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Article

# Not Seeing the Forest for the Trees: The Oversight of Defaunation in REDD+ and Global Forest Governance

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**Abstract:** Over the past decade, countries have strived to develop a global governance structure to halt deforestation and forest degradation, by achieving the readiness requirements for Reducing Emissions from Deforestation and forest Degradation (REDD+). Nonetheless, deforestation continues, and seemingly intact forest areas are being degraded. Furthermore, REDD+ may fail to consider the crucial ecosystem functions of forest fauna including seed dispersal and pollination. Throughout the tropics, forest animal populations are depleted by unsustainable hunting to the extent that many forests are increasingly devoid of larger mammals—a condition referred to as empty forests. Large mammals and birds, who often disperse seeds of larger more carbon-rich tree species, are preferentially targeted by hunters and the first to be depleted. Such defaunation has cascading ecosystem effects, changing forest structure and composition with implications for carbon storage capacity. Failure to address defaunation would therefore be a major oversight in REDD+, compromising its long-term viability. We carried out a desktop study reviewing REDD+ documents and national implementation efforts in Colombia, Ecuador, Nigeria, Tanzania, and Indonesia to assess the extent to which they address hunting and acknowledged the ecosystem functions of fauna. We also assessed sub-national REDD+ projects to determine whether they recognized hunting and if and how they incorporated hunting management and wildlife monitoring at the project level. Moreover, we assessed to what extent sub-national REDD+ projects addressed the long-term impacts of the sustainability of hunting on forest ecosystem function including carbon storage. We found that hunting, the risk of defaunation, and its effects have been ignored in the REDD+ policy process at both the international and national levels. At the project level, we found some reference to hunting and the risks posed by the loss of forest fauna, albeit only addressed superficially. Our results underline the fact that forest ecosystems are being reduced to their carbon content and that, despite the rhetoric of biodiversity co-benefits, fauna is not treated as a functional component of forests. This neglect threatens to undermine forest ecosystem function and service delivery as well as long-term forest carbon assimilation capacity and hence, ultimately, to compromise REDD+ objectives.

**Keywords:** hunting; cascading effects; ecosystem functions; forest fauna; REDD+; forest governance

## 1. Introduction

Forests are major carbon sinks [1–4], but also harbor a myriad of plant and animal species [5,6] and provide resources on which millions of people depend [7,8]. Tropical forests are estimated to host 50 percent of the world's species [9], but deforestation and forest degradation drive the loss of biodiversity and genetic resources [5,10–12]. Reducing deforestation and forest degradation is seen

as having global benefits by reducing greenhouse gas emissions [13], which is essential to mitigating climate change. Local benefits include the prevention of soil erosion [14,15] and the stabilization of local and regional hydrological cycles [4,16], the conservation of biodiversity and genetic resources, and the protection of forest goods and services essential to the food security of adjacent communities [8,17].

More than a decade has passed since Reducing Emissions from Deforestation and forest Degradation (REDD+) reignited debates on forest governance across scales on the international agenda [18]. REDD+ can take various forms, including sustainable forest management and forest conservation, market-based transactions in carbon credits, and broader institutional reform for more effective forest governance across national administrative levels [19]. It has been portrayed as a cost-efficient strategy to address climate change through the reduction of greenhouse gas emissions from deforestation while promoting local livelihoods and enhancing the protection of other ecosystem services as well as biodiversity habitat [20]. However, critique concerning the inclusion and participation of local communities and indigenous groups [21–23], benefit sharing, and land and carbon rights [24,25] has been increasing with ontological debates about the reliance on market-based mechanisms and monetary valuation to protect forests [26–28]. Nevertheless, REDD+ is still considered perhaps the best option for a global mechanism to fight deforestation and forest degradation [29]. Many tropical forest countries have specific reference to REDD+ in their Intended Nationally Determined Contributions (INDCs) that describe the efforts of each country to reduce national emissions as part of the Paris agreement [30], and the expectations of REDD+ are still high [31].

The United Nations Framework Convention on Climate Change (UNFCCC) negotiations reiterated the co-benefits of forest conservation for climate change mitigation and non-carbon ecosystem services, such as biodiversity conservation, and enhanced welfare of local people [30]. However, the role of fauna in forest ecology and unsustainable hunting by local communities have important consequences that have often been left out in contemporary forest governance discussions, including REDD+ [32–34] and the analysis of drivers of deforestation and forest degradation [35]. The latest Food and Agriculture Organization (FAO) “State of the World’s Forests” report highlights the importance of sustainable management for forest ecosystem functions [36]. Thus, acknowledging and monitoring livelihoods effects as well as biodiversity are becoming increasingly important as stakeholders and policymakers demand that forest conservation take into account local livelihoods as well as biodiversity conservation [8]. However, in practice, forest governance as exemplified by REDD+ focuses mainly on trees and on measuring forest cover and carbon stocks [37].

### *1.1. The Role of Forest and Fauna in Livelihoods*

Forest goods and services are important in rural livelihoods in Sub-Saharan Africa, Asia, and Latin America [17]. Poor households tend to obtain a higher proportion of total annual income from forest resource use than high-income households [38], indicating that they are more reliant on forests and may suffer additional deprivation if forest access and use were curtailed or restricted as a consequence of, for instance, a REDD+ project. Forest income contributes to current consumption (energy, food, medicine, and construction materials), as a safety net providing food or income in times of crisis, and as a gap-filler in periods of seasonal hardship [17,39].

Wild meat—the meat of wild animals (also called bushmeat)—is an important forest product. In particular, poor households tend to rely on wild meat for food and as a gap-filler [40–42]. These functions increase rural households’ resilience to shocks, preventing them from falling into poverty [43,44]. In a global comparative study, 39% of surveyed households hunted [45], which provides a rough estimate suggesting that at least 150 million households across the tropics harvest and to some extent rely on wild meat from forests [42]. The role of wild meat income in rural livelihoods varies considerably between locations depending on fauna resources and diversification of income strategies [41,46,47]. However, despite a low contribution to cash income [45], wild meat may be an essential source of protein, fat, and important micronutrients in many locations [48,49]. Predictions

suggest widespread protein deficiency in a range of countries [50] and case studies suggest increased risk of anemia in children [51] if wild meat was unavailable.

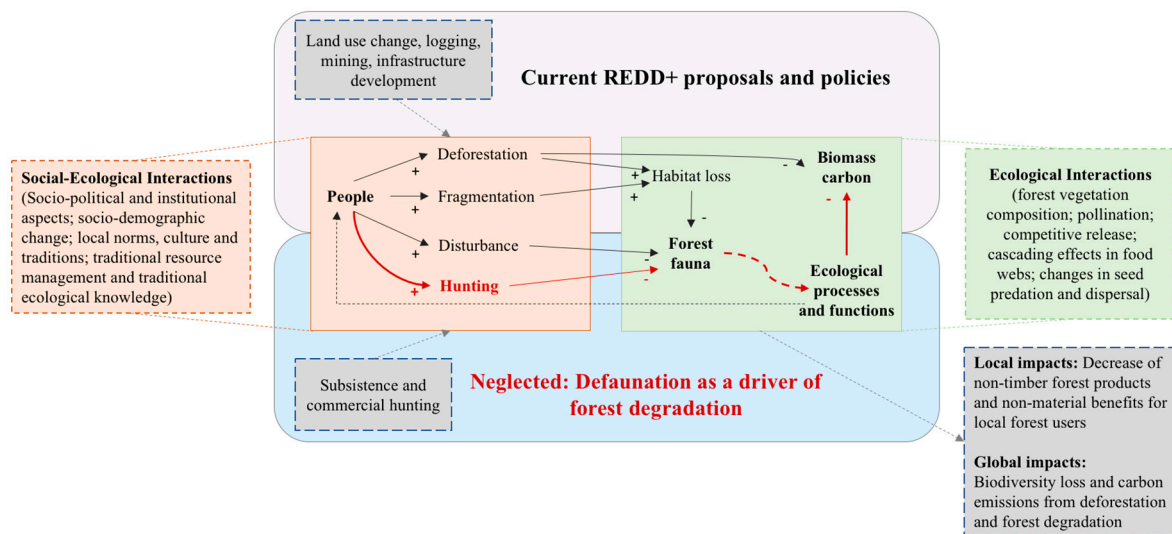
### 1.2. Consequences of Defaunation

The sustainability of hunting is questionable in many locations and empirical evidence reveals persistent declines and local extinctions of numerous species across Africa, Asia, and Latin America, particularly where hunting is supplying urban markets [52–55]. In many tropical forests, fauna is depleted to the extent that it has been referred to as the empty forest syndrome [56,57], and about 88% of tropical forests face the threat of defaunation through the combined effects of hunting, habitat fragmentation, selective logging, and other forms of human disturbance [58]. Depletion of fauna not only has negative repercussions for rural households who depend on this source of nutrition and income but may also affect the habitat itself as targeted larger frugivorous species often perform irreplaceable ecosystem functions [59–61].

