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Abstract: Monitoring socioecological impacts of policy interventions aimed at changing land use practices is a major challenge in sustainable development and conservation. Reducing emissions from deforestation and forest degradation (REDD+) intends to compensate local stakeholders for demonstrated carbon emission reduction and increased removals accounted for internationally, whilst promoting social and environmental benefits locally. Thus, monitoring REDD+ inherently requires the use of interdisciplinary data at different scales. Forest carbon monitoring, central to REDD+, is considerably advanced, yet the progress on social and environmental monitoring systems is uneven. We argue that scalar and interdisciplinary integration of REDD+ monitoring is crucial to uncover and understand trade-offs and synergies on which effectiveness, efficiency and equity of REDD+ may depend.

We review previous efforts in integrating environmental and social monitoring, as well as efforts specific to REDD+, and discuss how old and new knowledge can contribute towards integrated monitoring. We observe that there are many challenges, but strong advantages, in an integrated monitoring approach. The current emergence of diverging standards and methodologies with narrow focus can inform future integrative efforts but could, in the long run, hinder coherence in national processes. We conclude that recent technological advances open new opportunities to integrate information across scale and disciplines, leveraging and combining existing data with targeted additional measures. The application of mixed methods in data collection can foster integration, in particular from the local level upwards. However, this requires greater coordination at the higher levels to efficiently upscale multiple data streams. The unequal standpoint of carbon, social and environmental monitoring efforts provide a timely opportunity to promote integration, learn from advances in carbon monitoring, and build on existing and emerging platforms and tools that are locally to globally relevant.

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Towards integrated monitoring of REDD+

Abstract

Monitoring socioecological impacts of policy interventions aimed at changing land-use practices is a major challenge in sustainable development and conservation. Reducing emissions from deforestation and forest degradation (REDD+) intends to compensate local stakeholders for demonstrated carbon emission reduction and increased removals accounted for internationally, whilst promoting social and environmental benefits locally. Thus, monitoring REDD+ inherently requires the use of interdisciplinary data at different scales. Forest carbon monitoring, central to REDD+, is considerably advanced, yet the progress on social and environmental monitoring systems is uneven. We argue that scalar and interdisciplinary integration of REDD+ monitoring is crucial to uncover and understand trade-offs and synergies on which effectiveness, efficiency and equity of REDD+ may depend.

We review previous efforts in integrating environmental and social monitoring, as well as efforts specific to REDD+, and discuss how old and new knowledge can contribute towards integrated monitoring. We observe that there are many challenges, but strong advantages, in an integrated monitoring approach. The current emergence of diverging standards and methodologies with narrow focus can inform future integrative efforts but could, in the long run, hinder coherence in national processes. We conclude that recent technological advances open new opportunities to integrate information across scale and disciplines, leveraging and combining existing data with targeted additional measures. The application of mixed methods in data collection can foster integration, in particular from the local level upwards. However, this requires greater coordination at the higher levels to efficiently upscale multiple data streams. The unequal standpoint of carbon, social and environmental monitoring efforts provide a timely opportunity to promote integration, learn from advances in carbon monitoring, and build on existing and emerging platforms and tools that are locally to globally relevant.

Background

Reducing Emissions from Deforestation and forest Degradation plus enhancing forest carbon stocks (REDD+) has rapidly evolved from a climate change mitigation tool into a complex policy framework [1]. REDD+ now encompasses a broader view on forest conservation, enhancement of rural livelihoods through sustainable development and practices, while maintaining its original function of forest-based climate change mitigation. In particular, non-carbon outcomes (risks and co-benefits) have been at the forefront of the discussions on scope and breath of REDD+. The extent to which REDD+ should or should not be inclusive of further environmental [2*,3] or social objectives proposed [4,5], and how best to measure these multiple objectives, has become in itself a topic of discussion and research [1]. An initial focus on safeguarding social and environmental impacts of REDD+, embodied in the Cancun Agreements (Decision 1/CP.16) of the United Nations Framework Convention on Climate Change (UNFCCC), has more recently evolved into including non-carbon values as critical to both the legitimacy and effectiveness of REDD+ [6*]. This view was reinforced at the Conference of the Parties in Warsaw 2013 (COP19), with the decision for "incentivizing non-carbon benefits for the long-term sustainability of the implementation of the activities" and obliging countries to report on safeguards (Decision 1/CP.19).

This shift towards multiple objectives and increased complexity is therefore the result of a rich debate that accompanied the inception of REDD+, involving a wide range of stakeholders with different priorities and concerns. Research on early REDD+ activities has also demonstrated that REDD+ is inherently a "complex multilevel and multi-stakeholder process that tends to fulfil multiple goals beyond emission reduction" [6*]. Such conditions require inclusion of actors within and outside of the forest sector, and connections between local and global interests, which make REDD+ implementation challenging [7*,8*]. Importantly, many of these challenges are tightly linked to the ability to monitor and assess the impact of policies and ground-interventions over time to avoid unintended consequences. To monitor the impacts of REDD+, there must be clarity on what to measure, at what scale and effort, along with a clear pathway of reporting from local to international levels.

Advances in the development of systems for forest carbon monitoring elucidate the difficulties of linking local activities to carbon outcomes and including them in a seamless structure of reporting across levels [9]. Despite much financial and institutional investment and progress, a number of issues are still not fully overcome, from technical (e.g. detecting and quantifying small scale deforestation and degradation [10,11]) to differences in national capacity [11,12] and reporting objectives [13*,14*]. Similar challenges also burden social and environmental monitoring. For instance, the text related to the Cancun safeguards has been criticized for the lack of clear language and the binding development of performance indicators [15]. Yet, a balanced international guidance on how to measure and report on safeguards with respect for national sovereignty and minimizing transaction costs [16*] is needed. Developing scalable systems that satisfy the needs of stakeholders at each particular level, remains difficult.

As a result of the complexity of methods and technologies, compounded by competing agendas of the myriad of interest groups involved in REDD+, emerging monitoring efforts (such as third party standards) tend to focus on either carbon or non-carbon benefits and show limited integration across scales. A question arises on whether multiple, parallel and diverging monitoring choices will contribute to further isolate disciplinary camps and exacerbate scalar. Disciplinary and scale 'silos' present the core challenge in our ability to measure, understand and act upon processes interconnected in both dimensions. Integrated monitoring is essential for accurately assessing the trade-offs and synergies between effectiveness, efficiency and equity, understand methodological shortcomings and inform policy choices. While we recognize that focused, disciplinary approaches have contributed if not driven the REDD+ progress to date (e.g. carbon accounting), integration among carbon, social and environmental monitoring is needed to achieve more holistic outcomes. In this paper, we summarize the current key issues facing monitoring in REDD+ and discuss how integrated monitoring can be promoted by building on existing knowledge and emerging research.

Key data sources and gaps

In the UNFCCC framework, REDD+ emission reduction estimates are to be reported nationally to make countries eligible for performance-based payments. The UNFCCC recommends a step-wise approach for emission reduction assessments to allow flexibility in using available data (as starting point), improving capacities, and reducing uncertainties over time (moving up in different tiers of estimating carbon stock changes); a pathway that may vary depending on country circumstances [17].

The step-wise approach is a pragmatic solution to different national capacities and contexts, and is conceptually well formulated. However, its strength in terms of promoting best methodological practices, and provisioning data resources weakens as it moves to higher tiers (i.e. in the context of estimating carbon stock changes), as visualized in three color zones in Figure 1. For Tier 1 carbon stock data, default values are available for all countries, there are clear best practices and methods, and reporting back to the UNFCCC system is found to be less complicated (green zone). However, moving from Tier 1 to Tier 2, where data are collected within country, best practices are well documented, methodological choices are reasonably given, but data are limitedly available (grey zone). Tier 3 includes more detailed data on the relevant changes and process, where best practices are reasonably available, but methods and data are limited or often not available. Robust data is the basis for good reporting, but clear gaps exist in many developing countries [13*]; moreover, countries and other actors tend to shy away from taking on additional monitoring tasks in situations where key datasets are missing and basic capacities need to be established first.

[Figure 1]

The tiered model strictly relates to reporting of emission reductions, but the decreasing clarity on guidelines and practices with higher-order data is even more exacerbated for social and environmental monitoring. In principle, this situation underscores the difficulty in gaining detailed knowledge and yet maintaining a clear pathway for aggregated reporting. Additionally, the groups collecting data on carbon versus non-carbon outcomes of REDD+ are largely disconnected. For carbon monitoring, activity data and emission factors are most relevant. Data for social monitoring include rights, participation and livelihood benefits, and environmental monitoring requires data for biodiversity, soil, water and other ecosystem services. Scale- and discipline related challenges are therefore formidable; attempts for cross-scale and cross-disciplinary integration in REDD+ monitoring are, not surprisingly, largely absent. However, the requirements to build National Forest Monitoring Systems for many developing countries with current low capacity and structures in place, also presents a great opportunity to build on integration of activities and data for monitoring from the early stages.

