD drivers of change; FGD seasonal calendar; participatory mapping
		- Time structure: occupation time frames, livelihood activities by gender, and seasonal employment	
		- Sources of livelihoods: livelihood diversity, sources of income	
		- Dependency on natural resources: forest related livelihoods, as cash income or subsistence	
		- Local people's settlement: distance to urban areas, form of settlement (temporary or permanent)	
		- Infrastructure facilities: village infrastructure, people's access and mobility	
	Human resources	- Technical knowledge: level of education, experience with technology	HH survey; FGD forest management; FGD drivers of change; FGD seasonal calendar; participatory mapping
		- Local knowledge: knowledge about the territory, land uses, ownership distribution and regulations, forest management practices, drivers of deforestation and forest degradation.	
1-What conditions make it possible for local people to participate in MRV?	Local governance	- Status: villagers' social status or involvement in organizations that may influence participation	HH survey; KII general information; KII land tenure; KII experience mechanism; FGD forest management; FGD drivers of change; FGD sociogram; participatory mapping
		- External governance: government authorities in the village; villagers' relationships and experience with national government	
		- Internal governance: power relations between groups; local power relationships influence information sharing	
		- Land tenure: resources and land ownership; local tenure arrangements and regulations	

Table 3. *Cont.*

Research questions	Indicators	Factors	Methods used
2-What factors influence people's willingness to participate in PMRV?	Forest service valuation	- Forest service valuation: forest benefits; forest products; most important timber products, NTFPs and game - Village perspectives on forest trends: future state of forest; plans for the future use of forest and non-forest lands	HH survey; KII general information; KII land tenure; FGD forest management; FGD drivers of change
	Drivers of forest cover change	Drivers of change: current and past local land cover and land uses (livelihood activities); causes of change; link between forest changes and forest service trends; local forest management systems.	HH survey; KII general information; FGD forest management; FGD drivers of change
	Local motivation to participate	- Local participation: people's motivations to participate in groups, organizations or activities - Incentives: incentives or compensation provided by past projects or activities, traditional benefit sharing systems, and future village needs and desires.	HH survey; KII experience mechanism; FGD drivers of change
3-How can current and past organizations inform and support PMRV?	Village organizations	Village organizations: existing organizations and groups in the village, their roles and structures, organizations local people identify they want to work with or think match PMRV activities.	HH survey; FGD sociogram; KII experience mechanism
	Reporting experience	Reporting experience: local organizations' relationships with external authorities or groups, and experience in reporting.	KII experience mechanism; FGD Forest management; FGD sociogram
	Sharing mechanisms	Sharing mechanisms: village experience with benefit sharing or resource distribution, details about the structure and sharing mechanism.	HH survey; KII experience echanism; FGD sociogram
	Perceptions about organizations	Perceptions about organizations: villagers' perceptions of the role and structure of organizations in their village, including an assessment of functionality, trustworthiness and other relevant MRV capacities; reasons for wanting or not wanting to work with an organization	HH survey; FGD sociogram

Note: HH survey: Household Survey; KII: Key Informant Interview; FGD: Focus Group Discussion; NTFP: Non-Timber Forest Product; RS: Remote Sensing; GIS: Geographical Information Systems.

3.2. Reporting: a Governance Study of Information Flows

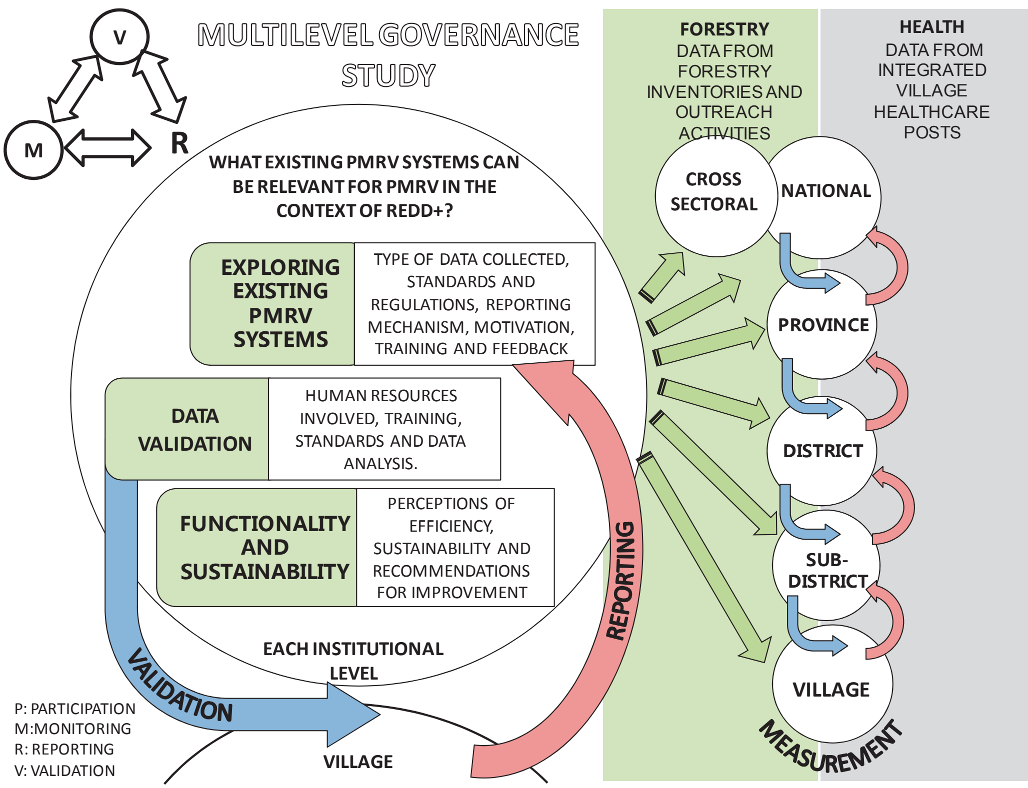
Two pre-existing systems, the Indonesian healthcare and forestry information systems, were chosen for an in-depth multilevel governance study (Figure 3). We worked in the same villages as for the other research activities. We also worked at higher governance levels: sub-district, district, provincial and national, to obtain a complete picture of how information flows across the different levels, to allow comparisons and reveal challenges.

We explored the healthcare system because community involvement in monitoring and reporting in "integrated health posts'' (*Pos Pelayanan Terpadu—Posyandu*) has existed in Indonesia for over 30 years. The current forestry dataflow was also studied in order to describe the current actors, organizations and institutions, level of community participation and possible challenges.

We studied how data is collected in both sectors at the community level, reported to higher institutional levels, and whether feedback and validation existed (Figure 3). We hoped that the implementation of PMRV (in the context of REDD+) could learn from these existing systems.

In Table 4 we summarize the two sectors according to the research questions, the main indicators and research methods. We kept as much as possible to the same structure for both sectors to allow comparison.

Figure 3. The governance research design.



During the interviews at each level, we asked about the existing systems' data flow, standard procedures, existence of training for those managing data, human resources in each organization, and the perception of what works and what could be improved in terms of efficiency and participation of local communities (Table 4).

Table 4. Research design for the multilevel governance study on reporting in the health and forestry sectors.

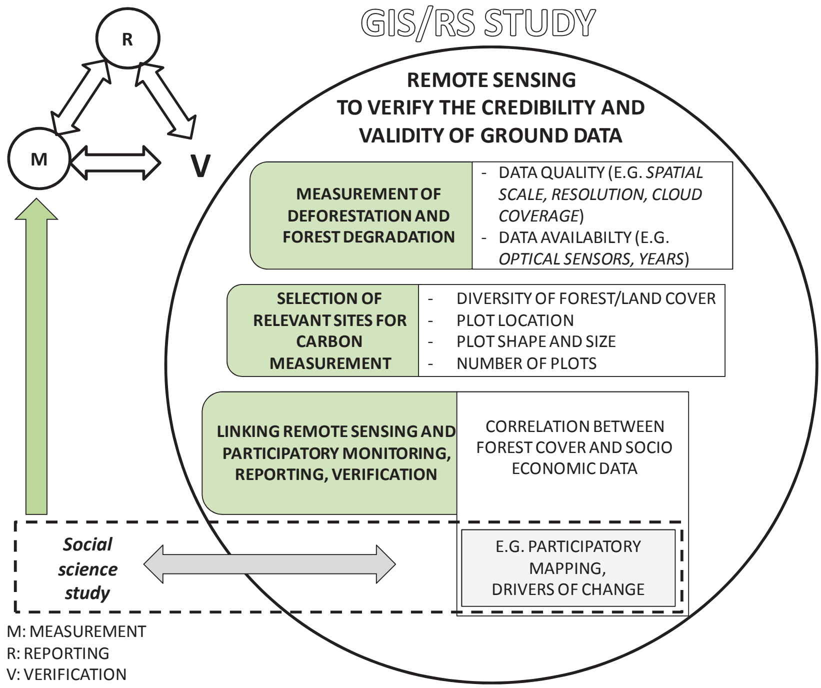
Research questions	Indicators	Factors	Methods used
1-How can existing systems in Indonesia that include MRV be used for PMRV in the context of REDD+?	People and organizations currently involved in MRV	Participant's motivation and contribution (level of participation in health system); characteristics of organizations or institutions involved: name, structure, human resources (people involved and training); how budget is allocated and by whom; and the type of data collected.	Forestry and health open-ended questionnaire interviews
	Standard procedures	Standard procedures for PMRV, targets and existing feedback at each level, and challenges of meeting the targets at various levels.	Forestry and health open-ended questionnaire interviews
	System sustainability	History of current system, development and objectives; characteristics of database information systems; and participant's criteria for a successful PMRV system.	Forestry and health open-ended questionnaire interviews
2-What is the existing approach to validate MRV data?	People involved in validation	Characteristics of individuals and groups involved in validation: competence, training, and commitment to data quality.	Forestry and health open-ended questionnaire interviews
	Validation procedures	Means of validation; standard procedures; frequency and purpose; and raw data, data cleaning mechanism, and preliminary analysis.	Forestry and health open-ended questionnaire interviews
3-How do various actors perceive the robustness of the current MRV systems?	Perceptions of functionality	Key informants' perceptions of the efficiency of the existing systems' functionality, reasons for inefficiency, strengths, and lessons learned.	Forestry and health open-ended questionnaire interviews
	Perceptions of sustainability	Criteria to ensure sustainability of the existing PMRV systems according to perceptions, including minimal human resources, budget, and facilities needed.	Forestry and health open-ended questionnaire interviews
	Possible or expected improvement	Recommendations to improve the existing systems, possible inclusion (in the system) of data the community have collected, improvement of data quality.	Forestry and health open-ended questionnaire interviews

3.3. Verification: Addressing the Gaps between Local and Scientific Perceptions

Measurement, Reporting and Verification needs cost effective and reliable methods for verification. We looked at the conditions needed to develop a relatively simple and cost-effective method using remote sensing and geographical information systems to collect information on land use (LU) and land cover change (LCC) (Figure 4). Using satellite imagery interpretation as well as information from local people, we identified the land uses, the drivers of deforestation and forest degradation, and their resulting impacts.

We considered the scale of deforestation and forest degradation, still using satellite data and spatial analysis, and the information needed to select relevant sites for local communities to estimate carbon stocks and drivers of forest cover change. We also developed, in collaboration with the social scientists, participatory mapping with the local communities.

Figure 4. The remote sensing research design.



To address the three objectives presented in Figure 4, we used different indicators (Table 5).

First, we studied how to best measure deforestation and forest degradation. A first indicator is data quality: we considered spatial resolution (size of the pixel), spectral resolution (wavelength width of each band), radiometric resolution (intensities of radiation), temporal resolution (for time series analysis), scale of data to be used, and the size of the area. We then considered the maximum tolerance of cloud coverage, clear and identifiable features in the image, and readiness of the data to be used. The last indicator was the availability of the data, whether it was free access or not, and its coverage of the research area.

Second, looking at relevant sites for carbon measurements we should understand the diversity and homogeneity of forest and land cover (Figure 4). The analysis focused on diversity of the land use types and forest cover, and their relevance to the monitoring of carbon stock and forest change. Details about plot measurements included location, shape and size, and number of plots needed.

Third, in order to link RS/GIS and the social science study we needed to determine how local people could be involved in the identification of critical areas, in which changes in forest cover are happening. Participatory mapping helped to characterize these critical areas for the selection of measurement plots.

Table 5. Research design for verification of local measurements using remote sensing and geographical information systems.

Research questions	Indicators	Factors	Methods used
1-What scale of deforestation and forest degradation can be measured using spatial data and remote sensing analysis?	Data resolution	Spatial resolution (pixel size); spectral resolution (wavelength width of each band); radiometric resolution (radiation intensities); temporal resolution (time series analysis), scale of data to be used; and the size of the area.	Desk study—RS and GIS analysis
	Data quality	Maximum tolerance of cloud coverage; clear and identifiable features in the image; and ready to use data.	Ground checks of land cover
	Data availability	Cost of the data (free access or pay) and data coverage of the research area.	Desk study—RS and GIS analysis
2-How to use RS/GIS to select relevant sites for local communities to monitor carbon and drivers of forest change?	Diversity or homogeneity of forest/land cover	Diversity of land use type and forest cover and relevance of monitoring carbon and forest change (comparability with different forest cover, land use and land cover change dynamics in the area).	Ground checks of land cover; desk study - RS and GIS analysis
	Measurement location	Accessibility of the measurement area (terrain conditions, local regulations), infrastructure available in the area and measurement requirements including the number of samples.	Desk study—RS and GIS analysis
	Measurement, shape and size	Shape and size of sample plot and element measured (above ground biomass or other).	Desk study—RS and GIS analysis
	Number of measurements	Minimum number of plots necessary to conduct the measurements and relations between the number of measurements and land diversity.	Desk study—RS and GIS analysis
3-How is RS/GIS relevant to PMRV development?	Correlation between forest cover and socio-economic data.	Link RS/GIS with social team through socio-economic survey and involvement of local people in plot determination and map validation.	Desk study—RS and GIS analysis

3.4. Description of the Methods Used by Each Research Component

A summary of the methods used in our research is presented in Table 6. This set of methods was developed based on the research questions previously identified in Table 2, and the indicators developed in Table 3, 4 and 5. In this section, we provide more detailed information on the main methods used for each component of the research.

Table 6. Description of the research methods.

	Method	Description
1	Household Survey	Using simple random sampling, these surveys covered topics including family demography, sources of income, livelihood diversity, forest product use, time utilization, and natural resource trends over the last 10 years. This method gives a representative sample of each village and quantitatively comparable information about forest dependency, livelihoods, income, knowledge, capacity, and availability.
2	KII General Information	These interviews were about village history, livelihood changes since the village was first settled until the present, current political structure, and current infrastructure.
3	KII Land Tenure	These interviews covered land access, use, management, exclusion, and transfer of rights as understood and practiced by the communities across their territories.
4	KII Experience Mechanism	These interviews provided information about current and past community experience with and perceptions of resource distribution, government aid, and outside organizations; the structure of resource distribution currently practiced by village organizations; and people's motivations to participate in these organizations.
5	FGD Forest management	These group discussions were about individuals' current actions, knowledge, and systems of monitoring and managing particular forest resources deemed important to them.
6	FGD Drivers of changes	These group discussions gave information about local knowledge and perceptions about past, current, and future forest cover change, the impact of such changes on ecosystems and communities, and how they felt these impacts could or should be addressed in the future.
7	FGD Seasonal calendar	These group discussions were about individuals' seasonal activities, a gradient of time availability for potential participation, and any gender differences between the two.
8	FGD Organizational sociogram	These group discussions discussed environmentally focused organizations in the community, relevant information about cooperation, conflict and authority, and those organizations individuals felt best suited the PMRV activities and those they would most like to work with.
9	Participatory mapping	This activity was conducted to spatially represent the communities' land use, land cover change, and photographic documentation of particular use and change areas. This method was designed to give us an understanding of how locals conceptualize their territory, use their resources, and perceive forest change in order to gain both local knowledge and spatial nuance for designing PMRV activities.
10	Forestry open-ended questionnaire interviews	Open-ended questionnaires allowed for in-depth interviews with informants involved in the monitoring, reporting and verification system. The questionnaires were adapted to each level of governance. Forestry questionnaires were adapted according to the organization being interviewed (private and public).

Table 6. *Cont.*

	Method	Description
11	Health open-ended questionnaire interviews	Open-ended questionnaires allowed for in-depth interviews with informants involved in the monitoring, reporting and verification system. The healthcare team conducted interviews with government workers at each level of governance and village health volunteers.
12	Desk study—RS and GIS analysis	The desk study work and data pre-processing, analyzed ground check data for land cover. We also generated initial land cover maps, and participatory maps of land cover and land use. The data used: Landsat, SPOT, ALOS, RapidEye, Google Earth Pro, land cover data from the Ministry of Forestry of Indonesia, the Forest Governance Agreement Map (Tata Guna Hutan Kesepakatan – TGHK), and spatial planning (Rencana Tata Ruang Wilayah—RTRW).
13	Ground checks of land cover	Collection of information to refine the land cover map(s) previously produced during the desk study. GPS points together with land cover identification have been collected in the three provinces (Kalimantan, Java and Papua).

Note: KII: Key Informant Interview; FGD: Focus Group Discussion; RS: Remote Sensing, GIS: Geographical Information Systems.

3.4.1. Methods Used in the Social Science Study

The methods developed were used in the three research sites to enable comparisons across different socio-economic and ecological contexts (Table 6).

Focus group discussions (FGD), conducted with men and women separately, provided information on the conditions to design and implement PMRV. This exercise, organized in groups of five or eight participants, allowed free discussion within the group and the collection of more exhaustive information. Focus group discussions covered a large group of topics, *i.e.*, local forest management, perceptions of the drivers of change and livelihoods (according to a seasonal calendar), and organizational sociogram to capture villagers' interactions with different organizations.

Household surveys, using random sampling, allowed a more systematic data collection at the village level on land status, dependency on forest products, individual participation in village activities, and perceptions of environmental trends. In total 409 households were surveyed.

Key informant interviews provided in-depth information on tenure, benefit sharing, and changes in livelihoods. We selected the informants during community meetings and informal discussions. In general, four villagers were interviewed per village.

Participant observations were also used. These were based on daily, opportunistic and random observations of villagers' activities by the researchers. Relevant observations were compiled in a logbook or field report that enabled a deeper understanding of local people's social and daily activities.

3.4.2. Methods Used in the Multilevel Governance Study

The main methods used for this study were open-ended questionnaires allowing in-depth interviews with individual informants involved in both the healthcare and forestry database systems

(Table 6). The questionnaires examined the scope and scale of community-based monitoring and the optimum scale achievable by communities that can provide scientifically meaningful data through successive levels of governance. Questionnaires were adapted according to each level of involvement and the organization being interviewed, whether it was private or government owned. Seventy-seven people were interviewed, including health volunteers in each village and civil servants working at the different governance levels.

3.4.3. Methods Used in the GIS/RS Study

We produced a first set of land cover maps for the three project sites, only based on analysis of satellite imagery, where compositions of forest structure differ due to different levels of deforestation and forest degradation (Table 6).

A second set of maps was produced on current and past land use and land cover (LULC) changes. We worked with the elders and other villagers, who have deep knowledge of their land, during focus group discussions. We used hardcopy false color composites of the remotely sensed data for each village and its surroundings as the base map. This could only be made after discussions with local key stakeholders (head of the village and customary head). One facilitator led the activity during the FGD. Transparent paper was used on top of the satellite image to draw polygons and symbols for each LULC type. Legends were added and notes were taken through the process. The resulting maps were converted into digital GIS format for clearer visualization and observation, but also for possible analysis. Ground checks were conducted with key informants to geo-reference the different key features and land cover previously identified, and to verify the position and truth of the data from the maps prepared during the FGD.

These LULC maps were superimposed on the satellite images. This helped to identify the gaps and overlaps between the two. We could also calculate statistical errors and assess accuracy and validity.

4. Discussion

The results from the different surveys described in this article were still being analyzed at the time of submission. Here we present the discussion of our methodological approach; further papers will present the results of the implementation of this approach. It is too early to propose a tool that embeds locally collected data into Indonesia's national database, as the REDD+ institutions and monitoring mechanisms still need to be clarified [33], and the national database is still under construction. We do not propose therefore a PMRV tool (ready to use), but an approach to help decision makers understand the local readiness concerning PMRV in Indonesia, and the best conditions required for it to work. We were able to identify the main advantages and potential caveats from using this integrated approach, and discuss whether PMRV is feasible or not and under what conditions.

4.1. An Integrated Approach

We studied local community participation in measurement, reporting and verification of carbon and non-carbon data. The literature (so far) has considered participatory MRV as a whole when defining the concepts [10,13]. When being more specific about the ways to achieve participation in MRV, the authors focused on individual letters (components) of MRV. For example, M—the role of local communities in carbon stocks and emission estimates [3,16,34], R—the importance of a clear and efficient system for reporting [9,35], and V – the way validation should be conducted [36].

In order to secure social safeguards at the local level, and to ensure that benefit sharing reaches local communities, local participation in REDD+ has been recognized as essential [7]. The difficulty is still to define the nature and extent of local participation. According to Larrazábal *et al.* [37] local participation should go beyond carbon monitoring and should involve local communities in defining not only the procedures but also the focus of the monitoring. We propose to consider local community involvement beyond the monitoring aspect. Reporting information that they collect about the forest conditions enables local people to play an active role in negotiations related to the reduction of deforestation and forest degradation at the village level. This in turn should allow them to better voice their needs in terms of conservation and development. This is a first step to involve local people not only in an MRV of actions (*i.e.*, reducing carbon emissions) but also in anticipation of MRV and the transactions related to REDD+ [5]. Verification in REDD+ MRV is conducted by an independent extra-national team to verify if the implementation of REDD+ is as agreed and planned. In the context of PMRV, verification, using remote sensing, concerns information reported by local communities on forest cover changes and carbon estimates. Local communities can also be part of the verification process. For example, participatory maps can be compared to those from remote sensing for quality control. These maps can then assist decision-makers in the correct use of local community information.

4.2. The Contributions Multidisciplinary Approaches Make to Research on PMRV

In this multidisciplinary approach we combined biophysical information (carbon stock estimations), social science information (local participation in measurements, reporting and verification), and remote sensing information (maps using satellite images and local people's knowledge). Which synergies can be highlighted? The first and most described in the literature is how local community participation can benefit remote sensing analysis [19]. The use of remote sensing is limited when it is the only tool for estimating biomass [38]. However, forest inventories can contribute to address this limitation [39]. Participatory mapping may also help by involving local people in drawing land cover maps according to their perceptions [40]. Local communities can identify vegetation types for each land cover [41]. Ground checks would still be necessary to confirm the gaps on remote sensing maps.

Decision makers have recognized the importance of identifying and monitoring the drivers of change [7]. Remote sensing and GIS cannot provide that much information on the drivers of change without local community participation. They give a more complete vision of why forest cover is changing [40] and hence the reasons for carbon stock fluctuations in time and space. Collaboration between remote sensing and social science is therefore essential for developing PMRV.

Remote sensing experts, when working together with local communities, can also provide information on critical areas that require particular attention for monitoring or plot measurements (e.g., areas of high conservation value [42]).

The importance of linking local level participation in data reporting and the national data reporting system also needs to be acknowledged. These links would strengthen accuracy in reported information and cooperation among the various stakeholders [43], and help synchronize information across the different governance levels [35]. It could also provide those considering REDD+ co-benefits and the role of each stakeholder in PMRV, with essential, contextual information. This would be particularly true for social science and multilevel governance studies aimed at understanding the role of local communities in reporting information, especially non-carbon data.

The social scientists in our study looked at local people's experience dealing with environmental programs, including data management, while the governance team focused on data flow and feedback from village to national levels. These two studies are complementary and their combined results will help when developing a participatory reporting system.

4.3. Why Should Local Communities Participate in MRV?

The importance of involving local communities in MRV has been widely recognized [7,13,37]. Often participatory monitoring approaches have been used as a reference for engaging local people in carbon stock estimations [14,16]. When we developed our approach, we worked on a set of indicators (see tables 3, 4 and 5) without assuming that local communities should or are willing to participate. There is more likelihood of villagers participating in a project if there is some form of benefit for the individual or group [44]. Incentives can be financial, political (e.g., empowerment, participation in decision making), or indirect benefits. The latter could involve sustainable forest management, for example community forestry. The local communities could use PMRV to monitor changes in the forests for which they are responsible.

However, local interest and incentives are not enough [44]. For example, if the villagers rarely go to the forest to look for forest products and their livelihoods depend essentially on rice cultivation or labor in plantations, then successful adoption of PMRV is unlikely, as they will lack environmental knowledge to have an effective contribution. This approach takes into account villagers' formal education from which they attain writing skills for note taking, writing reports *etc.*, skills in mathematics to measure tree diameter and height and/or computer skills to communicate the results of measurements.

Local participation should also be about reporting measurement results and monitoring to the national database. Some studies on participatory approaches propose to provide villagers with training in the use of Personal Digital Assistants (PDA) or using Short Message Service [5,45,46]. However, there are technical issues to overcome with these suggestions, for example, PDA can stop working and mobile phone (PDA) signals are often absent in the forest. Instead of proposing a new system, we decided to look at what already exists, how it could be improved, and to learn from past and current experience. There is a lot to learn from sectors not directly related to forestry, such as health care. The comparison between the structure and caveats in information flow systems of the health and forestry sectors should provide useful information to develop an efficient participatory reporting system.

Another interesting issue is whether local community participation should be promoted or not when addressing the issue of verification and validation. Participation in verification could be checking what use is made of the data they collect, what decisions may affect their livelihoods based on the information they provide, and what benefits from REDD+ they can expect. Local people could also help validate data collected through remote sensing for MRV based on Tier 3, even if there may be some technical issues (e.g., lack of local capacity, difficult access to the information). So far, validation through remote sensing has been proposed to check the accuracy of measurements made by local people. During our research, we compared satellite imagery analysis and interpretation based on remote sensing, and participatory mapping, without assuming from the start that one of these two methods is more precise or accurate.

In summary, local communities may participate in one or more MRV activities where they have the capacity or have acquired it; however, local willingness will have to be considered before launching PMRV on a national scale.

4.4. PMRV and Social Safeguards

Our approach did not consider all the co-benefits of REDD+, however, it did look at some of the social safeguards, a critical issue in REDD+ implementation [8]. We especially looked into two main safeguards: effective participation and tenure security. Villagers expressed their expectations and concerns about being involved in MRV for carbon and non-carbon data. We also looked into local people's relations with government authorities, and how land rights and land tenure were locally managed. If PMRV is proven feasible under specific conditions and situations, we will integrate information on tenure and the effectiveness of local people's participation into the PMRV tool.