Forest fauna perform many ecological functions, directly and indirectly influencing ecosystem processes including pollination, seed dispersal and affecting germination, plant regeneration and growth, and biogeochemical cycles [62,63]. Empirical studies across the tropics have shown that defaunation (i.e., the human-induced extinction of large and medium-sized mammals [62]) can have cascading effects on forest structure and dynamics [64–66]. Defaunation may change plant community composition, forest structure, and productivity to the extent that the long-term viability and service delivery of ecosystems is affected [60,63]. However, our ability to predict the consequences of defaunation is constrained by the complexity of ecosystem interactions and the long-time horizons over which these changes materialize [67,68].

The link between fauna and vegetation in tropical forests is highly relevant to the REDD+ debate due to the implications for forests' carbon storage capacity [69]. Brodie and Gibbs [70] proposed that hunting in tropical forests constitutes a climate threat. Removing dispersers of large tree-seeds depresses the recruitment of large-seeded trees, thereby increasing the likelihood of extinction for large-seeded tree species, that on average have a slightly higher wood density than small-seeded trees [71,72].

Few studies have so far examined the effect of defaunation on carbon storage due to the inherent complexity [67]. However, simulating the local extinction of trees depending on large frugivores for seed dispersal in 31 Atlantic forest communities in Brazil using a dataset on tree species composition and abundance, seed, fruit and carbon-related traits, and plant-animal interactions, Bello et al. [73] found that the extinction of even a small proportion of the large-seeded trees significantly eroded forest carbon storage capacity. Similarly, Peres et al. [74] modeled above-ground forest biomass under different scenarios of hunting-induced extinction of large frugivores in the Brazilian Amazon and found that defaunation would lead to loss of above-ground biomass in the range of 2.5–37.8% by disproportionately affecting large-seeded heavy-wooded species that are primarily dispersed by megafrugivores such as ateline primates and tapirs. A pan-tropical study of the potential effects of defaunation on above-ground carbon storage simulating extinctions of large-seeded animal-dispersed species found that carbon stocks in African, Indian, and American tree communities declined by 1–5% and 2–12% in 50% and 100% seed disperser removal scenarios, respectively [75]. Hence, there is sufficient support for the hypothesis postulating a long-term effect of hunting on forest carbon storage capacity and that defaunation will undermine REDD+ climate change mitigation efforts although researchers have only recently begun to examine this link using vegetation modelling [67]. Furthermore, an application using bioeconomic modelling reveals that total potential revenue was maximized at low hunting effort by increasing sellable carbon credits [34]. Figure 1 presents a conceptual framework for defaunation as a major oversight in current approaches to forest governance, including REDD+.



**Figure 1.** A conceptual framework of defaunation as the missing piece in forest governance.

### 1.3. Objectives

Currently, forest monitoring under REDD+ accounts mainly for vegetation cover, carbon stock, and baseline carbon emissions [76,77], typically relying on remote sensing [78,79]. Moreover, forest governance and management focus mainly on technical aspects considering forest as a form of land cover separate from the ecological and social-ecological system dynamics that are an inherent feature of natural forests. Panfil and Harvey (2015), for example, examined how 80 existing REDD+ projects addressed biodiversity conservation through monitoring plans. They found that none of the projects had specific biodiversity conservation goals and that only nine mentioned poaching as a specific biodiversity threat. Thus, future REDD+ projects and national-level REDD+ programs need to articulate explicit biodiversity goals, and identify and address the threats to biodiversity, linking REDD+ projects to national and international biodiversity conservation efforts, which is currently not the case [80]. We investigated whether fauna as a particular feature of biodiversity, hunting, and the potential consequences of defaunation for forest ecosystem function were addressed across international, national and sub-national levels of governance. To this end, we examined to what extent fauna and hunting are explicitly referred to in REDD+ documents in international REDD+ policies, national REDD+ strategies and program documents, and sub-national REDD+ projects.

## 2. Materials and Methods

This study was conducted as a desk study but supported by previous research experience in projects concerned with REDD+ and forest governance. We focused on Colombia, Ecuador, Indonesia, Nigeria, and Tanzania because these countries are in the process of implementing REDD+ and due to their geographical distribution covering the three major tropical forest zones and their high fauna diversity.

In the first step, we searched relevant international decisions on forests by the conference of the parties to the UNFCCC (<https://unfccc.int/topics/land-use/resources/unfccc-documents-in-relation-to-reducing-emissions-from-deforestation-and-forest-degradation-in-developing-countries>), and reviewed the Forest Carbon Partnership Facility (FCPF) Methodological Framework, the latest Climate, Community and Biodiversity (CCB version 3) standards and the Plan Vivo standard for consideration of biodiversity, fauna/wildlife, and hunting.

In the next step, we searched most recent national REDD+ strategies and program documents at the UNFCCC REDD+ web platform (<https://redd.unfccc.int/>) and the UN-REDD (<http://www.un-redd.org/>) homepage for all REDD+ countries with tropical forests. We analyzed 49 national REDD+ documents (e.g., national REDD+ strategies, and National Program Documents) in 20 countries. For Colombia,

Ecuador, Indonesia, Nigeria, and Tanzania, we also reviewed the REDD Desk (<https://theredddesk.org/>) and the Forest Carbon Partnership Facility (<https://www.forestcarbonpartnership.org/>) homepages and the respective websites of governmental authorities responsible for REDD+ (e.g., the Ministries of Environment) for additional documents on the national implementation and progress of REDD+ (for a complete list of documents, consult Table S1, Supplementary Materials). We reached out to university staff, and staff members in the five national REDD+ offices and associated agencies involved in REDD+ readiness preparation and REDD+ project implementation to solicit their advice on relevant documents. We screened those documents for the following keywords in relation to REDD+: biodiversity (including biological diversity and biodiv\*), fauna (including wildlife, animal\*, defaun\*, and deplet\*), and hunting (including hunt\*, meat\* and poach\*) and examined the context in which these keywords were discussed when applicable. For documents written in Spanish or French, we translated these keywords. We excluded generic uses of these terms, for instance, those referring to the names of particular organizations (e.g., Flora and Fauna International) or to national legislation (e.g., hunting laws). We selected these keywords to determine whether or not the documents provided details about biodiversity, such as considering fauna, wildlife, or animals as a particular feature of forest biodiversity, or explicitly considering hunting as a driver of fauna depletion (i.e., defaunation) or the consequences of hunting for forest functions (e.g., the role of animals in seed dispersal).

Lastly, we searched the international database on REDD+ projects and programs (ID-RECCO) (<http://www.reddprojectsdatabase.org>), the Verra project database (<https://vcsprojectdatabase.org>), and the Plan Vivo ([www.planvivo.org](http://www.planvivo.org)) list of projects for registered and ongoing sub-national REDD+ projects in the five countries (for a complete list of projects, consult Table S2, Supplementary Materials). We excluded reforestation and afforestation projects and projects for which no documentation was available. We reviewed available project design documents using the same approach as described above. Where these keywords appeared, we analyzed the context in which they were mentioned, such as acknowledging the importance of wild meat in local livelihoods and food security, the risk of unsustainable hunting and biodiversity loss to forest function and ecosystem service provision, and the potential implications of defaunation. We also examined the selected sub-national projects for strategies on monitoring of hunting and species population trends.

### 3. Results

#### 3.1. Forest Biodiversity and the UNFCCC

We found six decisions from the Conference of the Parties meetings that are relevant to forests and the implementation of REDD+ (Table 1). Of these, two refer to biodiversity and biological diversity in the text of the decisions, although to a very limited extent. None of these decisions specifies biodiversity in the context of forest fauna, or mention hunting as a driver of biodiversity loss. Consequently, none of the documents considers the ecosystem functions of mammals or the implications of defaunation for forest long-term ecosystem function including carbon sequestration.

**Table 1.** Biodiversity in UNFCCC documents and decisions on forests and REDD+.

Document Reference	Text Excerpts Referring to Forests and/or Biodiversity	Keywords Mentioned		
		Biodiversity	Forest Fauna	Hunting
United Nations Framework Convention on Climate Change (UNFCCC; 1992), Article 4, 1d	Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems;	No	No	No
UNFCCC/CP/2007/6/Add.1-COP 13 Bali	Decision 2/CP.13 "Recognizing that reducing emissions from deforestation and forest degradation in developing countries can promote co-benefits and may complement the aims and objectives of other relevant international conventions and agreements,"	No <sup>1</sup>	No	No

Table 1. Cont.