Old challenges and new prospects for integrated monitoring

Integration of socioeconomic and biophysical information in spatially explicit, scalable manner to inform monitoring and implementation is a long standing challenge that predates REDD+. Since the 1990s, there has been an increasing acknowledgement that linking remote sensing science, typically applied to biophysical studies, and social science, can create synergies for understanding complex human-ecological systems. Remote sensing allows for cross-scale and time series analyses on socially relevant data [18]. Models combining remote sensing and ground-based social data can help to understand complex land-use change dynamics [19].

Nonetheless, the theory is sobered by the practical implications of combining two profoundly different scientific traditions. Variables in which social scientists are interested are not readily measurable from space; whilst remote sensing targets “where” a phenomena occurs, the social dimension is usually interested in “what” or “why” such phenomena occur, and may or may not be expressed as a function of space and place. Moreover, jointly modeling biophysical and socioeconomic variables is challenged by temporal lags and spatial-diffusion processes; the processes themselves can be buffered, amplified, inverted, or otherwise transformed before the resulting change in the landscape can be seen and measured [20]. The difficulty in linking individual decisions to emerging changes in land use and land cover [20] is particularly relevant to impact attribution of REDD+ interventions.

The following key issues outlined by Lausch *et al*. [21] summarize the main obstacles:

- standardized data processing techniques, which are vital for the spatial and temporal comparability of results;
- the selection of a manageable set of indicators which embraces the structural properties of landscapes; and
- the choice of appropriate spatial units which allow for an integration of indicators (which tend to relate to cross-border phenomena) and socio-economic indicators (which are usually available for administrative entities or areas).

Recent research, both within and outside REDD+, have drastically improved our ability to tackle these challenges through advances in technology and methods. A recently published global map of forest cover change, also referred to as the Hansen data [22**] is a staggering example of recent progress, despite critiques for missing important local context related details [23–25]. The World Resources Institute’s Forest Watch (http://www.globalforestwatch.org), built on a related web-based platform, integrated further information layers beyond forest cover: it allows spatial registration of non-spatial data, on a user-friendly interface accessible to non-spatial analysts. Such products are a testimony to the possibility of collecting and presenting information free of scale constraints, albeit also underlining the challenges in maintaining fine scale accuracy. Similarly, there is a recent emergence of several toolkits aiming at facilitating managing and policy making at jurisdictional or landscape scale, through the spatially-explicit representation of multidisciplinary data [26–31*]. Typically, toolkits to support decision making differ in their specific data requirements with respect to integrated monitoring over time. However, they do provide progress and insights in how scale-robust indicators can be developed in an integrated way.

For several years, the Food and Agriculture Organization of the United Nations (FAO) has also advanced integrated socioeconomic and biophysical data collection strategies through National Forest Inventories (NFIs) and National Forestry Monitoring Assessments (NFMAs). These initiatives focus on monitoring the state and changes of forests, and on their social, economic and environmental functions. Further, they aim to build national capacities and harmonize methods, forest related definitions and classification systems among countries. These approaches have been deployed in countries across the tropics, and have produced mixed biophysical and socioeconomic data that are directly relevant to REDD+ monitoring. The World Bank's Poverty Mapping provides a spatially explicit combination of census and household-level data towards informing policies that are better tailored to local conditions [32], leveraging secondary and primary datasets to achieve cross-scale integration of social monitoring. A variety of national-level secondary datasets are publicly available, such as the World Bank's Living Standards Measurement and various demographic and health surveys, data that can be complemented by primary data collection in the field to develop and test indicators for cross-scale aggregated reporting in the context of REDD+.

Promising innovation also comes from the Sustainable Amazon Network initiative [33**], which is developing tools to achieve cross-scale, multidisciplinary assessment of tropical land use change; the study aims to quantify ecological consequences of forest clearance, forest degradation and exploitation, and agricultural change at different spatial scales. The authors argue that research has often concentrated either on very broad scale (i.e the Amazon basin), which often depends upon very coarse-scale data, or on detailed work on a few intensively studied research sites, which misses the variability in environmental and land-use gradients that drive much social and ecological change. As an alternative, the authors propose that more work is needed at the 'mesoscale' level, to respect "the importance of both local (farm) and regional (state and biome) processes and objectives in a way that work focused on either smaller or larger scales cannot readily achieve" [33**, p. 5].

Building effective multi-sector and interdisciplinary research and or monitoring programmes at large spatial scales remains one of the most difficult challenges facing sustainability science. However, existing knowledge shows that the application of mixed methods at multiple scales in social and environmental monitoring can lead more accurate understanding of cross-scale processes, and provide entry points for disciplinary integration that remains largely unexplored. REDD+ is currently playing a key role in the theoretical and practical advances in this field. Building on old and new available knowledge [34*,35], REDD+ can harness opportunities for further progress that lie within reach to achieve integrated monitoring (Figure 2).

Integration across scales and disciplines in REDD+ monitoring

[Figure 2].

Innovative approaches to tackling scale issues can also be found in recent, REDD+ specific efforts. The experience of carbon accounting of specific REDD+ implementation activities suggests that reporting needs to take a bottom-up approach where local level emission reduction estimates are assimilated and verified at the subnational level, further fed into the national system where they are verified and reported to the UNFCCC internationally. This nesting and verification is important to make sure that there are no omissions, leakage, double counting and overlapping claims over carbon rights occurring at any scale of the jurisdictions and consistency with national greenhouse gas (GHG) inventory.

As part of this recognized necessity of locally driven, bottom-up approach, community-based MRV 's potential has recently been explored in a number of initiatives [36**]. Community-based monitoring (CBM) is proving useful for ground-truthing of remote-sensed data. In Guyana, such a CBM effort has helped uncover large amounts of false-positives (areas defined as deforested when forest is still standing) from LANDSAT data [37**]. In a similar case in Panama researchers found discrepancies between fine-scale Rapideye satellite imagery and data from the field [38*]. Conversely, remote sensing was more accurate in characterizing specific land cover types such as short fallows. In another study, Pratihast *et al.* [39**] suggest that combined CBM and remote sensing is proving an efficient way to gain detailed knowledge at different scales. Remote sensing retains a primary role in detecting where (location) and how much (area) change is happening, whilst community-collected data can best inform the timing and drivers of degradation, therefore providing resolution on spatio-temporal lags. These studies demonstrate how scalar data integration, in particular local data feeding into large scale data acquisition, can improve the overall quality by building on complementarity of their different strengths. Data on human activities that affect forests are useful for both biophysical and socio-economic monitoring, and therefore amenable to cooperation and deployment of mixed-approaches. The authors also underline that well-trained community members, supported by advancing hand-held technology, can cost-effectively achieve data quality comparable to expert observation.

Community based monitoring also highlights innovations in integrated monitoring of environmental and social co-benefits, with initiatives that rely on local stakeholders' involvement to explicitly link socioeconomic and biophysical data collection. In a CBM project in Guyana, community members were trained to collect data on 'co-benefits', including forest product harvests and community well-being, alongside ground-truthing spatial information [37**]. Boissiere *et al*. [40*] describe an innovative community-based strategy that combines remote sensing, ground-truthing of biophysical data, socio-economic data collection, and also multilevel governance research - an interdisciplinary approach to monitoring across scales that deserves further attention. In principle however, scaling up of environmental and socioeconomic information can follow the same route of carbon MRV: local data collection, although not always simple to achieve [41], can complement and improve larger scale datasets. Similarly as global maps of forest cover change, comprehensive spatial data on global biodiversity distribution and threats are becoming available [42**,43], accessible online (www.biodiversitymapping.org) and there are clear connections between these products. Datasets measuring changes in forest carbon emissions can be used to assess changes in biodiversity, water and soil resources. Integration of carbon and environmental objectives at the design stage, can help modulate and optimize the balance between carbon and co-benefits [44,45], help clarify monitoring needs and improve project performance.

Environmental data is typically not tied to political and jurisdictional borders; as a consequence, these data are somewhat less bound to national ownership where capacity is low. They are more reliant on high-level frameworks, in particular the Convention on Biological Diversity and the Intergovernmental Platform on Biodiversity and Ecosystem Services. A three-tiered approach reflecting different national capacities, similarly to carbon, has also been proposed for integrating biodiversity concerns in REDD+, further calling for greater coordination between UNFCCC and IPCC [34*]. By contrast, socioeconomic monitoring is often tightly linked to sub-national jurisdictions and ultimately national borders. Integration between socioeconomic and environmental monitoring therefore needs to resolve issues of potentially divergent boundaries of analysis.