5. Conclusions: Realizing PMRV

We have presented a framework to study the feasibility of PMRV in different contexts in Indonesia, not to directly develop PMRV. The implementation of this framework is to be considered in further research. If considered an effective, efficient and viable solution for MRV, for addressing issues of co-benefit sharing and social safeguards, and local interest and willingness to participate is secured, PMRV will still need to be developed as a tool and adopted by the REDD+ institutions. Such a tool should be linked to the national and subnational levels especially regarding information sharing. To be operational, it needs to be embedded in the national MRV, not only to follow IPCC guidelines, but also to take into account each specific local situation. Before reaching that stage, the scientific community must agree first on the relevance of involving local communities in MRV, to what extent local people should be engaged, and to identify the steps and conditions for PMRV to be feasible.

We tested our approach in seven pilot sites in Indonesia; however, in order to get a better sample of different situations for comparison, more sites need to be added, not only in Indonesia but also in other countries where REDD+ is recognized as an important issue. In selecting these new sites, different contexts must be taken into account, including areas where REDD+ demonstration activities are being implemented, and in different landscapes.

Once the feasibility of PMRV is clarified, key stakeholders and decision-makers need to be involved in the discussion. This would include national REDD+ agencies, scientific community, donors, and civil society. Their role would be to develop a solid system based on clear understanding of each local situation, challenges, and stakeholders' expectations.

Beyond the topic of MRV and the more general research on climate change, working on local participation is of interest to researchers studying, for example, community based conservation and development, how to engage local farmers in agricultural innovation, or participatory monitoring of natural resources. However, we do need to understand what local communities lose and gain from being involved in activities away and beyond their daily activities in order to avoid taking their participation for granted.

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Author Contributions

Manuel Boissière and Guillaume Beaudoin prepared the introduction (Section 1), methods section (Section 2), a part of Section 3 on the results, the discussion (Section 4), and conclusion (Section 5), Carola Hofstee prepared the section on multilevel governance (Section 3.2.), and Serge Rafanoharana prepared a part of the Section 2.1, Section 3.3, and Section 3.4.3.

Conflicts of Interest

The authors declare no conflict of interest.

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Integrating CBM into Land-Use Based Mitigation Actions Implemented by Local Communities

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Abstract: In 2009, the conference of the parties of the United Nations Framework Convention on Climate Change recognized the need to engage communities and indigenous groups into the systems to monitor, report and verify the results of REDD+. Since then, many countries have started to prepare for REDD+ implementation. This article reviews early experiences under development in 11 projects financed by the Alliance Mexico REDD+ located in four Early Action Areas to identify the potential integration of Community Based Monitoring (CBM). The evaluation of the projects is made based on a multi-criteria analysis which considers the potential to produce information relevant for national monitoring systems and the prospects for sustained monitoring practices over time. Results indicate there are challenges to harmonizing monitoring practices and protocols between projects since activities proposed differ greatly from one project to another. Technical specifications for integrating local data into national systems are thus required. The results of these projects can help to identify best practices for planning and implementing REDD+. Findings indicate that in general, resources and capacities to gather, analyse and report information as part of CBM systems are in place in the projects, but usually these reside with non-local experts (*i.e.*, NGOs and Academia); however, there are notable examples where these capacities reside in the communities. If national forest monitoring systems are geared to include information gathered through locally-driven processes REDD+ should promote activities that produce local benefits, but countries would need to build local capacities for managing and monitoring natural resources and would also need to create agreements for sharing and using local data. Otherwise, national systems may need to rely on monitoring practices external to communities, which depend on the continued availability of external financial resources.

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1. Introduction

REDD+ is a policy being negotiated under the United Nations Framework Convention on Climate Change (UNFCCC). It aims to assist developing countries to reduce emissions from deforestation and forest degradation and increase forest carbon stocks (e.g., [1]). In the context of REDD+, information at high levels of accuracy and precision is required to produce inventories and reports on carbon emissions and removals for national and international communications and as part of the systems to monitor, report and verify REDD+ implementation (MRV), as well as for national systems for monitoring of forests (NFMS) [2,3]. However, the final objective of this programme is to implement actions on the ground, responding to local needs without compromising local livelihoods and biodiversity. The UNFCCC has explicitly recognised the need for local communities and indigenous groups to participate in activities as part of MRV systems for REDD+ [2]. REDD+ is being implemented in phases, initiated at a preparation stage, followed by implementation of initial activities at the sub-national level before moving towards full national level implementation [4]. Successful implementation of REDD+ on the ground, including continued local monitoring of activities and results requires the design of schemes that promote participation in the long term.

Within the phased implementation of REDD+, countries are starting to implement demonstration activities in early action areas (EAA). There are various activities and initiatives under development as part of REDD+ in México that are being implemented jointly with other parties. These include actions for the preparation and implementation of the national strategy, the preparation of the institutional arrangements and early actions. The objective of this article is to discuss the potential contribution of community based monitoring (CBM) to NFMS and MRV for REDD+. The analyses focuses on the case of Mexico, with emphasis on the early actions that are being carried on by the Alliance Mexico REDD+ in four EAAs. Potential contribution of CBM to national systems is discussed in terms of the prospects for the provision of information in the long-term and the completeness and compatibility with the institutional systems.

The Alliance is initially financing the implementation of a number of 3-year projects to create local capacities for REDD+ in four early action areas [5]. The United States Agency for International Development (USAID) is funding the Alliance as a capacity building measure for the implementation and achievement of an appropriate framework for the implementation of the Emission Reductions Initiative in Mexico, alongside the objectives of Mexico's draft national REDD+ strategy (ENAREDD+, in Spanish). The work of the Alliance, which is led by The Nature Conservancy (TNC), is being carried out by a number of different organizations in collaboration with the Ministry of Environment, Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAT) and the National Forestry Commission, Comision Nacional Forestal (CONAFOR) [6], including Rainforest Alliance, the Woods Hole Research Centre, and Espacios Naturales para el Desarrollo Sustentable (ENDESU). This article analyses the potential for CBM within these projects, to discuss the prospects for the permanence of such monitoring practices in the mid and long terms and for their contribution to the national systems for REDD+.

The structure of the document is as follows: first background information on CBM, climate change mitigation and implementation of REDD+ in Mexico is presented in Section 2. Section 3 presents the methods used to evaluate and compare the projects. In order to assess the potential for CBM, the projects are described and evaluated in terms of the activities to be implemented, the infrastructure and capacities and the degree of engagement of local actors into the projects. Section 4 presents the results and discussion. Finally, conclusions are presented in Section 5.

2. Background

2.1. Community Based Monitoring

Participatory or locally based monitoring approaches grouped here under the term Community Based Monitoring (CBM), can be described as processes that involve local people directly in data collection and/or data interpretation for environmental monitoring using relatively simple methods [7–10]. CBM schemes have been implemented in developed and developing countries to monitor different environmental attributes such as biodiversity and wildlife (e.g., [7]), hydrological services (e.g., [11]) or carbon in forests [12,13]. In fact, there are more than 1200 applications of participatory approaches for development and environmental issues reported in the literature [14].

Developing countries often lack systems and trained personnel to enable local participation and thus most environmental monitoring efforts rely on researchers/professionals funded by remote agencies, external to study areas (e.g., [15]); these schemes are often expensive, based on non-endemic know-how and may be non-sustainable in the long-term once external funding ends [8,16]. Nevertheless, there are various types of initiatives to produce information through monitoring schemes with varying level of involvement of 'external' actors and local communities. Danielsen *et al.* [8] provide a useful classification for such schemes, which can be used for the analysis of monitoring practices:

Type I: externally driven and run monitoring programmes;
Type II: externally designed monitoring schemes with local data collection;
Type III: collaborative design of monitoring with external interpretation of the data;
Type IV: collaborative design of monitoring with local interpretation of the data; and,
Type V: autonomous monitoring schemes, designed and run entirely by local people.

The type of monitoring that can be implemented in an area depends on the type of incentives and motivations for local participation and also on the degree of development of the required skills and local resources for monitoring (e.g., equipment and infrastructure). CBM is more likely to be sustainable over time if it is built on existing institutions, if it does not generate conflicts between government and traditional authorities and if data is stored and analysed locally [7]; this might mean that the process of implementation should be simple, appropriate to local needs and developed at a slow pace despite the pressures from external actors (e.g., funding bodies) [7,17]. Monitoring schemes with higher involvement of communities can help to build social capital, and facilitate a prompt response for forest management decision-making, if the schemes are developed within a supportive legal framework [8] and communities have rights to manage and use forest resources [18–20].

Following Danielsen *et al.* [8], the share of costs between external and local actors varies along the spectrum from type I–V; while local monitoring is cheaper in operational activities (due to lower wages and transport costs), it will require relatively high initial costs (*i.e.*, equipment and capacity building) [7,8]. If monitoring is locally relevant it may be more sustainable since valuation of local benefits will promote participation (types III–V) [8]; nevertheless monitoring programs should not rely on this 'low cost' monitoring, since if real local benefits are not enough to cover the participation costs, monitoring will not occur [8,18,21]. Previous research highlights the potential to develop monitoring schemes of types II–III when practices are institutionalised in official organizational and governance schemes to enable the provision of support/feedback by officials and other technical experts (e.g., [8,22]). External support is needed for including CBM into national monitoring systems for REDD+ since, first, this is an external initiative at international level and second, because institutions, skills and infrastructure are usually not in place yet for the interpretation of field data. This is necessary to produce more elaborated estimates of carbon stocks, baselines and leakage at the statistical levels expected for national and international schemes.

2.2. CBM and MRV for REDD+

CBM can become the backbone for a nested structure for REDD+ particularly if the following conditions are met: firstly, national monitoring systems need to include the appropriate infrastructure for data registration, storage and processing; secondly, standard procedures for monitoring practices are required to create a consistent and transparent system; and thirdly, the communities and public offices managing MRV systems need to benefit from collaboration by creating win-win conditions [23]. Local information produced through CBM can help to increase the detail of the information of national systems (*i.e.*, geographical data, emissions factors and information of carbon stocks) and can help to evaluate the impact of specific management practices; there are specific opportunities to engage CBM in monitoring systems by hiring local brigades to intensify official inventory programmes and through information sharing from forest management plans, on-going forest carbon projects and projects working with other certification schemes [24].

CBM can be helpful to understand and address local drivers of deforestation and forest degradation and also to provide information on changes in carbon stocks and forest areas [23]. There are experiences indicating that communities can monitor forest carbon stocks by undertaking local inventories using GPS and hand-held computers with accurate levels similar to those from professional foresters (e.g., [23]). For example, projects in Tanzania and Nepal have shown that villagers are able to use a GPS accurately [25]; this is less time consuming and more reliable than using a compass [26].

In addition to data gathering, CBM schemes can include participatory geographic information systems (PGIS) as a tool for monitoring forest carbon stocks and forest area [27] and also to monitor deforestation and forest degradation [28]; through PGIS, maps can be constructed in a collaborative process involving indigenous researchers, cartographers and GIS specialists (e.g., local knowledge can be gathered from elders, hunters, women and all relevant members of a community) [28]; however, usually these processes are conducted by technical staff from NGOs or academia and thus the know-how is not resident in the communities.

In many cases, local people contribute in CBM by collecting data, but for various reasons information is often processed outside the community. These correspond to the first classes of monitoring schemes described by Danielsen *et al*. [8]. However, there are cases in which PGIS has been implemented locally thus transferring additional skills to local actors. For instance, in the Siaya district of Kenya, a PGIS project was established to monitor the impact of brick-making industry on forests [29]; spatial data was processed on-site at the Ugunja Community Resource Center. In order to implement such a local system, a number of issues had to be addressed first (*i.e.*, unreliable electricity supply and unsuitable computing equipment, technical services and economic resources to run the laboratory). In order to succeed, the project needed predictable funding to pay for the personnel. Another important aspect was related to technical capacities; it was necessary to develop solid skills to accomplish the objectives of the project. Volunteer trainees learned to collect data, develop databases, design maps and use a GPS. Additionally, they learned more complex tasks such as downloading and converting GPS data, and planning, design and management of GIS databases. The project enabled the community to gather strong evidence linking brick-making and declining forest areas [29]. At national level, countries face different challenges to build capacities for the integration of CBM into MRV systems [23], this is also true at sub-national levels given the heterogeneity of communities and degrees of involvement of local actors in forest management.

With regard to existing and potential sources of local information, there are various opportunities to integrate CBM into NFMS and MRV for REDD+ [24] since these systems require information on forest areas and carbon stocks with high levels of resolution and frequent updating. First, there is the information that communities can gather as part of public programmes, this includes hiring communities to establish inventory plots as part of national or regional forest inventories following standardized protocols (*public programmes*); the motivation of the communities to gather the information in this case will be linked to the external benefits from public programmes. This overlaps with scheme of type II in the classification of Danielsen *et al.* [8] (scheme with lower involvement of communities). The second option is the information that communities gather and use as part of their management of natural resources motivated by the potential to access direct benefits (e.g., timber, non-timber forest products (NTFP), environmental services) (*local interest*); depending on the skills of the local actors and often on the involvement of external allies (e.g., NGOs). These activities may range from types III to V in the classification of Danielsen *et al.* [8] where communities play more active roles but may not necessarily follow standard monitoring procedures. The third option for integrating local data into national systems relates to the information collected during participation in private incentive schemes such as carbon markets or certification programmes (e.g., organic, certified timber) [24]. In this case, communities participate to receive an external benefit, building upon local management practices and following standardized monitoring protocols (*private incentives*); as in the previous option, depending on the skills of local actors, in these schemes they can engage in more activities and may correspond to types II to IV in the classification by Danielsen *et al.* [8]. The main differences between these three cases are the motivations for participation and the methods used to gather the information. In order to integrate the information of the last two options into national systems, it is necessary to reach agreements with local actors who formally own the information [24].

2.3. REDD+ in Mexico

Prior to COP 16 in Cancun, Mexico prepared a document to define its Vision on REDD+ [30]; two years later in November 2012, CONAFOR published a draft version of its national REDD+ strategy (ENAREDD+ in Spanish) [31], and a revised draft was circulated around a Technical Consulting Committee (CTC) for comments (July–August 2013). The ENAREDD+ draft [31], establishes that REDD+ implementation will involve a broad sustainable rural development approach, with a landscape focus aligned to the principles of the strategy and with social and environmental safeguards. In line with the General Climate Change Law, the draft of the strategy states the target of reaching zero carbon losses in original ecosystems by 2020; it also aims to reduce emissions from degradation, increase the areas under sustainable management and those regenerating naturally, as well as to conserve and enhance carbon stocks.

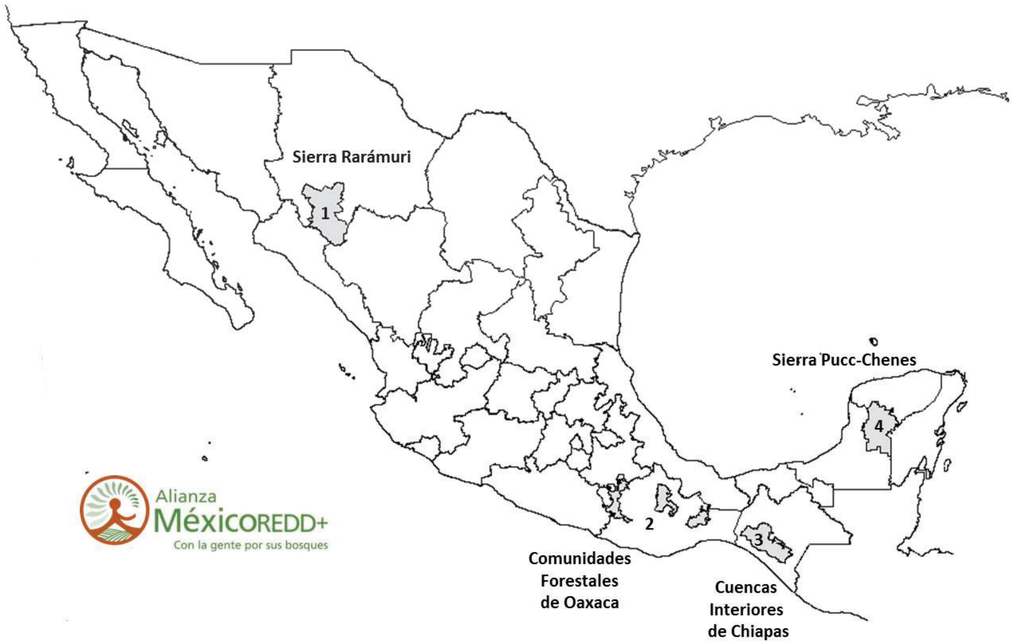
Based on a landscape approach, one of the objectives stated in the strategy is the integration of monitoring into the institutional arrangements at different scales. For this, activities to be implemented will be planned locally as means to create local governance schemes promoting the participation of communities, for instance via inter-municipal associations. In line with the texts adopted at the COP, the MRV system should consider the methods and guidance of IPCC [32,33] and the implementation will follow three stages (*i.e.*, preparedness, implementation of actions and policies and full MRV). It has been established in local legislation that the National Forest and Soil Inventory, which is at the core of the NFMS in the country, will include the information of the MRV system and that this should be created within a period of three years, starting on June 2012 [34]. The NFMS should be robust and include a transparent MRV system; it should promote local participation by exploring different approaches to improve community forest management while contributing to national systems. This system should be a tool to support land management at local level combined with different approaches of local monitoring to improve community territorial management.

In addition to the activities developed by the Alliance Mexico REDD+ there are other initiatives being undertaken in the country. In 2010, the Ministries of Environment of Mexico and Norway signed an agreement of understanding to develop activities related to REDD+ including the design of a MRV system (at least to a Tier 2 level), promoting South-South capacity building and the design of local incentives [35]; the official name of the project is *"Fortalecimiento del proceso de preparación para REDD+ en México y el fomento de la Cooperación Sur-Sur*" although it is usually known as the Mexico-Norway project. CONAFOR is also implementing a project in collaboration with the French Development Agency and the Spanish Agency for International Cooperation and Development funded by the Latin American Investment Facility (LAIF) of the European Union, to replicate the creation of local governance systems for REDD+ [36]. The objective of the *LAIF project* is to replicate the inter-municipal association scheme adopted in the EAA of Ayuquila River Basin in Jalisco in other watersheds and EAAs of high priority in order to build local capacities to link activities for rural development and sustainable forest management in REDD+ [36]. The three initiatives are assessing a monitoring governance based approach in communities within the EAAs.

2.4. Activities Financed by the Alliance Mexico REDD+

In this context, the Alliance is providing resources for the implementation of REDD+ activities in 11 projects located within the EAA of Sierra Rarámuri of Chihuahua (2 projects), the Pucc-Chenes Mountain Range in Yucatan Peninsula (3 projects), the inner watersheds of Chiapas (3 projects) and forest based communities of Oaxaca (3 projects) (Figure 1). These projects are implementing different activities to mitigate climate change including a wide variety of actors, strategies and scope. The projects were granted resources for three years based on competitive proposals submitted by different organisations that integrate local alliances for implementation.

Figure 1. Early action areas. Alianza Mexico REDD+ (image provided by TNC).



The activities proposed in the projects can affect carbon emissions or removals in forests in many different ways. Strategies include some actions that are to be developed directly in forestland (*i.e.*, sustainable management of forest), some that take place off-forest (*i.e.*, improved agricultural practices, reforestation), others that involve a group of regional policies (*i.e.*, community land-use plans; environmental law enforcement), and/or a group of activities that can be oriented towards capacity building. It is recognised that action outside forested areas is necessary to address different drivers of deforestation and forest degradation (e.g., agricultural practices) (e.g., [37,38]). Additionally, the activities to be implemented by each project can vary as regards the potential to provide information compatible with national monitoring systems (*i.e.*, activity data or information on forest areas, changes in area and management practices; and data on carbon stocks and stock changes for different reservoirs). In order to assess the potential of the projects to produce information to national systems, thus activities can be grouped into three general types that are described below.

Case A. Strategies that can produce geographical data (maps) but not data to quantify levels and changes in carbon stocks. Some REDD+ activities might have a diffuse effect on forest management, making it hard to predict the impact on carbon stocks; moreover, they may not initially include the implementation of carbon monitoring practices or targets to reduce emissions. Examples of such activities are the formulation of local land-use plans, general training on best agroforestry practices or the exclusion of cattle in forested areas. Local actors can produce activity data (*i.e.*, area) and integrate it into a PGIS as part of project design and follow-up. Information could refer for instance to the areas of forest that have a local land-use plan, or the ejidos, communities and municipalities that have received training or the polygons where certain activities are being implemented. Such local geographical information could be integrated into the NFMS and identified accordingly as an extra stratum for analysis.

Case B. Strategies that can generate geographical data and some estimates of carbon stock changes. A second case would be the activities that in addition to geographical data could provide information on gains or losses in certain carbon stocks, though not through a comprehensive local forest inventory. Examples of these activities could be the installation of improved cook stoves (in which case, the reduction of fuel-wood extraction could be estimated based on usage) or the restoration of degraded forests by tree planting (for which calculations of biomass growth could be made). It is necessary to identify the specific data types that would need to be produced to identify suitable methods to estimate impacts of the strategies on carbon stocks, emissions or removals. In this case, the information on estimated stock changes in individual reservoirs could be included in national systems [24].

Case C. Strategies for which complete local information can be generated (Geographical & Carbon). This category corresponds to actions including the implementation of local, repeated, forest inventories, which include all the relevant carbon reservoirs. This would correspond to areas with commercial forest management plans or areas participating in carbon sequestration markets. The local forest inventory data could be combined with that of national inventories. This would however require that local inventories follow standardised protocols and the prescribed verification processes associated with the different schemes.

3. Methods

REDD+ is at an early stage in Mexico and the first projects in the EAAs are just starting. In order to assess the potential for integrating CBM into these projects, the following methodology was followed. First, the individual project proposals as submitted to TNC were reviewed to assess the potential for integrating CBM into these [39–49]; additionally interviews were made to project managers and a survey to evaluate the inclusion of different features related to CBM was applied to all 11 projects during the summer 2013. Appendix 1 presents basic information on each project. The potential contribution of CBM to national forest monitoring systems for REDD+ is evaluated using a multi-criteria analysis [50]. The projects are ranked according to different criteria for analysis (Table 1). At a later step, a weighted score for each project is obtained by assigning different levels of importance to each of the criteria.

Table 1. Criteria for evaluating potential contribution of projects to national systems for REDD+ and for the implementation of monitoring practices in the long-term.

Criteria	Description
Potential contribution to national monitoring systems (50%)	
Scale (25%)	The contribution to REDD+ is assessed by determining the scale of direct implementation of the activities in reference to the direct influence area of the project (*i.e.*, area where local actors have jurisdiction to implement activities) and the size of the EAA. This is made based on the description of each project [39–49]. Projects are ordered based on the scale of their contribution.
Expected Information (25%)	The activities proposed by projects are classified as A, B or C (Section 2.4, potential to produce information on activity data and on carbon stocks and stock changes); a quantitative characterisation is made for these activities by assigning a value of 1 for activities of type A, 2 for B and 3 for C. Once all the activities proposed by the projects are evaluated, a sum of the values is made and projects are ordered from those with higher to those with lower scores.
Infrastructure and Roles for MRV (25%)	The inclusion of monitoring in the projects is evaluated with regard to the formal inclusion of MRV, resources available and local capacities. If these practices have been included explicitly in the project, it receives 1 point. If the project has the required infrastructure necessary for collecting and processing the information (*i.e.*, equipment for forest inventories, computer, internet access and GIS software), the project receives 2 points; however if the project has only part of the resources required it receives 1 point. Finally, if specific monitoring activities are defined for local actors, the project receives one more point. A total value is obtained per project and these are ordered from higher to lower scores.
Completeness of Monitoring (25%)	The completeness of monitoring is evaluated in terms of the carbon reservoirs included, the specific options to produce geographical information (*i.e.*, activity data) and the inclusion of activities to monitor leakage. Projects received a point for each factor included in their monitoring plans, and are also ordered accordingly to total score.
Temporal Sustainability of Monitoring Practices (50%)	
Motivation (50%)	The activities proposed by each project are classified in terms of expected linkage to public, local or private interests to identify the motivation for implementation (Section 2.2); a value of 3 is assigned to activities linked to local interests, 2 for private incentives and 1 for public programmes. For this criterion totals are also obtained and projects are ordered accordingly.
Roles in Projects (50%)	Finally projects are evaluated with regard to the type of actors participating in the projects and the roles they play. Two points are granted if the project was proposed by a local actor (ejido/community); if local actors participate in the project but they are not leading it, the project is granted one point. Lastly, the project is granted a point if an NGO/academic institution with the required know-how for MRV is part of the project. Totals are obtained and projects are ordered according to the scores.

The evaluation is made in two dimensions, firstly considering the potential to provide information to national systems and secondly, analysing the potential to provide this information in the long term; each of these main criteria is worth 50% of the final mark for the projects. In order to assess the contribution to monitoring systems, projects are described in terms of (a) the geographical scales of the activities to be implemented; (b) the type of information that can be gathered as part of CBM (*i.e.*, activity data and emission factors); (c) the resources available and roles associated with monitoring; and (d) the completeness of the monitoring practices (*i.e.*, carbon reservoirs, geographical information and monitoring of leakage). Each of these four elements has a weight of 25%. For the evaluation of the prospects for long-term provision of information, two additional factors are assessed: first, the motivation to implement the activities described in the projects and the second, the engagement of local actors and other participants in project management. These factors contribute by 50% to the evaluation of the temporal sustainability of CBM in the projects. Here, it is assumed that monitoring activities led by local actors motivated by access to local direct benefits will be more likely to be sustainably in the long term as these represent more autonomous monitoring types [8]. For each criterion, the projects are evaluated and ranked, starting with those that are more likely to produce useful information for national systems and promote long-term collaboration. Finally, a weighted score is obtained for each project.

4. Results and Discussion

4.1. Scale of Direct Implementation

Table 2 below presents data on the projects in relation to the area of the EAA and the projects' influence area. It can be seen that in most cases, although each project includes a number of different communities or ejidos, the projects cover only a very small part of the EAAs. Nevertheless, it is expected that as part of other deliverables of the projects, there will be a growing number of practical activities to be replicated and implemented in the mid and long terms in the areas of influence of the projects.

As regards the area for direct implementation of activities, the projects IDESMAC and UZACHI have the highest marks. IDESMAC proposes to implement best practices for coffee production over 10,000 ha. UZACHI will work towards the reduction of land use changes over an area of 3,000 ha. On the other hand the projects of Ejido Trinidad and AMBIENTARE did not specify the scale of their project in terms of area for implementation.

Looking at Table 2, it is clear that most of the activities/strategies envisaged in most of the projects take place over relatively small management units. This means that data from the national or even state level inventories will most likely not be able to measure the effect of specific practices, as their density of sampling is too low to capture the impact of changes in these (e.g., activities take place outside the plots; national inventories do not monitor relevant reservoirs; satellite images do not detect changes below the canopy). Gathering local data is therefore essential to understand how these activities impact forest area, carbon stocks and their associated changes. Monitoring the results from these pilot activities through CBM can help to identify better options for implementation of REDD+ based on specific management practices.