Document Reference	Text Excerpts Referring to Forests and/or Biodiversity	Keywords Mentioned		
		Biodiversity	Forest Fauna	Hunting
UNFCCC/CP/2009/11/Add.1-COP 15 Copenhagen	Decision 4/CP.15 “Recognizing the importance of promoting sustainable management of forests and co-benefits, including biodiversity, that may complement the aims and objectives of national forest programmes and relevant international conventions and agreements,”	Yes	No	No
UNFCCC/CP/2010/7/Add.1 (Cancun Safeguards); Decision 1/CP.16, Appendix 1, paragraph 2	Appendix 1, 2(e) “Following safeguards should be promoted and supported ‘That actions are consistent with the conservation of natural forests and biological diversity, ensuring that the actions referred to in paragraph 70 of this decision are not used for the conversion of natural forests, but are instead used to incentivize the protection and conservation of natural forests and their ecosystem services, and to enhance other social and environmental benefits (Taking into account the need for sustainable livelihoods of indigenous peoples and local communities and their interdependence on forests in most countries)’”	Yes	No	No
UNFCCC/CP/2013/10/Add.1-COP 19 Warsaw	Decision 9/CP.19 – “22. Recognizes the importance of incentivizing non-carbon benefits for the long-term sustainability of the implementation of the activities referred to in decision 1/CP.16, paragraph 70, and noting the work on methodological issues referred to in decision 1/CP.18, paragraph 40;”	No	No	No
UNFCCC/CP/2015/10/Add.3-COP 21 Paris	Decision 18/CP. 21 – “Decides that methodological issues related to non-carbon benefits resulting from the implementation of the activities referred to in decision 1/CP.16, paragraph 70, do not constitute a requirement for developing country Parties seeking to receive support for the implementation of the actions and activities referred to in decision 1/CP.16 or results-based payments pursuant to decision 9/CP.19”	No	No	No
FCP <sup>2</sup> Carbon Fund Methodological Framework 2016	“Non-Carbon Benefits: any benefits produced by or in relation to the implementation and operation of the ER Program, other than ERs and Monetary and Non-Monetary Benefits, as specified in the ER Program Document, and, as relevant, any Safeguards Plans. Such Non-Carbon Benefits may include, but not be limited to, the improvement of local livelihoods, building of transparent and effective forest governance structures, making progress on securing land tenure, and enhancing or maintaining biodiversity and/or other ecosystem services.”	Yes	No	No
Climate, Community & Biodiversity Standards: v3.1 <sup>3</sup> (2017)	Well-designed projects also contribute to biodiversity conservation by restoring and protecting the world’s natural ecosystems, saving threatened animal and plant species from extinction and maintaining resilient and productive natural life-support for humankind. Through effective planning and implementation, all of these positive outcomes can be achieved cost-effectively.	Yes	No	No

Table 1. Cont.

Document Reference	Text Excerpts Referring to Forests and/or Biodiversity	Keywords Mentioned		
		Biodiversity	Forest Fauna	Hunting
Plan Vivo Standard (2013) <sup>4</sup>	<p>Project interventions may include any improved land management activities that can generate demonstrable ecosystem service benefits, improve the livelihoods of participants and maintain or enhance biodiversity.</p> <p>The protection of, or provision of, biodiversity is often characterized as one of a variety of ecosystem services. Maintenance of biodiversity is arguably better understood as an overarching requirement for all ecosystem services in that biodiversity is a prerequisite for healthy ecosystems which provide a range of ecosystem services. Because of this, regardless of the focus of the PES scheme, Plan Vivo project interventions must be designed in a way that maintains or enhances biodiversity.</p>	Yes	No	No

<sup>1</sup>. Biological diversity is mentioned in relation to the UN Convention on Biological Diversity only;

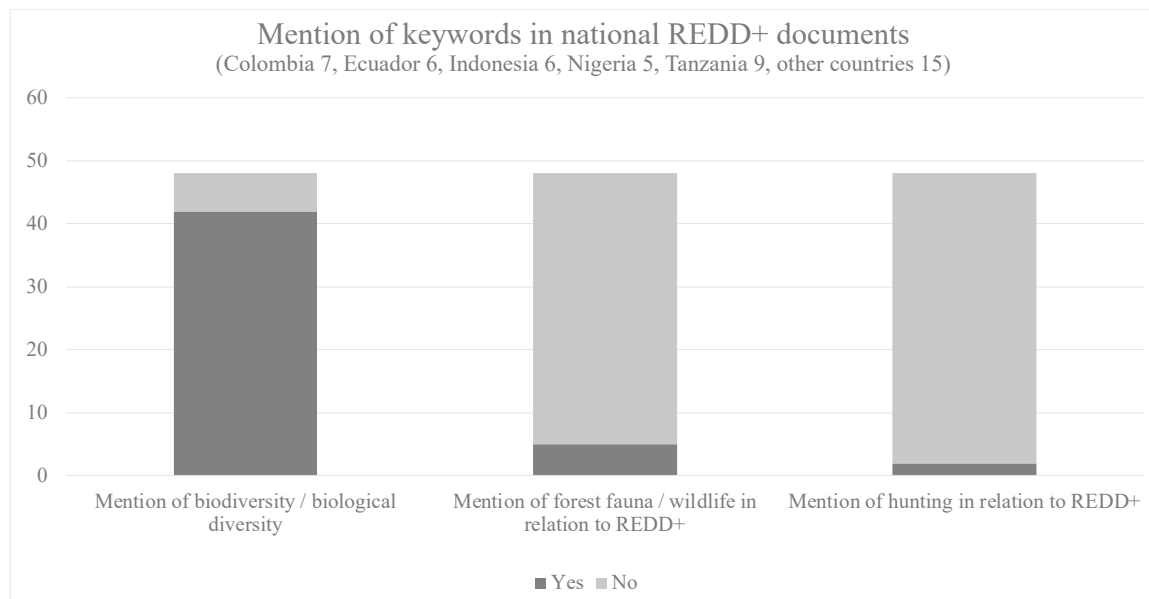
<sup>2</sup> <https://www.forestcarbonpartnership.org/sites/fcp/files/2016/July/FCPF%20Carbon%20Fund%20Methodological%20Framework%20revised%202016.pdf>; <sup>3</sup> [https://verra.org/wp-content/uploads/2017/12/CCB-Standards-v3.1\\_ENG.pdf](https://verra.org/wp-content/uploads/2017/12/CCB-Standards-v3.1_ENG.pdf); <sup>4</sup> <http://www.planvivo.org/docs/Plan-Vivo-Standard.pdf>.

### 3.2. National REDD+ Programs

The terms biodiversity and biological diversity were used frequently in the national REDD+ documents from all countries for which we were able to review national program documents and REDD+ strategies (Figure 2, Table S1 in Supplementary Materials). However, fauna and hunting were rarely mentioned or addressed, and we found no single document that mentioned all three terms. For Tanzania, the report on participatory forest management and REDD+ mentions necessary legal clarification of tenure and beneficiaries of carbon sales in Wildlife Management Areas [81]. For Indonesia, the national REDD+ strategy only in very general terms describes that the strategy among other objectives aims to develop systematic and consolidated processes and approaches to save Indonesia's natural forests and flora and fauna within them (Indonesia REDD+ Task Force 2012). The Ecuadorian REDD+ National Program Report from 2015 makes only very general reference to biodiversity as a direct and indirect benefit of REDD+ implementation [82]. However, the Ecuadorian REDD+ Action Plan has biodiversity as a central theme and refers to it as a strategic resource in relation to the national REDD+ efforts that shall be aligned and implemented in line with, for example, the National Biodiversity Strategy [83]. In Colombia, the National Program Document refers to biodiversity in very general terms as a co-benefit of REDD+ [84]. In Nigeria's REDD+ National Program Report, there is no reference to biodiversity, forest fauna, or hunting [85], while the REDD+ Readiness Preparation Proposal from 2014 makes general reference to biodiversity and its importance as a criteria for assessment under REDD+ in Cross River State (Nigeria's REDD+ pilot state) and presents the legal frameworks that regulate hunting at the state level [86].

The Forest Carbon Partnership Facility supports Nigeria, Colombia, Indonesia, and Tanzania in their readiness efforts. These countries therefore have to report on activities that directly aim to conserve biodiversity, including if the National REDD+ program objective/s explicitly target biodiversity conservation and if the approach to non-carbon benefits explicitly incorporates biodiversity conservation. However, none of the Annual Country Reports from these four countries goes into detail about what constitutes biodiversity or mentions hunting as a threat to forest fauna.





**Figure 2.** Mention of keywords in national program documents, national communication to the UNFCCC reports, and other published REDD+ documents for the five countries and the national REDD+ strategies and national program documents for 15 other tropical forest REDD+ countries (see Table S1, Supplementary Materials for the complete list of countries and documents included).

### 3.3. Sub-National REDD+ Projects

We analyzed 17 registered REDD+ projects (described in detail in Table S2, Supplementary Materials). We excluded projects registered under the “reforestation and afforestation” categories because the impact of hunting and the role of animals for forest ecosystem function is different in these types of projects compared to standing natural forests. We found ten projects in Colombia, five projects in Indonesia, and two in Tanzania. Ecuador and Nigeria had no ongoing and registered REDD+ projects in the two databases, although there are a number of REDD+ activities and pilot projects in Nigeria, including in Nigeria’s Cross River State [87]. However, these are not registered nor certified and we could not find validated reports about these projects. Similarly, although a few REDD+ pilot projects are listed in Ecuador, none of these appears to be active and validated reports were not available in the databases we consulted.