Adopting a stepwise approach for environmental monitoring, dovetailing with socioeconomic reporting at the national scale could provide the common base needed. As exemplified by Bellfield et al. [37**], local level data collection can serve as starting point for integrating different disciplines, but can only become effective through greater coordination on the upscaling of these data streams between the national and international level. While the rules for estimation and accounting can vary for the different objectives and scales, the same data can often serve multiple objectives. The diversity in integrated monitoring standards and accounting rules are, thus, much less related to variability in underlying data than in rules to analyze and assess them. The combination of locally-led field measurements, remote sensing and spatial registration of non-spatial data holds great potential for achieving scalar and disciplinary integration, but requires a common language and common ground (in terms of data), and the development of performance indicators that are: i) easy to understand; ii) applicable at multiple scales; iii) applicable to any location; iv) efficient to measure and monitor; v) sustainable in providing data; and vi) able to be improved over time [14*].

Conclusions:

In this paper, we describe the challenges and opportunities for implementing multi-scalar and interdisciplinary monitoring for REDD+ activities. Integrated monitoring is needed to understand the trade-offs and synergies among these multiple objectives of REDD+, as these cannot be captured at just one scale, or with just one methodology. Ultimately, better understanding these trade-offs and synergies is critical to reducing emissions whilst meeting other environmental and social objectives effectively, efficiently, and equitably.

The proliferation of agenda- or topic-specific monitoring standards reflects both the need for experimentation and interpretation within existing high-level frameworks. While this diversity provides a rich set of options and experiences to learn from, we urge caution around their congruence with national objectives. We recognize that it will not always be efficient or even desirable to integrate scale and discipline, and that the degree of integration that is appropriate depends on the specific objectives of the monitoring effort. However, as monitoring needs to move towards national ownership, the most context-appropriate lessons from these standards must be incorporated into unified and integrated national monitoring systems. REDD+ is emerging in a world of “big data”, with notable efforts to create global and/or pan-tropical interdisciplinary datasets, and technological progress supporting efforts to better understand both biophysical processes and human-environment interactions. However, there is a still a common disconnect between the widely-available large area data on forest change derived from remote sensing, and the fine-scale data needed to monitor forest degradation processes and changes in social and environmental conditions. Integrated monitoring needs to take advantage of the multiple data streams (i.e. field measurements and remote sensing data analysis, or global datasets for national-level use, national inventories, etc.), and use them for inter-calibration and validation.

Research needs to promote conditions where integration is clearly an opportunity rather than an additional burden. Further work is needed to achieve complementarity of data collected at different scales and through different methods. Analysis of different monitoring systems needs to clarify how synergies between coarse and fine scale data can be realized to capture local processes and outcomes for aggregated reporting at broader scales. In this context, the potential for community-based assessments of joint social and environmental conditions to foster disciplinary integration remains largely unexplored.

As the international community demands tangible measures to stabilize the climate system, countries need to produce transparent, accurate and comparable estimates of emission reductions. As these objectives must be achieved while respecting social and environmental values over time, integrated monitoring for climate change mitigation strategies impact across jurisdictions for REDD+ and beyond is a pressing necessity.

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1. Visseren-Hamakers IJ, Gupta A, Herold M, Peña-Claros M, Vijge MJ: **Will REDD+ work? The need for interdisciplinary research to address key challenges**. *Curr. Opin. Environ. Sustain.* 2012, **4**:590–596.

2*. Venter O, Hovani L, Bode M, Possingham H: **Acting Optimally for Biodiversity in a World Obsessed with REDD+**. *Conserv. Lett.* 2013, **6**:410–417.

3. Barlow J, Parry L, Gardner TA, Ferreira J, Aragao LEOC, Carmenta R, Berenguer E, Vieira ICG, Souza C, Cochrane MA: **The critical importance of considering fire in REDD+ programs**. *Biol. Conserv.* 2012, **154**:1–8.

4. Agrawal A, Nepstad D, Chhatre A: **Reducing Emissions from Deforestation and Forest Degradation**. *Annu. Rev. Environ. Resour.* 2011, **36**:373–396.

5. Ghazoul J, Butler RA, Mateo-Vega J, Koh LP: **REDD: a reckoning of environment and development implications**. *TRENDS Ecol. Evol.* 2010, **25**:396–402.

6*. Visseren-Hamakers IJ, McDermott C, Vijge MJ, Cashore B: **Trade-offs, co-benefits and safeguards: current debates on the breadth of REDD+**. *Curr. Opin. Environ. Sustain.* 2012, **4**:646–653.

7*. Murdiyarso D, Brockhaus M, Sunderlin WD, Verchot L: **Some lessons learned from the first generation of REDD+ activities**. *Curr. Opin. Environ. Sustain.* 2012, **4**:678–685.

8*. De Sassi C, Sunderlin WD, Sills EO, Duchelle AE, Ravikumar A, Resosudarmo IAP, Luttrell C, Joseph S, Herold M, Kweka D, et al.: **REDD+ on the ground: Global insights from local contexts**. In *REDD+ on the Ground: A Case Book of Subnational Initiatives Across the Globe*. Edited by Sills EO, Atmadja S, de Sassi C, Duchelle AE, Kweka D, Resosudarmo IAP, Sunderlin WD. Center for International Forestry Research; 2014:420–439.

9. Skutsch M, Turnhout E, Vijge MJ, Herold M, Wits T, den Besten JW, Balderas Torres A: **Options for a National Framework for Benefit Distribution and Their Relation to Community-Based and National REDD plus Monitoring**. *FORESTS* 2014, **5**:1596–1617.

10. Ziegler AD, Phelps J, Yuen JQ, Webb EL, Lawrence D, Fox JM, Bruun TB, Leisz SJ, Ryan CM, Dressler W, et al.: **Carbon outcomes of major land-cover transitions in SE Asia: great uncertainties and REDD plus policy implications**. *Glob. Chang. Biol.* 2012, **18**:3087–3099.

11. Joseph S: **Challenges to measure emission sources and sinks in REDD+ subnational initiatives**. In *In REDD+ on the Ground: A Case Book of Subnational Initiatives Across the Globe*. Edited by Sills EO, Atmadja S, de Sassi C, Duchelle AE, Kweka D, Resosudarmo IAP, Sunderlin WD. Center for International Forestry Research; 2014:22–23.

12. Joseph S, Herold M, Sunderlin WD, Verchot L V: **REDD plus readiness: early insights on monitoring, reporting and verification systems of project developers**. *Environ. Res. Lett.* 2013, **8**:034038.

13*. Romijn E, Herold M, Kooistra L, Murdiyarso D, Verchot L: **Assessing capacities of non-Annex I countries for national forest monitoring in the context of REDD+**. *Environ. Sci. Policy* 2012, **19-20**:33–48.

14*. Duchelle AE, Herold M, de Sassi C: **Monitoring REDD+ impacts: Cross scale coordination and interdisciplinary integration**. In *Sustainability Indicators in Practice*. Edited by Latawiec A, Agol D. De Gruyter/ Harvard University Press; in press

15. Chhatre A, Lakhanpal S, Larson AM, Nelson F, Ojha H, Rao J: **Social safeguards and co-benefits in REDD+: a review of the adjacent possible**. *Curr. Opin. Environ. Sustain.* 2012, **4**:654–660.

16*. Jagger P, Brockhaus M, Duchelle A, Gebara M, Lawlor K, Resosudarmo I, Sunderlin W: **Multi-Level Policy Dialogues, Processes, and Actions: Challenges and Opportunities for National REDD+ Safeguards Measurement, Reporting, and Verification (MRV)**. *Forests* 2014, **5**:2136–2162.

17. IPCC: **Agriculture, Forestry and Other Land Use**. In *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Edited by Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K. IGES; 2006.

18. Liverman D, Moran EF, Rindfuss R, Stern P: *People and pixels : linking remote sensing and social science*. National Academy Press; 1998.

19. Rindfuss R, Stern P: **Linking remote sensing and social science: The need and the challenges**. In *People and Pixels : Linking Remote Sensing and Social Science*. Edited by Liverman D, Moran EF, Rindfuss RR, Stern PC. National Academy Press; 1998:1–27.

20. Geoghegan J: **"Socializing the Pixel" and "Pixelizing the Social" in Land-Use and Land-Cover Change**. In *People and Pixels: Linking Remote Sensing and Social Science*. 1998:51–69.

21. Lausch A: **Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability**. *Ecol. Indic.* 2002, **2**:3–15.

22**. Hansen MC, Potapov P V, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman S V, Goetz SJ, Loveland TR, et al.: **High-resolution global maps of 21st-century forest cover change.** *Science.*. 2013, **342**:850–3.

Map global forest loss and gain from 2000 to 2012 using globally consistent record of forest change. They conclude that forest loss was highest in the tropics, where reduction in deforestation in Brazil was offset by increased deforestation in other countries

23. Tropek R, Sedláček O, Beck J, Keil P, Musilová Z, Símová I, Storch D: **Comment on "High-resolution global maps of 21st-century forest cover change".** *Science* 2014, **344**:981.

