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Opinion Article

Biodiversity monitoring protocols for REDD+: can a one-size-fits-all approach really work?

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Abstract
Development of a standard monitoring protocol for assessing the impacts of REDD+ (Reduced Emissions from Deforestation and Degradation) projects on biodiversity is desirable. Drawing on the conservation literature and our personal experience, we review whether such a one-size-fits-all approach is justifiable on scientific and practical grounds. We conclude that achieving a model biodiversity monitoring protocol suitable for use in all potential REDD+ sites is probably an unrealistic objective, owing to the huge differences among the world's forests in terms of structure, species composition, ecological interactions and ecosystem services provided. Moreover, to provide useful feedback for conservation managers, ecological monitoring programmes must be designed around a project's conservation goals, which will vary from project to project, owing to these differences in forest ecology and human threats faced. Thus, site-specific biodiversity monitoring programmes are needed. No single monitoring method is likely to be optimal, or even suitable for use, in all REDD+ forests. Instead, we suggest that a standard approach be adopted, in which ecological monitoring research is (i) designed to reflect a project's biodiversity conservation goals; (ii) based upon scientifically-tractable, policy-relevant questions regarding the impacts of management interventions on the ecosystem; (iii) founded on detailed knowledge of the habitat type in question; (iv) includes monitoring of a number of indicators, as appropriate to the project; and (v) defines appropriate reference/baseline conditions against which progress can be assessed.

Keywords: Reduced Emissions from Deforestation and Degradation; REDD+; forest; biodiversity monitoring; biodiversity benefits.

Resumen
La elaboración de un protocolo estándar de monitoreo para evaluar los impactos de los proyectos de REDD + (Reducción de Emisiones por Deforestación y Degradación) sobre la biodiversidad es una acción conveniente. Basándose en la literatura de la conservación y nuestra experiencia personal, se revisa si el enfoque de *modelo único* es justificable en el terreno científico y práctico. Llegamos a la conclusión de que lograr un modelo de protocolo de monitoreo de la biodiversidad adecuado para su uso en todos los sitios potenciales de REDD + es probablemente un objetivo poco realista, debido a las enormes diferencias entre los bosques del mundo en términos de estructura, de composición de especies, de interacciones ecológicas y de los servicios ambientales proporcionados. Por otra parte, para proporcionar información útil para los administradores de conservación, los programas de monitoreo ecológico deben ser diseñados en torno a los objetivos de conservación de un proyecto, que pueden variar de un bosque a otro, debido a las diferencias ecológicas y a las amenazas humanas a las que se enfrentan. Por lo tanto, programas de monitoreo locales de la biodiversidad son necesarios. No existe un método único de monitoreo óptimo o adecuado aplicable en todos los bosques de REDD +. En su lugar, se sugiere adoptar un enfoque del modelo en el que la investigación del monitoreo ecológico sea (i) diseñada para reflejar los objetivos de un proyecto de conservación de la biodiversidad; (ii) este basada en preguntas científicamente manejables y políticamente relevantes en relación a los impactos de las intervenciones de gestión de los ecosistemas; (iii) este fundada en el conocimiento detallado de los bosques en cuestión; (iv) que incluya el monitoreo de una serie de indicadores apropiados al proyecto; y (v) que defina las condiciones de referencia adecuadas con las cuales se evaluará el progreso.

Palabras clave: Reducción de Emisiones de la Deforestación y la Degradación; REDD +; bosque; monitoreo de la biodiversidad; beneficios de la biodiversidad.

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1. Introduction

Owing to the large amounts of carbon stored in forests and their diverse biological communities, the development of forest protection initiatives through Reduced Emissions from Deforestation and Degradation (REDD+) projects offers high hopes for biodiversity conservation, as a "co-benefit" of protecting forests to reduce carbon emissions [1-3]. Although the anticipated impact of REDD+ on biodiversity conservation in most forests is positive, such an impact cannot be guaranteed. Indeed, the impact of REDD+ on biodiversity could potentially be negative if low-carbon, high-biodiversity forests are replaced with high-carbon, low-biodiversity forests; or protection of high-carbon forest in one area leads to displacement of threats to other, more biodiverse, forests [3-5]. Thus, biodiversity monitoring programmes are clearly needed to accompany REDD+ and ensure that the impacts of emission reduction activities on biodiversity are positive, rather than negative [6-8].