All ten projects in Colombia mention subsistence hunting as an important livelihood strategy for local people and all except one project (REDD+ Project Resguardo Indígena Unificado Selva de Mataven) mention current hunting practices as a potential risk to forest biodiversity. Subsistence hunting in Colombia is legal for people who are part of a community with legally recognized territories, for instance, inside indigenous reserves. Although none of these projects mentions any current restrictions on hunting, eight projects plan to involve community members in future hunting management, such as the development of hunting regulations, the implementation of local patrols, and the development of monitoring plans that will also be used to assess hunting trends (Table S2, Supplementary Materials). Furthermore, project documents explicitly mention that to maintain forest structure and composition it is key to preserve the area’s biodiversity and rare ecosystems, and aim to eliminate hunting of large to medium-sized mammals (e.g., Choco Darien Conservation Corridor REDD Projects, p. 64). The BIOREDD/USAID projects, validated by the Rainforest Alliance, specify that “gradual involvement of the community members in restricting hunting and fishing of key threatened species will be sought” and that these restrictions should ultimately consider sustainable yields and have policies allowing only local, non-commercial harvesting of these species in the appropriate season/phase of their life cycle (Table S2, Supplementary Materials).

In Tanzania, the project documents of the Mjumita Community Forest Project mention that illegal hunting for wild meat is conducted in all participating villages [88], and refer to the proposed development of a monitoring plan to evaluate outcomes in relation to the projects' biodiversity objectives. However, no link is made between fauna and carbon storage capacity. Additionally, in Tanzania, Carbon Tanzania has developed a community project with the Hadzabe—a group of traditional hunter-gatherers in the Yaeda Valley in northern Tanzania, generating internationally verified carbon offsets and reinforcing the land and natural resource rights of the Hadza people (see Table S2, Supplementary Materials). So far, the project administrators have completed land use plans and above-ground biomass surveys and worked with authorities to promote the prosecution of poachers. However, the project does not explicitly link depletion of fauna and forest ecosystem services.

All five Indonesian projects mention hunting, albeit to different extents. Only the Katingan Peatland Restoration and Conservation project specifically identifies hunting pressure as a threat to biodiversity. Strategies to reduce hunting pressure include monitoring of hunting effort and impacts to ensure sustainable use, creating alternative livelihoods and increased protection through patrolling and ensuring enforcement to prevent the exploitation of endangered and protected species. The Rimba Raya Biodiversity Reserve project identifies severe overhunting of some species as a threat to biodiversity but explicitly does not attempt to dissuade or prevent “normal” hunting so that the project does not impose additional costs on the local population. None of the Indonesian REDD+ projects makes the link between forest fauna and carbon storage. Several other project documents including REDD+ feasibility studies in the Lamandau River Wildlife Reserve in Central Kalimantan Province in Indonesia [89] identify hunting as threats to biodiversity and forest ecosystems but do not explicitly describe the causal pathway (see Figure 1) or make the link to carbon storage capacity. However, the Plan Vivo-certified Bujang Raba Community PES project mentions a more detailed species monitoring strategy, including hunting bans for any endangered or threatened species (see Table S2, Supplementary Materials).

#### 4. Discussion

The removal of large frugivores from tropical forest areas has impacts on forest ecosystems and may already have altered tree composition in some tropical forests (see above). The depletion of particularly large frugivorous mammals, typically preferred by hunters, is pervasive across the tropics resulting in empty forests [11,55,57,90,91]. Evidence suggests that unsustainable hunting can lead to defaunation, which in turn eliminates animal dispersal and increases the mortality of large-seeded carbon-rich trees [70]. Loss of predators has further synergistic effects on seed mortality [92]. Moreover, tree species dependent on animal dispersers tend to have high wood density and large stature, and a recruitment failure and reduction in the prevalence of these trees will lead to decreased forest biomass and hence carbon storage capacity in most tropical regions [73,74,92]—in essence, compromising REDD+ objectives.

Apart from affecting carbon sequestration capacity, defaunation may have negative implications for the food security of local communities. The fruits of many wild animal-dispersed trees that can be harvested sustainably from the forest are important resources in local people's livelihoods [93]. Without seed dispersers, these trees are at risk of disappearing. Depletion of fauna through hunting, whether for subsistence or commercial purposes, will also directly affect numerous rural households that depend on forest fauna as a source of protein and revenue either for current consumption or as a security net in times of crisis [42,45].

Furthermore, defaunation may have unpredictable cascading ecosystem effects reducing or drastically altering forest structure, composition, and ecosystem service provisioning. Managing forests solely for carbon storage, the primary objective in REDD+, fails to consider the complex interactions and interdependence of plants and animals in tropical forests [69]. Furthermore, focusing on carbon stocks does not necessarily preserve biodiversity per se nor consider species-specific dependencies, genetic diversity, minimum viable area, or population sizes of threatened species, or the broader landscape connectivity [94].

The development of REDD+ over the past decade has been shaped by discussions about social and ecological safeguards and which aspects to include or exclude [95] in order to avoid overburdening REDD+ with a multitude of add-ons and to limit the transaction costs of negotiations in the REDD+ agenda-setting phase [96]. Starting in 2009, important social and environmental safeguards were included in order to make REDD+ more equitable and to respond to biodiversity conservation concerns as a co-benefit [95]. We found that the higher-level policy documents as well as sub-national project plans did to some extent address biodiversity, fauna, and hunting. However, hunting and defaunation as a driver of forest degradation and the link between fauna and forest ecosystem function were not mentioned at the international or national level. Rather than an oversight, this may represent a deliberate political choice to avoid adding further complexity to REDD+ negotiations and implementation. This may be attributed to resistance to accept the transaction costs of taking on these additional “add-ons” in a REDD+ negotiation process, readiness, and implementation phase that has already been complex and lengthy. Although biodiversity has moved from a side issue to an inherent feature in REDD+ discourses, decisions, and national programs over the last decade, we show that the ecological functions of biodiversity are still only mentioned superficially. Their meaningful inclusion in REDD+ implementation and sub-national projects will require that fauna as an integral component of forest ecosystems, and hunting as a direct driver of faunal loss, be addressed explicitly.

At the sub-national level, fauna and hunting were much more likely to be considered in project documents than in the supporting national REDD+ framework (see above). This may be a result of the prior focus of implementing organizations (typically non-governmental conservation organizations (NGOs)) that have often been involved in forest and biodiversity projects before engaging with REDD+, expanding the search for financial support into the carbon market. It is also likely due to the fact that the projects we found are registered under the voluntary carbon standard and approved by the Climate Community and Biodiversity Alliance (CCBA) or Plan Vivo Standards that require more detail on environmental safeguards. Therefore, a number of projects identified and assessed the role of wild meat in rural livelihood strategies and monitored fauna populations as part of their commitment to assess the social and biodiversity impacts of the projects. For instance, a majority of the Colombian REDD+ projects that we analyzed mentioned hunting explicitly as an important livelihood strategy but also as a threat to specific animal species, and included fauna and hunting in future monitoring strategies.

Nevertheless, monitoring fauna populations in tropical forests is difficult and costly [97] and, without alternative sources of food or income, comes at a cost to local people. For instance, there are forestry concessions in Gabon that are operating under sustainable forest management practices certified by the Forest Stewardship Council (FSC) where hunting is controlled and road access to areas of high conservation value is restricted by concession holders who have the manpower and financial means to do so [98]. This, however, may have negative implications by limiting local people's ability to access essential wild food sources. In the frequent case where the forest owner is the state, a regional administrative unit, or even local communities, the prevention of hunting could be in the long-term interests of policymakers and elite community leaders to reduce the potential costs of defaunation as lost income from selling carbon credits in future performance-based payments for carbon sequestration [34]. However, while the impacts of depleted fauna populations on carbon storage are likely far into the future, the costs of restricting access to this resource for marginalized groups is likely to affect food security at present [99].

Forest monitoring is a crucial component of REDD+ projects, and the monitoring strategies of these generally build on existing guidelines for forest monitoring. However, such guidelines typically do not include monitoring of fauna or species commonly hunted, such as the density or presence/absence of fauna performing important ecosystem functions including seed dispersal and pollination. The failure to monitor fauna is a considerable shortcoming, particularly in light of the prevalent high hunting pressure in most tropical forest regions, the importance of forest fauna in maintaining ecosystem function, and the reported long-term consequences of defaunation for carbon sequestration. Options for increasing the cost-effectiveness of monitoring include index-based information from local hunters

reporting species caught [100,101]. Interviews with local community members about forest fauna and the perceived abundance of a range of important key species represent another useful and relatively inexpensive method to assess forest ecosystem health [102].

Global forest governance maintains a technical and bureaucratic view of forests and lacks a social-ecological system perspective [103]. This is reflected in the currently applied definitions of forest that fail to consider forests as ecosystems containing fauna and people and that lack a holistic vision of forests as complex adaptive systems whose resilience is linked with that of the society in which they occur [104]. Moreover, analyses of forest degradation rarely account for hunting of fauna and likely associated changes in ecological functions, thus omitting the interlinkages between forest fauna and flora [35,79].