24. Bellot F-F, Bertram M, Navratil P, Siegert F, Dotzauer H: *The high-resolution global map of 21st-century forest cover change from the University of Maryland (" Hansen Map ") is hugely overestimating deforestation in Indonesia*. 2014.

25. Reimer F, Asner GP, Joseph S: **Advancing reference emission levels in subnational and national REDD+ initiatives: a CLASlite approach.** *Carbon Balance Manag.* 2015, **10**:5.

26. Hessel R, Reed MS, Geeson N, Ritsema CJ, van Lynden G, Karavitis CA, Schwilch G, Jetten V, Burger P, van der Werff Ten Bosch MJ, et al.: **From Framework to Action: The DESIRE Approach to Combat Desertification.** *Environ. Manage.* 2014, **54**:935–50.

27. Schwilch G, Bestelmeyer B, Bunning S, Critchley W, Herrick J, Kellner K, Liniger HP, Nachtergaele F, Ritsema CJ, Schuster B, et al.: **Experiences in monitoring and assessment of sustainable land management**. *L. Degrad. Dev.* 2011, **22**:214–225.

28. Fleskens L, Nainggolan D, Stringer LC: **An Exploration of Scenarios to Support Sustainable Land Management Using Integrated Environmental Socio-economic Models**. *Environ. Manage.* 2014, **54**:1005–1021.

29. Bohnet IC, Roebeling PC, Williams KJ, Holzworth D, van Grieken ME, Pert PL, Kroon FJ, Westcott D a., Brodie J: **Landscapes Toolkit: An integrated modelling framework to assist stakeholders in exploring options for sustainable landscape development**. *Landsc. Ecol.* 2011, **26**:1179–1198.

30. Kienast F, Frick J, Strien MJ Van, Hunziker M: **The Swiss Landscape Monitoring Program – A comprehensive indicator set to measure landscape change**. *Ecol. Modell.* 2015, doi:10.1016/j.ecolmodel.2014.08.008.

31*. Rodríguez-Loinaz G, Alday JG, Onaindia M: **Multiple ecosystem services landscape index: A tool for multifunctional landscapes conservation**. *J. Environ. Manage.* 2015, **147**:152–163.

32. Bedi T, Coudouel A, Simler K: *More than a pretty picture: using poverty maps to design better policies and interventions*. World Bank Publications; 2007.

33**. Gardner T, Ferreira J, Barlow J, Lees AC, Parry L, Guimarães IC, Berenguer E, Abramovay R, Aleixo A, Andretti C, et al.: **A social and ecological assessment of tropical land uses at multiple scales : the Sustainable Amazon Network**. *Phil Trans R Soc B* 2013, **368**:20120166.

A multidisciplinary research initiative involving more than 30 partner organizations working to assess both social and ecological dimensions of land-use sustain- ability in eastern Brazilian Amazonia: of great interest also for its multidisciplinary and integrated research design

34*. Gardner TA, Burgess ND, Aguilar-Amuchastegui N, Barlow J, Berenguer E, Clements T, Danielsen F, Ferreira J, Foden W, Kapos V, et al.: **A framework for integrating biodiversity concerns into national REDD+ programmes**. *Biol. Conserv.* 2012, **154**:61–71.

35. Holmes I, Potvin C: **Avoiding Re-Inventing the Wheel in a People-Centered Approach to REDD**. *Conserv. Biol.* 2014, **28**:1380–1393.

36**. Pratihast AK, Herold M, De Sy V, Murdiyarso D, Skutsch M: **Linking community-based and national REDD+ monitoring: a review of the potential**. *Carbon Manag.* 2014, **4**:91–104.

This article reviews some of the key issues regarding CBM and options to link CBM and national forest monitoring systems. It highlights the importance of local drivers of deforestation and degradation and, thus, the relevance of community involvement in REDD+ implementation and monitoring

37**. Bellfield H, Sabogal D, Goodman L, Leggett M: **Case Study Report: Community-Based Monitoring Systems for REDD+ in Guyana**. *Forests* 2015, **6**:133–156.

Outlines findings from a community MRV project with communities in the North Rupununi, Guyana; the study shows that a CBM approach can help in understanding local deforestation drivers and measuring carbon stocks; and for providing information on safeguards through social and environmental assessments, including the role of hand-held technology for up-scaling efforts. Provides one of the still rare examples of interdisciplinary CBM.

38*. Vergara-Asenjo G, Sharma D, Potvin C: **Engaging Stakeholders: Assessing Accuracy of Participatory Mapping of Land Cover in Panama**. *Conserv. Lett.* 2015, published online.

39**. Pratihast A, DeVries B, Avitabile V, de Bruin S, Kooistra L, Tekle M, Herold M: **Combining Satellite Data and Community-Based Observations for Forest Monitoring**. *Forests* 2014, **5**:2464–2489.

This article proposes a framework for integrating community-collected data with remote sensing in National Forest Monitoring Systems for REDD+ MRV. It compares CBM data to expert data quality, and highlights complementarity of locally collected and remote-sensed data.

40*. Boissiere M, Beaudoin G, Hofstee C, Rafanoharana S, Boissière M: **Participating in REDD plus Measurement, Reporting, and Verification (PMRV): Opportunities for Local People?** *FORESTS* 2014, **5**:1855–1878.

41. Gardner T a, Barlow J, Araujo IS, Avila-Pires TC, Bonaldo AB, Costa JE, Esposito MC, Ferreira L V, Hawes J, Hernandez MIM, et al.: **The cost-effectiveness of biodiversity surveys in tropical forests.** *Ecol. Lett.* 2008, **11**:139–50.

42**. Jenkins CN, Pimm SL, Joppa LN: **Global patterns of terrestrial vertebrate diversity and conservation.** *Proc. Natl. Acad. Sci. U. S. A.* 2013, **110**:E2602–10.

This article describes the efforts in mapping global priority areas using the latest data on mammals, amphibians, and birds at higher scale resolution, and conclude that priority areas for biodiversity conservation have a higher yet insufficient rate of protection globally. The database is available at www.biodiversitymapping.com

43. Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO: **The biodiversity of species and their rates of extinction, distribution, and protection.** *Science* 2014, **344**:1246752.

44. Thomas CD, Anderson BJ, Moilanen A, Eigenbrod F, Heinemeyer A, Quaife T, Roy DB, Gillings S, Armsworth PR, Gaston KJ: **Reconciling biodiversity and carbon conservation.** *Ecol. Lett.* 2013, **16 Suppl 1**:39–47.

45. Grussu G, Attorre F, Mollicone D, Dargusch P, Guillet A, Marchetti M: **Implementing REDD plus in Papua New Guinea: Can biodiversity indicators be effectively integrated in PNG's National Forest Inventory?** *PLANT Biosyst.* 2014, **148**:519–528.

Figure 1. The strength of the Stepwise system in explaining best practices, recommending methodological choices and provisioning data resources. The green zone shows all three components in the monitoring system are well developed to address the reporting requirements, grey zone point out limited guidance on methodological choices and provisioning of data, and the red zone indicate sparsely distributed best practices, methods and data.

Figure 2. Opportunities for disciplinary (color zones for carbon MRV, environmental and social monitoring) and scalar (parallel layers, from global, to national and local level moving outwards) integration for REDD+ monitoring. The colored concepts and arrows represent current and potential areas for cross-scale integration of monitoring within the corresponding disciplinary domain. Black arrows and concepts show opportunities for disciplinary integration. We propose that scalar integration can be achieved through the complementary use of fine- and coarse scale data, with local data collection used to calibrate, validate and update remote sensing data (for carbon) and spatially-explicit social and environmental data. Disciplinary integration can also be promoted at the local level. Experiences with community-based monitoring of social (e.g wellbeing, equity) and environmental outcomes (e.g biodiversity surveys, perception changes in ecosystem services) further than carbon monitoring (biomass surveys, degradation activities) remain limited but show great potential. We argue that human activity data provides the needed common ground for assessing interdisciplinary phenomena beyond land use and forest cover change. A major challenge remains in the coordination of upscaling these data between stakeholders with different focus and priorities at the national and international level.

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Towards integrated monitoring of REDD+

Abstract

Monitoring socioecological impacts of policy interventions aimed at changing land-use practices is a major challenge in sustainable development and conservation. Reducing emissions from deforestation and forest degradation (REDD+) intends to compensate local stakeholders for demonstrated carbon emission reduction and increased removals accounted for internationally, whilst promoting social and environmental benefits locally. Thus, monitoring REDD+ inherently requires the use of interdisciplinary data at different scales. Forest carbon monitoring, central to REDD+, is considerably advanced, yet the progress on social and environmental monitoring systems is uneven. We argue that scalar and interdisciplinary integration of REDD+ monitoring is crucial to uncover and understand trade-offs and synergies on which effectiveness, efficiency and equity of REDD+ may depend.