In a recent commentary in this journal, Waldon *et al.* [9] call for standardised protocols for REDD+ biodiversity monitoring, given the current paucity of guidance materials and need for scientific rigour. These authors suggest that two techniques – camera trapping for large mammals and acoustic monitoring for bats – meet the criteria for a model biodiversity monitoring protocol for REDD+. They further suggest that such a model protocol should: (i) monitor changes and trends in populations of key taxa, which should serve as indicators of habitat quality and disturbance; (ii) use methods that are repeatable, minimally susceptible to observer bias, and achievable with minimal training and equipment; (iii) be useful in many environments; (iv) ensure statistical validity for detecting changes of a pre-determined scale; and (v) be cost effective compared to other methods. These aims are common to many monitoring efforts and in recent years have been the focus of the Tropical Ecology, Assessment and Monitoring initiative (TEAM; www.teamnetwork.org) [10], which has developed protocols that can be used to compare forested sites and scaled up to monitor global trends in tropical biodiversity. Here, we review whether the adoption of a one-size-fits-all approach of the type suggested by Waldon *et al.* [9] for ground-based (i.e. "Tier 3" [8]) biodiversity assessment of individual REDD+ projects is justifiable on scientific and practical grounds, and offer suggestions for a more refined approach to biodiversity monitoring for REDD+.

2. Camera trapping for large mammals and acoustic surveying for bats as 'model' biodiversity monitoring protocols

Camera traps

The advantages of camera traps as a model protocol are that the technology is well tested in a wide variety of forest ecosystems; methods enable the detection of cryptic species that are often globally or locally threatened; individual animals can often be identified, allowing generation of density estimates; established tools exist to facilitate data storage and analysis; units can operate 24-7 for extended periods, allowing collection of large amounts of data; the method is non-invasive, minimally biased and provides archivable data; and the images produced often have educational or promotional value [9, 11-13]. While we concur that these advantages make camera trapping a potentially useful biodiversity monitoring tool for REDD+, a number of considerations and disadvantages warrant further discussion.

Most importantly, vertebrates, particularly large mammals -- the frequent focus of camera trapping surveys -- breed relatively slowly, are highly mobile between areas, frequently show inconsistent or delayed responses to disturbance, and are often subject to additional specific threats, with the result that they are typically considered to be poor ecological disturbance indicators and responses may occur too late for proactive management [14-17]. For example, many populations of large cats, such as tigers (*Panthera tigris*), are threatened by hunting – both directly for body parts and indirectly through hunting of their prey base for bushmeat – and by habitat loss [18, 19], thereby reducing their utility as an indicator of ecological disturbance or the general 'biodiversity value' of a forest. Other felid species face similar hunting threats [20, 21], and comparable problems also exist with other large-bodied mammal species, such as primates. Monitoring of these charismatic groups is frequently still highly desirable, however, as they are often the primary conservation focus in an area and serve an important role as flagship species, helping attract highly valuable funding and publicity to projects.

Furthermore, the effectiveness of camera traps in different forest types is highly dependent on study design. Key issues discussed by Waldon *et al.* [9] include the number of cameras needed, the area of forest to be covered, the distance needed between cameras, data analysis and the need for extended survey periods to obtain accurate density estimates (minimum 3-6 months; higher if focussing on wide-ranging mega-fauna) [11-13, 22, 23]. For example, a total 704 camera-trap nights (or 4 weeks, if using 24 camera traps) were required to capture the first image of a clouded leopard (*Neofelis diardi*) in the carbon-rich peat forests of Sabangau, Indonesian Borneo [11]. Flat-headed (*Prionailurus planiceps*) and marbled cats (*Pardofelis marmorata*) were only detected after 3,498 and 5,423 camera-trap nights (or 21 and 32 weeks), respectively [11]. These time frames may not be feasible within the demands of a REDD+ project, with the result that either the number of camera traps used (and, hence, expense) would need to be dramatically increased, or alternative monitoring methods will need to be considered. Clearly, the lower the density of target species, the less cost efficient the method becomes.