## 5. Conclusions

While human activities directly affecting forests, including deforestation (e.g., clear cutting) and forest degradation (e.g., sporadic logging) have received increasing attention by the UNFCCC, a third “de”, namely defaunation, has to a great extent been overlooked. Reviewing official UNFCCC documents, we found no mention or consideration of the ecosystem consequences of overhunting or defaunation. This oversight extends to the national REDD+ documents from the five countries that we analyzed. Although they did mention fauna and the importance of forests as habitat for biodiversity, they did not explicitly acknowledge the important ecosystem functions performed by forest fauna or consider the potential long-term implications of defaunation for forest ecosystems.

The Convention on Biological Diversity is preparing a post-2020 Global Biodiversity Framework, which will likely have stronger targets for signatory countries and will further embed biodiversity considerations in the Sustainable Development Goals. We present evidence that defaunation as an important factor in forest degradation is virtually overlooked in international climate negotiations and forest governance. The assumption that forest cover and habitat protection equal effective biodiversity conservation is misleading [56,57,105–107], and must be challenged. The fact that defaunation and particularly the loss of large seed dispersers through unsustainable hunting have lasting repercussions throughout the forest ecosystem, decreasing tree diversity, carbon storage and overall forest resilience, must similarly be acknowledged and considered in forest governance broadly and for REDD+ as an international mechanism, for forest governance to be viable in the long term.

Forest biodiversity is currently considered a co-benefit of REDD+ [32]. However, we argue that the term “forest biodiversity” must encompass animal diversity and abundance—which the Warsaw Framework and other REDD+ guiding documents only implicitly acknowledge [19,30] and that sustainable management and conservation of forest fauna must be a goal in itself. The adverse impacts of warmer temperatures, intensified droughts, and selective logging on forests are well known [58,108], but the long-term effects of fauna depletion and defaunation on otherwise undisturbed forests are insufficiently acknowledged. In many parts of the world, people rely on wild game for food and income [42], but with rising human populations and improved access, forests are being emptied of fauna to supply urban demand by the so-called bushmeat trade.

Monitoring the magnitude of hunting and taking steps to ensure sustainable wildlife management in forest areas are important from both a social and food security perspective as well as a climate policy and conservation perspective. We do not suggest that local hunting for subsistence should be prohibited as it is an important source of nutrients in addition to an income for rural communities in many locations with few alternatives. Furthermore, most countries that are implementing REDD+ are signatories to international conventions on the rights of indigenous peoples, including the International Labor Organization’s Convention 169 or the United Nations Declaration on the Rights of Indigenous Peoples [109,110]. Therefore, we call for the inclusion of hunting in forest governance through REDD+ and other mechanisms that aim to protect standing forests from deforestation and forest degradation. Monitoring mainly tree cover or carbon stock is insufficient in this regard.

Hunting is a driver of forest degradation, and the assessment of hunting pressure, and the status of forest fauna, should therefore be included in the design, implementation, and, subsequently, the monitoring, reporting and verification methodologies of REDD+ projects. Unsustainable hunting and its consequences for biodiversity and forest fauna are often neglected in current forest governance [32,33]. Where hunting is unsustainable, it should be reduced. This may be achieved by offering environmental education about the role of forest fauna in maintaining ecological functions [111], by strengthening tenure rights of local and indigenous communities [112], by re-establishing traditional regulations and norms about hunting [113], by establishing no-take zones and quotas, and seasonal restrictions on species offtake [114], and by providing alternative sources of food and income generation [115,116].

Rules and regulations, as well as mitigation approaches, should be developed in close deliberation with local hunters and resource users. Similarly, monitoring of fauna could benefit from collaboration with hunters in community-based wildlife monitoring approaches taking advantage of local ecological knowledge [97]. To some extent, REDD+ projects on the ground already appear to monitor fauna and hunting, although the link between defaunation and carbon storage is not acknowledged. Making this link visible probably requires a more inclusive and holistic approach to forest governance—one that is informed by forest ecology and that acknowledges the ecological interactions between forest fauna and vegetation, and ultimately also the human use of forest fauna. Hunting and species loss contribute to forest degradation, and it is crucial to ensure that biodiversity safeguards and REDD+ project proposals become more explicit in addressing hunting and fauna loss in their approach and implementation. Along the same lines, biodiversity and fauna monitoring as well as hunting management must be built explicitly into national and project level monitoring, reporting, and verification (MRV) methods. Otherwise, there is a risk that we lose the forest for the trees. We hope that the growing evidence of the intricate relationship between hunting and defaunation and tree species abundance, tree species diversity, and long-term carbon storage capacity of tropical forests will further the development of the “discursive-institutional spiral” that shapes and reframes debates on REDD+ [95].

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/1999-4907/10/4/344/s1>, Table S1: Review of national REDD+ documents for keywords, Table S2: List of all sub-national REDD+ projects assessed (excluding reforestation and afforestation projects and those projects for which no documents were available) listed in the international database on REDD+ projects and programs ([reddprojectdatabase.org](http://reddprojectdatabase.org)), the Verra project database, and the Plan Vivo list of projects for registered and ongoing sub-national REDD+ projects in Colombia, Indonesia, and Tanzania. No ongoing projects with available documentation were found for Ecuador and Nigeria.

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## References

1. Malmer, A.; Murdiyarso, D.; Bruijnzeel, L.A.; Ilstedt, U. Carbon sequestration in tropical forests and water: A critical look at the basis for commonly used generalizations. *Chang. Biol.* **2010**, *16*, 599–604. [[CrossRef](#)]
2. Canadell, J.G.; Raupach, M.R.; Canadell, J. Managing Forests for Climate Change Mitigation. *Science* **2008**, *320*, 1456–1457. [[CrossRef](#)]
3. Van der Werf, G.R.; Morton, D.C.; DeFries, R.S.; Olivier, J.G.J.; Kasibhatla, P.S.; Jackson, R.B.; Collatz, G.J.; Randerson, J.T. CO<sub>2</sub> emissions from forest loss. *Nat. Geosci* **2009**, *2*, 737–738. [[CrossRef](#)]
4. Jackson, R.B.; Randerson, J.T.; Canadell, J.G.; Anderson, R.G.; Avissar, R.; Baldocchi, D.D.; Bonan, G.B.; Caldeira, K.; Diffenbaugh, N.S.; Field, C.B.; et al. Protecting climate with forests. *Environ. Res. Lett.* **2008**, *3*, 044006. [[CrossRef](#)]