We review previous efforts in integrating environmental and social monitoring, as well as efforts specific to REDD+, and discuss how old and new knowledge can contribute towards integrated monitoring. We observe that there are many challenges, but strong advantages, in an integrated monitoring approach. The current emergence of diverging standards and methodologies with narrow focus can inform future integrative efforts but could, in the long run, hinder coherence in national processes. We conclude that recent technological advances open new opportunities to integrate information across scale and disciplines, leveraging and combining existing data with targeted additional measures. The application of mixed methods in data collection can foster integration, in particular from the local level upwards. However, this requires greater coordination at the higher levels to efficiently upscale multiple data streams. The unequal standpoint of carbon, social and environmental monitoring efforts provide a timely opportunity to promote integration, learn from advances in carbon monitoring, and build on existing and emerging platforms and tools that are locally to globally relevant.

Background

Reducing Emissions from Deforestation and forest Degradation plus enhancing forest carbon stocks (REDD+) has rapidly evolved from a climate change mitigation tool into a complex policy framework [1]. REDD+ now encompasses a broader view on forest conservation, enhancement of rural livelihoods through sustainable development and practices, while maintaining its original function of forest-based climate change mitigation. In particular, non-carbon outcomes (risks and co-benefits) have been at the forefront of the discussions on scope and breath of REDD+. The extent to which REDD+ should or should not be inclusive of further environmental [2*,3] or social objectives proposed [4,5], and how best to measure these multiple objectives, has become in itself a topic of discussion and research [1]. An initial focus on safeguarding social and environmental impacts of REDD+, embodied in the Cancun Agreements (Decision 1/CP.16) of the United Nations Framework Convention on Climate Change (UNFCCC), has more recently evolved into including non-carbon values as critical to both the legitimacy and effectiveness of REDD+ [6*]. This view was reinforced at the Conference of the Parties in Warsaw 2013 (COP19), with the decision for “incentivizing non-carbon benefits for the long-term sustainability of the implementation of the activities” and obliging countries to report on safeguards (Decision 1/CP.19).

This shift towards multiple objectives and increased complexity is therefore the result of a rich debate that accompanied the inception of REDD+, involving a wide range of stakeholders with different priorities and concerns. Research on early REDD+ activities has also demonstrated that REDD+ is inherently a “complex multilevel and multi-stakeholder process that tends to fulfil multiple goals beyond emission reduction” [6*]. Such conditions require inclusion of actors within and outside of the forest sector, and connections between local and global interests, which make REDD+ implementation challenging [7*,8*]. Importantly, many of these challenges are tightly linked to the ability to monitor and assess the impact of policies and ground-interventions over time to avoid unintended consequences. To monitor the impacts of REDD+, there must be clarity on what to measure, at what scale and effort, along with a clear pathway of reporting from local to international levels.

Advances in the development of systems for forest carbon monitoring elucidate the difficulties of linking local activities to carbon outcomes and including them in a seamless structure of reporting across levels [9]. Despite much financial and institutional investment and progress, a number of issues are still not fully overcome, from technical (e.g. detecting and quantifying small scale deforestation and degradation [10,11]) to differences in national capacity [11,12] and reporting objectives [13*,14*]. Similar challenges also burden social and environmental monitoring. For instance, the text related to the Cancun safeguards has been criticized for the lack of clear language and the binding development of performance indicators [15]. Yet, a balanced international guidance on how to measure and report on safeguards with respect for national sovereignty and minimizing transaction costs [16*] is needed. Developing scalable systems that satisfy the needs of stakeholders at each particular level, remains difficult.

As a result of the complexity of methods and technologies, compounded by competing agendas of the myriad of interest groups involved in REDD+, emerging monitoring efforts (such as third party standards) tend to focus on either carbon or non-carbon benefits and show limited integration across scales. A question arises on whether multiple, parallel and diverging monitoring choices will contribute to further isolate disciplinary camps and exacerbate scalar. Disciplinary and scale 'silos' present the core challenge in our ability to measure, understand and act upon processes interconnected in both dimensions. Integrated monitoring is essential for accurately assessing the trade-offs and synergies between effectiveness, efficiency and equity, understand methodological shortcomings and inform policy choices. While we recognize that focused, disciplinary approaches have contributed if not driven the REDD+ progress to date (e.g. carbon accounting), integration among carbon, social and environmental monitoring is needed to achieve more holistic outcomes. In this paper, we summarize the current key issues facing monitoring in REDD+ and discuss how integrated monitoring can be promoted by building on existing knowledge and emerging research.

Key data sources and gaps

In the UNFCCC framework, REDD+ emission reduction estimates are to be reported nationally to make countries eligible for performance-based payments. The UNFCCC recommends a step-wise approach for emission reduction assessments to allow flexibility in using available data (as starting point), improving capacities, and reducing uncertainties over time (moving up in different tiers of estimating carbon stock changes); a pathway that may vary depending on country circumstances [17].

The step-wise approach is a pragmatic solution to different national capacities and contexts, and is conceptually well formulated. However, its strength in terms of promoting best methodological practices, and provisioning data resources weakens as it moves to higher tiers (i.e. in the context of estimating carbon stock changes), as visualized in three color zones in Figure 1. For Tier 1 carbon stock data, default values are available for all countries, there are clear best practices and methods, and reporting back to the UNFCCC system is found to be less complicated (green zone). However, moving from Tier 1 to Tier 2, where data are collected within country, best practices are well documented, methodological choices are reasonably given, but data are limitedly available (grey zone). Tier 3 includes more detailed data on the relevant changes and process, where best practices are reasonably available, but methods and data are limited or often not available. Robust data is the basis for good reporting, but clear gaps exist in many developing countries [13*]; moreover, countries and other actors tend to shy away from taking on additional monitoring tasks in situations where key datasets are missing and basic capacities need to be established first.

[Figure 1]

The tiered model strictly relates to reporting of emission reductions, but the decreasing clarity on guidelines and practices with higher-order data is even more exacerbated for social and environmental monitoring. In principle, this situation underscores the difficulty in gaining detailed knowledge and yet maintaining a clear pathway for aggregated reporting. Additionally, the groups collecting data on carbon versus non-carbon outcomes of REDD+ are largely disconnected. For carbon monitoring, activity data and emission factors are most relevant. Data for social monitoring include rights, participation and livelihood benefits, and environmental monitoring requires data for biodiversity, soil, water and other ecosystem services. Scale- and discipline related challenges are therefore formidable; attempts for cross-scale and cross-disciplinary integration in REDD+ monitoring are, not surprisingly, largely absent. However, the requirements to build National Forest Monitoring Systems for many developing countries with current low capacity and structures in place, also presents a great opportunity to build on integration of activities and data for monitoring from the early stages.

Old challenges and new prospects for integrated monitoring

Integration of socioeconomic and biophysical information in spatially explicit, scalable manner to inform monitoring and implementation is a long standing challenge that predates REDD+. Since the 1990s, there has been an increasing acknowledgement that linking remote sensing science, typically applied to biophysical studies, and social science, can create synergies for understanding complex human-ecological systems. Remote sensing allows for cross-scale and time series analyses on socially relevant data [18]. Models combining remote sensing and ground-based social data can help to understand complex land-use change dynamics [19].

Nonetheless, the theory is sobered by the practical implications of combining two profoundly different scientific traditions. Variables in which social scientists are interested are not readily measurable from space; whilst remote sensing targets “where” a phenomena occurs, the social dimension is usually interested in “what” or “why” such phenomena occur, and may or may not be expressed as a function of space and place. Moreover, jointly modeling biophysical and socioeconomic variables is challenged by temporal lags and spatial-diffusion processes; the processes themselves can be buffered, amplified, inverted, or otherwise transformed before the resulting change in the landscape can be seen and measured [20]. The difficulty in linking individual decisions to emerging changes in land use and land cover [20] is particularly relevant to impact attribution of REDD+ interventions.

The following key issues outlined by Lausch *et al*. [21] summarize the main obstacles:

- standardized data processing techniques, which are vital for the spatial and temporal comparability of results;
- the selection of a manageable set of indicators which embraces the structural properties of landscapes; and
- the choice of appropriate spatial units which allow for an integration of indicators (which tend to relate to cross-border phenomena) and socio-economic indicators (which are usually available for administrative entities or areas).