Table 2. Projects' influence area and area for direct implementation in the different EAA.

EAA (ha) *	Project	Project Influence Area (Ha) (% EAA)	Direct Implementation (Area; % EAA; % Project Influence Area)	Rank **
Chihuahua (1,883,895 ha)	Ejido Chinatu	113,736 (6.0%)	Fire protection 5000 ha, prescribed fire 100 ha, 20 km fire breakers, 1000 ha for conservation (water), 10 km black lines, 30 km dead organic matter soil conservation practices; 10 ha reforestation (5000 ha; 0.27%; 4.4%).	3
	Ejido Trinidad	88,030 (4.7%)	-	10
	Sub-Total EAA	201,766 (10.7%)		
Chiapas (1'059,157 ha)	BIOMASA	123,200 (11.6%) (Villaflores Municipality)	80 ha prescribed fires, 20 km black lines, 70 km fire breakers (80 ha; 0.01%; 0.1%).	5
	AMBIO	30,000 (2.8%)	Pilot parcels in 3 communities (pastureland and cropland management) (30 ha; 0.003%, 0.1%).	6
	IDESMAC	119,177 (8.6%)	10,000 ha with improved coffee management (10,000 ha; 0.94%; 8.4%).	1
	Sub-Total EAA	272,377 (25.7%)		
Yucatan Peninsula (1'381,924 ha)	BIOASESORES	105,541 (10%)	12 pilot parcels (12 ha; 0.001%; 0.01%).	8
	PRONATURA	22,984 (1.7%)	Study over 250,000 ha.	9
	NUKUCH KA AX	12,101 (0.9%)	15 pilot parcels (15 ha; 0.001%; 0.1%).	7
	Sub-Total EAA	140,626 (10.2%)		
Oaxaca (1'154,839 ha)	MESOFILO	25,371 (2.2%)	40 ha of enriched fallows, 4% households reduce 50% fuelwood consumption (Approximately 20 households) (40 ha; 0.003%; 0.2%).	4
	AMBIENTARE	22,223 (1.9%)	200 m^2 nursery with capacity for 25,000 plants.	10
	UZACHI	59,225 (5.1%)	Reduction of land use change in about 3,000 ha, working with 54 community members directly (3000 ha; 0.3%; 5.1%).	2
	Sub-Total EAA	106,820 (9.2%)		

* Areas of the EAA obtained from [6]; ** The rank shows the order considering the area for direct implementation of activities as percentage of the project influence area.

4.2. Type of Activities Implemented

Table 3 presents below the list of actions proposed for each the 11 projects; it is interesting to note they differ greatly. This represents a challenge in designing a monitoring system since it should consider the particularities of the different activities while maintaining the compatibility of the results. Activities are described in terms of the location where they take place (forest/off-forest) and whether they refer to interventions to enhance local governance and capacities or specific factors related to monitoring systems and REDD+. Actions proposed by the projects are described in terms of the expected geographic information and on carbon stocks that can be gathered (as A, B or C, as described above in Section 2.4), and also in terms of the typical type of motivation for implementation (*i.e.*, Public, Local or Private, as described in Section 2.2). Activities associated with private motivation include those oriented to carbon markets and other certification schemes, and in the broader sense cash/market-oriented activities and research oriented projects. Using these criteria each project is evaluated by taking into account the different activities proposed. Hence, there are two ranks presented in Table 3, first that related to the information that can be gathered and included in national monitoring systems; and secondly, a rank for the type of motivation for the implementation. The projects with the highest marks in terms of information to be gathered are UZACHI followed by Ejido Trinidad and MESOFILO. UZACHI included various activities that can produce information on activity data and information on the different carbon reservoirs through forest inventories, projects oriented to carbon markets, development of local allometric equations and carbon accounting.

The second criterion concerns the motivation associated with the implementation of each activity. Columns 7–9 present the classification of each activity based on whether these are associated with public programmes, local interests or private incentives. When one activity can be linked to more than one option, the highest value is recorded. The strategies presented in Table 3 could be analysed in detail to define whether they have been included in the projects as a response to external incentives or to local interests. However, this analysis would require a deeper documentation of the projects including interviews to members of the communities involved in each project, which is beyond the scope of this work. In terms of the type of motivation for implementation, the projects with the highest marks are UZACHI, Ejido Trinidad and AMBIO. These are the projects in which more of the activities proposed may generate local benefits and respond to the interests of the community.

If local information is used only for local internal interests, it could happen that protocols for measurement, evaluation and storage of data would not be as stringent as those for externally driven projects; and it may not fulfil the requirements for external use in national systems. Hence, in order to integrate the information to be produced by the projects with national systems, the first task would be to harmonise the protocols for data gathering, processing and reporting so that all the projects use a common approach. In some cases it would be necessary to design and create *ad hoc* monitoring schemes for the relevant carbon reservoirs (e.g., when the activity does not have carbon monitoring as an initial objective). However, for cases B and C, once the data is produced and processed it should be possible to determine the resulting reduction of emissions or carbon removals in terms of tCO_2e/ha-yr.

Table 3. Definition and classification of the actions proposed as described in the projects of the Alliance.

Actions	Location of Activity or Type of Activity	Expected Information to be Gathered			Type of Activity (Case) *	Type of Motivation *			Projects Mentioning the Activity/Intervention										
		1. Activity Data	2. Some Carbon Reservoirs	3. All Carbon Reservoirs		1. Public	2. Local	3. Private	1. Ejido Chinatu	2. Ejido Trinidad	3. BIOMASA	4. AMBIO	5. IDESMAC	6. BIOASESORES	7. PRO-NATURA	8. NUKUCH KA AX	9. MESOFILO	10. AMBIEN-TARE	11. UZACHI
Improved Forest Management	Forest	X	X	X	C	X	X		X	X		X	X			X	X	X	X
Forest Management Certification Schemes	Forest	X	X	X	C		X	X		X			X						
Forest Conservation	Forest	X	X		B	X	X	X											X
Restoration Critical Areas	Off-forest	X	X		B	X	X	X											
Fire Management Practices	Forest	X	X		B	X	X		X	X	X			X	X		X	X	
Soil Conservation Practices	Off-forest	X	X **		B	X	X		X		X						X	X	
Improved Coffee	Off-forest	X	X **		B		X	X			X		X				X		
Beekeeping (reforestation/restoration for…)	Off-forest	X	X		B		X	X					X		X				
Camedor Palm Production	Off-forest	X	X **		B		X	X			X		X						
Ecotourism	Off-forest	X			A		X	X							X				
PES	Forest	X	X		B	X													X
Reforestation/Afforestation	Off-forest	X	X		B	X	X	X	X							X		X	
Improved Grazing/ Ranching	Off-forest	X	X		B		X	X	X		X	X		X	X	X	X		
Improved Fallow	Off-forest	X	X		B		X	X						X			X		
Agroforestry	Off-forest	X	X		B		X	X		X				X					
Organic Agriculture	Off-forest	X	X		B		X	X		X						X			
Improved Corn Production	Off-forest	X			A		X			X		X		X		X	X		
Biological Pest Control	Off-forest	X			A		X			X						X			
Protein Banks	Off-forest	X			A		X	X				X							

Table 3. *Cont.*

Actions	Location of Activity or Type of Activity	Expected Information to be Gathered: 1. Activity Data	2. Some Carbon Reservoirs	3. All Carbon Reservoirs	Type of Activity (Case) *	Type of Motivation *: 1. Public	2. Local	3. Private	Projects Mentioning the Activity/Intervention: 1. Ejido Chinatu	2. Ejido Trinidad	3. BIOMASA	4. AMBIO	5. IDESMAC	6. BIOASESORES	7. PRO-NATURA	8. NUKUCH KA AX	9. MESOFILO	10. AMBIEN-TARE	11. UZACHI
Productive Activities Low Carbon Development	Off-forest	X	X		B		X					X	X		X	X			
Food Production at home	Off-forest	X			A		X		X										
Eco Techniques	Off-forest	X	X		B	X	X	X									X		
Tree Nurseries	Off-forest	X			A	X	X	X				X		X				X	
Carbon Markets	Off-forest	X	X	X	B/C			X											X
Land use Plans	Governance/ Capacities	X			A	X	X			X	X	X	X		X		X	X	X
Governance, Coord. Plann.	Governance/ Capacities	X			A	X	X		X	X	X	X		X	X		X		
Financing Benef. Shar.	Governance/ Capacities	X			A	X		X					X						
Market Access	Governance/ Capacities	X			A			X			X	X				X			X
Best Practices	Governance/ Capacities	X	X **		B		X						X	X					X
Pilot Activities	Governance/ Capacities	X	X **		B		X					X		X	X	X			
Training, Cap. Building	Governance/ Capacities	X	X **		B	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Evaluation Protocols	Monitoring	X	X		B	X	X			X	X	X		X	X				X

Table 3. *Cont.*

Actions	Location of Activity or Type of Activity	Expected Information to be Gathered: 1. Activity Data	2. Some Carbon Reservoirs	3. All Carbon Reservoirs	Type of Activity (Case) *	Type of Motivation *: 1. Public	2. Local	3. Private	Projects Mentioning the Activity/Intervention: 1. Ejido Chinatu	2. Ejido Trinidad	3. BIOMASA	4. AMBIO	5. IDESMAC	6. BIOASESORES	7. PRO-NATURA	8. NUKUCH KA AX	9. MESOFILO	10. AMBIEN-TARE	11. UZACHI
Wildlife Inv.	Monitoring	X			A	X	X	X		X							X		X
Forest Inventory	Monitoring	X	X	X	B/C	X	X	X	X	X	X							X	X
Carbon Accounting	Monitoring	X			A	X		X			X	X	X				X	X	X
Monitoring Water and Env. Serv.	Monitoring	X			A	X	X	X			X								X
Development of Allometric Equations	Monitoring	X	X		B	X	X	X											X
Online Repository of Information	Monitoring				NA	X	X	X											X
Community Mapping	Monitoring	X			A	X	X	X										X	
GPS use	Monitoring	X			A	X	X	X										X	
Identification of Drivers	REDD+	X			A	X	X	X											
Total of Actions to be Implemented									9	13	13	13	12	11	10	10	14	1 1	16
Rank Considering Expected Information to be Gathered									7	2	4	5	4	6	8	7	3	6	1
Rank Considering the Type of Motivation of Activities to be Implemented									7	1	3	1	5	4	5	6	2	5	1

* For evaluation, regarding the expected information, projects receive 1 point in case A, 2 for B and 3 for C; regarding the type of motivation projects receive 1 for Public Programmes, 2 for Private Incentives and 3 for Local Interests. For the activities with more than one possible values the highest one is used; ** It is not clear how/if carbon accounting will be incorporated into these practices; *** Reforestation/Afforestation practices take place in non-forest land, however if the projects are successful after 20 years areas can be reclassified as forests; NA. Not Applicable.

4.3. Infrastructure and Capacities for MRV

In order to gain a more detailed view of the monitoring practices in the project, a questionnaire was sent to project leaders which included questions about inclusion or the creation of a MRV system, the different roles expected from the different actors and capacities and infrastructure available. Table 4 presents a summary of the responses obtained to these questions.

Table 4. Roles and infrastructure for the monitoring, report and verification (MRV) of activities of the projects financed by the Alliance.

Project *	MRV Formally Included	Responsible for Analysis and Reporting	Infrastructure	Role/Capacities of Communities	Role/Capacities External Experts	Rank **
Ejido Chinatu	No	Project information to be reported by external consultants	Consultants provide equipment including GIS software.	Capacities for MRV are needed	Forest management, Capacities for MRV (technicians)	3
Ejido Trinidad	No	Forest technicians elaborate reports according to forest management plans	Computer, internet, brigades and GIS software available.	N.S.	Forest management	3
BIOMASA	No	Consultants	Field equipment to estimate fuels, computer and GIS software	N.S.	N.S.	3
AMBIO	No	N.S.	Brigade, computers and GIS software	Data gathering	Analysis	2
IDESMAC	-	-	-	-	-	5
BIOASESOR ES	Yes	Consultants	-	Capacities for MRV are needed	Measurement and monitoring, some capacities are required	4
PRONATURA	Yes (M only)	Consultants	Brigade, computers and GIS software	Capacities required for data gathering	Capacities for MRV are needed	2
NUKUCH KA AX	Yes	Experts and communities	Brigade, computers and GIS software	Capacities for MRV are needed	Capacities for MRV are needed	2
MESOFILO	Yes (MR only)	Experts and academia	Computer and brigade equipment, not mentioned GIS software	Capacities for MRV are needed	SIG and Project management, capacities for MRV needed	3
AMBIENTAR E	Yes	N.S.	Brigade, computers and GIS software	Need to build capacities for monitoring, PGIS and inventories.	SIG, inventories, and reporting.	2
UZACHI	Yes	Analysis Academia, Report, UZACHI	Brigade, computers and GIS software	There is a high degree of social organization	Information management and methodology	1

N.S. Not specified; * IDESMAC project did not complete the questionnaire; ** Projects received one point for the formal inclusion of MRV; one point if the project has access to the required equipment and infrastructure and another point if local actors/communities have defined roles.

In Table 4, it can be seen that not all the projects have included practices for MRV in their design and in some cases there is reference only to the monitoring or reporting of information. In general, all the projects have access to computers, internet connection, basic equipment for forestry inventories and GIS software. However, most of these resources are not part of the assets of the communities but of consultants, NGOs and academia, who are charged with processing the data. This corresponds to Danielsen *et al.* [8] Type II (or possibly Type III, where communities act mostly as gatherers of local data) as regards community involvement. NUKUCH KA AX and UZACHI are exceptions since local participants will participate in analysis and reporting. Capacities for the local analysis of information have not been developed consistently and homogenously across communities participating in the projects. The prominent role envisioned for communities as part of CBM will be that of data gathering and only AMBIO and UZACHI acknowledged that the required capacities for this are in place; these two projects obtained the highest marks in the evaluation on this criterion although AMBIO did not include specific MRV activities as part of their project proposal since this would require additional resources.

4.4. Completeness of Monitoring

Project leaders were specifically asked if CBM had been considered as part of the monitoring activities in the assessment of specific variables related to carbon reservoirs and geographical information. Table 5 presents the responses obtained.

Although in some cases projects did not include specific provisions for setting up an MRV system, the activities to be implemented will generate information that could possibly be integrated into such a system. However, as noted above, it will be necessary to standardize monitoring practices since there are large variations across EAA and even among projects in the same regions. The projects that obtained the highest ranks were BIOASESORES and UZACHI. Conversely, the projects with the lower marks are AMBIO, MESOFILO and NUKUCH KA AX. The case of AMBIO indicates that although the members of the project may have the required skills and resources to perform monitoring practices, resources for this are needed and the scope and resources granted were not enough to include monitoring of the activities proposed. Most of the projects have included practices to monitor biomass and carbon stocks in trees (the principal carbon reservoirs); it will be easy to standardize monitoring practices for monitoring trees and this can set a common point of departure. It will take more time to develop and deploy comparable methods to monitor other carbon pools such as dead organic matter (fuelwood is a resource of local interest in rural areas), as to develop a system for the representation of lands and different forms of leakage.

Table 5. Information to be generated by the projects. Is CBM considered for the generation of the following information? *.

Variable	Ejido Chinatu	Ejido Trinidad	BIOMASA	AMBIO	BIOASESORES	PRONATURA	NUKUCH KA AX	MESOFILO	AMBIENTARE	UZACHI	Total
Carbon Reservoirs (Stocks and Changes)											
Biomass (Above and below ground, trees, shrubs and herbs)	Yes	Yes **	Yes	No **	Yes	Yes **	NS	Yes **	Yes	Yes	10
Soil (Organic, Mineral)	No	Yes **	No	No **	Yes	No	No	No	No	Yes	5
Dead Organic Matter and Litter	Yes	Yes **	Yes	No **	Yes	No	No	Yes **	No	Yes	8
Emissions from disturbances (fire, pests, meteorological)	No	No	No	No	Yes	Yes **	No	No	No	Yes	5
Storage in Harvested Wood Products (Timber, other)	NO	No	Yes	No	Yes	Yes **	No	No	No	No	3
Illegal Logging (reports)	No	No	No	No	Yes	Yes **	No	No	No	No	4
Information on Representation of Lands											
Representation of Lands (Stratification, vegetation type, areas with different management practices)	Yes	Yes	Yes	No **	Yes	Yes **	No	No	Yes **	Yes	7
Mapping the area of each stratum	Yes	Yes	No	No **	Yes	Yes	No	No	Yes **	Yes	6
Monitoring land use change of forest areas.	Yes	Yes	No	No **	Yes	Yes **	No	No	Yes **	Yes	8
Monitoring changes in canopy cover.	Yes	Yes **	No	No	No	No	No	No	No	Yes	3
Leakage											
Displacement of extractive activities (timber, fuel-wood, soil).	Yes	Yes	Yes	No	Yes	Yes **	Yes	No **	Yes **	Yes	8
Displacement of grazing activities.	Yes	Yes	Yes	No	Yes	Yes **	Yes	No	Yes **	Yes	8
Displacement of agricultural practices.	Yes	Yes	Yes	No	Yes	Yes **	Yes	No	Yes **	Yes	8
Rank	4	3	5	8	1	3	6	7	5	2	

The answers shown as 'Yes' receive 1 point for the evaluation; * IDESMAC did not complete the questionnaire; ** Project leaders provide a brief description of the methods.

4.5. Roles and Actors

One of the objectives of creating local capacities for CBM is to produce systems that could be sustained over time, preferably without the need for external incentives. In this context, the prospects for creating sustainable CBM schemes are defined as the potential to maintain REDD+ activities and their monitoring once the support from the Alliance ends. All other things being equal, it may be expected that with more community involvement (higher on Danielsen's scale [8]), sustainability will be more likely. Table 6 presents the type of stakeholders participating in the projects, identifying the type of project proponent (leader).

Table 6. Members of local alliances and involvement of local communities.

Project	Project Proponent (Type)	Other Members of Local Alliance				Rank
		Local Actors	NGO/Consult.	Acad.	Gov.	
Ejido Chinatu	Local Actors		*			2
Ejido Trinidad	Local Actors		X	X		1
BIOMASA	NGO	X	X	X		2
AMBIO	NGO	X	X	X		2
IDESMAC	NGO	X	X	X		2
BIOASESORES	NGO	X	X	X		2
PRONATURA	NGO	X	X			2
NUKUCH KA AX	Local Actors	X	X			2
MESOFILO	NGO	X				2
AMBIENTARE	NGO	*			X	3
UZACHI	Local Actors			X		1

Projects received 2 points if the projects were proposed by a local actor/community, 1 point if local actors are included as part of the projects, and 1 more point if the project includes a technical member (*i.e.*, NGO/Consultant or an academic institution); Consult.: Consultants; Acad.: Academia; Gov.: Government; * Actors are not specified formally as members of the local alliance for the implementation of the project.

Table 6 shows there are different actors participating in these projects: local actors (ejidos or producers' unions), NGOs or consultants, academia and public offices. The projects were proposed officially by an individual actor to the Alliance, and each proposal mentions who the other official members of the project are (local alliance). Four projects were proposed directly by local actors (communities or productive unions); these are the ejidos Chinatu and Trinidad in Chihuahua and the unions of NUKUCH KA AX in the Yucatan Peninsula and UZACHI in Oaxaca. In these projects, local actors have developed interest, capacities and initiative to engage into REDD+ related activities and thus might have a good chance of continuing efforts in the mid and long terms. The projects with the highest ranks are UZACHI and Ejido Trinidad.

The remaining seven projects were proposed by NGOs, many of which had long standing experience in collaborating with local actors in local management of natural resources (e.g., AMBIO, PRONATURA). In terms of specific abilities and capacities for data management and processing, all the projects with the exception of Ejido Chinatu include either NGO/consultants and/or academic institutions. In these projects, some critical tasks will be done by the experts external to communities (e.g., proposal writing, project planning, data management and GIS analysis), but it would be important to identify how communities could start to adopt and lead these activities. If NGOs have predictable and sufficient sources of funding to cover their overheads this might help to run the projects and create local capacities for the implementation of REDD+ activities in the longer term. This offers a period of opportunity to initiate processes to build local capacities and mechanisms for the adoption of locally driven sustainable management practices and local governance schemes, including monitoring. Ejido Chinatu mentioned that external consultants will participate in the analysis of information. They will be hired by the ejido, but are not a formal party in the project.

The participation of academia can also provide long term access to specialized know-how and trained personnel as long as researchers and students have funding and time. In this case, it will be necessary to prevent potential conflicts related to data ownership, management and publication. Sometimes, part of the technical information collected and analysed by researchers is withheld until it has been published in academic journals. These actors should have the capacities and infrastructure to process and store the information, however if the objective is to transfer these capacities and facilities to local communities some specific activities need to be implemented.

There is however one project in which local actors are not officially members of the partnership according to project documentation, this is AMBIENTARE. This project obtained the lower marks in the evaluation of this criterion. The project was proposed by an NGO in collaboration with environmental governmental offices (CONANP/SEMARNAT); the document mentions that the project will be implemented in three communities and two ejidos from three different municipalities however they are not mentioned as being project members.

4.6. Summary of Results

Table 7 presents the overall evaluation of the projects financed by the Alliance taking into account the potential contribution to national monitoring systems and the prospects for long term sustainability of monitoring schemes based on the multi-criteria analysis.

The evaluation produced separated rankings for the contribution to monitoring systems and for the evaluation of the prospects for temporal sustainability. In both cases, the project led by UZACHI had the highest marks. This project will implement activities that may produce information compatible with national systems and that may also motivate long-term implementation and monitoring. The project is led by a local organisation with the skills and infrastructure needed to undertake monitoring and analysis of information. In terms of potential contribution to monitoring systems the projects PRONATURA, NUKUCH KA AX and AMBIENTARE had the lowest marks. These projects propose actions over relatively small areas, such that their activities will not generate complete information that can be integrated into national systems; moreover, their proposed monitoring practices include few parameters. Regarding the prospects for sustained monitoring over time, in addition to these three projects, IDESMAC also had a lower score. The case of AMBIENTARE imposes great challenges for the continued practice of monitoring since local actors were not mentioned as members of the project.

Table 7. Overall evaluation of potential contribution to MRV systems and temporal sustainability of monitoring schemes of the projects financed by the Alliance Mexico REDD+.

Project	Potential Contribution to National Monitoring Systems (50%)					Temporal Sustainability of Monitoring Practices (50%)			Final Score (Rank)	Classification (Danielsen *et al.* [8])
	Scale (25%)	Expected Information (25%)	Infrastructure and Roles for MRV (25%)	Completeness of Monitoring (25%)	*Total Score (Rank)*	Motivation (50%)	Roles in Projects (50%)	*Total Score (Rank)*		
Ejido Chinatu	3	7	3	4	4.25 (2)	7	2	4.50 (8)	4.38 (6)	III
Ejido Trinidad	10	2	3	3	4.50 (3)	1	1	1.00 (1)	2.75 (2)	III
BIOMASA	5	4	3	5	4.25 (2)	3	2	2.50 (4)	3.38 (4)	II
AMBIO	6	5	2	8	5.25 (5)	1	2	1.50 (2)	3.38 (4)	II
IDESMAC	1	4	5	9	4.75 (4)	5	2	3.50 (6)	4.13 (5)	II
BIOASESORES	8	6	4	1	4.75 (4)	4	2	3.00 (5)	3.88 (4)	II
PRONATURA	9	8	2	3	5.50 (6)	5	2	3.50 (6)	4.50 (7)	II
NUKUCH KA AX	7	7	2	6	5.50 (6)	6	1	3.50 (6)	4.50 (7)	III–IV
MESOFILO	4	3	3	7	4.25 (2)	2	2	2.00 (3)	3.13 (3)	II
AMBIENTARE	10	6	2	5	5.75 (7)	5	3	4.00 (7)	4.88 (8)	I
UZACHI	2	1	1	2	1.50 (1)	1	1	1.00 (1)	1.25 (1)	III–IV

Table 7 enables the identification of particular strengths for each project as well as a general overview. The last column in Table 7 describes the type of monitoring scheme for each project based on the classification proposed by Danielsen *et al.* [8] and on the evaluation made in this work. One project (AMBIETNARE) corresponds to type I of monitoring schemes, this is an externally driven intervention that is most likely to stop once the external support ends. The majority of the projects correspond to type II, these are the projects led by external NGOs but include the participation of local actors. In these cases while communities may have participated in the design of the project and identification of the management activities to be implemented, the main role they will play in the monitoring will be data gathering. There are technical parties in the projects (NGOs and Academia) with the resources and skills that will lead the analysis and interpretation of information that can be used for external reports in a first instance for the Alliance. Finally, there are four projects classified as type III or IV in the typology of Danielsen *et al.* [8]. These are collaborative projects with a higher degree of participation and leadership of the local actors. In projects of type III, external partners assist the communities in the analysis and interpretation of information (Ejido Chinatu and Ejido Trinidad). Only the projects UZACHI and NUKCH KA AX identified members of the communities as actors responsible for analysis and reporting of information; these projects fall between type III and IV because there are also other external actors collaborating in these tasks.

4.7. Further Steps: Project eREDD+

The review of the 11 projects financed by the Alliance shows that in general, the resources to implement local monitoring activities through CBM activities are in place. In most cases, these capacities reside in specialised organisations such as NGOs and academia. However, the review of these projects showed that at least two projects have also developed the required skills and could transit towards more autonomous schemes. Nevertheless, although the infrastructure and capacities are in place it is necessary to dedicate appropriate resources for the implementation of monitoring systems based on CBM, as the case of the project led by AMBIO illustrates. Moreover, it is necessary to define the activities that could be included in REDD+ (e.g., in forest and off forest areas) along with the technical requirements for the participation of communities in national systems (e.g., methods, formats, procedures).

Considering the need for a common base for CBM and stemming from the early experiences of the Alliance Mexico REDD+, there is a new project being developed called "Strengthening of local capacities for CBM in Mexico". The goal of this project is to research, develop and test methods to integrate data from ground-based CBM with remote sensing, GIS and web-enabled reporting tools, in the context of a nested monitoring system. During a first stage of the project, a web-based platform will be designed and created to capture, transmit, store, systematize, analyse and present results based on CBM for a wide range of data users (*i.e.*, eREDD+ System). The system will standardize monitoring practices across the projects financed by the Alliance, including the basic requirements for the integration of information to national systems and it is expected that it will reduce the barriers and costs of CBM. At a later stage such information will be made available from the different studies and strategies implemented by the Mexico REDD+ Alliance and strategic partners. For these, the pilot initiative will develop tools and methodologies, while providing training to a group of ejidos/communities on a CBM protocol. This project is an initiative from the Mexico REDD+ Alliance, Mexico-Norway Project, FAO and LAIF working together with local communities, academic institutions and civil society organisations.