5. Butchart, S.H.M.; Walpole, M.; Collen, B.; Van Strien, A.; Scharlemann, J.P.W.; Almond, R.E.A.; Baillie, J.E.M.; Bomhard, B.; Brown, C.; Bruno, J.; et al. Global Biodiversity: Indicators of Recent Declines. *Science* **2010**, *328*, 1164–1168. [[CrossRef](#)]
6. Myers, N.; Mittermeier, R.A.; Mittermeier, C.G.; Da Fonseca, G.A.B.; Kent, J. Biodiversity hotspots for conservation priorities. *Nat. Cell Boil.* **2000**, *403*, 853–858. [[CrossRef](#)]
7. Sunderland, T.C.H.; Powell, B.; Ickowitz, A.; Foli, S.; Pinedo-Vasquez, M.; Nasi, R.; Padoch, C. *Food Security and Nutrition: The Role of Forests*; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2013.
8. Wunder, S.; Angelsen, A.; Belcher, B. Forests, Livelihoods, and Conservation: Broadening the Empirical Base. *World Dev.* **2014**, *64*, S1–S11. [[CrossRef](#)]
9. Dirzo, R.; Raven, P.H. Global State of Biodiversity and Loss. *Annu. Resour.* **2003**, *28*, 137–167. [[CrossRef](#)]
10. Turner, I.M. Species Loss in Fragments of Tropical Rain Forest: A Review of the Evidence. *J. Appl. Ecol.* **1996**, *33*, 200. [[CrossRef](#)]
11. Estrada, A.; Garber, P.A.; Rylands, A.B.; Roos, C.; Fernandez-Duque, E.; Di Fiore, A.; Nekar, K.A.-I.; Nijman, V.; Heymann, E.W.; Lambert, J.E.; et al. Impending extinction crisis of the world's primates: Why primates matter. *Sci. Adv.* **2017**, *3*, e1600946. [[CrossRef](#)]
12. Barlow, J.; Lennox, G.D.; Ferreira, J.; Berenguer, E.; Lees, A.C.; Mac Nally, R.; Thomson, J.R.; Ferraz, S.F.D.B.; Louzada, J.; Oliveira, V.H.F.; et al. Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. *Nat. Cell Boil.* **2016**, *535*, 144–147. [[CrossRef](#)]
13. Pearson, T.R.H.; Brown, S.; Murray, L.; Sidman, G. Greenhouse gas emissions from tropical forest degradation: An underestimated source. *Carbon Balance Manag.* **2017**, *12*, 3. [[CrossRef](#)]
14. Pimentel, D. Soil Erosion: A Food and Environmental Threat. *Environ. Dev. Sustain.* **2006**, *8*, 119–137. [[CrossRef](#)]
15. Southgate, D.; Whitaker, M. Promoting Resource Degradation in Latin America: Tropical Deforestation, Soil Erosion, and Coastal Ecosystem Disturbance in Ecuador. *Econ. Dev. Cult. Chang.* **1992**, *40*, 787–807. [[CrossRef](#)]
16. Makarieva, A.M.; Gorshkov, V.G. Biotic pump of atmospheric moisture as driver of the hydrological cycle on land. *Hydrol. Earth Sci.* **2007**, *11*, 1013–1033. [[CrossRef](#)]
17. Angelsen, A.; Jagger, P.; Babigumira, R.; Belcher, B.; Hogarth, N.J.; Bauch, S.; Börner, J.; Smith-Hall, C.; Wunder, S. Environmental Income and Rural Livelihoods: A Global-Comparative Analysis. *World Dev.* **2014**, *64*, S12–S28. [[CrossRef](#)]
18. Pistorius, T. From RED to REDD+: The evolution of a forest-based mitigation approach for developing countries. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 638–645. [[CrossRef](#)]
19. UNFCCC. *Decisions adopted by the Conference of the Parties—Decision 1/CP.16*; United Nations Framework Convention on Climate Change: Cancun, Mexico, 2011.
20. Kanowski, P.J.; McDermott, C.L.; Cashore, B.W. Implementing REDD+: Lessons from analysis of forest governance. *Environ. Sci. Policy* **2011**, *14*, 111–117. [[CrossRef](#)]
21. Stiem, L.; Krause, T. Exploring the Impact of Social Norms and Perceptions on Women's Participation in Customary Forest and Land Governance in the Democratic Republic of Congo—Implications for REDD+. *Int. For. Rev.* **2016**, *18*, 110–122. [[CrossRef](#)]
22. Nuesiri, E. Feigning Democracy: Performing Representation in the UN-REDD Funded Nigeria-REDD Programme. *Conserv. Soc.* **2017**, *15*, 384–399. [[CrossRef](#)]
23. Aguilar-Støen, M. Global forest conservation initiatives as spaces for participation in Colombia and Costa Rica. *Geoforum* **2015**, *61*, 36–44. [[CrossRef](#)]
24. Chomba, S.; Kariuki, J.; Lund, J.F.; Sinclair, F. Roots of inequity: How the implementation of REDD+ reinforces past injustices. *Land Use Policy* **2016**, *50*, 202–213. [[CrossRef](#)]
25. Karsenty, A.; Vogel, A.; Castell, F. "Carbon rights", REDD+ and payments for environmental services. *Environ. Sci. Policy* **2014**, *35*, 20–29. [[CrossRef](#)]
26. Fletcher, R.; Dressler, W.; Büscher, B.; Anderson, Z.R. Questioning REDD+ and the future of market-based conservation. *Conserv. Biol.* **2016**, *30*, 673–675. [[CrossRef](#)]
27. Corbera, E. Problematizing REDD+ as an experiment in payments for ecosystem services. *Curr. Opin. Environ. Sustain.* **2012**, *4*, 612–619. [[CrossRef](#)]
28. Cabello, J.; Gilbertson, T. A colonial mechanism to enclose lands: A critical review of two REDD+-focused special issues. *Ephemera* **2012**, *12*, 162–180.

29. Angelsen, A.; Brockhaus, M.; Duchelle, A.E.; Larson, A.; Martius, C.; Sunderlin, W.D.; Verchot, L.; Wong, G.; Wunder, S. Learning from REDD+: A response to Fletcher et al. *Conserv. Biol.* **2017**, *31*, 718–720. [[CrossRef](#)]
30. UNFCCC. *Adoption of the Paris Agreement—Draft decision -/CP.21*; United Nations Framework Convention on Climate Change: Paris, France, 2015; p. 32.
31. Hein, J.; Guarin, A.; Frommé, E.; Pauw, P. Deforestation and the Paris climate agreement: An assessment of REDD + in the national climate action plans. *For. Policy Econ.* **2018**, *90*, 7–11. [[CrossRef](#)]
32. Hinsley, A.; Entwistle, A.; Pio, D.V. Does the long-term success of REDD+ also depend on biodiversity? *Oryx* **2015**, *49*, 216–221. [[CrossRef](#)]
33. Krause, T.; Zambonino, H. More than just trees—Animal species diversity and participatory forest monitoring in the Ecuadorian Amazon. *Int. J. Biodivers. Sci. Serv. Manag.* **2013**, *9*, 225–238. [[CrossRef](#)]
34. Brodie, J.F. Carbon Costs and Bushmeat Benefits of Hunting in Tropical Forests. *Ecol. Econ.* **2018**, *152*, 22–26. [[CrossRef](#)]
35. Weatherley-Singh, J.; Gupta, A. Drivers of deforestation and REDD+ benefit-sharing: A meta-analysis of the (missing) link. *Environ. Sci. Policy* **2015**, *54*, 97–105. [[CrossRef](#)]
36. FAO. The state of the world's forests 2018—Forest pathways to sustainable development. In *The State of the World*; Food and Agricultural Organization of the United Nations: Rome, Italy, 2018; p. 139.
37. Gardner, T.A.; Burgess, N.D.; 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* (Suppl. C), 61–71. [[CrossRef](#)]
38. Angelsen, A.; Dokken, T. Environmental Reliance, Climate Exposure, and Vulnerability—A Cross-Section Analysis of Structural and Stochastic Poverty. In *Policy Research Working Paper 7474—Shock Waves: Managing the Impact of Climate Change on Poverty*; The World Bank: Washington, DC, USA, 2015; p. 47.
39. Angelsen, A.; Dokken, T. Climate exposure, vulnerability and environmental reliance: A cross-section analysis of structural and stochastic poverty. *Dev. Econ.* **2018**, *23*, 257–278. [[CrossRef](#)]
40. De Merode, E.; Homewood, K.; Cowlshaw, G. The value of bushmeat and other wild foods to rural households living in extreme poverty in Democratic Republic of Congo. *Boil. Conserv.* **2004**, *118*, 573–581. [[CrossRef](#)]
41. Schulte-Herbruggen, B.; Cowlshaw, G.; Homewood, K.; Rowcliffe, J.M. The Importance of Bushmeat in the Livelihoods of West African Cash-Crop Farmers Living in a Faunally-Depleted Landscape. *PLoS ONE* **2013**, *8*, e72807. [[CrossRef](#)] [[PubMed](#)]
42. Nielsen, M.R.; Meilby, H.; Smith-Hall, C.; Pouliot, M.; Treue, T. The Importance of Wild Meat in the Global South. *Ecol. Econ.* **2018**, *146*, 696–705. [[CrossRef](#)]
43. Angelsen, A.; Wunder, S. *Exploring the Forest-Poverty Link: Key Concepts, Issues and Research Implications*; CIFOR Occasional Paper; Center for International Forestry Research: Bogor, Indonesia, 2003.
44. Babulo, B.; Muys, B.; Nega, F.; Tollens, E.; Nyssen, J.; Deckers, J.; Mathijs, E. The economic contribution of forest resource use to rural livelihoods in Tigray, Northern Ethiopia. *For. Policy Econ.* **2009**, *11*, 109–117. [[CrossRef](#)]
45. Nielsen, M.R.; Pouliot, M.; Meilby, H.; Smith-Hall, C.; Angelsen, A. Global patterns and determinants of the economic importance of bushmeat. *Boil. Conserv.* **2017**, *215*, 277–287. [[CrossRef](#)]
46. Tieguhong, J. Supplies of bushmeat for livelihoods in logging towns in the Congo Basin. *J. Hortic. For.* **2009**, *1*, 65–80.
47. Kümpel, N.F.; Milner-Gulland, E.J.; Cowlshaw, G.; Rowcliffe, J.M. Incentives for Hunting: The Role of Bushmeat in the Household Economy in Rural Equatorial Guinea. *Hum. Ecol.* **2010**, *38*, 251–264. [[CrossRef](#)]
48. Sarti, F.M.; Adams, C.; Morsello, C.; Van Vliet, N.; Schor, T.; Yagüe, B.; Tellez, L.; Quiceno-Mesa, M.P.; Cruz, D. Beyond protein intake: Bushmeat as source of micronutrients in the Amazon. *Ecol. Soc.* **2015**, *20*. [[CrossRef](#)]
49. Rowland, D.; Ickowitz, A.M.Y.; Powell, B.; Nasi, R.; Sunderland, T. Forest foods and healthy diets: Quantifying the contributions. *Environ. Conserv.* **2017**, *44*, 102–114. [[CrossRef](#)]
50. Fa, J.E.; Currie, D.; Meeuwig, J. Bushmeat and food security in the Congo Basin: Linkages between wildlife and people's future. *Environ. Conserv.* **2003**, *30*, 71–78. [[CrossRef](#)]
51. Golden, C.D.; Fernald, L.C.H.; Brashares, J.S.; Rasolofoniaina, B.J.R.; Kremen, C.; Rasolofoniaina, B.J.R. Benefits of wildlife consumption to child nutrition in a biodiversity hotspot. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 19653–19656. [[CrossRef](#)] [[PubMed](#)]