Recent research, both within and outside REDD+, have drastically improved our ability to tackle these challenges through advances in technology and methods. A recently published global map of forest cover change, also referred to as the Hansen data [22**] is a staggering example of recent progress, despite critiques for missing important local context related details [23–25]. The World Resources Institute’s Forest Watch (http://www.globalforestwatch.org), built on a related web-based platform, integrated further information layers beyond forest cover: it allows spatial registration of non-spatial data, on a user-friendly interface accessible to non-spatial analysts. Such products are a testimony to the possibility of collecting and presenting information free of scale constraints, albeit also underlining the challenges in maintaining fine scale accuracy. Similarly, there is a recent emergence of several toolkits aiming at facilitating managing and policy making at jurisdictional or landscape scale, through the spatially-explicit representation of multidisciplinary data [26–31*]. Typically, toolkits to support decision making differ in their specific data requirements with respect to integrated monitoring over time. However, they do provide progress and insights in how scale-robust indicators can be developed in an integrated way.

For several years, the Food and Agriculture Organization of the United Nations (FAO) has also advanced integrated socioeconomic and biophysical data collection strategies through National Forest Inventories (NFIs) and National Forestry Monitoring Assessments (NFMAs). These initiatives focus on monitoring the state and changes of forests, and on their social, economic and environmental functions. Further, they aim to build national capacities and harmonize methods, forest related definitions and classification systems among countries. These approaches have been deployed in countries across the tropics, and have produced mixed biophysical and socioeconomic data that are directly relevant to REDD+ monitoring. The World Bank's Poverty Mapping provides a spatially explicit combination of census and household-level data towards informing policies that are better tailored to local conditions [32], leveraging secondary and primary datasets to achieve cross-scale integration of social monitoring. A variety of national-level secondary datasets are publicly available, such as the World Bank's Living Standards Measurement and various demographic and health surveys, data that can be complemented by primary data collection in the field to develop and test indicators for cross-scale aggregated reporting in the context of REDD+.

Promising innovation also comes from the Sustainable Amazon Network initiative [33**], which is developing tools to achieve cross-scale, multidisciplinary assessment of tropical land use change; the study aims to quantify ecological consequences of forest clearance, forest degradation and exploitation, and agricultural change at different spatial scales. The authors argue that research has often concentrated either on very broad scale (i.e the Amazon basin), which often depends upon very coarse-scale data, or on detailed work on a few intensively studied research sites, which misses the variability in environmental and land-use gradients that drive much social and ecological change. As an alternative, the authors propose that more work is needed at the 'mesoscale' level, to respect "the importance of both local (farm) and regional (state and biome) processes and objectives in a way that work focused on either smaller or larger scales cannot readily achieve" [33**, p. 5].

Building effective multi-sector and interdisciplinary research and or monitoring programmes at large spatial scales remains one of the most difficult challenges facing sustainability science. However, existing knowledge shows that the application of mixed methods at multiple scales in social and environmental monitoring can lead more accurate understanding of cross-scale processes, and provide entry points for disciplinary integration that remains largely unexplored. REDD+ is currently playing a key role in the theoretical and practical advances in this field. Building on old and new available knowledge [34*,35], REDD+ can harness opportunities for further progress that lie within reach to achieve integrated monitoring (Figure 2).

Integration across scales and disciplines in REDD+ monitoring

[Figure 2].

Innovative approaches to tackling scale issues can also be found in recent, REDD+ specific efforts. The experience of carbon accounting of specific REDD+ implementation activities suggests that reporting needs to take a bottom-up approach where local level emission reduction estimates are assimilated and verified at the subnational level, further fed into the national system where they are verified and reported to the UNFCCC internationally. This nesting and verification is important to make sure that there are no omissions, leakage, double counting and overlapping claims over carbon rights occurring at any scale of the jurisdictions and consistency with national greenhouse gas (GHG) inventory.

As part of this recognized necessity of locally driven, bottom-up approach, community-based MRV 's potential has recently been explored in a number of initiatives [36**]. Community-based monitoring (CBM) is proving useful for ground-truthing of remote-sensed data. In Guyana, such a CBM effort has helped uncover large amounts of false-positives (areas defined as deforested when forest is still standing) from LANDSAT data [37**]. In a similar case in Panama researchers found discrepancies between fine-scale Rapideye satellite imagery and data from the field [38*]. Conversely, remote sensing was more accurate in characterizing specific land cover types such as short fallows. In another study, Pratihast *et al.* [39**] suggest that combined CBM and remote sensing is proving an efficient way to gain detailed knowledge at different scales. Remote sensing retains a primary role in detecting where (location) and how much (area) change is happening, whilst community-collected data can best inform the timing and drivers of degradation, therefore providing resolution on spatio-temporal lags. These studies demonstrate how scalar data integration, in particular local data feeding into large scale data acquisition, can improve the overall quality by building on complementarity of their different strengths. Data on human activities that affect forests are useful for both biophysical and socio-economic monitoring, and therefore amenable to cooperation and deployment of mixed-approaches. The authors also underline that well-trained community members, supported by advancing hand-held technology, can cost-effectively achieve data quality comparable to expert observation.

Community based monitoring also highlights innovations in integrated monitoring of environmental and social co-benefits, with initiatives that rely on local stakeholders' involvement to explicitly link socioeconomic and biophysical data collection. In a CBM project in Guyana, community members were trained to collect data on 'co-benefits', including forest product harvests and community well-being, alongside ground-truthing spatial information [37**]. Boissiere *et al*. [40*] describe an innovative community-based strategy that combines remote sensing, ground-truthing of biophysical data, socio-economic data collection, and also multilevel governance research - an interdisciplinary approach to monitoring across scales that deserves further attention. In principle however, scaling up of environmental and socioeconomic information can follow the same route of carbon MRV: local data collection, although not always simple to achieve [41], can complement and improve larger scale datasets. Similarly as global maps of forest cover change, comprehensive spatial data on global biodiversity distribution and threats are becoming available [42**,43], accessible online (www.biodiversitymapping.org) and there are clear connections between these products. Datasets measuring changes in forest carbon emissions can be used to assess changes in biodiversity, water and soil resources. Integration of carbon and environmental objectives at the design stage, can help modulate and optimize the balance between carbon and co-benefits [44][45], help clarify monitoring needs and improve project performance.

Environmental data is typically not tied to political and jurisdictional borders; as a consequence, these data are somewhat less bound to national ownership where capacity is low. They are more reliant on high-level frameworks, in particular the Convention on Biological Diversity and the Intergovernmental Platform on Biodiversity and Ecosystem Services. A three-tiered approach reflecting different national capacities, similarly to carbon, has also been proposed for integrating biodiversity concerns in REDD+, further calling for greater coordination between UNFCCC and IPCC [34*]. By contrast, socioeconomic monitoring is often tightly linked to sub-national jurisdictions and ultimately national borders. Integration between socioeconomic and environmental monitoring therefore needs to resolve issues of potentially divergent boundaries of analysis.

Adopting a stepwise approach for environmental monitoring, dovetailing with socioeconomic reporting at the national scale could provide the common base needed. As exemplified by Bellfield et al. [37**], local level data collection can serve as starting point for integrating different disciplines, but can only become effective through greater coordination on the upscaling of these data streams between the national and international level. While the rules for estimation and accounting can vary for the different objectives and scales, the same data can often serve multiple objectives. The diversity in integrated monitoring standards and accounting rules are, thus, much less related to variability in underlying data than in rules to analyze and assess them. The combination of locally-led field measurements, remote sensing and spatial registration of non-spatial data holds great potential for achieving scalar and disciplinary integration, but requires a common language and common ground (in terms of data), and the development of performance indicators that are: i) easy to understand; ii) applicable at multiple scales; iii) applicable to any location; iv) efficient to measure and monitor; v) sustainable in providing data; and vi) able to be improved over time [14*].

Conclusions:

In this paper, we describe the challenges and opportunities for implementing multi-scalar and interdisciplinary monitoring for REDD+ activities. Integrated monitoring is needed to understand the trade-offs and synergies among these multiple objectives of REDD+, as these cannot be captured at just one scale, or with just one methodology. Ultimately, better understanding these trade-offs and synergies is critical to reducing emissions whilst meeting other environmental and social objectives effectively, efficiently, and equitably.

The proliferation of agenda- or topic-specific monitoring standards reflects both the need for experimentation and interpretation within existing high-level frameworks. While this diversity provides a rich set of options and experiences to learn from, we urge caution around their congruence with national objectives. We recognize that it will not always be efficient or even desirable to integrate scale and discipline, and that the degree of integration that is appropriate depends on the specific objectives of the monitoring effort. However, as monitoring needs to move towards national ownership, the most context-appropriate lessons from these standards must be incorporated into unified and integrated national monitoring systems. REDD+ is emerging in a world of "big data", with notable efforts to create global and/or pan-tropical interdisciplinary datasets, and technological progress supporting efforts to better understand both biophysical processes and human-environment interactions. However, there is a still a common disconnect between the widely-available large area data on forest change derived from remote sensing, and the fine-scale data needed to monitor forest degradation processes and changes in social and environmental conditions. Integrated monitoring needs to take advantage of the multiple data streams (i.e. field measurements and remote sensing data analysis, or global datasets for national-level use, national inventories, etc.), and use them for inter-calibration and validation.