5. Conclusions

There are two requisites that need to be reconciled in national monitoring systems for REDD+ including CBM: on the one hand the process should ideally include active participation of local actors from a bottom-up approach, not least because this may enhance the prospects for sustainable monitoring schemes. On the other hand national systems need to establish a set of protocols and a minimum of standards to ensure that the information generated at the local level can be integrated into the larger MRV system and NFMS. The challenge at project level is to create a unified monitoring scheme, which is compatible with national systems and also provides useful information for local management. Such a scheme should engage communities already prepared to manage their natural resources more actively into monitoring, analysis, interpretation and use of information.

For effective monitoring in REDD+ it is clear that collaboration will be needed between communities and projects at the local level. In the case of Mexico, the draft ENAREDD+ states clearly that local implementation will start at the ejido and municipality levels. This work made a review of 11 projects being implemented in Mexico to explore the potential to include CBM and to produce information compatible with national monitoring systems for REDD+. The results indicate that the capacities and resources to produce local information for national monitoring systems are in place at the project level. In most cases, these resources reside in NGOs and academia, but also in communities, which have a higher degree of organisation. However, in many projects the prominent role of local communities in CBM will be data gathering. Hence, in most of the cases, at least initially, the processes for integrating local information into monitoring systems would be externally driven. In the fewer cases when more autonomous locally driven schemes could be implemented, information will be produced and used according to local interests; these cases may maintain monitoring activities in the long term [8].

There are two important challenges in integrating local information into the national monitoring systems of REDD+. First, since projects will implement many different activities (see Table 3), the information will not be entirely compatible with national systems (*i.e.*, parameters, formats, protocols); and secondly, since the information is owned by communities, an agreement will be needed to share and include sensitive information into the reporting systems of REDD+ [24]. A comprehensive strategy to include CBM into national systems for REDD+ will need to consider these issues. If a country aims to produce monitoring schemes driven by local actors, an initial investment is required to provide the necessary resources (*i.e.*, computers, software, satellite imagery, internet connection) and to create local capacities including technical and organisational skills. The organisational skills refer not only to the planning and management of CBM plans, but in a broader sense to the management of natural resources of local interest. Moreover, it is necessary to identify the activities that produce more benefits at the local level while contributing to the objectives of REDD+ since these will increase the chances of designing enduring interventions. Projects under development in EAAs can contribute to evaluate the contribution of different management practices to the reduction of emissions and promotion of carbon enhancements. Thus, carbon emissions/removal factors obtained through projects could be integrated into the design of further REDD+ activities. It will be necessary to define and create the platforms to integrate local information into the national monitoring systems for REDD+.

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Appendix

The description of the projects presented below is based on the documents of the projects, interviews to project coordinators and responses to the questionnaires.

EAA Chihuahua

Ejido Chinatu [39]

The objective of the project proposed by the ejido Chinatu is to restore the Turuachi river basin located in the state of Chihuahua; for this, the project will implement natural resource preservation practices, including sustainable forest management and the implementation of community planning instruments. The section of the basin to be restored is located in the ejido Chinatu, in the municipality of Guadalupe y Calvo that hosts nine indigenous communities; the project is developed in the Tarahumara region. The ejido has an area of 113,736 ha (12% of the municipality's area), from which 95,137 ha are forest (15% of the total municipality's forest land); out of this land, 42,609 ha are the exploitable woods pine and oak. The project will be developed in an area with forest-land use vocation of 86,090 ha specifically in the 5000 ha of the Turuachi river basin where there are 9 communities all part of the ejido Chinatu.

Ejido Trinidad [40]

The project's main objective is to achieve the sustainable and integral development of three ejidos from the Guadalupe y Calvo municipality in Chihuahua. It aims to contribute to a development model that should be economically competitive, socially and culturally equitable, ecologically sustainable and regionally balanced. The municipality has a total population of 53,499 and an area of 9629.05 km^2 from which 65.2% is covered by forestland (pine-oak forests). Other main land uses are agriculture and grasslands for grazing, the main crops harvested in the municipality are maize, oatmeal and bean. The ejidos that will be involved in the project are La Trinidad (48,013 ha), El Nopal (4417 ha), and Catedral (35,600 ha) involving 11 communities overall. Land is communally owned and is used mainly in forestry. The project is proposed by Ejido La Trinidad in collaboration with other actors (*i.e.*, a consultancy firm, a civil association and a local university). The ejidos have forest management plans for timber extraction; La Trinidad has been certified under the FSC. The ejidos have experience with reforestation practices, PES programs (*i.e.*, hydrological services, 5076.06 ha in La Trinidad, 462.01 ha in El Nopal), soil conservation and restoration practices and wildlife management.

EAA Chiapas

BIOMASA [41]

The project was proposed by Biodiversidad, Medio Ambiente, Suelo y Agua, A.C. Its main objective is to boost pilot models of productive and environmental alternatives in four microbasins in the Villaflores municipality, located in the Sierra Madre de Chiapas. This will be achieved by implementing sustainable forest management strategies and environmental safeguards, and by strengthening local abilities to contribute to the communities' REDD+ preparation. The project will be located in the limit and buffer zones of the "La Sepultura" biosphere reserve and the natural resources protection area "La Frailescana". Villaflores has a 1232.2 km^2 area, from which 50,000 ha are pine, oak, and evergreen forests. The four microbasins of the El Tablón river, where the project will take place, are Champerico, Nuevo Horizonte, Villahermosa, and Nueva Palestina. These hold 11 ejidos, a 20,000 ha surface (from which 15,000 are commonly owned), and 2950 inhabitants.

AMBIO [42]

The project presented by Cooperativa AMBIO S.C. de R.L. aims to create a low emission rural development strategy in the area by leading productive activities toward sustainable practices and participative planning processes in order to improve the legal framework to favor social participation. Located at the Sierra Madre de Chiapas, the Natural Resources Protection Area (APRN) La Frailescana is an important biological corridor that provides several environmental services. It is located in four municipalities of Chiapas (La Concordia, Ángel Albino Corso, Jiquipilas, and Villaflores); 25.5% of these municipalities' area is forestland, 26.4% is agricultural areas and 14.9% is grassland. The most important agricultural products are bean, maize, and sorghum. Existing vegetation in APRN La Frailescana includes low and high evergreen forest, low and high deciduous forest and oak and pine forests, however they are decreasing in area. The most abundant covers are secondary vegetation, grasslands and seasonal agricultural lands. The project will benefit 16 communities, accounting for more than a thousand families distributed in more than 30,000 ha.

IDESMAC [43]

The project's objective is to implement a strategy for territorial development at different levels to reduce emissions from degradation and deforestation in eight agricultural sites from Reserva de la Biósfera El Triunfo (REBITRI). The project was proposed by Instituto para el Desarrollo Sustentable en Mesoamérica, A.C. REBITRI has a 119,177 ha area with ten different types of vegetation: deciduous and evergreen forests, oak-pine forest and cloud forest. The reserve holds endemic and endangered species. It works as a rainwater catchment area to feed Mexico's most important hydroelectric system and nine rivers that work as a water source for different towns and irrigation systems. The agricultural sites are located in four municipalities from the state of Chiapas: Ángel Albino Corzo (Santa Rita and Querétaro), La Concordia (Plan de la Libertad and La Concordia), Montecristo de Guerrero (Toluca and Montecristo de Guerrero), and Siltepec (Ángel Díaz and Honduras) these cover 48,653 ha and hosts 3018 people (total population of the four municipalities is 115,753). Main productive activities are agriculture, palm gathering, commerce, crafting and livestock.

EAA Yucatan Peninsula

BIOASESORES [44]

The objective is to design, plan, and develop a concept and pilot model of MREDD+ development in four pieces of land in the Puuc-Chenes region in the municipalities of Tekax and Oxkutzcab in Yucatán and Hopelchen in Campeche through low carbon emission activities, capacity building and communication development, and the implementation of safeguards and MRV system. The ejidos participating are: San Agustin (Tekax), Yaaxachen (Oxkutzcab), Bolonchen and Yaxche (Hopelchen). The total influence area is 105,541 ha. The existent ecosystem is medium deciduous forest, however the conditions of resources vary from one community to another. The main crops grown in these municipalities are maize and pastures; however, the land is mainly forest (85% of the area).

PRONATURA [45]

The project was proposed by Pronatura Península de Yucatán, A.C. Its objective is to strengthen the technical and organizational capacities of the Puuc-Chenes corridor through the development of local and regional land management and governance mechanisms that will link rural development and sustainable management programs in Hopelchén. The project will be located in the Puuc-Chenes region in Hopelchén, Campeche, which total area is 89% forest. Existing vegetation are forests, herbaceous and shrub secondary vegetation, grasslands, and seasonal agriculture. The region's importance resides in the fact that it is a corridor between two ecological reserves. Three ejidos were chosen for this project: Chun ek (15,700 ha, 124 inhabitants, 23 communal land owners), Ramón Corona (3854 ha and 39 communal land owners), and Francisco J. Mújica (3700 ha and 37 communal land owners). This covers 33% of Hopelchén's area. Hopelchén's population is mainly indigenous (76%). It is estimated that the project will benefit 90 people directly and 200 indirectly.

NUKUCH KA AX [46]

The project aims to develop and implement pilot parcels in five ejidos of the Forest Management Unit (UMAFOR) 3106 by developing capacities and transforming productive activities through intensive pastureland management systems, improved maize production, and organic agriculture. It was proposed by Asociación Regional de Agrosilvicultores del Sur de Yucatán Nukuch Ka Ax A.C. The chosen ejidos and the municipality in which they are located are described as follows: Tekax has 87% to forest and 10% to agriculture; San Juan Tekax and Becanchen (10,069 ha and 298 communal land owners, 36% of surface is covered by secondary vegetation, 18.2% by dry forest, and 45.5% by agricultural land); Tzucacab, 74% of the territory is occupied by forest and 21% by agriculture; San Isidro (2031.5 ha and 25 communal land owners) and Ekbalam. From Oxkutzcab, which land is occupied 78% by forest-land and 21% by agriculture; Xul will be partly reforested to diversify activities.

EAA Oaxaca

MESOFILO [47]

The project proposed by Grupo Mesófilo A.C. aims to implement in a participative way actions that may fortify the conservation of natural resources and incentives to assure the continuity of ecosystems in the Rincón de Ixtlán zone, Sierra Norte de Oaxaca, as a contribution to carbon emission reduction. The project covers an area of 25,371 ha (35% of the municipality's area) of communally owned land and is located in Sierra Norte. Involved localities are: San Miguel Tiltepec (9769.82 ha), San Juan Yagila (1576.61 ha), Santa Cruz Yagavila (1469.03 ha), Santa María Zoogochí (687.21 ha). The project intends to benefit 250 people directly and 1800 people indirectly (27% of the municipality's total population). Marginalization in the area is high.

AMBIENTARE [48]

The main objective of the project is to develop land and forest resource management instruments and to strengthen capacities related to different REDD+ components to avoid degradation and lead to better management practices in three communities and two ejidos in Santa Catarina Zapoquila, San Juan Suchitepec, and San Francisco Teopan in Oaxaca. The zone holds a population of 1259 people, distributed in 16 rural communities living with high poverty and marginalization conditions. The project will benefit 75 people directly and 831 people indirectly. The ecosystems found in the area are coniferous and hardwood forests. Around 22,223 ha (75% of the municipalities' total area) have no management plan and 4845 ha are productive and settlement areas. From the total area, 59% is secondary vegetation, 22% is grassland and 19% is forest-land. The project was proposed by AMBIENTARE, A.C.

UZACHI [49]

The Project was proposed by the UZACHI (union of local producers). Its main objective is to develop a participative community monitoring scheme that allows the measurement of the carbon reserves increment based on data from de National Forest Inventory and measurement units, as well as measurement of emission levels linked to better practices on natural resources management and considering monitoring of water and biodiversity environmental co-benefits. The project will reside in the following communities: La Trinidad, Capulálpam de Méndez, Santiago Xiacuí, Santa María Jaltianguis, San Juan Evangelista Analco (all of these located in the Sierra Norte), San Juan Ozolotepec, and Santa María Lachixonace (located in the Sierra Sur), covering an area of 57,464 ha.

Conflicts of Interest

The authors declare no conflict of interest.

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Options for a National Framework for Benefit Distribution and Their Relation to Community-Based and National REDD+ Monitoring

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Abstract: Monitoring is a central element in the implementation of national REDD+ and may be essential in providing the data needed to support benefit distribution. We discuss the options for benefit sharing systems in terms of technical feasibility and political acceptability in respect of equity considerations, and the kind of data that would be needed for the different options. We contrast output-based distribution systems, in which rewards are distributed according to performance measured in terms of carbon impacts, with input-based systems in which performance is measured in term of compliance with prescribed REDD+ activities. Output-based systems, which would require regular community carbon inventories to produce Tier 3 data locally, face various challenges particularly for the case of assessing avoided deforestation, and they may not be perceived as equitable. Input-based systems would require data on activities undertaken rather than change in stocks; this information could come from community-acquired data. We also consider how community monitored data could support national forest monitoring systems and the further development of national REDD+.

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1. Introduction

International debate on the design of an international policy for Reducing Emissions from Deforestation and forest Degradation (REDD+) has been going on since 2003. A three-phased approach was adopted at the 15th Conferences of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen in 2009. Under such an approach, countries would first receive assistance to build up their capacities, then to experiment with strategies to reduce deforestation and degradation before moving on to a fully fledged system under which they could expect financial rewards tied to performance compared to agreed baselines or reference levels [1–3]. With financial support from the UN-REDD programme (UN-REDD+), the Forest Carbon Partnership Facility (FCPF) and various bilateral donors, a number of countries are well into phase 1 or starting phase 2, and the formal adoption of a REDD+ framework by the Parties at COP19 in Warsaw is a major step forwards in turning the idea into reality. A major role for communities has been foreseen, not only in managing forests, but also in monitoring tasks related to this [4], and there have been many projects promoting methods that could be used for community based monitoring (CBM) for REDD+ [5,6]. However, with all these positive advances, some of the challenges of implementing this complex policy at national and local level are also becoming more evident [7]. As countries move from the basic capacity development phase into Phase 2 of REDD+ and start to envisage how performance-based activities could be built into national programmes, several important questions arise relating to CBM, benefit sharing and how the related data will tie into national REDD+ data systems.

We start from the position that CBM is likely to be promoted in national REDD+ programmes, even though it is not yet clear what form it will take and what data it will provide. While CBM protocols could focus on carbon stock changes in community forests, they could also be designed to gather data on activities undertaken rather than on results. Either way, the use of CBM may be very important in increasing both the accuracy and the transparency of monitoring processes, but the choice of data to be included would have direct bearing on the suitability of such monitoring with respect to benefit sharing.

In this paper, we present and discuss a range of feasible options for benefit distribution systems that governments could select from. We use the term "benefit" here to refer to the direct rewards that participants within a national REDD+ system would receive in Phase 3 as an inducement, and we assume that the main source of these benefits is the finance raised as a result of international trading of the carbon credits, whether this is through a fund or a market; these inducements might be transferred to the stakeholders in the form of cash or in kind. We do not consider funds relating to preparatory phases, e.g., for capacity building, to be "benefits" in this sense, and in this paper we are not considering co-benefits (such improved micro-climates, water supply *etc.*) that may also accrue to participating communities.

An important question is how the financial benefits of future carbon credits and/or other REDD+ payments will be distributed within national programmes or initiatives started at the level of sub-national jurisdictions, since although UNFCCCC REDD+ was conceived as a scheme to operate at the national level, it has been agreed that in some cases, particularly where national governments do not have full authority over some jurisdictions, sub-national programmes will be accepted (e.g., province or state level REDD+ programmes). For simplicity, we talk in terms of national programmes for the purposes of this article [8]. These benefits may be the main incentives for the participation of individual stakeholders in REDD+ activities within national programmes; before opting in, potential participants will want clarity on what rewards they could expect, and under what conditions they will be eligible to receive them. Not only will they need information relating to their own opportunities under REDD+, it is clear that at societal level there will be need for transparency and a legitimate rationale to justify how the financial benefits from REDD+ are to be distributed between the different participants. These might for example be individuals or communities whose territory includes forest areas and who might contribute to REDD+ by improving their forest management approach or by making changes in other ways (e.g., management of cattle) to reduce pressure on the forest. However, given that community monitoring of such REDD+ activities will in many cases accompany these activities, the question arises of whether, and how, this will be used in assessing the relative contribution of different participants, and therefore whether it could and should be used as a basis for the distribution of benefits. A further question concerns how such community monitored data might be integrated with the data systems at national level which will be used by countries in reporting to UNFCCC on their national achievements relative to reference levels.

The assumption is often implicitly made that within national programmes the financial benefits that accrue from international sources should simply be shared between participating stakeholders according to the performance of each participant, calculated in terms of the tons of carbon each participant saves, a model which we refer to as an "output-based benefit distribution system". However, although a carbon-performance metric based on output (amount of carbon saved through REDD+ activities) may be appropriate for distribution of benefits at the international level [9], there are a number of reasons why it is less suitable for the distribution of benefits *within* countries or jurisdictions. There are alternative metrics for distribution of REDD+ benefits that could be considered, using subsidies which are tied to performance in terms of inputs and effort, rather than in terms of (carbon) outputs. We refer to models of this type as "input-based benefit distribution systems". The distinction between input-based and output-based models is well known in literature on Payment for Environmental Services (PES) [10–12], where the terms "action based" and "results-based" are sometimes used [13]. Input-based systems are much more common in PES systems, that is, payments are made on a per hectare basis for changes in management which are assumed to bring about improvements in the flow of environmental services, rather than for the delivery of the services themselves, partly because capacity to observe and measure the environmental services themselves is limited [11].

The choice between these different types of benefit distribution model needs to be based on careful comparison of their implications with regard to three critical characteristics: (a) technical feasibility, particularly as regards baselines; (b) political acceptability, particularly as regards equity and who could be included as a participant; and (c) data requirements, particularly with regard to data that could be gathered by CBM. We start by describing the two models for benefit distribution, including some variations on the input-based approach, in Section 2, before going on to compare them in terms of these three critical issues in Section 3. In Section 4, we consider whether and how systems of data collection to support benefit distribution at the local level might be linked to national systems for REDD+ monitoring and Measuring, Reporting and Verification (MRV). Conclusions are summarized in Section 5.

2. The Difference between Output-Based and Input-Based Systems for REDD+ Benefit Distribution

International REDD+ as proposed under the UNFCCC is in the long run predicated on an output-based benefit distribution system in the sense that by Phase 3, countries are to be rewarded on the basis of reduced emissions or increased removals of carbon dioxide from the atmosphere, as assessed using a baseline or reference level. Countries will only be rewarded for carbon savings which are additional in terms of this baseline, and they will be rewarded proportionally to the quantities involved. As noted above, many observers have assumed that within countries, the same principle should hold: benefits should flow to those who participate in reducing the emissions, on the basis of their individual achievements in reducing emissions through reduced rates of deforestation and/or degradation or though increasing removals of carbon from the atmosphere through forest enhancement [14–16]. This follows the idea of market based incentives [3,9] or a "payment by output" approach that has come into vogue in various domains of public policy and public management, including the environment [17], and this principle will be followed regardless of whether international finance for REDD+ comes from a true carbon market based on off-sets, or from a fund. It reflects a model of economic incentives in which the underlying assumption is that people will try harder if they are rewarded proportionally to their achievements; in terms of UNFCCC policy the underlying rationale is that it will lead to the most cost-efficient mitigation of emissions. Interestingly, many (though not all) REDD+ type projects which pre-date UNFCCC and national approaches to REDD+ and which sell their carbon credits on the Voluntary Carbon Market (VCM) are also rewarded in this way; their funds are, as might be expected, directly related to their carbon performance. However, in those where credits are issued for reductions in deforestation (rather than for tree planting and other forest enhancement activities, which have different characteristics in terms of accounting [18]) the *internal* distribution of benefits among the project participants (say, between the members of participating communities at the local level) is not generally carried out according to individual performance [19,20]. There are important reasons for this. Firstly, a system in which payment is tied to individual achievement would require a baseline for each and every participant, against which performance could be assessed. Secondly, it may in practice be difficult to identify and define who should receive the benefits (*i.e.*, which participants have not deforested, but would have done in the absence of the REDD+ project). Thirdly, a system based on individual achievement may offend basic principles of equity [18]. As we will demonstrate and explain in this paper, exactly the same kinds of challenges arise in the distribution of benefits among participants within national level REDD+ programmes (say, between different participating rural communities).

The alternative to the output-based benefit distribution model is one that distributes rewards on the basis of effort or input in the implementation of REDD+ activities. As noted above, in most Payment for Environmental Services (PES) systems, landowners are offered a flat rate payment per hectare if they agree not to deforest, or to carry out a set of prescribed activities for sustainable use which are assumed to conserve forest and retain or increase carbon stocks or biodiversity (see for example [21] for the case of Mexico; [22] for the case of Costa Rica; and [23] for the case of Ecuador). Though called a "payment for environmental services", in these programmes the payment is in fact a subsidy, and it is paid on the assumption that the actions undertaken will have positive effects on the quantity and quality of the services. The improvement in the supply of environmental services is not directly measured, although payments are usually made after checking that the activities have indeed been carried out, to ensure conditionality. However, additionality is not usually assessed; it is clear that in many cases payments do not result in additional effects, since many of the participants would not have deforested anyway [21,23] (for an extended discussion of the efficiency of payments in this respect under PES, see [24,25]). In input-based systems, potential participants are free to decide if it is worth their while to participate, based on the size of the incentive offered. Payments may be higher in areas with particularly important ecological characteristics ("graded flat rates"), and may be restricted to areas which are genuinely under threat of deforestation. This input-based system of distribution of benefits relies on calculation of overall carbon achievements of a large area (state or national level), the financial value of which form the basis of the fund to be distributed. It is therefore fundamentally different from the output-based one which pays each participant on the basis of the direct measurement *ex-post* of carbon achievements.

A sophisticated variation on the input-based model is payment by opportunity cost, in which the level of the reward or benefit is set based on an estimate of what the landowner/community would have to sacrifice financially by conserving the forest or managing it in a sustainable way rather than deforesting or degrading it for personal economic gain (note that here we are considering opportunity costs only in the sense of how these might vary within any one country. It is of course true that the opportunity costs of REDD+ vary between countries, an issue that leads to inequalities in the extent to which different countries could potentially participate, but this is beyond the scope of this paper.). This is based on the idea that implementation costs are not uniform, and that scaling of payments to reflect this will enable more people to participate. There are two ways to estimate opportunity costs: (1) payment levels could be set centrally for each type of likely land use change in given regions; the per hectare rates of payment in areas threatened by avocado or palm oil plantations, for example, would be much higher than rates of payment in areas threatened by less profitable commodities such as maize; (2) payment levels are fixed through an auction system, in which potential participants bid, proposing the level of payment they consider would match their costs; a central organization would then select which bids to accept, *i.e.*, choosing the most cost effective bids on offer. The knowledge that selection will be made in this way should encourage potential participants to put in their lowest possible bids. Opportunity costs models, particularly the second type, are considered by some economists to offer the most efficient form of incentives as in theory at least they should result in carbon savings at lowest costs. Many observers of PES however dispute this, noting that opportunity costs do not reflect the full costs of the environmental service delivered since they do not include transaction costs [26,27]. Transaction costs (for example, the cost of acquiring the necessary data), may vary considerably between the different models, as we show below. It has also been noted that opportunity costs vary greatly over space and are usually highest for large landowners in areas of greatest deforestation threat [24,28,29], which raises the question of social equity in targeting. Borrego and Skutsch [30] have shown that the opportunity costs of shifting cultivation vary by a factor of 5 within one community, as richer individuals with larger parcels invest more and get much higher returns. A policy of paying the poorer members of the community at a lower rate than the richer members is not likely to be popular. Moreover, experience indicates that the suppliers of the environmental service prefer fixed payments [31].

3. Critical Comparison of Output- and Input-Based Benefit Distribution Systems

In order to make sound choices in the design of a benefit distribution system, the characteristics of the different possible systems needs to be considered. Here, we consider three important sets of characteristics. We first look at the different technical challenges associated with baselines for output- and input-based systems, secondly at their respective political and equity implications, and finally at their data requirements, including the cost of gathering the data that would be needed to implement them.

3.1. Technical Considerations

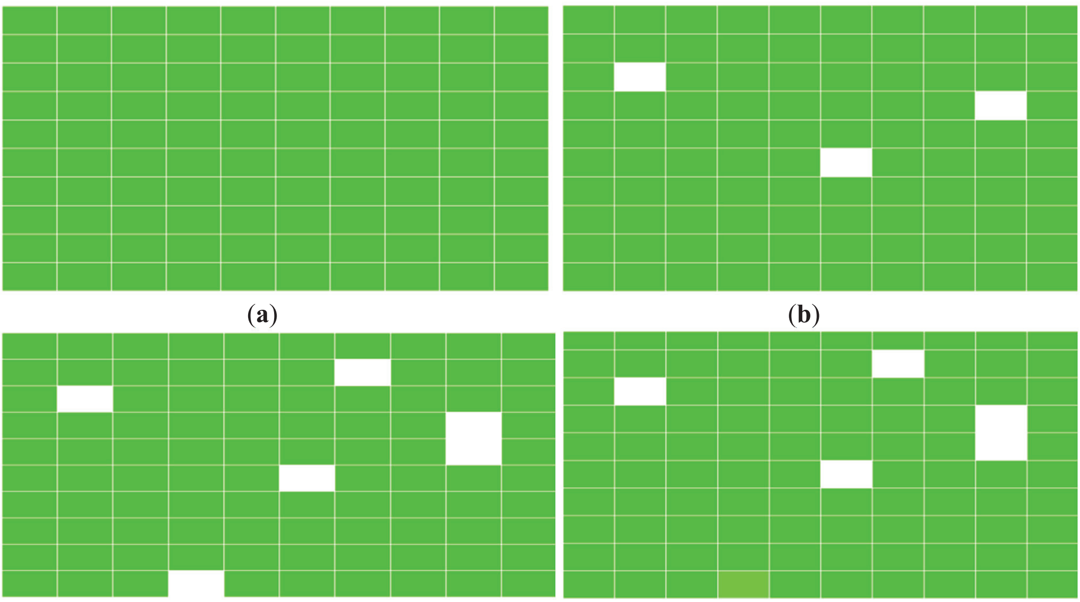
3.1.1. Baselines for Output-Based Benefit Distribution

Payment by output requires a baseline against which performance can be assessed; the baseline represents "business as usual", *i.e.*, it is a projection of what the carbon losses from the forest stock would have been if no action were to be taken under REDD+. It is usually based on historical trends, and it is in essence hypothetical or counterfactual. The national level baseline is called the reference emission level or reference level depending on whether or not it includes forest enhancements. Baselines can also be set up for smaller areas within a national territory: for example, REDD+ type projects in the VCM have baselines which usually cover the project area and a zone surrounding this area, to ensure that any local project leakage will be included. Such projects however are usually made up of multiple forest owners or forest owning communities.