52. Robinson, J.G.; Bennett, E.L. (Eds.) *Hunting for Sustainability in Tropical Forests*; Columbia University Press: New York, NY, USA, 2000.
53. Milner-Gulland, E.J.; Bennett, E.L. Wild Meat: The Bigger Picture. *Trends Ecol. Evol.* **2003**, *18*, 351–357. [[CrossRef](#)]
54. Gray, T.N.E.; Hughes, A.C.; Laurance, W.F.; Long, B.; Lynam, A.J.; O’Kelly, H.; Ripple, W.J.; Seng, T.; Scotson, L.; Wilkinson, N.M. The wildlife snaring crisis: An insidious and pervasive threat to biodiversity in Southeast Asia. *Biodivers. Conserv.* **2018**, *27*, 1031–1037. [[CrossRef](#)]
55. Ripple, W.J.; Abernethy, K.; Betts, M.G.; Chapron, G.; Dirzo, R.; Galetti, M.; Levi, T.; Lindsey, P.A.; Macdonald, D.W.; Machovina, B.; et al. Bushmeat hunting and extinction risk to the world’s mammals. *Soc. Open Sci.* **2016**, *3*, 160498. [[CrossRef](#)]
56. Redford, K.H. The Empty Forest. *BioScience* **1992**, *42*, 412–422. [[CrossRef](#)]
57. Wilkie, D.S.; Bennett, E.L.; Peres, C.A.; Cunningham, A.A. The empty forest revisited. *Ann. N. Y. Acad. Sci.* **2011**, *1223*, 120–128. [[CrossRef](#)]
58. Malhi, Y.; Gardner, T.A.; Goldsmith, G.R.; Silman, M.R.; Zelazowski, P. Tropical Forests in the Anthropocene. *Annu. Resour.* **2014**, *39*, 125–159. [[CrossRef](#)]
59. Kurten, E.L. Cascading effects of contemporaneous defaunation on tropical forest communities. *Boil. Conserv.* **2013**, *163*, 22–32. [[CrossRef](#)]
60. Dirzo, R.; Young, H.S.; Galetti, M.; Ceballos, G.; Isaac, N.J.B.; Collen, B. Defaunation in the Anthropocene. *Science* **2014**, *345*, 401–406. [[CrossRef](#)]
61. Young, H.S.; McCauley, D.J.; Galetti, M.; Dirzo, R. Patterns, Causes, and Consequences of Anthropocene Defaunation. *Annu. Ecol. Evol. Syst.* **2016**, *47*, 333–358. [[CrossRef](#)]
62. Dirzo, R.; Miranda, A. *Altered Patterns of Herbivory and Diversity in the Forest Understory: A Case Study of the Possible Consequences of Contemporary Defaunation*; Wiley: Hoboken, NJ, USA, 1991; pp. 273–287.
63. Galetti, M.; Dirzo, R. Ecological and evolutionary consequences of living in a defaunated world. *Boil. Conserv.* **2013**, *163*, 1–6. [[CrossRef](#)]
64. Beaune, D.; Fruth, B.; Bollache, L.; Hohmann, G.; Bretagnolle, F. Doom of the elephant-dependent trees in a Congo tropical forest. *Ecol. Manag.* **2013**, *295*, 109–117. [[CrossRef](#)]
65. Caughlin, T.T.; Ferguson, J.M.; Lichstein, J.W.; Zuidema, P.A.; Bunyavejchewin, S.; Levey, D.J. Loss of animal seed dispersal increases extinction risk in a tropical tree species due to pervasive negative density dependence across life stages. *Proc. R. Soc. B Biol. Sci.* **2015**, *282*, 20142095. [[CrossRef](#)]
66. Terborgh, J.; Nuñez-Iturri, G.; Pitman, N.C.A.; Valverde, F.H.C.; Álvarez, P.; Swamy, V.; Pringle, E.G.; Paine, C.E.T. Tree recruitment in an empty forest. *Ecology* **2008**, *89*, 1757–1768. [[CrossRef](#)]
67. Berzaghi, F.; Verbeeck, H.; Nielsen, M.R.; Doughty, C.E.; Bretagnolle, F.; Marchetti, M.; Scarascia-Mugnozza, G.; Scarascia-Mugnozza, G. Assessing the role of megafauna in tropical forest ecosystems and biogeochemical cycles - the potential of vegetation models. *Ecography* **2018**, *41*, 1934–1954. [[CrossRef](#)]
68. Harrison, R.D.; Tan, S.; Plotkin, J.B.; Slik, F.; Detto, M.; Brenes, T.; Itoh, A.; Davies, S.J. Consequences of defaunation for a tropical tree community. *Ecol. Lett.* **2013**, *16*, 687–694. [[CrossRef](#)]
69. Bunker, D.E.; Declerck, F.; Bradford, J.C.; Colwell, R.K.; Perfecto, I.; Phillips, O.L.; Sankaran, M.; Naem, S. Species Loss and Aboveground Carbon Storage in a Tropical Forest. *Science* **2005**, *310*, 1029–1031. [[CrossRef](#)] [[PubMed](#)]
70. Brodie, J.F.; Gibbs, H.K. Bushmeat Hunting As Climate Threat. *Science* **2009**, *326*, 364–365. [[CrossRef](#)] [[PubMed](#)]
71. Wright, I.J.; Ackerly, D.D.; Bongers, F.; Harms, K.E.; Ibarra-Manriquez, G.; Martinez-Ramos, M.; Mazer, S.J.; Muller-Landau, H.C.; Paz, H.; Pitman, N.C.A.; et al. Relationships among ecologically important dimensions of plant trait variation in seven neotropical forests. *Ann. Bot.* **2007**, *99*, 1003–1015. [[CrossRef](#)]
72. Queenborough, S.A.; Mazer, S.J.; Vamossi, S.M.; Garwood, N.C.; Valencia, R.; Freckleton, R.P. Seed mass, abundance and breeding system among tropical forest species: Do dioecious species exhibit compensatory reproduction or abundances? *J. Ecol.* **2009**, *97*, 555–566. [[CrossRef](#)]
73. Bello, C.; Galetti, M.; Pizo, M.A.; Magnago, L.F.S.; Rocha, M.F.; Lima, R.A.F.; Peres, C.A.; Ovaskainen, O.; Jordano, P. Defaunation affects carbon storage in tropical forests. *Sci. Adv.* **2015**, *1*, e1501105. [[CrossRef](#)] [[PubMed](#)]