Of further consideration are the operation requirements and costs of running a camera-trapping programme, which are not discussed by Waldon *et al.* [9]. For example, OuTrop's long-term camera trapping project in Sabangau [11, 24] currently employs 24 continually-operational units. Additional expenses on this project include twice-monthly battery replacements; salaries for field staff to replace the batteries and download images; repairing and replacing broken units (5-10 units require repairing or replacing each year); and computers, memory cards and memory card readers to download and store images. Although these expenses amount to a total additional annual cost of ~USD 2,000, associated scientific salary costs can be tens of thousands of dollars, if foreign expertise/consultants are required for interpreting the images and analysing data. Thus, while camera trapping may appear cost effective in many situations, it may not be the most cost-effective method for all REDD+ projects.

We therefore suggest that camera trapping may be useful for inclusion *as part of* a REDD+ biodiversity monitoring programme, particularly where capture rates of target species are high, costs are relatively low, species being studied are known to respond consistently and rapidly to changes in habitat condition, and suitable flagship conservation species exist that can be used to help raise the profile of a project. Despite this potential utility, we further suggest, however, that large mammals may not always be appropriate indicators *of contemporary ecological disturbance*, and that camera trapping for large mammals may not be the optimum approach for all potential REDD+ forests and projects.

Bats

The advantages of using bats as a model monitoring group are that the group has a broad global distribution, is speciose, includes many threatened species, has a relatively stable taxonomy, provides important ecosystem services and responds predictably to changes in habitat condition, which reflects changes in arthropod prey communities and/or availability of fruit [9, 25]. We concur that there are considerable advantages associated with acoustic monitoring of bats, which could make this a very useful tool for biodiversity monitoring within REDD+. Whether this approach will be optimal in all REDD+ projects in all forest habitats is less certain, however, owing to several problems that have yet to be overcome in the tropics.

Firstly, ultrasonic acoustic detectors will clearly not detect non-echolocating species, thereby excluding at least 186 species of Old World fruit bat (Pteropodidae: 15% of the World's bats) from monitoring programmes. Secondly, many forest-dependent tropical bat species use relatively quiet and short-duration echolocation pulses [26, 27], resulting in reduced probability of detection by acoustic methods in forest environments. This is particularly true in the New World, where acoustic surveys may be more difficult because a large proportion of echolocating bats are from the family Phyllostomidae, which use very short and relatively quiet sounds during hunting that are easily missed when using a detector [26]. To overcome these biases, location-specific solutions are required, such as additional monitoring of calls in the non-ultrasonic range (for, e.g., Old World fruit bats), physical trapping, and use of camera traps near flowers or fruits in the neotropics.

Moreover, as recognised by Waldon *et al.* [9], verified vocal signatures have not been recorded for all forest bat species. Even in well documented areas, such as Europe, it is not possible to distinguish all species from calls alone [28]. In the tropics, bat call libraries are poor and identification is even more problematic. Species identification is further complicated by large variations in calls among individuals, sexes, habitats and geographic areas; e.g., [29, 30]. Thus, even in areas where bat calls are well documented, high levels of expertise and, hence, high salary costs and computing time, are required to distinguish species reliably. Of particular concern for acoustic monitoring in the palaeotropics is that a large proportion of forest bat communities (in terms of both species and abundance) are comprised of vespertilionid species of the subfamilies Kerivoulinae and Murininae, particularly in carbon-rich peat forests [31]. Not only do these bats all use very similar calls that cannot be reliably distinguished, but the calls are also quiet and short range [27], with the result that they are typically under-represented in acoustic inventories.

This lack of call documentation in many areas, plus the fact that many bat species will not be detected via acoustic methods, means that physical capture surveys, typically using either mist nets or harp traps, are still essential to document bat species accurately in tropical forests and particularly to obtain initial recordings of their calls [32, 33]. Physically trapping and identifying bats requires high expertise, and can involve substantial time and funds, but these costs can be lower than for acoustic methods, and are comparable to those for many other animal groups. Although physical bat trapping will be needed initially in many cases, it is worth noting that biases in data obtained towards those species that are detectable and identifiable via specific methods (in this case, acoustic analysis of calls) may be acceptable in some circumstances, providing that this inherent bias is recognised when discussing the implications of the results and inappropriate extrapolations are avoided [15].