We consider first the case of reduction of emissions (from deforestation) for which REDD+ activities are stimulated over a given area, and are successful (the case of emissions from degradation raises even more challenges, since lack of historical forest inventory data in most countries means that it is not possible to construct a baseline for these carbon losses.) At the end of the period during which REDD+ activities have been undertaken, it is possible to compare the actual deforestation rate of the whole area against the baseline, but it is very difficult to know which of the many individuals/communities would have deforested in the absence of the project, but did not [18]. For example, if a region is made up of 100 forest parcels of equal size, and has had a historical deforestation rate of 3%, it would, under a business as usual scenario, be expected to lose the equivalent of three parcels of forest every year in the future. If as a result of REDD+ activity, the rate of loss is reduced to two parcels per year, the region would receive credits equivalent to one parcel. The difficulty, however, is to know which of the many parcels that did not deforest in that year should receive these credits. As Figure 1 shows, in year 3, there would be 95 parcels that are not deforested, but the credits available for distribution are equivalent to the forest stock of only one parcel. Since most deforestation is unplanned, it is impossible to know to which of the 95 owners or communities the credits should be attributed. In practice, this means that it is impossible to relate the "avoided deforestation" to individual owners/communities, and thus to determine who should be rewarded.

This is a major dilemma facing national REDD+ programmes, in which the intention is to enroll communities and landowners as participants. Credits will be calculated at national level, based on overall losses and gains against the reference emission level. Many communities will not deforest, but it will not be possible to ascertain which ones *would have* deforested in the *absence* of REDD+. This difficulty is a direct outcome of the requirement under REDD+ that carbon savings should be additional; credits are not issued for all forest that is not deforested, but only for that amount of forest that would have been deforested but was not.

Figure 1. Example showing the difficulty of identifying who should receive benefits relating to the reduction of deforestation within a large geographical area. (**a**) Year 1: Region has 100 intact forest parcels; (**b**) Year 2: before REDD+ 3 parcels are cleared: rate of loss 3%; (**c**) Year 3: without REDD+ Continuing at 3% loss, 6 parcels would be cleared by the following year; (**d**) Year 3: with REDD+ However, with REDD+, the rate of loss is reduced to 2%. One parcel is "saved", but it is impossible to determine *which* one.



(**a**) (**b**) (**c**) (**d**)

The apparent solution to this problem would be to create a baseline for every individual property, showing their individual past deforestation trends and making individual forward predictions for their "business as usual" situations. However, apart from the huge transaction costs that would be involved in developing so many baselines, there are difficulties in applying deforestation baselines to each and every small property, since the temporary clearances associated with cyclical harvesting and certain agricultural practices (e.g., shifting cultivation) would average out in time at broader geographical scale. Moreover, a benefit distribution system based on individual baselines would risk presenting perverse incentives. Those responsible for a parcel which has never been deforested in the past will be at a disadvantage compared to those who have considerably deforested their forests in the past, since the latter will be able to claim more credits when they start to improve their management [32]. This kind of metric is unlikely to be considered legitimate by the general public, as it does not reward those who have always maintained their forest well, a point that we will discuss in more detail below in the section on political and equity considerations.

Secondly, we consider the case of increased removals of carbon dioxide from the atmosphere through forest enhancement, which is technically different in terms of baselines from reduced deforestation and degradation. It presents other possibilities, and could be credited in a different manner. For example, if through improved management, the owners or managers of forest parcels are able to increase forest cover, or to increase the density of biomass within the existing forest areas, these increases in stock can readily be measured on site [5,33] and could therefore, unlike reductions in deforestation and degradation, be attributed directly to the owners or managers [18]. For example, in the Scolel Té programme in Chiapas, Mexico, which follows the Plan Vivo system and sells credits on the voluntary carbon market, farmers are encouraged to increase tree cover in their coffee plantations; increases in tree biomass are measured on their fields, and they receive a payment which is directly proportional to the increment [34]. The same strategy has been used in a number of projects in Tanzania which involve tree planting [35]. This strategy can also work at the community level: in a REDD+ pilot project in Nepal, for example, communities are rewarded for increases in stock in the communal forests [36], partly on the basis of their performance. This is also the methodology used in afforestation and re-forestation projects under the Clean Development Mechanism (CDM). The measurement of increases in stock in these forests does not rely on counterfactual assessments, which are inherent in the assessment of avoided deforestation/degradation. Although a baseline will be required to check that the forest was not growing of its own accord before the project began (*i.e.*, to satisfy the requirement of additionality), such baselines are relatively simple to develop and there is considerable experience in this from CDM projects and in the Voluntary Carbon Sector. It might also be possible to develop a methodology that uses independent expert judgment.

3.1.2. Baselines for Input-Based Benefit Distribution

In benefit distribution systems based on inputs, on the other hand, all landowners participating in the REDD+ programme would receive benefits, provided they carry out the prescribed activities and do not deforest, as is the practice in most PES schemes in developing countries and e.g., in Europe for the case of some agri-environmental grants. It is also the principle behind most forest certification systems [37]. Although a reference emission level would be necessary at national level to gauge the overall national achievements in REDD+, no carbon baselines would be needed to measure carbon performance of the participants. Instead, benefits could be based on simple flat rate payments, graded flat rates, or opportunity costs, as described above. All that would be needed would be some proof that participants had complied with the programme requirements. The challenge, however, is that if the financial benefits were to be sourced only from the carbon credits, the money would have to be shared between a very large number of participants, meaning that each participant would receive a very small amount. Alternatively, the money could be used for community infrastructure and facilities; nevertheless it would involve small amounts since it would have to be shared between all participants in compliance. In the case illustrated in Figure 1, the profits from the carbon credits issued as a result of the reduced deforestation equivalent to one holding would have to be shared between all 95 owners who had not deforested. It is also clear that paying everyone, every year, when in reality only a few would have deforested in any one year, is not very efficient from an economic perspective; this strategy has been heavily criticized for example in the case of the programme Bolsa Floresta in Brazil [38]. Moreover, there would be no incentive for extra effort in forest management, as everyone would get an equal payment for the same minimum set of activities, even if they voluntarily implement additional activities.

Given the technical difficulties with output-based payments related to the impossibility of determining who should be paid and the apparent economic "inefficiencies" of input-based systems (which pay a large number of people who would not have deforested anyway), plus the fact that input-based systems will never be able to generate sufficient funds to pay all participants a significant subsidy, Balderas Torres and Skutsch [18] proposed a dual system of payments. In this system, communities/landowners could receive input-related payments for participation in a REDD+ programme in connection with reductions in deforestation and forest degradation measured at the jurisdictional or national level, and financed from the fund derived at national or state level from sale of aggregate credits calculated at that level. In addition, they could receive an output payment for any measured increases of stock which they could demonstrate on their own property. The input-related payments to each participant would necessarily be small, given that the fund would pay out to all participants, not merely those that are responsible for additionality. However, the output payments would vary according to real achievements, and, as explained above, these are much easier to measure than counterfactual reductions in deforestation, and require no real baseline since increments would be physically measured at intervals throughout the crediting period; any increases above the starting value would be rewarded. This could stimulate the better management of large areas of degraded forest through relatively simple means such as restricting off-take to levels which are sustainable. Since claiming credits for such growth would require local data, communities could be required to include monitoring as part of their management strategy. As we will discuss in Section 3.3, there would of course have to be third party checks, or the threat of them, to ensure that growth rates are not exaggerated.

3.2. Political and Equity Considerations

We now turn to the second critical issue: how output- and input-based distribution systems compare when considered from the point of view of political acceptability and particularly as regards equity, which is a major concern of many REDD+ observers. There have been a number of literature reviews around the issue of equity in benefit distribution for REDD+ [39–41] and these demonstrate that the vast majority of articles on benefit distribution in REDD+ take the line that the key issues are social equity and rights [19,42–46]. This reflects the heavy engagement of NGOs and civil society organizations in REDD+, representing in particular the rights of indigenous peoples.

A recent article [47] makes it clear that "equity" in REDD+ can be interpreted in many different ways. It suggests that equity in benefit distribution could be understood as (a) "merit-based", *i.e.*, benefits go only to those who have achieved carbon savings (which would result from what we have called "output-based" benefit distribution; systems of this kind may be considered "equitable" because those who receive payments are the ones who have "earned" the benefits). Equity may alternatively be understood as (b) rights-based, *i.e.*, benefits going (only) to those who have rights over the resources; or (c) needs-based, *i.e.*, benefits should be distributed to favor groups that are marginalized and vulnerable, as in pro-poor approaches. Needs-based here refers to needs in the general societal sense, not to needs as regards e.g., capacity building for REDD+.

The choice between these different equity principles can be hotly debated on ideological grounds, but it is important also to understand the extent to which output- and input-based distribution mechanisms can provide for equity in each of these forms [48–50]. Most obviously, communities or landowners with a history of good forest conservation will have flat baselines and would therefore not receive benefits under a merit or output-based system, because they can hardly improve on what they have been doing in the past, a situation which would be considered highly inequitable in most societies, and which is quite likely to act as a perverse incentive, as discussed above. An input-based system which would reward all those who carry out good practices, whether they started this earlier or as a result of the REDD+ project, is therefore likely to be perceived by the general public as much "fairer" [31], and should be preferred in this sense. If, however, the system is based on inputs payments which vary to reflect opportunity costs, this could easily be perceived as "unfair", as it raises questions about procedural equity in terms of who calculates the appropriate opportunity cost for each participant, and how; and it increases the chances of collusion and corrupt practice in this regard.

A rights-based approach to equity raises problems in that rights over forest are frequently not formalized. Tenure or rights would first have to be established, a process that could delay implementation of REDD+ for many years. However, even in countries where rights to forest land are legally in the hands of clearly defined agrarian communities, as in Mexico, a rights-based approach could be controversial, as there are increasing numbers of people within these communities who are not formally members of the community and who do not have a vote in community decision making or rights to the common property, either because they did not inherit these rights or because they have sold them. Many individuals may be excluded from financial benefits if the rights-based principle is applied *within* the communities participating, and this would be a problem, regardless of whether an output-based or an input-based distribution system was to be selected.

There are, however, other rights issues which are less discussed and which may have different outcomes under output- and input-based systems. This arises when we consider that people or communities other than those who own forests might have rights to a share of REDD+ benefits. It is well known that many of the drivers of deforestation have their origins outside the forests, in particular the expansion of agricultural and grazing land, which may be stimulated by population growth, in-migration, increases in prices of crops and meat, or increased external demand. It is clear that to succeed, REDD+ will have to tackle such drivers directly. A national government might for example choose to stimulate agricultural practices that reduce pressure on forests. It would therefore be quite reasonable if some of the financial benefits derived from international sales of REDD+ credits or carbon funds were to be invested in the promotion of these practices, if it can be shown that this is an effective way of conserving forests. The underlying principle here is that it is not only the owners or managers of forests who could be eligible for benefits, but also actors outside the forest ([51]; see also [52] for the case of agroforestry). There could also be many stakeholders, such as intermediary agencies, who might legitimately claim a share of the financial rewards from REDD+, if they are implicated in generating participation of forest users, farmers, *etc.* in REDD+ activities which result in decreased emissions or increased sequestration of carbon in forests. The case has also been made that part of the financial benefit of REDD+ should be allowed to flow to agricultural research institutes that are carrying out research to minimize the impacts of drivers (R. Mathews, p.c).

It would however be very difficult to make direct quantitative assessments of the impact of any such action (whether by a farmer or by a supporting agency) on the rate of reduction of deforestation in a given area, with a view to rewarding individuals on the basis of deforestation avoided. It is clear that an output-based accounting mechanism would not work here. Some kind of input-based system would be needed to establish both the legitimacy of the claims, and the size of the benefits to be assigned to them.

Finally, there have been many calls for "pro-poor" approaches to REDD+ that approach equity of benefit distribution in terms of needs [43,53,54]. The underlying problem here is that in general, it is probably not the most marginalized and poverty stricken members of society who are responsible for most deforestation or even for degradation. Although the role of poverty in deforestation is contested, and evidence is mixed [55–57], if we consider first the problem at the level of the individual, the really poor in rural settings are generally laborers working for other farmers, without their own land or cattle, or having very small holdings. Those who clear forest for expansion of agriculture need capital, and those responsible for large-scale degradation (through logging, forest grazing, *etc.*) tend to be those with more resources at their disposal. It may therefore be difficult to achieve carbon savings by directing output-based benefits towards the poorest in society; in fact, it may be a contradiction in terms. Apart from the problem that the needs-based approach directs benefits to those individuals who are not responsible for deforestation (and may thus be an inefficient strategy in terms of reducing emissions), it may also in practice be very difficult to direct benefits to the poorest individuals who have no land resources of their own, even in an input-based system, as they may not have the land resources to participate at all.

If the distribution of benefits happens between communities rather than between individuals, as will often be the case in national REDD+ programmes, the question arises of whether poorer communities deforest more than richer communities. If this were true, output-based distribution systems would be unlikely to reach the poor. One way to overcome these problems at the community level might be to design hybrid approaches to achieve equity in benefit sharing. Among the few publications on this, the three watershed pilot REDD programmes in Nepal [36] uses a weighting mechanism such that 60% of the financial reward is allocated on the basis of needs (using a set of social indicators describing each community), 24% on the basis of existing forest stock, and only 16% on the basis of output, which is measured as increase in stock in the forest (forest enhancement). In Vietnam, an even more complicated weighted index has been developed (the "K" index), which involves both input and output indicators [58]. However, both of these innovative approaches are in pilot phase and it is not yet clear whether they can be considered successful.

3.3. Data Considerations

It is clear that benefit distribution systems crucially depend on data, and this includes not just data on carbon fluxes but also data on how REDD+ activities are undertaken and what they consist of. At the national level, countries will have to produce robust data on carbon stock changes in order to claim carbon credits and bring in the funds necessary to support REDD+ activities. Increasing the accuracy and level of confidence of the data; for example, moving from Tier 1 to Tier 3, should in principle increase the number of credits that could potentially be claimed. In order to achieve greater data certainty, governments may need to monitor change at the local level using local inventories which feed into and support the national forest monitoring system. Whether these same data should be used as the basis for benefit distribution is, as we have shown, open to question, although it is clear that the choice of monitoring and measuring parameters and indicators will inevitably shape and constitute what REDD+ will be [59]. Given the important political implications of data, it is crucial to assess possible differences in data requirements between input- and output-based systems.

Output-based benefit systems require very accurate data on carbon outputs at the level of each participant, which would necessitate ground level inventories (Tier 3 data). Input-based payment systems on the other hand would be associated with regional or national estimates of carbon stock change, carried out using remote sensing and Tier 1 or 2 carbon data, and with local information on the nature of the activities that are being carried out. The generation of detailed information about changing carbon stocks at the local level, which output-based systems would need, is an expensive undertaking [60], particularly if carried out by professional staff. Transaction costs of measuring carbon stock change at the local level may be reduced if the forest owners or REDD+ actors/implementers themselves are involved in this monitoring, but despite the fact that such measurements may be as accurate as those carried out by professionals [5,6,61,62], this does not resolve underlying data uncertainties. Although the monitoring of changes in forest carbon stocks through measurement of key parameters, such as diameter at breast height in a set of permanent sampling plots, is often presented as a scientific procedure which can be perfected [59,63], in reality there are significant uncertainties involved. Efforts to bring down these uncertainties are inherently costly [64,65], even though in most cases only above-ground carbon stocks are measured, ignoring the complexities of the other carbon pools. In addition to measurement errors, the use of tree parameters to calculate carbon stocks relies on allometric equations which give, at best, rough approximations, as it is rare to find equations to match all the kinds of trees in the sample and default equations are needed. To deal with these kinds of uncertainties, conservative estimates are used. This might cause participants to feel cheated, although such conservatism is essential to maintain the integrity of the programme. This problem has been discussed by Sommerville *et al.* 2011 [66] for the case of biodiversity, and although the differences between carbon and biodiversity assessment are considerable, it is clear that in both cases the cost of administering reward or benefit distribution systems based on performance as ascertained through local measurements would likely be high, not least because systems which link payments directly to outputs in terms of tons of carbon would encourage participants to over-estimate their achievements and might even encourage fraud [67,68]. To counteract this, strict regimes of verification would be required, with associated costs. This would itself entail the need for a grievances office for participants. Basically, any benefit distribution system based on outputs would be costly to administer. On the other hand, it would yield very detailed data at the local level that could be a valuable input to national carbon accounting, enabling densification of data on carbon stock changes in areas where REDD+ activities are being undertaken.

In contrast, input-based systems only require data verifying that the agreed REDD+ activities have been undertaken and maintained successfully, as is the practice in forest certification. The estimates of carbon stock change for input-based systems (carried out at the state or national level using remote sensing and Tier 1 or 2 data) would inevitably be less secure, and therefore command less confidence in international markets, *i.e.*, would result in conservative payments. However, though such systems would also necessitate the involvement of some external third party for checks and balances, the reporting process would be much easier, cheaper and less burdensome. It would certainly be possible to require participants to make regular inventories of their forest-related activities and even their carbon stocks as part of their management agreement, even if payments are not based on the change in stocks. There would be much less temptation to exaggerate the carbon impacts of the programme if the payments were decoupled from these, and thus there would be less need for very careful verification of data. An additional benefit would be that since reporting focuses mainly on the activities carried out, it would be possible to link activities to changes in carbon stock levels, in other words, to use the data for an assessment of the effectiveness of different management strategies, which would be very helpful in improving public policy on REDD+.

A summary of the issues discussed in Section 3, showing the strengths and weakness of output- and input-based distribution systems is presented in Table 1.

Table 1. Strengths and weaknesses on output- and input-based benefit distribution systems under national REDD+.

Criteria			Output-Based Benefit Distributions Systems		Input-Based Benefit Distribution Systems	
			Strengths	Weaknesses	Strengths	Weaknesses
Technical issues	Baselines		Simple, parcel-based baselines are needed to measure increments in forest stocks. It is easy to identify which individual or communities have increased their stocks and base rewards on this	Not possible to determine who deserves avoided deforestation credits unless individual baselines are constructed	Baselines not required	
	Economic efficiency		Only the additional carbon savings will be rewarded	Construction of individual baselines would be very costly		All participants receive rewards, even those who would not have deforested in absence of REDD+. Payments will therefore be very small per participant
Political acceptability and equity	Ability to deliver merit-based equity		Would deliver merit-based equity			Would not deliver merit-based equity
	Ability to deliver rights—based equity	Rights of forest owners	Rights to forest are weak in many countries and it is well known that they need to be strengthened if REDD+ is to succeed. In this respect it makes no difference whether an output-based or an input-based benefit distribution system is selected			
		Rights of REDD+ actors outside forest		Would not permit actors outside the forest to receive benefits, as their actions cannot be quantitatively related to stock changes in the forest	Would permit a division of benefits to include actors outside the forest	
	Ability to deliver needs/poverty based equity			Not likely to benefit poor people as in general the poor are not the main actors behind deforestation	Could be used to benefit poorer individuals and communities	
Data requirements	Accuracy of data required			Very high, and needs strict verification	Data requirements low, though higher if opportunity costs model is used	
	Transaction costs			High	Low	

4. Relating Data for Benefit Sharing to National Forest Monitoring Systems

Many national governments are already setting up national forest monitoring systems, which will be used among other things to support national measuring, reporting and verification (MRV) of their REDD+ activities as required by UNFCCC and international carbon funds. These MRV requirements are fixed by UNFCCC and need to be fulfilled by the national monitoring system, which has to capture the carbon impacts of the sum of all the REDD+, and other activities over the whole national forest area. These national forest monitoring systems will need to include information on drivers of deforestation and on the effectiveness of different programmes and policies in dealing with these drivers and in reducing emissions. They will be essential in providing feedback to the country on what works and what does not work under REDD+, to justify and prioritize REDD+ activities addressing key drivers [69,70]. In addition to these international requirements, the national monitoring system should cater for the needs of the national REDD+ programme implementation, including benefit distribution. A link could be established between data needed to support the benefit distribution system, focusing on activities and change in management practice, and data that is already being systematized in the national monitoring system. The fact that many REDD+ activities may address actions and actors that are outside forests implies that monitoring should include other areas in addition to forests [70]. The national system would need to be able to track and monitor REDD+ activities by the multiple actors involved both inside and outside the forest and could provide the basis and verification for the input-based benefit distribution mechanism. In this way, national forest monitoring systems would evolve to underpin and stimulate strategies and priorities for REDD+ implementation, to track REDD+ activities and their impacts (both carbon and non-carbon), and to support the generation and sharing of benefits for the multiple REDD+ actors involved, as well as providing data for reporting on REDD+ performance in terms of greenhouse gas emissions to the international community. They could be used to link the success and failure of different types of incentives and rewards to the activities undertaken in different parts of the country and, at a broad scale (though not at the level of the individual parcel) to achievements in reducing emissions at the national level.

Moreover, if a dual benefit distribution (*i.e.*, payments based on both outputs and inputs) were to be introduced, with output-based payments for increases in stock, there would be locally generated data on changing stock levels in the forests, as a result of community biomass stock monitoring. This would of course only exist for those parts of the forest where these activities take place, *i.e.*, it would be patchy, but it would represent an important source of data, additional to national forest inventories, providing information on stock levels which could validate and densify data in the national system.

5. Conclusions

In this paper, we have argued that a transparent, legitimate and easy to understand benefit distribution system will be essential to the success of REDD+ as countries move into Phase 2 and start to implement activities at the local level, initially on a pilot scale but with a view to fully-fledged performance-based REDD+ in the near future. We argue that there are advantages and disadvantages to both output- and input-based benefit distribution systems. Benefit distribution systems based on output metrics (calculations relating to reductions of emissions of carbon associated with reductions in deforestation and degradation) are difficult, if not impossible, to implement at the level of individual forest parcels, such as forests owned and managed by communities or small landowners, since it is not possible to identify who, out of the many land owners who have not deforested in any given time period, would have deforested in the absence of REDD+, and thus deserve the rewards (a technical problem). In reality, and to ensure public and political acceptability of the programme, all forest owners who carry out sustainable forest management practices may need to be rewarded, at least in areas where there is a clear risk of deforestation, whether or not they would have engaged in unsustainable practices in the absence of REDD+. It is very doubtful that output-based benefit distribution systems would be considered equitable by the general public, because this would not reward those who have always conserved their forests. Moreover, output-based payments are based on measurements which involve considerable uncertainty at the local level, and which involve heavy transaction costs and risk of the REDD+ mechanism becoming too complex to be effectively implemented [7].

Input-based benefit distribution systems, in which stakeholders receive benefits according to their participation in the REDD+ activities such as conservation or sustainable management of forests or sustainable agricultural practices, are in many ways preferable to output-based systems. We argue that they are technically more feasible, more politically acceptable and easier to administer, with associated lower costs, partly because of lower requirements for detailed carbon monitoring. One option is to distribute benefits according to opportunity costs, either through a centrally fixed payment level for each type of likely land use change (which corresponds with different opportunity costs) or through a system of bidding by interested actors. However, though in theory more economically efficient, opportunity cost models will involve considerable transaction costs because appropriate payments levels would have to be calculated for each participant, and this would raise procedural equity issues and increase the potential for corrupt practice. Another option, which is more transparent and simple in administrative terms, is that a central agency pays flat rates per hectare in return for good forest management or agricultural practice, either using a universal rate or different rates to account for varying land use activities, which is in fact the payment method used in most PES schemes including some agri-environmental subsidies within the European Union. This, however, would mean that many participants would be paid for activities which are not additional in carbon accounting terms, meaning that this system will not be very cost-effective.

As we have shown in this article, both input-based and output-based models have advantages and disadvantages in terms of efficiency, legitimacy and political feasibility. We suggest that the best solution might be a hybrid system in which stock increases (forest enhancements) are rewarded on an output basis at the level of the individual forest parcel, while the financial returns from reductions in emissions from deforestation and degradation (assessed at regional level) would be used to fund input-based incentives. This would imply that only increases in stock should be rewarded on the basis of local measurements of stock change over the REDD+ period (as ascertained by CBM), while avoided deforestation and degradation would be monitored at a regional scale. The fund derived from sale of the resulting carbon credits could be used to encourage activities both within and outside the forest, reaching a broader range of actors; it would therefore not be restricted to forest owners. This mixed system would result in a higher level of economic efficiency than a purely input-based system because at least the rewards for stock increments would only be paid to those who actually produce such increments.

Whatever benefit distribution system is chosen, it is important to recognize that if countries wish to promote CBM as part of the monitoring for REDD+ as recommended by UNFCCC, they should think carefully about what the function of these data will be with regard to the way that benefits are to be distributed, and to provide protocols for the CBM that meet these requirements.

Finally, we suggest that data associated with input-based benefit distribution systems at the local level could usefully supplement national monitoring systems, as in addition to carbon data, these will require information on the success of different public policies or programmes in reducing emissions. In this sense, the requirements for national forest monitoring systems are evolving to more than simply accounting for carbon. Data systems are needed to underpin and stimulate strategies and priorities for REDD+ implementation, by tracking REDD+ activities and their impacts (both carbon and non-carbon), and supporting the generation and sharing of benefits for the multiple REDD+ actors involved, in addition to their obligatory role in the reporting of REDD+ performance in terms of green house gas emissions to the international community. A dual system of benefit sharing as proposed in this paper would certainly require CBM at the local level, which could feed important information both on carbon and on the range of interventions undertaken at that level into an improved national data system.

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Author Contributions

Margaret Skutsch prepared the first draft; Esther Turnhout, Marjanneke Vijge, Martin Herold, Tjeerd Wits, Jan Willem den Besten and Arturo Balderas Torres then contributed sections and improved the text. Margaret Skutsch responded to the reviewers’ comments in the first instance.

Conflicts of Interest

The authors declare no conflict of interest.

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Case Study Report: REDD+ Pilot Project in Community Forests in Three Watersheds of Nepal

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Abstract: Reducing emissions from deforestation and forest degradation (REDD+) is an international climate policy instrument that is expected to tap into the large mitigation potential for conservation and better management of the world's forests through financial flows from developed to developing countries. This paper describes the results and lessons learned from a pioneering REDD+ pilot project in Nepal, which is based on a community forest management approach and which was implemented from 2009–2013 with support from NORAD's Climate and Forest Initiative. The major focus of the project was to develop and demonstrate an innovative benefit-sharing mechanism for REDD+ incentives, as well as institutionally and socially inclusive approaches to local forest governance. The paper illustrates how community-based monitoring, reporting, and verification (MRV) and performance-based payments for forest management can be implemented. The lessons on REDD+ benefit sharing from this demonstration project could provide insights to other countries which are starting to engage in REDD+, in particular in South Asia.