74. Peres, C.A.; Emilio, T.; Schiatti, J.; Desmouliere, S.J.M.; Levi, T. Dispersal limitation induces long-term biomass collapse in overhunted Amazonian forests. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 892–897. [[CrossRef](#)] [[PubMed](#)]
75. Osuri, A.M.; Ratnam, J.; Varma, V.; Alvarez-Loayza, P.; Astaiza, J.H.; Bradford, M.; Fletcher, C.; Ndongou-Hockemba, M.; Jansen, P.A.; Kenfack, D.; et al. Contrasting effects of defaunation on aboveground carbon storage across the global tropics. *Nat. Commun.* **2016**, *7*, 11351. [[CrossRef](#)]
76. Harris, N.L.; Brown, S.; Hagen, S.C.; Saatchi, S.S.; Petrova, S.; Salas, W.; Hansen, M.C.; Potapov, P.V.; Lotsch, A. Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. *Science* **2012**, *336*, 1573–1576. [[CrossRef](#)]
77. UNFCCC. *Decision 11/CP.19 Modalities for National Forest Monitoring Systems*; United Framework Convention on Climate Change: Warsaw, Poland, 2013; p. 43.
78. Neha, J.; Edward, T.A.M.; Natalia, W.; Jorge, T.; Julian, M.R.; Andrea, E.; Murray, C.; Martin, R.J.; Rasmus, F. Mapping dynamics of deforestation and forest degradation in tropical forests using radar satellite data. *Environ. Res. Lett.* **2015**, *10*, 034014.
79. Guariguata, M.R.; Heymell, V.; Sabogal, C.; Thompson, I.D.; Okabe, K.; Bahamondez, C.; Nasi, R. An Operational Framework for Defining and Monitoring Forest Degradation. *Ecol. Soc.* **2013**, *18*, 20.
80. Panfil, S.N.; Harvey, C.A. REDD+ and Biodiversity Conservation: A Review of the Biodiversity Goals, Monitoring Methods, and Impacts of 80 REDD+ Projects. *Conserv. Lett.* **2015**, *9*, 143–150. [[CrossRef](#)]
81. Blomley, T.; Lukumbuzya, K.; Brodnig, G. *Participatory Forest Management and REDD+ in Tanzania*; The World Bank: Washington, DC, USA, 2011; p. 32.
82. UN-REDD. *National Programme Final Report—Ecuador*; Ministry of Environment of Ecuador: Quito, Ecuador, 2015; p. 95.
83. MAE. *Bosques para el Buen Vivir—Plan de Acción REDD+ Ecuador (2016–2025)*; Ministry of Environment of Ecuador: Quito, Ecuador, 2016; p. 223.
84. UN-REDD. *UN-REDD Colombia National Programme Document*; Ministry of Environment and Sustainable Development: Bogotá, Colombia, 2015; p. 70.
85. UN-REDD. *National Programme Annual Report—Federal Republic of Nigeria*; UN-REDD: Abuja, Nigeria, 2015; p. 39.
86. Federal Republic of Nigeria. *REDD+ Readiness Preparation Proposal (R-PP)*; Federal Ministry of Environment: Abuja, Nigeria, 2014; p. 170.
87. UN-REDD. *Community Based REDD+ Country Plan for Nigeria*; UNREDD and The GEF Small Grants Programme: Abuja, Nigeria, 2015; p. 28.
88. PlanVivo. *Reducing Emissions from Deforestation and Forest Degradation in the Yaeda Valley, Northern Tanzania*; Plan Vivo: Edinburgh, UK, 2015; p. 49.
89. Joshi, L. J.; van Noordwijk, M.; Pradhan, U. *Investment in Carbon Stocks in the Eastern Buffer Zone of Lamandau River Wildlife Reserve, Central Kalimantan Province, Indonesia: A REDD+ Feasibility Study*; World Agroforestry Center (ICRAF) Southeast Asia Regional Office: Bogor, Indonesia, 2010; p. 105.
90. van Vliet, N.; Quiceno Mesa, M.P.; Cruz-Antia, D.; Neves De Aquino, L.J.; Moreno, J.; Nasi, R. The uncovered volumes of bushmeat commercialized in the Amazonian trifrontier between Colombia, Peru & Brazil. *Ethnobiol. Conserv.* **2014**, *2014*, 3.
91. Nasi, R.; Taber, A.; Van Vliet, N. Empty forests, empty stomachs? Bushmeat and livelihoods in the Congo and Amazon Basins. *Int. For.* **2011**, *13*, 355–368. [[CrossRef](#)]
92. Culot, L.; Bello, C.; Batista, J.L.F.; Couto, H.T.Z.D.; Galetti, M.; Couto, H.T.Z. Synergistic effects of seed disperser and predator loss on recruitment success and long-term consequences for carbon stocks in tropical rainforests. *Sci. Rep.* **2017**, *7*, 7662. [[CrossRef](#)]
93. Effiom, E.O.; Nuñez-Iturri, G.; Smith, H.G.; Ottosson, U.; Olsson, O. Bushmeat hunting changes regeneration of African rainforests. *Proc. Soc. B Boil. Sci.* **2013**, *280*, 20130246. [[CrossRef](#)]
94. Phelps, J.; Friess, D.A.; Webb, E.L. Win-win REDD+ approaches belie carbon-biodiversity trade-offs. *Biol. Conserv.* **2012**, *154*, 53–60. [[CrossRef](#)]
95. den Besten, J.W.; Arts, B.; Verkooijen, P. The evolution of REDD+: An analysis of discursive-institutional dynamics. *Environ. Sci. Policy* **2014**, *35*, 40–48. [[CrossRef](#)]
96. Gallemore, C. Transaction costs in the evolution of transnational polycentric governance. *Int. Environ. Agreem. Politics Law Econ.* **2017**, *17*, 639–654. [[CrossRef](#)]

97. Marrocoli, S.; Nielsen, M.R.; Morgan, D.; Van Loon, T.; Kulik, L.; Kühl, H. Using wildlife indicators to facilitate wildlife monitoring in hunter-self monitoring schemes. *Ecol. Indic.* in press.
98. Precious Woods. *Résumé Public du Plan d'Aménagement*; Precious Woods: Libreville, Gabon, 2018; p. 31.
99. Cawthorn, D.-M.; Hoffman, L.C. The bushmeat and food security nexus: A global account of the contributions, conundrums and ethical collisions. *Food Res. Int.* **2015**, *76*, 906–925. [[CrossRef](#)]
100. Vieira, M.A.R.D.M.; Von Muhlen, E.M.; Shepard, G.H. Participatory Monitoring and Management of Subsistence Hunting in the Piagaçu-Purus Reserve, Brazil. *Conserv. Soc.* **2015**, *13*, 254. [[CrossRef](#)]
101. Rist, J.; Cowlshaw, G.; Rowcliffe, M.; Milner-Gulland, E. Hunter Reporting of Catch per Unit Effort as a Monitoring Tool in a Bushmeat-Harvesting System. *Conserv. Biol.* **2010**, *24*, 489–499. [[CrossRef](#)]
102. Meijaard, E.; Mengersen, K.; Buchori, D.; Nurcahyo, A.; Ancrenaz, M.; Wich, S.; Atmoko, S.S.U.; Tjiu, A.; Prasetyo, D.; Nardiyono; et al. Why Don't We Ask? A Complementary Method for Assessing the Status of Great Apes. *PLoS ONE* **2011**, *6*, e18008. [[CrossRef](#)] [[PubMed](#)]
103. Lindahl, K.B.; Sténs, A.; Sandström, C.; Johansson, J.; Lidskog, R.; Ranius, T.; Roberge, J.M. The Swedish forestry model: More of everything? *For. Policy Econ.* **2017**, *77*, 44–55. [[CrossRef](#)]
104. Chazdon, R.L.; Brancalion, P.H.S.; Laestadius, L.; Bennett-Curry, A.; Buckingham, K.; Kumar, C.; Moll-Rocek, J.; Vieira, I.C.G.; Wilson, S.J. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *AMBIO* **2016**, *45*, 538–550. [[CrossRef](#)] [[PubMed](#)]
105. Antunes, A.P.; Fewster, R.M.; Venticinque, E.M.; Peres, C.A.; Levi, T.; Rohe, F.; Shepard, G.H. Empty forest or empty rivers? A century of commercial hunting in Amazonia. *Sci. Adv.* **2016**, *2*, e1600936. [[CrossRef](#)] [[PubMed](#)]
106. Stokstad, E. The empty forest. *Science* **2014**, *345*, 396–399. [[CrossRef](#)]
107. Harrison, R.D. Emptying the Forest: Hunting and the Extirpation of Wildlife from Tropical Nature Reserves. *BioScience* **2011**, *61*, 919–924. [[CrossRef](#)]
108. Huntingford, C.; Zelazowski, P.; Galbraith, D.; Mercado, L.M.; Sitch, S.; Fisher, R.; Lomas, M.; Walker, A.P.; Jones, C.D.; Booth, B.B.B.; et al. Simulated resilience of tropical rainforests to CO<sub>2</sub>-induced climate change. *Nat. Geosci.* **2013**, *6*, 268–273. [[CrossRef](#)]
109. International Labour Organization (ILO). *C 169 Indigenous and Tribal Peoples Convention, 1989*; ILO: Geneva, Switzerland, 1989.
110. UNDRIP. *United Nations Declaration on the Rights of Indigenous Peoples*; United Nations: New York, NY, USA, 2008.
111. Rakotomamonjy, S.N.; Jones, J.P.G.; Razafimanahaka, J.H.; Ramamonjisoa, B.; Williams, S.J. The effects of environmental education on children's and parents' knowledge and attitudes towards lemurs in rural Madagascar. *Anim. Conserv.* **2015**, *18*, 157–166. [[CrossRef](#)]
112. Duporge, I.; Hodgetts, T.; Brett, M. What spatially explicit quantitative evidence exists that shows the effect of land tenure on illegal hunting of endangered terrestrial mammals in sub-Saharan Africa? A systematic map protocol. *Environ. Évid.* **2018**, *7*, 27. [[CrossRef](#)]
113. van Vliet, N. "Bushmeat Crisis" and "Cultural Imperialism" in Wildlife Management? Taking Value Orientations Into Account for a More Sustainable and Culturally Acceptable Wildmeat Sector. *Front. Ecol. Evol.* **2018**, *6*, 112. [[CrossRef](#)]
114. Mockrin, M.H.; Redford, K.H. Potential for spatial management of hunted mammal populations in tropical forests. *Conserv. Lett.* **2011**, *4*, 255–263. [[CrossRef](#)]
115. Wright, J.H.; Hill, N.A.; Roe, D.; Rowcliffe, J.M.; Kumpel, N.F.; Day, M.; Booker, F.; Milner-Gulland, E.J. Reframing the concept of alternative livelihoods. *Conserv. Biol.* **2016**, *30*, 7–13. [[CrossRef](#)] [[PubMed](#)]
116. Wicander, S.; Coad, L. Can the Provision of Alternative Livelihoods Reduce the Impact of Wild Meat Hunting in West and Central Africa? *Conserv. Soc.* **2018**, *16*, 441. [[CrossRef](#)]