Furthermore, differences in bat communities and vegetation structure among forests are known to influence the precise methods needed to ensure the efficiency of acoustic sampling of calls, and the maximum attainable efficiency of the method in general [34, 35]. For example, Canadian coniferous forests are reported to contain large numbers of calling bats [35], whereas many European coniferous forests are practically devoid of echolocating bats [36]. Similarly, whereas bat detector surveys can be conducted from cars in Ireland [37], such an approach would unlikely be feasible in bat species-rich tropical rainforests, even if adequate access roads were available. Finally, the height and positioning of stationary detectors can influence results obtained [38].

We therefore believe that acoustic monitoring of bat calls can form a valuable *component of* REDD+ biodiversity monitoring programmes in many areas, but the utility of this method in some parts of the tropics currently remains quite limited. Nevertheless, because bats have very high potential as ecological disturbance indicators and fulfil important ecosystem services [25], further research to address methodological issues with acoustic surveys is clearly needed.

3. Can a one-size-fits-all approach ever work?

Our analysis indicates that camera trapping for large mammals and acoustic monitoring for bats can be effective monitoring solutions in some tropical areas, but that the model biodiversity monitoring protocol suggested by Waldon *et al.* [9] will not be suitable for use in all forests, and may not be the most (cost) effective approach in others. It is important to note that, although our discussion here focuses on these two methods and concerns mammals (following [9]), we anticipate that this same conclusion would be reached regardless of the methods or indicator group in question.

While desirable, achieving a model biodiversity monitoring protocol suitable for use in all forests potentially included under REDD+ is probably, in fact, an unrealistic objective. The forests of the world – ranging from boreal coniferous forests to tropical jungles – differ enormously in their character, species assemblages, ecological interactions, nature and intensity of anthropogenic threats faced [39]. The practicalities and costs of conducting research in these forests also differ, and it is therefore unlikely that any standard biodiversity monitoring protocol could ever be effective in all potential REDD+ forests. In his authoritative review of ecological monitoring in forests, these facts lead Gardner [15: p. xxvi] to conclude that "vast differences in the ecological and social context of different landscapes preclude the notion that any single 'one-size-fits-all' recipe book exists". Moreover, biodiversity conservation aims will differ among projects, depending on the species that are found in/might be expected to recolonise a forest, their conservation status, the ecosystem services provided by the forest, the nature and intensity of human threats faced, and local policies and other conservation incentives. Because ecological monitoring is intended to provide feedback on, and help improve the effectiveness of, management interventions in achieving their conservation aims, ecological monitoring programmes must always be designed with respect to these aims [15, 40, 41].

Thus, for example, REDD+ projects in southern Sumatra might establish tiger conservation as a primary conservation goal (for which camera trapping would be a highly appropriate monitoring tool); whereas projects in Borneo, which has no tigers, might focus instead on other flagship species that are surveyed using different methods, such as the orang-utan. Other projects may not focus on specific target conservation species at all, but may instead aim to maintain 'natural' species compositions or ecosystem services desired by local communities. Even if one method could be identified that provides useful feedback for conservation managers in relation to all of these conservation goals, large differences in monitoring survey effort required may be required to achieve one goal over another (e.g., much greater survey effort would be required to monitor rare target conservation species or document the full diversity of species within a group, than to state whether community composition is changing at all in response to human activities). Further, this variation among forests can influence the utility of, and results obtained from, surveys on different taxa, as illustrated above in our discussion of the effectiveness of bat acoustic survey techniques in different habitats.

Consequently, project-specific biodiversity monitoring programmes are needed, based on the biodiversity conservation aims of the project and a solid foundation of knowledge on the habitat type in question. Because of this inability to implement a standardised monitoring protocol in all REDD+ forests, independent peer review of monitoring projects prior to, during and after implementation will remain essential for maintaining the scientific integrity of biodiversity monitoring for REDD+.

Waldon *et al.* [9] also suggest that maintaining a centralised data processing location using highly-trained experts will be cost effective and beneficial for large-scale and many small-scale projects. While we recognise that this approach may be beneficial in terms of data quality maintenance, it is questionable whether it would lead to reduced costs for a REDD+ project. We also argue that data processing should comprise a network of facilities, with responsibilities and data ownership remaining in forest countries. Many of the most highly-trained scientists are from developed nations, who demand much higher salaries than scientists in developing nations, where many REDD+ projects will be based. Thus, if protocols can be designed to enable data analysis to be performed by local scientists or, potentially better still, local field assistants, then salary costs will be reduced, with many local personnel being potentially employable with the same amount of funds needed to pay one developed country scientist [42]. Moreover, this approach also increases the training and capacity building provided to in-country scientists and local communities, and increases local employment opportunities.