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1. Introduction

Deforestation and forest degradation have received worldwide attention because of the implications for climate change. It has recently been estimated that around 12% of annual greenhouse gas (GHG) emissions are attributable to land cover changes, including forest losses [1,2]. Under the United Nations Framework Convention on Climate Change (UNFCCC), a policy known as Reducing Emissions from Deforestation and Forest Degradation (REDD+) is being introduced. This is a performance-based policy instrument aimed at reducing anthropogenic emissions of GHG [3,4] by rewarding countries that are able to reduce rates of deforestation and degradation and increase the rate of removals of carbon dioxide from the atmosphere by forest enhancement. The goal of reducing deforestation is not new. In the past, many countries have made regulatory policies aimed at curtailing deforestation [5]. However, most such regulatory instruments have proven ineffective. In the South Asian Association for Regional Cooperation (SAARC) countries from 1990 to 2005, all member countries except Bhutan and India reported decreasing forest cover and growing stock (Table 1), despite the fact that many of these countries were actively engaged in programs for community management (Table 2). REDD+, with its performance-based incentives, is widely regarded as a new approach with a greater chance of success.

Table 1. Change in forest resources in the SAARC countries (1990–2005).

Variable	Year	Unit	AFG	BGL	BHU	IND	SLN	NEP	PAK
Forest area	1990	1000 ha	1309	882	3035	63,939	2350	4817	2527
	2005	1000 ha	867	871	3195	67,701	1993	3636	1902
Change in forest area	1990–2005	1000 ha	−442	−11	160	3762	−357	−1181	−625
		%	−33.8	−1.2	5.3	5.6	−15.2	−24.5	−24.7
Change in growing stock	1990–2005	1000 m^3/year	−925	−570	+11,500	+37,100	−2019	+13,600 [a]	−10,200
Carbon stock in living biomass	1990	million tons	38	84	296	2,223	90	602	330
	2005	million tons	38	82	324	2615	66	485	243
Change in total carbon stock in living biomass	1990–2005	million tons	0	−2	28	392	−24	−117	−87

AFG, BGL, BHU, IND, SLN, NEP, PAK = Afghanistan, Bangladesh, Bhutan; India; Sri Lanka; Nepal; Pakistan; [a] an increase from 1990–2000 was followed by a decrease to 2005; Source: [6].

Table 2. Community-managed forests in SAARC countries.

Country	Management Modality	Area/Length Managed	Forest User Groups/Communal Land	Source
Bangladesh	Social Forestry	40,387 ha woodlot plantation, agroforestry plantation, 48,420 km strip plantation	n.a.	[7]
Bhutan	Social Forestry	21,025 ha, <1% national forest land	As of July 2009, 173 community forests with 8650 households	[8]
India	Joint Forest Management	>22 million ha, 33% forest land	By end 2006, around 69,200 villages involving 21 million households	[9]
Nepal	Community Forestry	1.65 million ha	17,685 CFUGs involving 2.2 million households	[10]
Pakistan	Social Forestry	31% of total forest area	18% communal forest, 13% Guzara forests	[11]
Sri Lanka	Community Forestry	more than 7000 ha of forestland	By January 2009, 55 community groups registered with approved management plan	[12]

1.1. REDD+ in the SAARC Context

Following the 2009 Conference of Parties (CoP16) [13] all SAARC countries have endorsed REDD+ and are working on developing implementation strategies. In the case of Nepal, six co-benefits of implementing REDD+ have been identified by the Government's REDD Cell [14] in addition to the financial incentive, these are: enhancement of local livelihoods; increase in the value of biodiversity; better ecosystem services to people and the environment; more resilient ecosystem-based climate change adaptation; improved governance, institutional setup, and policies for natural resource management at local to national levels; and contribution to achieving the objectives of other MEAs that the countries have ratified to (UNFCCC, Aichi Targets and other provisions of the Convention on Biological Diversity, Ramsar, CITES, and UNCCD).

To realize such co-benefits, it is essential for REDD+ finance to be adequate and to cover more than simply the REDD+ compliance cost [15]. Opportunity costs differ between locations, and the co-benefits can sometimes be greater than the REDD+ benefits. When these co-benefits are clear, REDD+ could garner more interest and support, especially in South Asia where there is a large population whose livelihoods depend on forest-based resources. Co-benefits are an important aspect for REDD+ implementation as it is unlikely that the REDD+ payment will be sufficient to stimulate incentive for improved conservation and sustainable management.

This paper describes one of the first REDD+ demonstration projects within the region, which is based on community management practice. It concerns a project which is being implemented in three watersheds of Nepal. The objective of this paper is to provide and disseminate lessons learnt from this project as input to the national REDD+ formulation processes, particularly in the other SAARC countries. In particular, the paper describes the methods used for community monitoring of the carbon, an innovative system developed for distribution of the benefits and the governance structure that was developed to support the approach. The study employed an extensive review of project documents, and relevant literature including several independent research studies conducted on project sites (not related to the project or the project donors) and drawing upon the sharing of experiences in different national, regional and project-site based seminars and workshops.

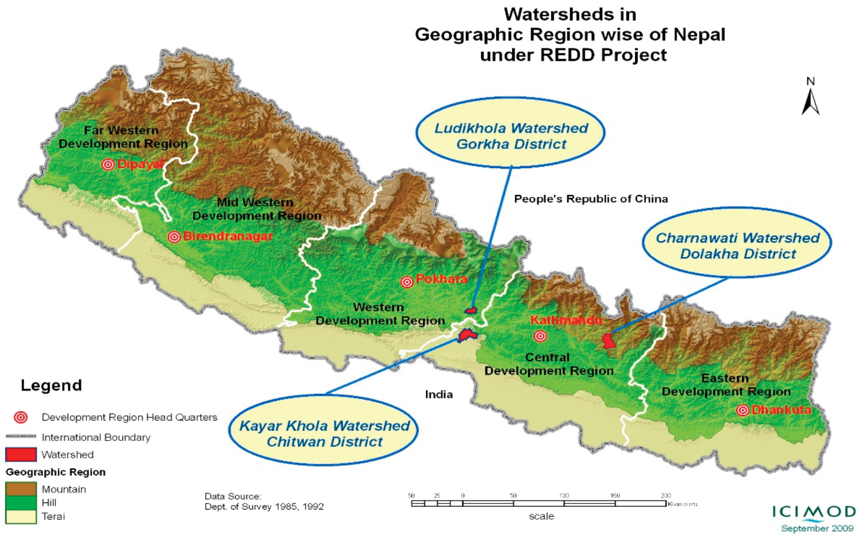
1.2. The Norad REDD+ Pilot Project

The project was entitled "Design and setting up of a governance and payment system for Nepal's community forest management under reduced emissions from deforestation and forest degradation (REDD+)" and was implemented by a consortium of three agencies—International Centre for Integrated Mountain Development (ICIMOD), Asian Network of Sustainable Agriculture and Bio-resources (ANSAB), and the Federation of Community Forestry Users, Nepal (FECOFUN) from 2009–2013, with financial support from Norad's Climate and Forest Initiative. The project aimed to demonstrate an innovative mechanism for governance and benefit sharing of REDD+ payments in the community forestry sector, which involved strengthening the capacity of civil society to participate in the REDD+ process. It covered more than 10,000 ha in three watersheds (Charnawati in Dolakha, Kayarkhola in Chitwan, Ludikhola in Gorkha), with 112 community forests, and users from 18,000 households with 90,000 people (Figure 1). The demonstration covered three different geographical regions representing the mountains (high altitude), hills (medium altitude) and the plains (low altitude) as shown in Figure 1.

A baseline on carbon, demographic condition and identification of drivers of deforestation and degradation was established in 2010 after the project's onset and training was provided for community forest user groups to undertake carbon inventory. The forest carbon stock data were collected annually in 570 permanent plots established in the base year. As a part of this project, a Forest Carbon Trust Fund (FCTF) was established in 2011 to institutionalize the REDD+ payment mechanism and carbon payments were disbursed annually based on incremental carbon and socio-economic indicators. These payments were utilized under different headings underlined in FCTF guidelines. The project's effectiveness at the end has been measured with reference to the baseline.

The demonstration project was carried out in collaboration with existing local-level community forest user groups (CFUGs), which are autonomous and self-governing institutions who have been carrying out management of forests in their areas for many years. Community forestry in Nepal, which upholds the rights of people from local communities to manage and utilize the forest resources, has been hailed as a successful strategy for forest conservation and has resulted in improvement of forest cover, increase in production of forest products to support subsistence livelihoods, replenishment of greenery in denuded hills, biodiversity conservation, and increases in socioecological resilience against climate change [16–21].

Figure 1. Location of project sites in the three watersheds in Nepal.



Many of these outcomes of community forest management are congruous with the objectives of REDD+ under the UNFCCC. The presence of established institutions and mechanisms for community management in Nepal provided an enabling environment for REDD+, although the question of additionality needs further consideration. This is because in the long run, REDD+ performance payments to a country such as Nepal will be based on measured improvements on the past situation regarding emissions and carbon stocks, as represented by a national baseline (Reference Emission Level). Community forest management has been effectively combating deforestation and degradation for many years at least in some parts of the country, so in principle only improvements over what has already been achieved will be eligible for performance payments. Although, as we will show, the project certainly promoted additional activities which have speeded up the sequestration of carbon, the full additionality of this cannot be assessed at present.

The demonstration project described here was set up in part to trial a system of REDD+ payments to local communities to support and incentivize improved forest management. In particular, these improvements include the incorporation of monitoring of carbon stocks in the management process, as described below in Section 2.1. The pilot also designed and set up a governance system for implementing REDD+ at the community level (2.2) and it devised payment criteria (2.3) which are in part related to performance as regards carbon and in part related to social variables, to ensure social safeguards are complied with and that the project responds to local circumstances, as for example represented by the six co-benefits identified by the REDD Cell. This is in line with the many calls for equity and social justice that have been made in the context of REDD+ [22,23].

2. Outcomes and Impact

2.1. Community Involvement in Monitoring, Reporting, and Verification

The project developed forest carbon stock measurement guidelines following IPCC 2006 standards, and trained and supported CFUGs to carry out annual forest measurements. Other authors have noted that local MRV may be cheaper than, and as accurate as, national-level alternatives [24] and that collecting data on their own forests engages local communities and reduces the costs of technology and experts [25]. Communities have been able to measure stock using standard forest inventory methods and mapping techniques based on hand-held information and communication technologies [26]. They have been shown to be proficient at diameter measurements, boundary delineation, and to carry out species identification more effectively than outside professionals. Their involvement in monitoring activities is also said to enhance transparency [27]. The involvement of local communities in forest monitoring has been said to promote a feeling of ownership [28], and may motivate people to take on REDD+ responsibilities. When communities are responsible for forest management, it makes particular sense to involve them in forest monitoring.

The demonstration project therefore included a sub-national level Monitoring, Reporting and Verification (MRV) system in which monitoring responsibilities were devolved to local communities through a participatory method with an opportunity to seek guidance and supervision from the District Forest Office (DFO). MRV is an important activity for performance-based forest management, particularly if the scale of payment and incentive at the local level is to be based on carbon performance, which was the intention in this case. Moreover, community-based monitoring can provide a data source for national level MRV, as well as local [29].

2.2. Forest Carbon Trust Fund and Improved Forest Governance

Governance is critical for the success of meaningful REDD+ interventions. REDD+ governance demands an appropriate mechanism to fulfill the REDD+ objectives while minimizing the risk of mismanagement that can lead to reduced biomass and less payment. The governance structure for the pilot project was centered on a Forest Carbon Trust Fund (FCTF). This involved financial resources provided by NORAD for the specific purpose of designing and operating a local level performance based payment system. It should be noted that the NORAD finance was itself not performance related, it was a lump sum payment. The local level distribution of benefits mechanism was devised to ensure that financial resources, initially through the NORAD seed grant, but in the long term through regular carbon financing would reach the communities in a transparent and accountable manner and meet the resource mobilization criteria specified in the 2011 Climate Change Policy of Nepal. The project prepared Operational Guidelines for the FCTF and met with stakeholders to explain the REDD+ payment criteria and define payment utilization headings.

The project set up several multi-stakeholder institutional structures to implement, oversee, and monitor REDD+ payments and ensure that distribution and mobilization was transparent and accountable. The CFUGs in each watershed were grouped to form a Watershed REDD Network to operate as a focal point for all REDD+ related activities at the watershed level. Members of the executive committee were nominated from each CFUG in the watershed. The networks bridged the payment from national level to the CFUGs by making claims for payment and disbursing payments to CFUGs based on the claims made. District Monitoring Committees were formed in each district with representatives from stakeholders such as DFOs, civil society organizations, district chapters of relevant federations, and private sector representatives. These committees were responsible for administering the REDD+ payments and registering and verifying the data used for claims before they were sent to the Project Management Unit (PMU) in Kathmandu. The project was implemented and coordinated at the central (national) level by the PMU, with monitoring by a central level Forest Carbon Trust Fund Advisory Committee (FCTFAC) with representatives from the Ministry of Forests and Soil Conservation-REDD Forestry and Climate Change Cell, the Dalit NGO Federation (DNF), Nepalese Federation of Indigenous Nationalities (NEFIN), Himalayan Grassroots Women's Natural Resource Management Association (HIMAWANTI), FECOFUN, ANSAB, ICIMOD, and the three watershed level REDD Networks. The FCTFAC verified the data sent from the watersheds and decided on the REDD+ payment. Annual auditing of payments was carried out by a Nepalese auditing firm using the FCTF Guidelines. This helped in keeping costs low and in-country while satisfying the need of outside and independent verification.

The stringent administration of carbon data and REDD+ payments, and the multi-layer monitoring system, supported REDD+ governance and also resulted in more general improvement in the community forest governance. After the project implementation, most of the executive committees held regular meetings. The representation and participation of women and socially marginalized communities increased in the executive committees in CFUGs receiving the seed grants. Management of the CFUGs improved as the REDD+ compliance process required them to have more frequent meetings, open bank accounts, maintain transparent financial records, and perform targeted activities for marginalized groups, including auditing of funds, thus motivating CFUGs to be more active and operate as institutions. Improved community forest governance was one of the co-benefits of REDD+ implementation.

2.3. Innovative Payment System and Benefit Sharing

The FCTF Operational Guidelines determined the REDD+ payment and benefit sharing process. A nested system was used for the financial transfers from central to community level through watershed level institutions. The money from FCTF was paid to Watershed REDD Networks at each site. The Watershed REDD Networks then distributed the money to individual CFUGs. This mechanism bridged the community and the national level, satisfying both the need to centrally administer payments, and to make payments to CFUGs that ultimately reach to households. REDD+ payments were made for three years from FCTF. The pilot did not use certified emission reduction credits.

The benefit sharing system could have been based purely on emissions metrics: those actors who have demonstrated reductions or removals are provided a level of benefits linked to the quantity of reduced emissions or enhanced removals. However, this would not necessarily have resulted in an equitable distribution of benefits as the scale of involvement of the actors may vary. Since the geography of Nepal is diverse, there is a huge difference in the size, altitude, growth rates and quality (cover and density) of the community forests, and also the population who depended on these forests. Hence in terms of equity, payments based strictly on performance would not have been perceived as “fair”.

To address this challenge, broader eligibility criteria were used to identify which actors should receive benefits and how much. The benefit sharing system of the pilot project adopted a multi-criteria approach, based on both performance and socio-economic variables. Performance was measured in terms of the amount of carbon stored and sequestered, *i.e.*, forest enhancement, not reduction of deforestation and degradation, since in the areas concerned community forest management had been operating for some years and had already succeeded in halting these processes. Forty percent of the payment to a participating community was based on their achievements in terms of such forest carbon stock (24%) and enhancement (16%). Carbon stock is the carbon pool stored at start of the project period and enhancement is the annual increment. The remaining part was weighted to favor CFUGs with households with a greater number of indigenous people (IP) (with a weight of 10%), with Dalit ethnic composition (15%), and female population (15%), and households in poverty (20%) as shown in Table 3. This mechanism was intended to ensure that REDD+ benefits are felt by marginalized groups, and to avoid elite capture. The measurements were carried out at watershed level with carbon measurement plots laid out in every CFUG which were demarcated individually within the watershed. Thus, CFUGs were the unit for carbon measurement. Socioeconomic data was available for each CFUG. In order to reduce the risk of cheating by reporting high values of carbon, locals were made to measure the carbon stocks in their neighboring forests, *i.e.*, by mixing the villagers during field survey.

Table 3. Criteria for making pilot reducing emissions from deforestation and forest degradation (REDD+) payments to community.

Criteria for Payment	Percentage
CF Carbon Stock	24%
CF Carbon Increment	16%
Indigenous People’s Household	10%
Dalit Household	15%
Poor Household	20%
Sex Ratio	15%

These criteria helped in ensuring that disadvantaged and marginalized groups received some payments even if they did not achieve high performance in the sequestration of carbon. In addition the social weighting gave communities a feeling of agency as REDD+ payments were utilized to expand existing social and poverty related activities through co-financing. The total payments are shown in Table 4. A minimum payment of USD 100 was introduced after the first year to increase the incentive to participate.

These payments were disbursed to each community forest user group and were utilized for various socio-economic (climate change awareness and capacity building, livelihood generation *etc*.) in addition to forest management activities. These carbon fund expenditures made at the CFUG level ultimately became channeled to the households, largely in the form of improved knowledge and skills for forest management, switching to fuel efficient cooking technologies, employment generation, incremental income, improved community infrastructures, *etc*. This helped in ensuring community participation even though per household cash payments were very low.

Table 4. Total payments in three years and breakdown according to different criteria.

Watershed (District)	No. CF	Total (USD)	Payment According to Different Criteria (USD)						
			Carbon Stock (ton)	Carbon Increment	IP HHs	Dalit HHs	Women	Poor	Basic
Kayarkhola (Chitwan)	16	72,255	16,573	11,049	6,905	10,359	10,359	13,811	3,200
Charnawati (Dolakha)	58/65 [a]	132,879	28,939	19,293	12,058	18,086	18,086	24,116	12,300
Ludikhola (Gorkha)	31	79,866	17,679	11,787	7,366	11,050	11,050	14,733	6,200
Total	105/112 [a]	**285,000**	**63,192**	**42,128**	**26,330**	**39,495**	**39,495**	**52,660**	**21,700**

[a] in Chamawati, 58 CFs in 2011/2012 and 65 in 2013.

3. Other Characteristics of the Project

3.1. Pro-Poor and Livelihood Improvement Activities

REDD+ is not primarily a poverty reduction program. However, while addressing the drivers of deforestation and forest degradation, livelihood requirements must be met first and foremost of any forestry related interventions of the populations that depend on forest resources. The REDD+ finance was used to give poor households additional opportunities for income generation. Well-being ranking was carried out to identify poor and socially excluded forest users. The project implemented income-generating activities (IGAs) such as animal husbandry (goat rearing, pig-farming, cow farming, and poultry), high value agriculture (vegetable farming, mushroom cultivation, broom-grass cultivation, and apiculture), business (shops, grocery management), vocational skills (tailoring), and training. The IGA activities were selected by users at the watershed network level. In many cases, the watershed networks also used the REDD+ payment as micro-finance, and lent it to borrowers for IGA development at low (sometimes zero) interest rates.

The audit firm did random sampling of eight CFUGs from the project and did a detailed audit at this level. In the samples selected by the audit report, it was demonstrated that money transferred to the local CFUG level and targeted programs on livelihood improvement did reach the targeted groups, *i.e.*, the poor, women, Indigenous People and the Dalit community.

3.2. Interventions Ensuring Additionality

An important criterion for complying with REDD+ is additionality, proven by real emission reduction or real enhancement of forest carbon as a result of the project. Although a carbon baseline showing rate of increment of carbon stocks before the project began was not available, the project implemented various interventions to ensure forest carbon additionality including plantation, installation of alternative energy technologies, monitoring and control of forest fire, grazing management, and sustainable forest management.

The baseline study indicated that around 70% of people in the project area depended on fuelwood as their sole source of energy. The study suggested that alternative renewable energy would be an effective way of reducing local pressure and allowing the community forest to increase. Two schemes were introduced: biogas and improved cook stoves (ICS). A total of 284 biogas and 1490 improved cooking stoves were installed in poor and middle income households to reduce pressure on forest from fuelwood demand. The improved energy technologies benefited 1774 households, including 903 indigenous people households and 202 Dalit households. The saved carbon was not counted but will ultimately relate to changes in biomass in the community forest.

The project encouraged enrichment plantation of indigenous and culturally valuable tree species in community forests and private farmland. Filling gaps in forests through enrichment plantation is an important way of increasing forest carbon stocks and thus a potential REDD+ intervention. Plantation records play an important role in ensuring sustainability of regeneration as community forests are continuously harvested to meet basic needs. Altogether 254,584 trees were planted, of which 143,540 survived, on an area of 168 ha.

Various activities were conducted to control carbon loss, including control of forest fires. Using MODIS (Moderate Resolution Imaging Spectroradiometer, Terra and Aqua satellites of NASA) satellite-based technology, a monitoring and alert system was developed that forwards fire information by email or SMS to district forest officers, focal persons in the watershed network and FECOFUN, and local leaders so that immediate action can be taken. The REDD networks raised awareness of forest fire management and the CFUGs constructed forest fire lines. The incidence of forest fire was markedly reduced within project sites compared to non project sites. Avoiding forest fire was an important means of ensuring additionality of the pilot project.

3.3. Social Inclusion

Involvement of local communities is central to curbing deforestation, thus safeguards must be built into the REDD+ mechanism to ensure that community rights, practices, and interests are protected. A key challenge in ensuring full and effective participation, as well as in benefit sharing, is ensuring participation and benefit of marginalized and/or vulnerable people. The REDD+ project included social safeguards by including the population of indigenous people, Dalits, women, and poor households in the payment criteria. Furthermore, poverty reduction and livelihood improvement activities were included in the FCTF guidelines as activities qualifying for expenditure of REDD+ payments, and programs on awareness and capacity building on REDD and climate change were targeted to Dalits and indigenous people.

3.4. Changes in Forest State Following REDD+ Implementation

The participatory carbon monitoring strategy enabled an overall estimate to be made of carbon increments. Satellite images were used to classify forests into dense and sparse types and select areas for permanent plots. Four carbon pools (above ground biomass, below ground biomass, leaf litter biomass, and soil carbon) were measured by communities. Annual measurements showed that the carbon stock per unit area increased in all three watersheds (Figure 2). The weighted mean annual increment of all forest carbon stocks in all watersheds combined was 2.62 t/ha, 2.69 t/ha, and 3.53 t/ha in the three consecutive years. The CO_2 equivalent(e) saved as a result of enhanced biomass in the CFs is shown in Table 5. The improved management supported by the REDD+ project increased carbon sequestration in the community forests of between 10 and 33 t/ha over three years. Improved forest conditions are attributable to more conscientious practices adopted by community fueled by increased recognition that they can receive more financial rewards if they enhance forest carbon, as well as the activities mentioned in Section 3.2.

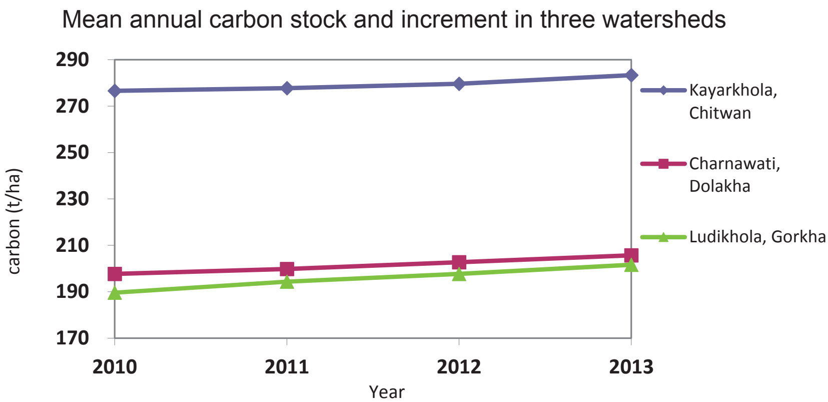


Figure 2. Trend line showing carbon stock per unit area in the three watersheds.

Table 5. Total Carbon-dioxide equivalent saved.

Watershed	Total tCO_2 e (2010)	Total tCO_2 e (2011)	Total tCO_2 e (2012)	Total tCO_2 e (2013)	Net tCO_2 e Emissions Saved (2013-2010)	Total CO_2 e Benefit (t/ha)
Charnawati	4,554,109	4,605,703	4,690,599	4,753,766	199,657	33.3
Kayarkhola	2,521,500	2,533,620	2,554,337	2,579,804	58,304	9.7
Ludikhola	1,448,638	1,485,419	1,505,546	1,534,016	85,378	14.2
Total	**8,524,247**	**8,624,742**	**8,750,482**	**8,867,586**	**343,339**	

It is acknowledged, as mentioned above, that not all the increment should be considered additional, since before the project began communities were managing the forests and the carbon stocks were in all probability increasing, albeit at a slower rate than under the pilot project. In the absence of a local historical baseline to capture past levels of increment, however, it was not possible to separate out how much of the growth was "business as usual" and how much was "additional".

3.5. Leakage

The project checked for leakage (displacement of emissions to adjacent leasehold forests) and deducted appropriate quantities of carbon from the project accounts if leakage was found to occur.

This was done using leakage plots that were established during the first year of the project; these were monitored annually using a similar method as in permanent sample plots in community forests. Leakage monitoring was done by CFUGs and the district monitoring committee. Also, some project activities were focused on preventing leakage, for example, fire control, grazing management, and plantation inside and outside community forest land.

4. Lessons and Conclusions

The pilot REDD+ project benefited from four decades of experience of CFM in promoting successful sustainable forest management by local communities in Nepal. This provided an ideal basis to experiment with a REDD+ payment mechanism and establish an effective, efficient, and equitable REDD+ procedure at a pilot scale. What the project shows in particular is (1) that improved forest management by communities can enhance growth rates of forest vegetation and thus result in higher levels of sequestration of carbon; (2) that communities are able, with training, to carry out accurate and reliable carbon surveys; (3) that it is possible to distribute financial benefits among participants based partly on the carbon performance by communities but also taking into account social needs and (4) that the participatory governance structure used in the project was effective, and could provide a model for other SAARC countries. It was also shown that there were co-benefits in the form of improved livelihoods, and institutional and technical capacities within communities. There are, however, a number of other lessons that can be drawn from the experience.

In terms of linking local level community monitoring (such as described in this report) to national REDD+ MRV, such systems can benefit from community monitoring in various way, particularly in terms of obtaining data on local level stock changes and impacts of REDD+ activities to supplement estimates made using other techniques such as remote sensing. For community monitoring to function well as an integral element within the national MRV system, however, governments need to formally define the role of community forest monitoring within the REDD+ MRV system. There are still challenges imposed by capacity constraints in up-scaling the program to the national level. The limited capacity of the government and civil society organizations to implement REDD+ effectively at a larger scale are of serious concern. Government needs to establish the necessary institutional architecture for REDD+ implementation such as REDD+ desk at district level and most importantly, there is a need to build the capacity of local people who manage forests.