Research needs to promote conditions where integration is clearly an opportunity rather than an additional burden. Further work is needed to achieve complementarity of data collected at different scales and through different methods. Analysis of different monitoring systems needs to clarify how synergies between coarse and fine scale data can be realized to capture local processes and outcomes for aggregated reporting at broader scales. In this context, the potential for community-based assessments of joint social and environmental conditions to foster disciplinary integration remains largely unexplored.

As the international community demands tangible measures to stabilize the climate system, countries need to produce transparent, accurate and comparable estimates of emission reductions. As these objectives must be achieved while respecting social and environmental values over time, integrated monitoring for climate change mitigation strategies impact across jurisdictions for REDD+ and beyond is a pressing necessity.

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1. Visseren-Hamakers IJ, Gupta A, Herold M, Peña-Claros M, Vijge MJ: **Will REDD+ work? The need for interdisciplinary research to address key challenges**. *Curr. Opin. Environ. Sustain.* 2012, **4**:590–596.

2*. Venter O, Hovani L, Bode M, Possingham H: **Acting Optimally for Biodiversity in a World Obsessed with REDD+**. *Conserv. Lett.* 2013, **6**:410–417.

3. Barlow J, Parry L, Gardner TA, Ferreira J, Aragao LEOC, Carmenta R, Berenguer E, Vieira ICG, Souza C, Cochrane MA: **The critical importance of considering fire in REDD+ programs**. *Biol. Conserv.* 2012, **154**:1–8.

4. Agrawal A, Nepstad D, Chhatre A: **Reducing Emissions from Deforestation and Forest Degradation**. *Annu. Rev. Environ. Resour.* 2011, **36**:373–396.

5. Ghazoul J, Butler RA, Mateo-Vega J, Koh LP: **REDD: a reckoning of environment and development implications**. *TRENDS Ecol. Evol.* 2010, **25**:396–402.

6*. Visseren-Hamakers IJ, McDermott C, Vijge MJ, Cashore B: **Trade-offs, co-benefits and safeguards: current debates on the breadth of REDD+**. *Curr. Opin. Environ. Sustain.* 2012, **4**:646–653.

7*. Murdiyarso D, Brockhaus M, Sunderlin WD, Verchot L: **Some lessons learned from the first generation of REDD+ activities**. *Curr. Opin. Environ. Sustain.* 2012, **4**:678–685.

8*. De Sassi C, Sunderlin WD, Sills EO, Duchelle AE, Ravikumar A, Resosudarmo IAP, Luttrell C, Joseph S, Herold M, Kweka D, et al.: **REDD+ on the ground: Global insights from local contexts**. In *REDD+ on the Ground: A Case Book of Subnational Initiatives Across the Globe*. Edited by Sills EO, Atmadja S, de Sassi C, Duchelle AE, Kweka D, Resosudarmo IAP, Sunderlin WD. Center for International Forestry Research; 2014:420–439.

9. Skutsch M, Turnhout E, Vijge MJ, Herold M, Wits T, den Besten JW, Balderas Torres A: **Options for a National Framework for Benefit Distribution and Their Relation to Community-Based and National REDD plus Monitoring**. *FORESTS* 2014, **5**:1596–1617.

10. Ziegler AD, Phelps J, Yuen JQ, Webb EL, Lawrence D, Fox JM, Bruun TB, Leisz SJ, Ryan CM, Dressler W, et al.: **Carbon outcomes of major land-cover transitions in SE Asia: great uncertainties and REDD plus policy implications**. *Glob. Chang. Biol.* 2012, **18**:3087–3099.

11. Joseph S: **Challenges to measure emission sources and sinks in REDD+ subnational initiatives**. In *In REDD+ on the Ground: A Case Book of Subnational Initiatives Across the Globe*. Edited by Sills EO, Atmadja S, de Sassi C, Duchelle AE, Kweka D, Resosudarmo IAP, Sunderlin WD. Center for International Forestry Research; 2014:22–23.

12. Joseph S, Herold M, Sunderlin WD, Verchot L V: **REDD plus readiness: early insights on monitoring, reporting and verification systems of project developers**. *Environ. Res. Lett.* 2013, **8**:034038.

13*. Romijn E, Herold M, Kooistra L, Murdiyarso D, Verchot L: **Assessing capacities of non-Annex I countries for national forest monitoring in the context of REDD+**. *Environ. Sci. Policy* 2012, **19-20**:33–48.

14*. Duchelle AE, Herold M, de Sassi C: **Monitoring REDD+ impacts: Cross scale coordination and interdisciplinary integration**. In *Sustainability Indicators in Practice*. Edited by Latawiec A, Agol D. De Gruyter/ Harvard University Press; in press

15. Chhatre A, Lakhanpal S, Larson AM, Nelson F, Ojha H, Rao J: **Social safeguards and co-benefits in REDD+: a review of the adjacent possible**. *Curr. Opin. Environ. Sustain.* 2012, **4**:654–660.

16*. Jagger P, Brockhaus M, Duchelle A, Gebara M, Lawlor K, Resosudarmo I, Sunderlin W: **Multi-Level Policy Dialogues, Processes, and Actions: Challenges and Opportunities for National REDD+ Safeguards Measurement, Reporting, and Verification (MRV)**. *Forests* 2014, **5**:2136–2162.

17. IPCC: **Agriculture, Forestry and Other Land Use**. In *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Edited by Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K. IGES; 2006.

18. Liverman D, Moran EF, Rindfuss R, Stern P: *People and pixels : linking remote sensing and social science*. National Academy Press; 1998.

19. Rindfuss R, Stern P: **Linking remote sensing and social science: The need and the challenges**. In *People and Pixels : Linking Remote Sensing and Social Science*. Edited by Liverman D, Moran EF, Rindfuss RR, Stern PC. National Academy Press; 1998:1–27.

20. Geoghegan J: **“Socializing the Pixel” and “Pixelizing the Social” in Land-Use and Land-Cover Change**. In *People and Pixels: Linking Remote Sensing and Social Science*. 1998:51–69.

21. Lausch A: **Applicability of landscape metrics for the monitoring of landscape change: issues of scale, resolution and interpretability**. *Ecol. Indic.* 2002, **2**:3–15.

22**. Hansen MC, Potapov P V, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman S V, Goetz SJ, Loveland TR, et al.: **High-resolution global maps of 21st-century forest cover change.** *Science.*. 2013, **342**:850–3.

Map global forest loss and gain from 2000 to 2012 using globally consistent record of forest change. They conclude that forest loss was highest in the tropics, where reduction in deforestation in Brazil was offset by increased deforestation in other countries

23. Tropek R, Sedláček O, Beck J, Keil P, Musilová Z, Símová I, Storch D: **Comment on “High-resolution global maps of 21st-century forest cover change”.** *Science* 2014, **344**:981.

24. Bellot F-F, Bertram M, Navratil P, Siegert F, Dotzauer H: *The high-resolution global map of 21st-century forest cover change from the University of Maryland (“ Hansen Map ”) is hugely overestimating deforestation in Indonesia*. 2014.

25. Reimer F, Asner GP, Joseph S: **Advancing reference emission levels in subnational and national REDD+ initiatives: a CLASlite approach.** *Carbon Balance Manag.* 2015, **10**:5.

26. Hessel R, Reed MS, Geeson N, Ritsema CJ, van Lynden G, Karavitis CA, Schwilch G, Jetten V, Burger P, van der Werff Ten Bosch MJ, et al.: **From Framework to Action: The DESIRE Approach to Combat Desertification.** *Environ. Manage.* 2014, **54**:935–50.

27. Schwilch G, Bestelmeyer B, Bunning S, Critchley W, Herrick J, Kellner K, Liniger HP, Nachtergaele F, Ritsema CJ, Schuster B, et al.: **Experiences in monitoring and assessment of sustainable land management**. *L. Degrad. Dev.* 2011, **22**:214–225.

28. Fleskens L, Nainggolan D, Stringer LC: **An Exploration of Scenarios to Support Sustainable Land Management Using Integrated Environmental Socio-economic Models**. *Environ. Manage.* 2014, **54**:1005–1021.

29. Bohnet IC, Roebeling PC, Williams KJ, Holzworth D, van Grieken ME, Pert PL, Kroon FJ, Westcott D a., Brodie J: **Landscapes Toolkit: An integrated modelling framework to assist stakeholders in exploring options for sustainable landscape development**. *Landsc. Ecol.* 2011, **26**:1179–1198.

30. Kienast F, Frick J, Strien MJ Van, Hunziker M: **The Swiss Landscape Monitoring Program – A comprehensive indicator set to measure landscape change**. *Ecol. Modell.* 2015, doi:10.1016/j.ecolmodel.2014.08.008.