4. Suggestions for more refined biodiversity monitoring for REDD+

Designing a good ecological monitoring programme to document changes in the biological community/ecosystem and explain why these changes are most likely to have occurred is a considerable scientific challenge [15, 41]. Changes may occur due to conservation management interventions, changes in threat status, or be due to natural stochastic variations. Determining which of these is the case is clearly crucial for establishing the biodiversity impacts of REDD+ emission reduction interventions. Sampling selected target taxa alone can only tell us that a change in the population has occurred, however, without telling us why [15]. This is further complicated by the fact that most REDD+ projects will generally employ a variety of different emission reduction interventions simultaneously within their management area, each of which will likely have different biodiversity impacts.

To overcome these challenges, we recommend that biodiversity monitoring programmes for REDD+ (i) reflect the project's biodiversity conservation aims; (ii) be based upon scientifically-tractable, policy-relevant questions regarding the impacts of management interventions on the ecosystem; (iii) that these questions be founded upon a detailed knowledge of the forest in question, including taxa present, possible seasonal changes in abundance and likely responses to different types of disturbance; (iv) include monitoring of a number of different types of indicator, as appropriate to the project and its conservation aims, including monitoring of threat occurrence, management intervention implementation, habitat condition, ecological disturbance indicators and flagship conservation species; and (v) define appropriate reference/baseline conditions, against which progress towards a more desirable state can be measured [15, 41, 43, 44]. As noted by Waldon *et al.* [9] and others [15, 41, 45], ensuring cost effectiveness is also important. Much can also be learnt from the growing body of work by groups such as the Tropical Ecology, Assessment and Monitoring Network (TEAM) initiative, which has developed survey protocols for key forest taxa in order to monitor global trends in tropical diversity [10, www.teamnetwork.org].

Monitoring habitat condition and ecological disturbance indicators is particularly useful, as this enables changes in biodiversity to be linked to changes in habitat condition, which can, in turn, be related to changes in human activities [15]. The most appropriate ecological disturbance indicators for monitoring will vary between projects, but these should show consistent and detectable responses to changes in habitat condition, be feasible and affordable to monitor over the long term, and, ideally, capture responses of other taxa and have high generality towards other forest systems [15]. Examples of potential ecological disturbance indicator taxa that may suit this purpose in particular forests include frugivorous birds and dung beetles (Coleoptera: Scarabaeidae) [45], and butterflies (Lepidoptera) [46]. In interpreting these data, and in particular when assessing species richness, care must be taken to account for potential differences in capture/detection probability of species over space and time, in order to avoid data misinterpretations and potential negative consequences arising therefrom [47]. Analysis of "functional traits" (e.g., body size, feeding guild) within selected ecological disturbance indicator groups may also be useful, can frequently be monitored by observers with a lower level of expertise (therefore lowering costs), and can often be more readily linked to changes in ecosystem function and service provision [48-50]. Because of the multiple monitoring options available, and the inherent advantages and disadvantages of each, *a-priori* multi-taxa assessments are required to enable selection of appropriate indicators for monitoring. Use of indicators across as wide a variety of spatial scales, taxa and trophic guilds as possible is also recommended, to enable more thorough understanding of the impacts of human activities at multiple levels [15].

While developed country scientists' involvement may still be desirable in many cases, much ecological monitoring can be conducted by local scientists and even scientifically unqualified local villagers/field assistants [42], especially if analysis of more easily-interpreted ecological traits is justifiable scientifically. In addition to reducing costs, this also provides important social co-benefits, in terms of local employment and in-country capacity building.

In conclusion, we suggest that a one-size-fits-all approach towards biodiversity monitoring for REDD+ is unlikely to be feasible or effective in many, if not most, forest areas, regardless of the specific methods used. This is particularly true if appropriate indicators of habitat condition and ecological disturbance are not incorporated into the monitoring programme. Instead, we suggest that it is vital that REDD+ ecological monitoring programmes be tailored to a particular project's aims and the forest habitat in question, which requires detailed knowledge of the forest habitat and its associated biodiversity. Such an approach should provide more concrete answers to questions relating to the assumed biodiversity benefits of REDD+ emission reduction management activities.

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