The demonstration project has been appraised, as mentioned above, as having a good impact not only on carbon sequestration rates but also on livelihood and institutional and technical capacity of local communities. Though socio-economic enhancement is secondary to carbon effectiveness within REDD+ policy, in reality it is of crucial importance for the sustainability of REDD+ initiatives. The project’s best practices included advancing REDD+ implementation by creating awareness, proper planning with baseline data, establishing of institutional structures, regular monitoring and evaluation, and supporting communities’ own ability to organize and manage their forests by addressing the livelihood concerns of the poor and socially marginalized. The lesson is that successful implementation of REDD+ at national level hence will depend on how well the concerns of livelihood and problems of inequality and exclusion are addressed, while trying to achieve the target of emission reduction.

A further key lesson of the demonstration project is the need to have appropriate social safeguards in place. Maintaining social inclusion (ethnicity, gender and well-being) in benefit sharing is crucial for bringing positive change in local communities behavior and enhancement of their sense of ownership and commitment to the program. The project promoted meaningful participation of underprivileged communities to some extent, but strong inclusive stakeholder engagement is still a challenge for national REDD+ to succeed given the conflicting interests of various stakeholders and the social traditions that militate against inclusion of the poor and underprivileged.

Preliminary evidence suggests that local forest dependent communities are capable of and interested in implementing REDD+, but only on condition that use of forest resources is not curtailed. It is essential to find the balance such that sustainable off-take of forest resources is permitted, to enable enhancement of tree growth while still permitting extraction for local needs. The project brought about behavioral change among the local people and their forestry practices such as more cautious harvesting of forest products and active participation in controlling forest fire or plantation. The seed grants significantly increased local awareness about the value of forests. The incentive from REDD+ payment for carbon was seen as a bonus over and above the many other forest goods and services people gain from the forests. Financial incentives for standing timber in particular provide an incentive for better forest management and conservation. However, with compliance to REDD+ come other challenges. The requirements of maintaining bank-accounts, record keeping, organizing and attending regular meetings and monitoring imply considerable costs to the communities. Though no actual cost-benefit estimation was made, it is obvious that payment-based incentives will work only if the additional time, labor and monetary costs, as well as cost of forgone benefits, do not significantly exceed payments. If payments are based purely on carbon increment rates and on the international market of carbon value, they would be unlikely to offset the increased burdens to the communities. The funding of this project by NORAD enabled a higher value to be given to carbon, to a level which adequately compensates the local communities. The lesson here is that unless the market value of carbon rises, it may be difficult to implement REDD+ projects of this type on a large scale.

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Author Contributions

The first author framed the paper and prepared the first draft of the manuscript. The second author provided critical inputs to the paper and helped to shape the final version. Third author supported in supplementing data about the project. Overall, all the authors have worked as a team for preparation of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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Case Study Report: Community-Based Monitoring Systems for REDD+ in Guyana

Helen Bellfield, David Sabogal, Lucy Goodman and Matt Leggett

Abstract: A fundamental component of initiatives to reduce emissions from deforestation and forest degradation (REDD+); will be the development of robust and cost-effective measuring, reporting, and verification (MRV) instruments for national forest monitoring and safeguard information systems. It is increasingly recognized that community-based monitoring (CBM) offers a positive model for greater participation and engagement of indigenous and forest-dependent communities within a REDD+ framework. Yet plans for CBM within REDD+ MRV systems remain limited, and there are currently relatively few concrete examples of CBM informing national forest monitoring systems. This paper outlines findings from a community MRV project with Amerindian communities in the North Rupununi, Guyana; and demonstrates that a CBM approach can enable key REDD+ requirements: in understanding local deforestation drivers and measuring carbon stocks; and for providing information on safeguards through social and environmental assessments. In addition, the authors discuss community capacity-building on smartphone technology for monitoring as a challenging yet viable pathway for scaling the use and adoption of indigenous knowledge and local skills for REDD+ programs.

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1. Introduction

Since its acceptance into the 2007 Bali Action Plan, REDD+, or reducing emissions from deforestation and forest degradation plus the role of conservation, sustainable management of forests, and the enhancement of forest carbon stocks, has become the preeminent focal strategy for climate mitigation and forest conservation. As tropical forest countries adopt and prepare for REDD+, a key priority will be meeting the United Nations Framework Convention on Climate Change (UNFCCC) mandate on the effective participation and role of forest-dependent communities in the design and implementation of REDD+ schemes [1,2]. In addition to accurately measuring and tracking changes in forest carbon stocks/flows, countries are obliged to report on the effectiveness of environmental intervention policies and activities for REDD+ and to assess social, environmental, and governance benefits through safeguard information systems (SIS)—a key requirement in order to access results-based finance from REDD+ [2–4].

It is increasingly recognized that involving local communities in forest monitoring can help maximize the efficiency, effectiveness, and equity of REDD+ through multiple pathways. For example, CBM can increase the participation and engagement of local forest-dependent populations in REDD+ by contributing to land tenure reform—for instance, through improved land title recognition—and may stimulate dialogue between stakeholders on conservation interventions [5].

Evidence suggests that involving local stakeholders in monitoring also enhances resource management for REDD+ [6]. In addition, CBM can play an important role in complementing and expanding national forest carbon inventories through the provision of additional data sources on carbon stock measurements. Studies have demonstrated that data collected through CBM can validate remote-sensing estimates to improve the accuracy of national emissions monitoring and reporting [7–11]. Furthermore, CBM can be advantageous in terms of lowering costs of data collection in the longer term, while delivering accurate and reliable data that is comparable to that collected by trained scientists [12–17]. The objective of this study is to present the framework in which CBM is being considered as part of a REDD+ Readiness project in Guyana. In this project, CBM is considered for gathering data and analyzing local drivers of deforestation and forest degradation, participatory mapping and ground truthing of satellite imagery, measuring carbon stocks through forest inventories, and providing information on local co-benefits and for safeguard monitoring systems. This report presents a brief description of the methods used and the results obtained so far. Later it presents a discussion of the implications for the design of REDD+ and inclusion of CBM in Guyana and draws the main conclusions.

The experience and knowledge of forest communities can be used through a CBM model to support and improve the quality of data collected for NFMS and help report forest changes in real-time and on a regular basis [13,17]. This is of particular importance in regions where forest change is complex and difficult to identify using remote sensing, such as in small-scale forest disturbance activities (e.g., charcoal extraction) or in the displacement of drivers of deforestation and carbon emissions from one area to another—*i.e.*, leakage [10,17]. Similarly, community members are well positioned for regularly checking and verifying the implementation of long-term REDD+ activities and associated carbon stock changes from forest regeneration and reforestation efforts in forest sites.

Lastly, CBM can provide valuable information on the impacts of REDD+ activities on ecosystem services, biodiversity, and wellbeing—vital for inclusion in future national SIS—which can help inform community responses and engagement with broader REDD+ and landscape scale conservation strategies [18–21]. However, concerns still remain over the widespread use of CBM in the collection of scientific data on forest monitoring. In particular, practitioners are skeptical that CBM can provide data to a sufficient degree of accuracy and quality, caution that CBM may worsen or precipitate community conflicts, or are concerned that multiple sub-national project-based community monitoring schemes will detract from what they believe should be a nationally managed forest monitoring process [22]. However, in response to the perceived benefits of CBM, early efforts are being made in several countries to integrate and embed these approaches into national REDD+ schemes [10,12,20,23].

CBM has been utilized in many different contexts and for different monitoring purposes (e.g., health) but predominantly on a site-by-site basis. Challenges therefore still remain for scaling up CBM to fit within national forest monitoring systems for REDD+ [10,12]. Current community engagement in sub-national REDD+ projects is also quite low; recent estimates suggest that 48% of voluntary REDD+ projects have no involvement of local stakeholders in forest monitoring and only 12% involve local stakeholders in monitoring biomass, biodiversity, and livelihoods [12]. Key challenges to integration at the national level include a lack of data compatibility between national and community level datasets, and limited interoperability with existing national level, technocratic, and top-down data regimes, particularly in their requirements for carbon stock estimation and reporting [10,13]. Furthermore, the lack of agreed data protocols and guidelines on the use of locally collected data, coupled with perceptions over the lack of accuracy and utility of community-acquired data, have slowed progress on integration [17,21]. Other challenges include securing long-term funding sources for the roll-out and use of CBM at scale; ensuring the approaches taken account for the "free, prior and informed consent" (FPIC) of communities; using local knowledge and building capacity appropriately; addressing issues of validity and robustness of community collected data; and overcoming the significant political obstacles and interests that often undermine local-level participation.

In this context, the findings from this study on existing participatory monitoring efforts underway in Guyana shed light on some of the challenges and opportunities of using CBM within the development of national MRV systems and wider REDD+ policy frameworks.

2. Background

2.1. REDD+ in Guyana

Guyana is a high forest cover and low deforestation (HFLD) country, with 18.5 million hectares (approximately 85%) of forest cover, and a deforestation rate just under 0.08% in 2012 [24]. National forests are, however, increasingly at risk of deforestation and degradation from large- and small-scale mining (accounting for 93% of deforestation), timber extraction, and infrastructure developments linked to these industries. There is also growing pressure from the expanding agricultural sector as a result of increased market integration and trade with neighboring countries, in particular Brazil [24]. Since 2006, Guyana has actively pursued a policy mechanism (REDD+) to avoid deforestation and, in 2009, signed a Memorandum of Understanding with Norway for the implementation of its Low Carbon Development Strategy (LCDS), a national plan to reorient Guyana's economy and move towards more sustainable extractive industries and forest management. This bilateral agreement established a framework for performance-related finance of up to $250 million over a five-year period until 2015 for the implementation of the LCDS. Avoiding deforestation, promoting low carbon development, and adapting to climate change are the three main pillars of the LCDS, linked to its REDD+ agenda [25].

Underpinning the LCDS are two critical components to achieving effectiveness and equity: (i) the development of a national monitoring, reporting, and verification system (MRVS) to measure and track changes in national forest carbon stocks and determine the level of performance-related payments under the Guyana–Norway agreement; and (ii) multi-stakeholder participation—in particular of indigenous forest dependent communities—in the design and implementation.

The engagement of forest-dependent communities in REDD+ is of particular relevance in Guyana, where 13.9% of national forest area is owned by Amerindian peoples [24]. While the LCDS initially only covers the State Forest Estate and excludes Amerindian and private land, the intention of the Government of Guyana is that titled Amerindian communities will be given the future option of participating in the LCDS and "opting in" to a REDD+ agreement with the government, in return for future benefits as a pro rata share of compensation payments that the country receives [26]. The technical structure of this opt-in mechanism is currently being developed by the Office of Climate Change and the Ministry of Amerindian Affairs [27]. Resulting payments could either be made directly to communities or indirectly through an Amerindian Development Fund.

2.2. Case Study/Early Activities

While the framework for ensuring full and effective participation of indigenous peoples and local communities is still unclear, the Guyana Forestry Commission, the government institution responsible for implementing the country's REDD+ MRV system, has been exploring sub-national participatory monitoring approaches at the community level as part of the national MRVS roadmap [28,29]. Under these commitments, 16 indigenous Makushi communities from the Annai District and surrounding Amerindian lands in the North Rupunini, covering a cumulative area of 311,531 hectares (Figure 1), were selected to pilot practical mechanisms for implementing REDD+ on the grounds that this could inform approaches for national policies on MRV, build local capacity, and generate learning and knowledge on the role of CBM in forest conservation.

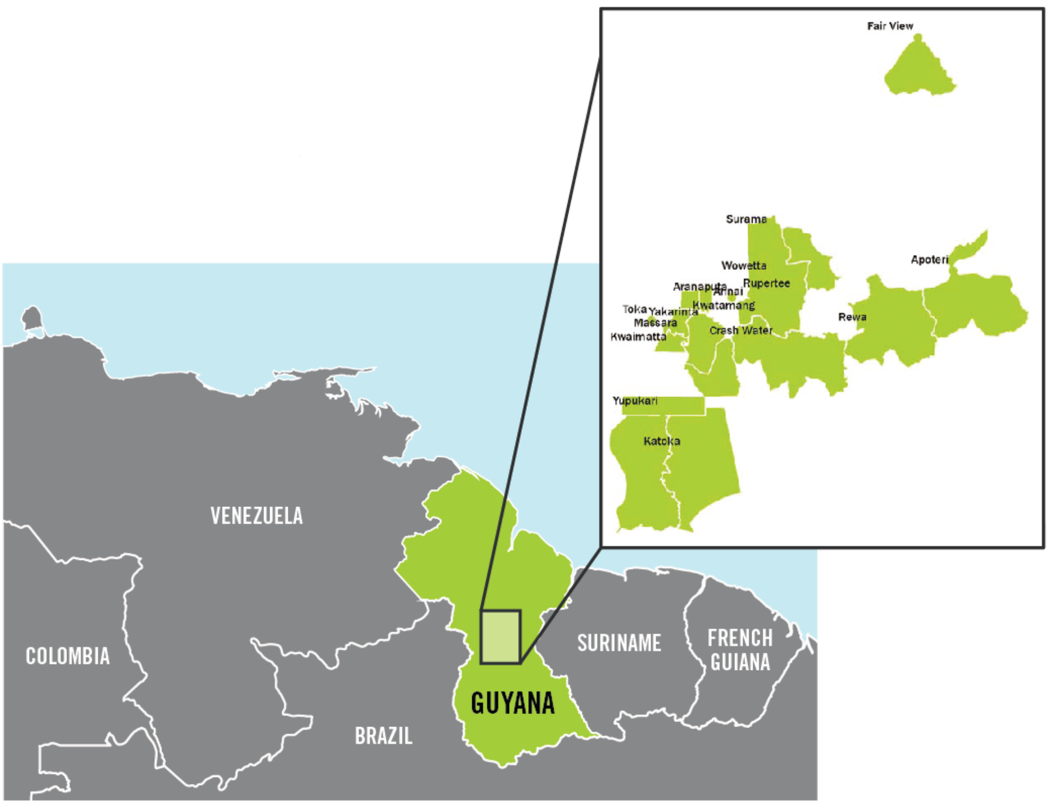


Figure 1. Map of the participating communities in the North Rupununi, Guyana.

The North Rupununi region is located in southwestern Guyana, encompasses areas of high cultural and ecological diversity, and has a landscape mosaic consisting of large areas of old growth tropical forest, savannah, and wetland ecosystems. The sustainability of local Amerindian Makushi livelihoods (e.g., farming, hunting, and fishing) in the region is increasingly threatened by the development of Guyana's interior, in particular threats from mining and road building and their associated sociocultural and environmental pressures. These developments have increased access to forest resources and formerly remote markets for both communities and external actors, driving a growing community awareness of the need for more sustainable and systematic management of forest resources.

3. Methods

In this context, a community MRV (CMRV) project was established in 2010 in collaboration with the North Rupununi District Development Board (NRDDB) (representing 16 Amerindian communities in the region), the Guyana Forestry Commission (GFC), the Iwokrama International Centre for Rainforest Conservation and Development (IIC), and the Global Canopy Programme (GCP) (project facilitators).

Through formally selecting Annai District (five of the 16 communities) as a Community Demonstration Site (CDS) within the national MRVS framework, this collaboration aimed to implement a community monitoring system that could contribute to the national MRV system through producing relevant reports and datasets on local drivers of deforestation and forest degradation, providing carbon stock measurements, and performing ground truthing exercises to help validate remote sensing data. While the results from this work within the CDS were intended to support and inform the development of the national MRV system, they also have clear relevance for community resource management and REDD+ monitoring and safeguards.

3.1. Local Monitoring of Co-Benefits

In addition to these monitoring targets under the Community Demonstration Site, community members from Annai District and the surrounding villages identified and prioritized the collection of additional information on hunting and fishing practices and timber and non-timber forest product harvests, including indicators on the consumption, availability, and perceptions of change in the use of these resources (Table 1). Information on community wellbeing indicators was also collected (Table 2), as well as land use data (e.g., urban areas, hunting grounds, fishing areas, farms, forest conservation areas, burial sites, and tourism zones) and information on community infrastructure, such as roads, schools, and health posts. This data was intended to support local decision-making on natural resource management and development at the village and district level.

Table 1. Sustainability indicators for natural resource use.

	Resource type				
	Timber	NTFP	Fish	Game	Water
Indicator	➢ Number HH extracting timber	➢ Number HH extracting NTFP	➢ Number HH extracting fish (top extractor HH)	➢ Number HH extracting game	➢ Water extraction points and sources
	➢ Seasonality of extraction	➢ Seasonality of extraction	➢ Seasonality of extraction	➢ Seasonality of extraction	➢ Quantity extracted (litres)
	➢ Quantity extracted (FBM/month)	➢ Quantity extracted (KG/month)	➢ Quantity extracted (KG/month)	➢ Quantity extracted (unit/month)	➢ Extraction methods
	➢ Extraction methods	➢ Extraction methods	➢ Extraction methods (techniques and tools)	➢ Extraction methods	➢ Proximity of contaminants to water sources (distance)
	➢ Species preference and demand (price per species)	➢ Species preference and demand (price per species)	➢ Species preference and demand (price per species)	➢ Species preference and demand (price per species)	➢ Water treatment frequency
	➢ Perceived timber scarcity over 5 years	➢ Perceived scarcity over 5 years	➢ Extraction effort and time	➢ Quantity commercialised	➢ Vegetation cover near water sources
	➢ Occurrence of illegal extraction	➢ Extraction location	➢ Quantity commercialised by species	➢ Extraction location (vegetation type)	➢ Perceived threats and changes to water quality and quantity
	➢ Quantity commercialisation		➢ Perceived fish size changes over 5 years	➢ Occurrence of illegal extraction	
	➢ Demand (price per species)		➢ Perceived fish scarcity over past 5 years (availability and location)	➢ Perceived scarcity of 5 past years (availability and location)	
	➢ Extraction location		➢ Extraction location, (distance)		
			➢ Demand (price per species)		
			➢ Occurrence of illegal extraction		
			➢ Occurrence of sport fishing		
			➢ Effectiveness of management plans (rules and enforcement)		

196

Table 2. Community-defined wellbeing indicators.

	Information type						
	Material Wealth	**Employment & enterprise**	**Social relations &governance**	**Culture & beliefs**	**Security**	**Education & skills**	**Health**
Indicator	➢ Number of HH with regular income	➢ Frequency of out-migration	➢ Frequency of food exchanges	➢ Frequency of church attendance	➢ Occurrence of theft	➢ Number of people with official education	➢ Perceived frequency of diseases
	➢ Existence of transport and communication infrastructure	➢ Perceived community development	➢ Number of HH participating in village activities	➢ Number off HH speaking native language	➢ Frequency of alcohol-related incidents	➢ Number of education facilities in the community	➢ Self-reported health & emotional wellbeing
	➢ Number of HH with farm inputs and livestock	➢ Availability and access to financial loans	➢ Number of HH married or in long-term partnership	➢ Purchase of food and water	➢ Frequency of illegal activities	➢ Perceived quality of education services	➢ Number of existing health facilities
	➢ Number of HH able to purchase food	➢ Community businesses	➢ Incidences of resource conflict	➢ Existence of traditional activities	➢ Frequency and length of flooding		➢ Number of HH with potable water
	➢ Number of HH with mobility		➢ Number of HH with extended family support	➢ Building material preference	➢ Frequency and length of droughts		➢ Distance of HH from contaminants
	➢ Electronic assets per HH						
			➢ Perceived level of cooperation				➢ Perceived quality of health services
			➢ Attendance of village meetings				➢ Leisure and sport facilities
			➢ Perceived quality of village leadership				➢ Water treatment and waste disposal facilities

3.2. Building Local Capacities

To implement the monitoring system, 32 community members from participating villages and five local project management staff were trained in forest biomass assessment and ground truthing methodologies, data entry, processing, and analysis using GIS software and other tools, as well as in semi-structured interviewing and communication techniques. Data were collected off-line by the 32 community monitors (text, images, area polygons, and point data) using adapted open source Open Data Kit (ODK) software on Android mobile smartphones. Data collection forms and protocols were designed by GCP in partnership with the NRDDB and community monitors. Data were then uploaded from phones to a central computer where they could be analyzed by the local project management staff and project facilitators (GCP, NRDBB, and IIC) using a range of tools: Microsoft Excel, ODK Aggregate and later SMap software, Arc GIS, QGIS, and Google Maps Engine.

3.3. Data Sharing

All data are owned by the communities. A data sharing protocol was developed within the communities to identify which data could be shared with external actors and the process for addressing data sharing requests. Under the Community Demonstration Site, the communities agreed to share the information collected on deforestation drivers, aboveground carbon stocks, and the ground-truthing results with GFC.

3.4. Assessing Drivers of Deforestation and Forest Degradation

In order to identify key drivers of forest change at the local level, a series of workshops were held with community members for them to initially understand and discuss national definitions of forests (areas of at least 1 ha with a minimum of 30% tree cover and minimum height of 5 meters), and deforestation and degradation (deforestation being one hectare or more of forest that is permanently cleared/clear cut). From these discussions, monitoring the impacts of community farming practices on forest change was prioritized out of a list of deforestation and degradation drivers identified by the communities, which also included community infrastructure, logging, and mining, due to the greater perceived impact on forest areas and livelihood relevance of farming amongst the communities.

Mapping Agricultural Areas

To quantify the impacts of farming practices on community forests, farm plots from 2011, 2012, and 2013 were visited. The location, shape, and size in hectares of these plots were recorded through farm visits by community monitors using the GPS functionality and ODK software on their mobile phones throughout the latter half of 2013 (respondents were asked to identify and allow community monitors to visit old and new farms from 2011, 2012, and 2013). This allowed digital polygons with individual data sets to be created (Figure 2). These polygons were then analyzed and visualized by the local project management team and project facilitators using QGIS and Google Maps Engine in order to assess land use change annually between 2011 and 2013 across all 16 communities.

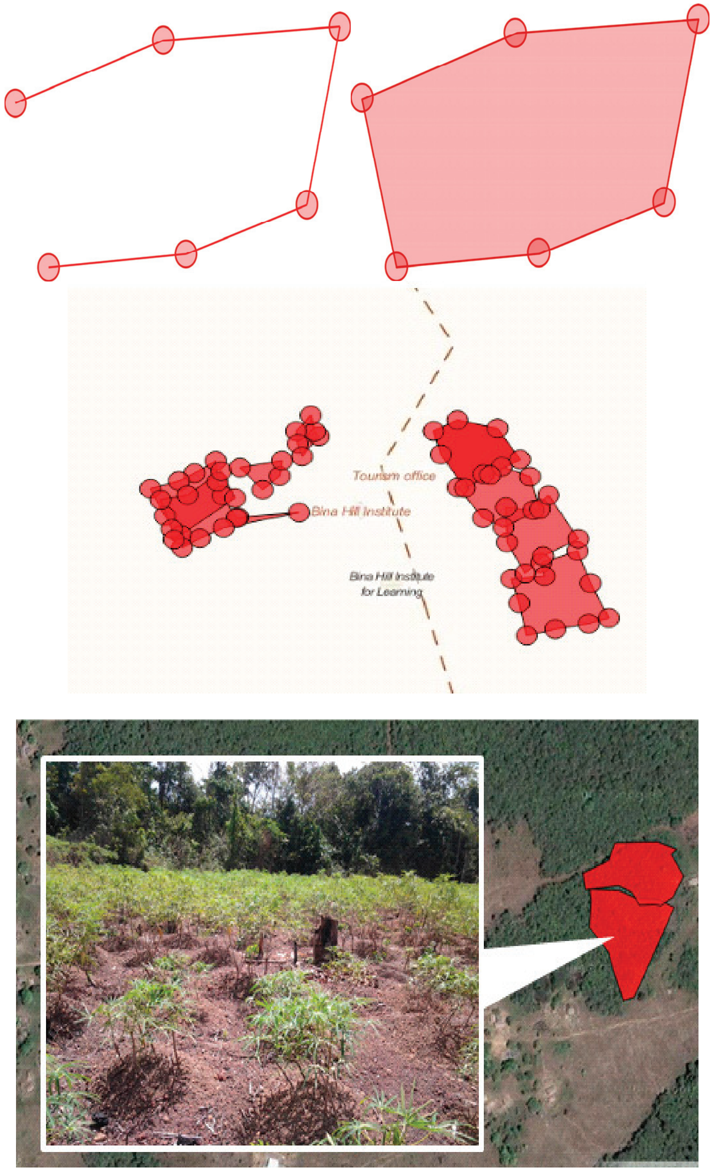


Figure 2. Mobile phones were used to record the points on the boundary of the farmland, capturing the area and shape of the farm; the resulting polygons are now visualized in Google Maps Engine.

3.5. Facilitating Community Measurement of Aboveground Biomass

To support the estimation of emissions factors for greenhouse gas emission calculation in Guyana, the communities estimated aboveground biomass within three forest types and within agricultural land. Biomass was estimated for three broad community-derived forest classifications:

1. "High bush": primary, high canopy forest comprising purple heart (*Peltogyne paniculata*) and associated species;
2. "Mixed bush": Mixed forests with tree species such as mora (*Dimopharidra mora*), wallaba (*Esperua falcate*). and green heart (*Nectandra flodier*) forests;
3. "Low bush": low-lying mixed swamp forest and scrub in areas prone to seasonal flooding.

Within these three types of woodland, 117 random plot locations were selected by local project staff and community monitors using satellite imagery and village maps, which represented the forest classifications. In each of the 16 communities, two paired plots were recorded in each forest type (high, medium, low) with two more in the forest type with the greatest area in that community's titled lands. Therefore, in total across all 16 communities, 57 plots were measured in high bush, which covers 18,461 ha of community titled land; 38 plots in mixed bush, which covers 9720 ha, and 22 plots in low bush, which covers 2392 ha.

A further 128 randomly selected biomass plots (randomized by drawing village household plots from a hat) for fallow farms (*minabs*) of four different age classes were also measured (5–10 years: 23 plots; 10–20 years: 34 plots; 20–30 years: 36 plots; >30 years: 50 plots); with two plots in each age class for each community's lands.

Circular nested plots of 0.125 ha were used (Figure 3). The GPS location at the center of the plot, forest height, soil type, slope of terrain, tree species, and diameter at breast height (DBH) were recorded by community monitors in each plot.

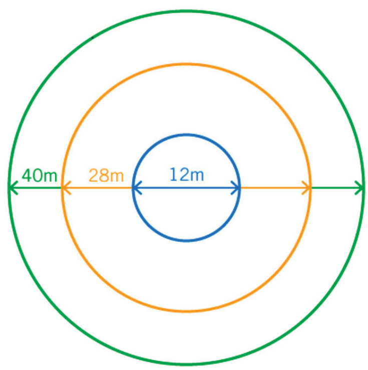


Figure 3. Circular nested plot design consisting of three circular plots with diameters of 12, 28, and 40 m. Within the 12-m diameter plot, all trees with a DBH of ≥ 5 cm were measured; within the circular ring between 12 and 28 m diameter plots, all trees with a DBH ≥ 25 cm were measured; and in the outer ring, between 28 and 40 m diameter plots, all trees with a DBH ≥ 50 cm were measured.