31*. Rodríguez-Loinaz G, Alday JG, Onaindia M: **Multiple ecosystem services landscape index: A tool for multifunctional landscapes conservation**. *J. Environ. Manage.* 2015, **147**:152–163.

32. Bedi T, Coudouel A, Simler K: *More than a pretty picture: using poverty maps to design better policies and interventions*. World Bank Publications; 2007.

33**. Gardner T, Ferreira J, Barlow J, Lees AC, Parry L, Guimarães IC, Berenguer E, Abramovay R, Aleixo A, Andretti C, et al.: **A social and ecological assessment of tropical land uses at multiple scales : the Sustainable Amazon Network**. *Phil Trans R Soc B* 2013, **368**:20120166.

A multidisciplinary research initiative involving more than 30 partner organizations working to assess both social and ecological dimensions of land-use sustain- ability in eastern Brazilian Amazonia: of great interest also for its multidisciplinary and integrated research design

34*. Gardner TA, Burgess ND, Aguilar-Amuchastegui N, Barlow J, Berenguer E, Clements T, Danielsen F, Ferreira J, Foden W, Kapos V, et al.: **A framework for integrating biodiversity concerns into national REDD+ programmes**. *Biol. Conserv.* 2012, **154**:61–71.

35. Holmes I, Potvin C: **Avoiding Re-Inventing the Wheel in a People-Centered Approach to REDD**. *Conserv. Biol.* 2014, **28**:1380–1393.

36**. Pratihast AK, Herold M, De Sy V, Murdiyarso D, Skutsch M: **Linking community-based and national REDD+ monitoring: a review of the potential**. *Carbon Manag.* 2014, **4**:91–104.

This article reviews some of the key issues regarding CBM and options to link CBM and national forest monitoring systems. It highlights the importance of local drivers of deforestation and degradation and, thus, the relevance of community involvement in REDD+ implementation and monitoring

37**. Bellfield H, Sabogal D, Goodman L, Leggett M: **Case Study Report: Community-Based Monitoring Systems for REDD+ in Guyana**. *Forests* 2015, **6**:133–156.

Outlines findings from a community MRV project with communities in the North Rupununi, Guyana; the study shows that a CBM approach can help in understanding local deforestation drivers and measuring carbon stocks; and for providing information on safeguards through social and environmental assessments, including the role of hand-held technology for up-scaling efforts. Provides one of the still rare examples of interdisciplinary CBM.

38*. Vergara-Asenjo G, Sharma D, Potvin C: **Engaging Stakeholders: Assessing Accuracy of Participatory Mapping of Land Cover in Panama**. *Conserv. Lett.* 2015, published online.

39**. Pratihast A, DeVries B, Avitabile V, de Bruin S, Kooistra L, Tekle M, Herold M: **Combining Satellite Data and Community-Based Observations for Forest Monitoring**. *Forests* 2014, **5**:2464–2489.

This article proposes a framework for integrating community-collected data with remote sensing in National Forest Monitoring Systems for REDD+ MRV. It compares CBM data to expert data quality, and highlights complementarity of locally collected and remote-sensed data.

40*. Boissiere M, Beaudoin G, Hofstee C, Rafanoharana S, Boissière M: **Participating in REDD plus Measurement, Reporting, and Verification (PMRV): Opportunities for Local People?** *FORESTS* 2014, **5**:1855–1878.

41. Gardner T a, Barlow J, Araujo IS, Avila-Pires TC, Bonaldo AB, Costa JE, Esposito MC, Ferreira L V, Hawes J, Hernandez MIM, et al.: **The cost-effectiveness of biodiversity surveys in tropical forests.** *Ecol. Lett.* 2008, **11**:139–50.

42**. Jenkins CN, Pimm SL, Joppa LN: **Global patterns of terrestrial vertebrate diversity and conservation.** *Proc. Natl. Acad. Sci. U. S. A.* 2013, **110**:E2602–10.

This article describes the efforts in mapping global priority areas using the latest data on mammals, amphibians, and birds at higher scale resolution, and conclude that priority areas for biodiversity conservation have a higher yet insufficient rate of protection globally. The database is available at www.biodiversitymapping.com

43. Pimm SL, Jenkins CN, Abell R, Brooks TM, Gittleman JL, Joppa LN, Raven PH, Roberts CM, Sexton JO: **The biodiversity of species and their rates of extinction, distribution, and protection.** *Science* 2014, **344**:1246752.

44. Thomas CD, Anderson BJ, Moilanen A, Eigenbrod F, Heinemeyer A, Quaife T, Roy DB, Gillings S, Armsworth PR, Gaston KJ: **Reconciling biodiversity and carbon conservation.** *Ecol. Lett.* 2013, **16 Suppl 1**:39–47.

45. Grussu G, Attorre F, Mollicone D, Dargusch P, Guillet A, Marchetti M: **Implementing REDD plus in Papua New Guinea: Can biodiversity indicators be effectively integrated in PNG's National Forest Inventory?** *PLANT Biosyst.* 2014, **148**:519–528.

Figure 1. The strength of the Stepwise system in explaining best practices, recommending methodological choices and provisioning data resources. The green zone shows all three components in the monitoring system are well developed to address the reporting requirements, grey zone point out limited guidance on methodological choices and provisioning of data, and the red zone indicate sparsely distributed best practices, methods and data.

Figure 2. Opportunities for disciplinary (color zones for carbon MRV, environmental and social monitoring) and scalar (parallel layers, from global, to national and local level moving outwards) integration for REDD+ monitoring. The colored concepts and arrows represent current and potential areas for cross-scale integration of monitoring within the corresponding disciplinary domain. Black arrows and concepts show opportunities for disciplinary integration. We propose that scalar integration can be achieved through the complementary use of fine- and coarse scale data, with local data collection used to calibrate, validate and update remote sensing data (for carbon) and spatially-explicit social and environmental data. Disciplinary integration can also be promoted at the local level. Experiences with community-based monitoring of social (e.g wellbeing, equity) and environmental outcomes (e.g biodiversity surveys, perception changes in ecosystem services) further than carbon monitoring (biomass surveys, degradation activities) remain limited but show great potential. We argue that human activity data provides the needed common ground for assessing interdisciplinary phenomena beyond land use and forest cover change. A major challenge remains in the coordination of upscaling these data between stakeholders with different focus and priorities at the national and international level.

Figure
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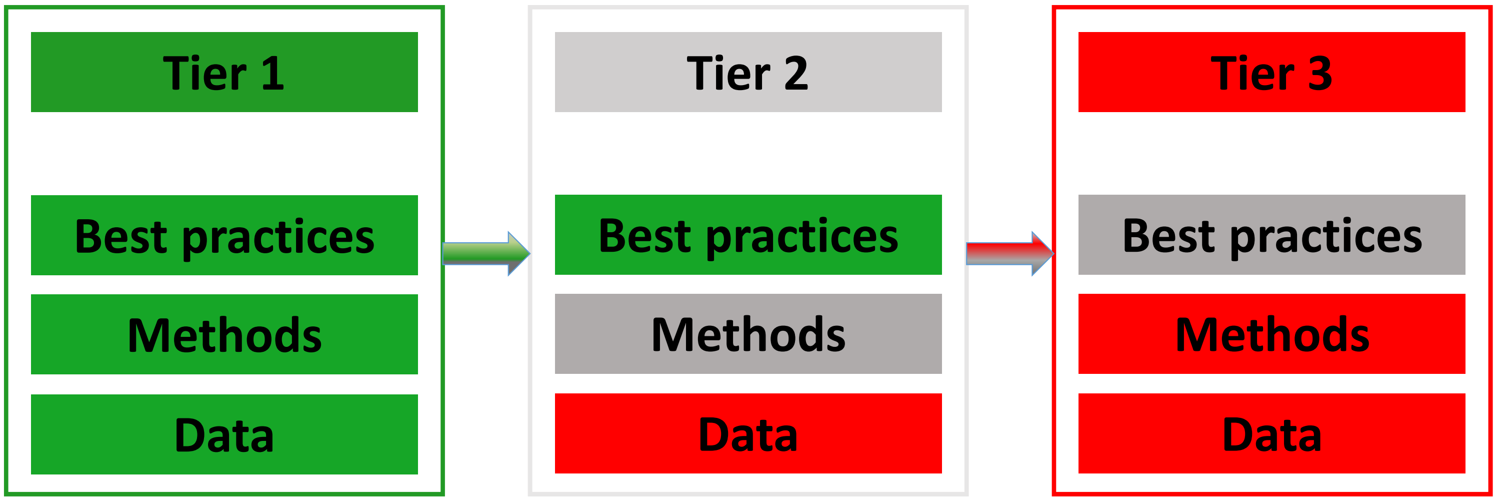

Figure 2

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