Aboveground biomass was then calculated using an allometric equation from Chave *et al.* [30] for moist forest stands. This is a generalized equation for tropical moist forest, and is not specific for any one type of tree; applied to all trees within the plot, it gives the biomass per plot from which the biomass per hectare can be calculated. According to Chave *et al.* [30] the error on the estimation of a tree's biomass is around ±5%.

$$(AGB)est = \rho \times \exp(-1.499 + 2.148\ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3) \quad (1)$$

D = diameter at breast height in cm;
ABG = aboveground biomass, tons of dry matter.

It was assumed that the carbon density of stems between 5 and 25 cm DBH was the same across the entire plot, and that the carbon density of stems of 25 cm and 40 cm DBH measured in the inner and middle nest was the same across the entire plot.

3.6. Supporting Communities to Ground Truth Satellite Data

In order to accurately understand forest change in Amerindian lands, community monitors ground-truthed areas of deforestation identified by the Guyana Forestry Commission in the Community Demonstration Site. Deforested areas were derived from the GFC from LANDSAT images acquired between 1990 and 2010. The local project management team, with the support of the project facilitators, applied a systematic sampling approach over a 250-m grid within the areas of deforestation identified in the Community Demonstration Site (Figure 4); grid points that fell in mountainous areas were omitted due to logistical impracticalities. Ground truthing exercises were then carried out by community monitors at each grid cross point, recording the vegetation type, land use activities taking place (e.g., active farm, fallow, fire, or no disturbance), the geo-location, and taking a photographic record of that point.

The results were then analyzed manually by the local project management team with the support of project facilitators using Arc GIS.

3.7. Monitoring Resources of Local Interest and Safeguards

During the participatory development of the monitoring framework, monitoring priorities for local resource management and development were identified by the communities in addition to the indicators developed under the Community Demonstration Site to contribute to the national MRVS. Indicators for these priorities—community maps, natural resources, and community wellbeing—were defined through participatory workshops. While these indicators were designed for local use, they have relevance in the context of how community-collected data can inform REDD+ safeguards.

3.7.1. Natural Resource Use

Qualitative and quantitative information on water use, timber/non-timber harvests, fishing and hunting practices was gathered through facilitated group discussions with “top extractors” and semi-structured household interviews undertaken by the community monitors using ODK. “Top extractor” groups were identified through meetings with village council members in each of the villages, and for household interviews a sample of 20 households was selected randomly in each of the 16 villages.

3.7.2. Community Wellbeing

Baseline data on wellbeing was generated by focusing on key social indicators identified by the communities at the onset of the project. The information was then collected by community monitors in two data collection cycles (November 2012–December 2013, and October 2013–December 2013) using ODK questionnaires aimed at 320 households and 16 village councils.

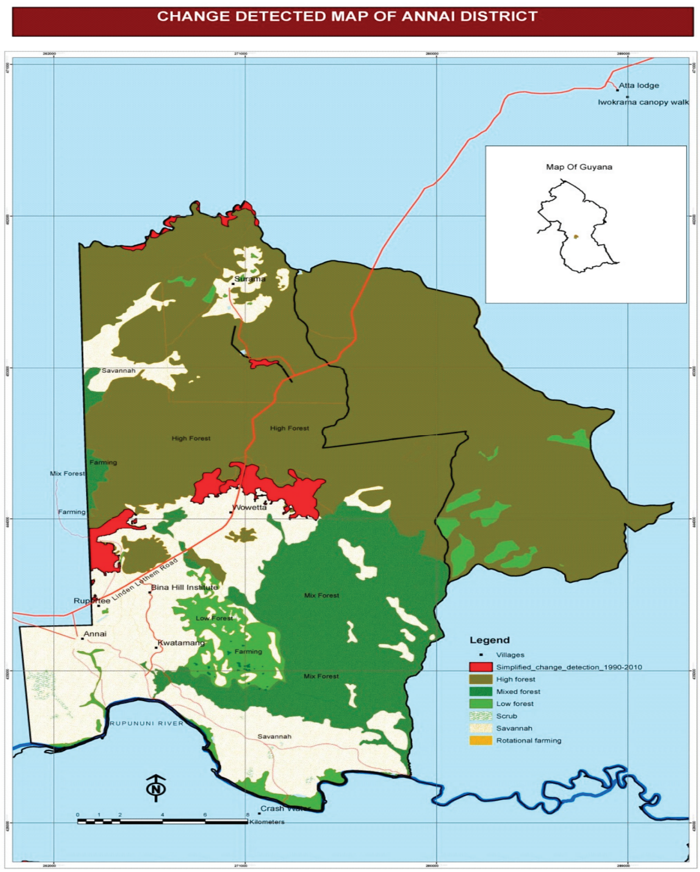


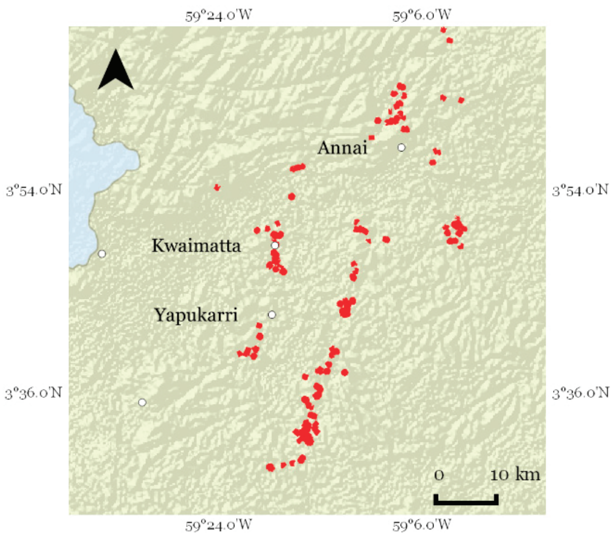
Figure 4. Deforestation areas (red) ground truthed within the Community Demonstration Site.

4. Results

4.1. Community Demonstration Site: Data Contributing to the National MRVS

4.1.1. Assessing Drivers of Deforestation and Forest Degradation: Farming Impacts

Results indicate that traditional farming area in the North Rupununi has more than doubled from 2011 to 2013 (Figure 5). In addition to the spatial information acquired through ODK, the structured questionnaires that accompanied them revealed further quantified information about agricultural practices, which could be used in reference level modeling. Traditional recorded farming area in the region has, according to the data generated by this project, gone up from 64.12 ha in 2011 to 117.42 ha in 2013. This near doubling of the farmland in two years demonstrates the utility of community-collected data in quantifying drivers of deforestation. Figure 5 visualizes farm expansion in a subsection of the area; these maps have been made available on Google Maps Engine, but are not yet used by the community as they do not have sufficiently good Internet access.



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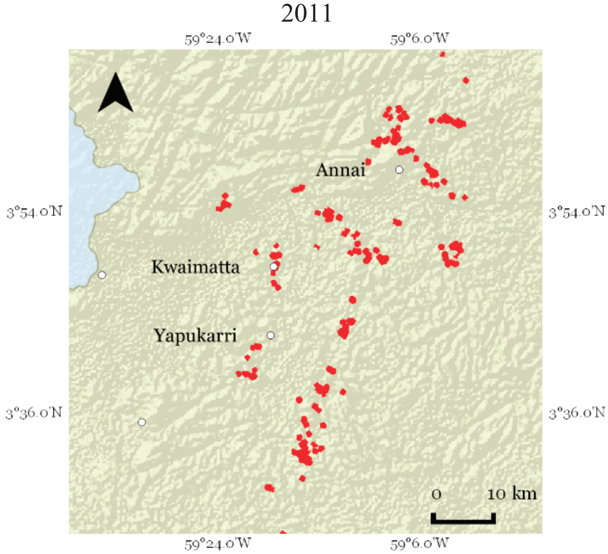

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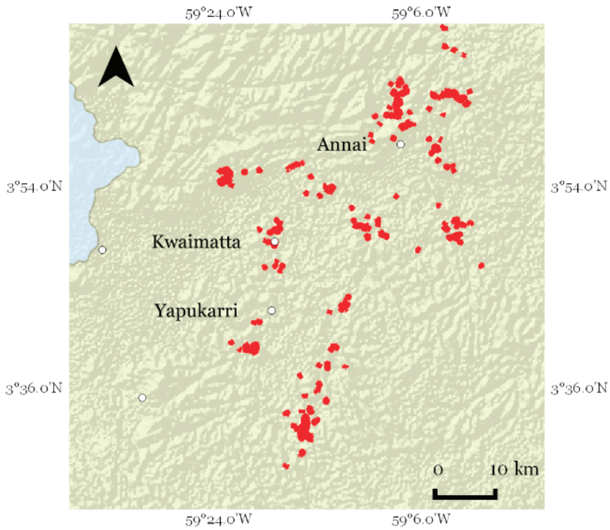
Figure 5. *Cont.*



2013

Figure 5. Traditional farming areas in the North Rupununi, 2011–2013.

Analysis of initial farming data collected from semi-structured interviews showed that 97% of respondents continue to practice traditional/rotational farming in the community, the remaining having adopted savannah farming techniques (commercial approaches). As a result, the majority of households tend to farm on largely forested areas at an average distance of eight kilometers from their homes. The size and number of plots depends on household size and kinship networks, but normally varies from 0.4 to 0.9 ha each depending on production type. Farm rotation periods average between 3 and 5 years with 10–15 years on fallow periods. Results from the Community Demonstration Site show that 75% of all farms from 2012 to 2013 were cut from fallow areas (*minabs* > 10 years old) with the remaining 25% cut from high bush forests.

Results from across the 16 communities showed that 74% of village households recognized in interviews that there is a gradual move towards more commercially-oriented farming practices. Twenty-six percent also point to an increasing use of pesticides and the introduction of new crop varieties, such as different varieties of cassava (*Manihot esculenta*) that are outside traditional farming techniques. Another recent trend that has emerged is the growing tendency to extend farms to cultivate cash crops like cassava as income-generating enterprises, resulting from increased market integration and demand for *farine* (a byproduct of cassava) from nearby mining camps and local markets. These extended farm plots average 2–2.5 hectares in size and retain elements of traditional cultivation patterns in that they remain within forested areas yet cover larger areas and have fewer crop varieties planted.

Results also show that there has been a decrease in plot rotation time. Respondents cited crop loss from faster weeds, poorer soils, and pests as key factors. In addition, 73% of the total households interviewed mentioned changes in the weather, warmer climates, and less predictability of the start and end of seasons as the most notable changes to farming rotation intervals. Indeed, 48% of households interviewed stated that they have changed the location (shifting to higher ground or savannahs) and frequency of clearing farm plots as a result. Prior to this study, data relating to community agriculture as a driver of deforestation was anecdotal, and reasons for the reduction in farm rotation time were poorly understood.

4.1.2. Measuring Aboveground Biomass

Results from the 128 biomass plots for fallow farms of four different age classes show that fallows increase in aboveground biomass with time and that the oldest fallows (172 ± 13 tons biomass/ha) have less than half the aboveground biomass of high bush (360 ± 40 tons biomass/ha) (Figure 6).

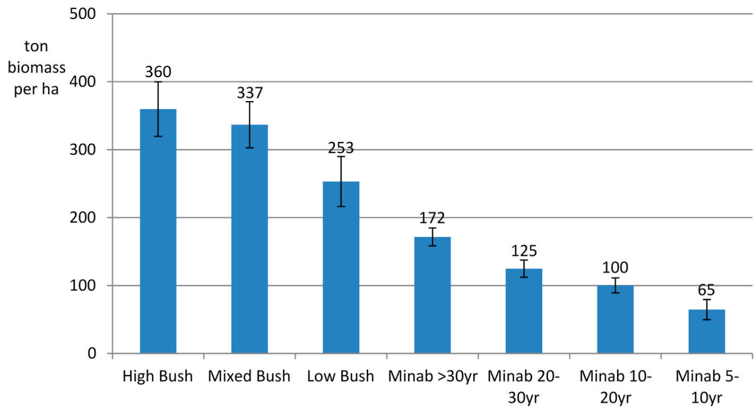


Figure 6. Aboveground biomass per hectare in different forest types in the North Rupununi.

The accuracy of the aboveground biomass data is being validated by the Guyana Forestry Commission, who are also developing improved forest classifications to enable the harmonization of community-collected data within national systems. However, the biomass values for high bush are within the range of values for lowland mixed forest from three previous forest inventories in Guyana reported by Alder & van Kuijk of 303.6, 360.9, and 385.9 tons/ha [31].

4.1.3. Ground Truthing Satellite Data

The community data demonstrated that the LANDSAT-derived deforestation dataset had many false positives; 60% of the 178 ground-truthed points within the deforested area were found to be forested with no signs of disturbance, more than 25% were fallow farms (*minabs* > 10 years old), and active farms were only found on 6% of points. Areas affected by fires were found at only four points (2%). Given the large disconnect between the findings on the ground and the deforestation dataset, further investigation is needed to verify the results and understand if this was a result of any issues in the orthorectification process, the small number of ground control points used, or a mismatch between projections of the different datasets. The local project management team will work with the GFC in order to verify the ground truth measurements and to assess the causes of the false positives found within the dataset.

4.2. Resources of Local Interest and Safeguards

4.2.1. Natural Resource Use: Timber Harvest

A variety of data on timber products, NTFPs, fishing, and game were collected, with the primary aim of informing local management decisions. However, these data are also relevant in testing the efficacy of communities in collecting information on potential REDD+ safeguard indicators; here we present results from the timber extraction survey that are also relevant to understanding forest degradation at the community level and REDD+ monitoring. Summary results from "top extractor" group discussions within the Community Demonstration Site (Annai District) provide an initial estimation of quantities of timber harvests, in board-feet (1 FBM or board foot measure = 0.00235973722 m^3), as well as information on the most targeted species and perceptions on scarcity (Figure 7).

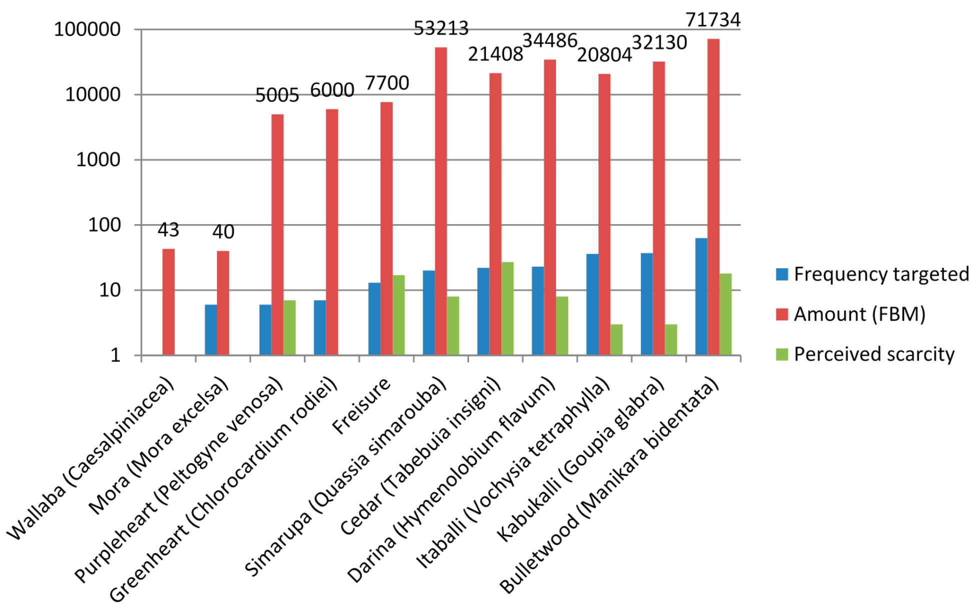


Figure 7. Extraction trends and amounts in FBM (1 month) in the Annai District.

This estimate of the extraction of timber (equivalent to about 596 m^3) is based on one month recall during January 2013 with a sample of "top-extractors"; thus the figures should be seen as an indication of the order of magnitude of current community logging cut and not total volumes. Timber harvests for subsistence purposes (building material and infrastructure) and commercialization occur at different scales throughout the year, with higher demand in the dry season because of improved access to forests. Only a low percentage of households in each community are top extractors engaging in commercial timber extraction. These individuals have the forest access as well as the necessary equipment and licenses to do so. However, community members reported the occurrence of unregulated extraction activities from external actors. More detailed inventories are needed to determine the impact of small-scale logging on forest degradation over time and to assess the effectiveness of current community management practices; however, this initial data can be used as a forest access indicator, and for monitoring drivers of deforestation.

4.2.2. Community Wellbeing

The community-defined indicators of wellbeing cover a range of topics including material wealth, employment, community relations, health, education, culture and beliefs, and security (Table 2). While results were collected and shared at the individual community level, the data sharing agreement requires that any wellbeing data that can be shared with external actors must be aggregated across the 16 communities.

Across the 16 communities, respondents identified alcohol abuse (34%), unemployment (27%), and theft (10%) as the most pressing social issues affecting the population. Wellbeing results also shed light on the prevalence of water and mosquito-borne diseases as the most frequent health issues across the region over the past two years (Figure 8), yet results also show that 95% of respondents consider themselves to be in good health.

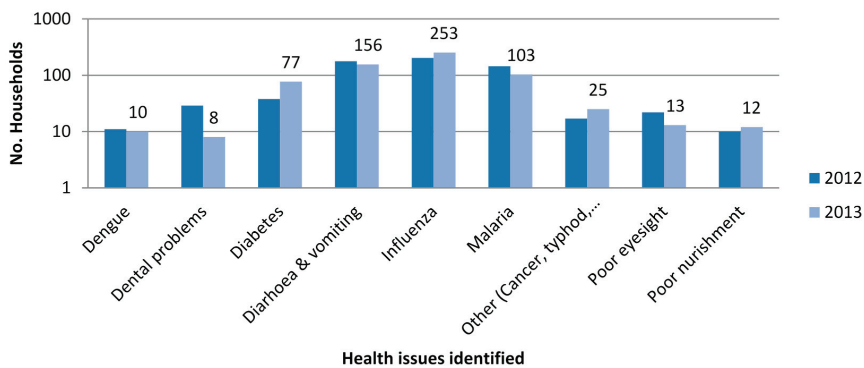


Figure 8. The most frequent health issues reported across the 16 communities in 2012 and 2013.

Results also provide important insights on interactions and social cohesion among communities in the North Rupununi. The perceived level of cooperation in the community was among the most pressing social issues, with roughly 9% of respondents choosing it as a key issue, and a quarter of respondents also describing it as "poor." Yet, food security and the reliance on family safety nets are seen as broadly positive across households, which provides a picture of social networks and reciprocity that exists within villages as opposed to inter-communal relations (Figure 9).

Outsiders from neighboring regions and countries settling and intermarrying, and the flow of people travelling through the region, were identified by respondents as a catalyst for cultural changes. Yet in terms of cultural prevalence, monitoring results show that 71% of respondents as a whole are fluent in the Makushi language, which suggests the retention of Makushi identity across the communities in the North Rupununi even with these growing internal changes. Results also highlight the local perceptions on the growing threat from illegal logging, mining, and fishing activities on community resources, with over half (51%) feeling threatened.

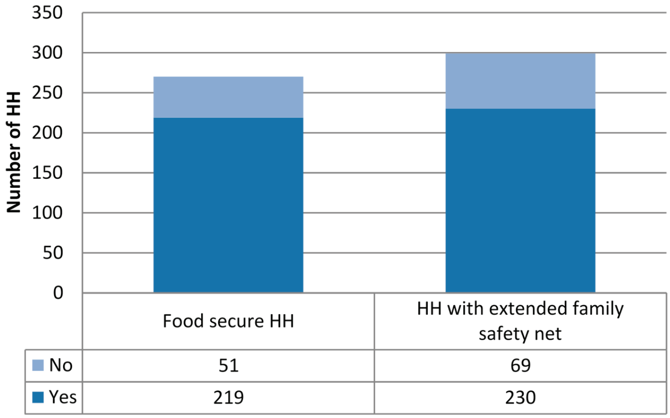


Figure 9. Perceptions on food security, safety nets, and external pressures.

After the introduction of the REDD+ mechanism, these data may serve in the assessment of changes in migratory patterns, social ills, health, and social cohesion, thereby contributing towards the national Safeguard Information System. Furthermore, the wide range of community-defined wellbeing indicators, which go beyond simple indicators of poverty, demonstrate the importance of engaging forest-dependent communities in providing information on social safeguards. A transparent data sharing protocol is essential in ensuring that data provided by communities is used appropriately.

5. Discussion

5.1. Contributions of Community-Based Monitoring to National MRV Systems for REDD+

Local drivers of deforestation and forest degradation are not often captured in national forest monitoring systems or through remote sensing and thus, particularly in countries where local drivers of deforestation and degradation are important, community-based monitoring offers an important source of information to complement existing datasets [10]. Furthermore, the results from Guyana suggest that while national classifications of deforestation drivers tend to omit traditional farming systems due to their regenerative nature and low permanence, their role in forest change is still unclear given the changing local realities resulting from responses to climate variables and other external pressures. Rotation patterns that characterize traditional farming and the growing role of cash crops need to be assessed further over time to understand the process of recuperation of fallow lands within forest areas; the community-collected data contributes towards this understanding and would support modeling of carbon flows in the region.

Further uncertainty on the impact of local land use practices has been generated from ground truthing results, which have revealed inconsistencies between remote sensing data and forest disturbance on the ground. While the results will need to be verified, they show the value of different levels of forest monitoring, and thus give further impetus for pushing for locally-generated data flows to improve forest monitoring systems. The results also point to the need to focus on remote sensing methodologies being applied to understand forest fragmentation and degradation, in order to further understand the role of traditional farming systems within this classification.

Communities' data from this study, consistent with regional estimates, contributed towards an understanding of aboveground carbon stocks that is in turn important for understanding the impact of land use practices on carbon stocks over time and in calculating emission factors. Understanding carbon sequestration rates and the potential loss or contribution of traditional farming practices to carbon stocks is important in determining the sustainable fallow and rotation periods needed for communities wanting to understand and participate in REDD+ schemes. In order to better understand the accumulation of biomass over time in fallow fields, measurements of narrower age classes could be captured if needed.

The results from the Community Demonstration Site and subsequent reporting to the GFC highlight the need to harmonize forest type classifications and species taxonomies when communities are contributing to national analysis. The divergence between community and national definitions demonstrates the challenges of linking indigenous knowledge systems of forests to national and scientific classifications. Standard protocols for data collection and reporting can also support the integration of community-collected data into national forest monitoring systems.

5.2. Providing Data for REDD+ Safeguard Information Systems

Beyond MRV, the variety of data collected on wellbeing and natural resource use has clear relevance for REDD+ monitoring and Safeguard Information Systems, through assessing the social and environmental impacts resulting from wider national interventions targeting community forest areas. While this has not been a direct focus under the national MRVS roadmap in Guyana, safeguards under bilateral agreements, such as the current Guyana–Norway agreement and a future international REDD+ mechanism, will require information on safeguards. As countries such as Guyana develop Safeguard Information Systems it will be important to extend CBM approaches and demonstrate the efficacy of community-collected data for REDD+ safeguards.

A key outcome of CBM beyond its national contributions is that communities participating in monitoring are more knowledgeable about the value of forest in their territories and REDD+ more broadly and thus more engaged, which can help in future decision-making related to the planned "opt-in" mechanisms under the LCDS in Guyana. Results from a project evaluation exercise showed that 85% of community leaders (*Toshaos* and village councilors) felt the priorities of their communities had been taken into account in drawing up the monitoring framework, which is fundamental for embedding monitoring results and aligning priorities at the local level. Beyond REDD+, CBM can assist communities in assessing and understanding their forests further, and in planning resource use and sustainable development that are in line with wider forest policy initiatives such as REDD+.

5.3. Harnessing Technology for Scale

REDD+ under the UNFCCC requires national level MRV, and thus both integrating and scaling-up locally-based CBM initiatives are key challenges for national forest monitoring systems.

The use of digital technology in overcoming data integration challenges and facilitating more efficient data collection, data processing, and sharing has been tested in a number of CBM projects [17]. Yet while technology has been an enabler for improving accuracy through reducing transcription errors, data processing, and quicker data sharing, it has also introduced new challenges in terms of building local capacity for data management and analysis, which is important for ownership and incentivizing control and buy-in by community members.

The case study demonstrates that participatory training approaches that are adapted to the local realities and cultural context and the development of guidelines and procedures to clarify data collection, processing, and reporting steps for monitoring can support the required capacity building on using technology-based monitoring systems. However, the local project management team is still reliant on the support of consultants and the project facilitators to analyze the data using advanced tools such as Arc GIS and Google Maps Engine.

5.4. Sustainability

The cost-efficacy of CBM is a key factor when considering its inclusion within national forest monitoring systems. While CBM can be advantageous in terms of lowering the cost of data collection over time, in the case of Guyana, the high initial costs of developing a CBM system using technology and local capacity building programs is a key challenge for scale.

Furthermore, the experience in Guyana shows that in order to regularly collect data and maintain a monitoring system, tangible local benefits are imperative. Community members undertaking this work need financial compensation for their service, as relying on community reciprocity or participation alone cannot compensate for the opportunity cost of engaging in more attractive economic activities (like mining) that can add considerably to the costs of sub-national monitoring models.

Community learning networks could play an important role in wider and more accessible capacity building programs to enable knowledge and information sharing at the local level on CBM. This approach was successfully trialed with community-to-community training on forest monitoring between CMRV project members from the North Rupununi and Wai Wai communities in the Konashen Community-Owned Protected Area. By utilizing the capacity of local institutions and actors, this approach can provide a role for communities in replicating and scaling the CBM approach nationally and reduce the upfront costs of implementing a CBM system.

However, without long-term, holistic, and sustainable financing for CBM, initiatives are constrained to the project level. At present, policy uncertainties at the national level on the MRVS and the future REDD+ mechanism have been barriers to progress in Guyana. Defining the benefit-sharing framework and opt-in mechanism for community performance-based payments under the national REDD+ program is an essential first step in clarifying community participation in REDD+ and further understanding the sustainability of CBM within it.

6. Conclusions

The results from subnational monitoring in Guyana show that communities are highly capable of identifying and assessing local drivers of deforestation; in carrying out ground-based validation of satellite data on forest change; and in measuring aboveground carbon stocks. All of these are key inputs for national forest inventories and monitoring systems and in developing the national MRV architecture in Guyana.

However, going beyond REDD+ MRV, community-collected data can also provide information for Safeguard Information Systems (SIS). While national SIS are in the early stages of development, the case study demonstrates not only the relevance of community-collected data for safeguards but the importance of engaging forest-dependent communities in the development of locally appropriate safeguards.

The integration of CBM in REDD+ is likely to depend on national and international priorities, costs, and the perceived capacity and role of communities in addressing key REDD+ requirements. Experiences in participatory monitoring initiatives among communities of the North Rupununi further support similar conclusions worldwide—that forest-dependent communities are best placed to identify and collect information that can contribute towards addressing national REDD+ requirements on MRV and SIS.

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Author Contributions

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Conflicts of Interest

The Global Canopy Programme has received funding from NORAD to coordinate the actors involved in this community MRV project.

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