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Review

Natural forest disturbances and the design of REDD+ initiatives

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ABSTRACT

Basing ecosystem management and conservation on the best available science is essential to meeting intended goals and minimizing surprises. To design effective, efficient, and equitable policies for the REDD+ initiatives, requires that drivers of deforestation and forest degradation are correctly identified, and that the ecological context of those drivers is correctly understood. Contemporary forest ecology and management are based on the recognition that forest ecosystems are dynamic, and that those dynamics are often driven by both anthropogenic- and naturally induced disturbances. Here we examine the degree to which the dynamic view of ecosystems is incorporated into the design of REDD+ initiatives. We conducted content analysis of the World Bank's Forest Carbon Partnership Facility's 36 REDD+ participating countries' Readiness Plan Idea Notes and/or Readiness Preparation Proposals. Across the 36 countries, drivers of deforestation and forest degradation could be grouped into categories of institutional policies, political–economic contexts and social settings. The result of our content analysis indicates that there is a lack of discussion of the dynamic character of ecosystems and of the potential influence of natural disturbances on the identified drivers of deforestation and forest degradation. We argue that REDD+ initiatives must take into account knowledge of natural disturbance regimes (including the size, frequency and severity of key disturbances) in their framing of the drivers of deforestation and forest degradation in order to better understand the ecological stage on which these projects will be implemented after the piloting phase. This paper proposes four approaches to integrate understanding of natural disturbances with the socio-political and economic drivers of deforestation and forest degradation within REDD+ participating countries.

1. Introduction

Basing ecosystem management and conservation on the best available science is essential to meeting intended goals and minimizing surprises. Accordingly, over the past decades much effort has been placed on incorporating correct ecological understanding into the design of reserves (e.g., Pickett and Thompson, 1978), forest management (e.g., Attiwill, 1994), and other initiatives. However, some important conservation efforts may still be inconsistent with contemporary ecological understanding. The possibility of significant international payment for projects aimed at reducing emissions from deforestation and degradation (REDD+) has attracted more than 50 tropical countries to pilot over 300 REDD+ projects (CIFOR, 2012). Academic and policy-oriented

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literature on REDD+ has been prolific within the last decade. Its central focus has been on addressing the technical issues – defined largely by the scientific and policy communities – that will improve the design and implementation of REDD+ so that its outcomes achieve the goals of effectiveness, efficiency and equity (Angelsen et al., 2012). Some studies have argued that the effectiveness, efficiency and equity of REDD+ initiatives require that drivers or root causes of deforestation and forest degradation are correctly identified so that incentive mechanisms could be appropriately established to alter the existing institutional, political and economic agents or motivations that have promoted deforestation and forest degradation (Verchot and Petkova, 2010; Kissinger et al., 2012). Others have hinted at the significant roles of ecological drivers, particularly natural disturbances, as potential risks that can compromise the integrity of REDD+ initiatives (Angelsen, 2008; Parrotta et al., 2012). Research on the influence of natural disturbances on the structure, composition and function of forest ecosystems has been one of the dominant themes for contemporary scientific studies on forest ecology and management (Dale et al., 2001; Oliveira et al., 2007; Long, 2009). In that context, this paper explores the extent to which the overarching framework within which identified drivers of deforestation and forest degradation are examined and understood for the purposes of REDD+ initiatives is consistent with contemporary scientific knowledge on natural disturbances.

This paper discusses the roles of natural disturbances in the context of sustainable forest management initiatives in general and emphasizes the potential relevance of this to understanding the drivers of deforestation and forest degradation identified in REDD+ participating countries. First, we briefly discuss select studies of natural disturbances and their roles in contemporary theory and practice of forest management initiatives. Second, we discuss the emergence and types of REDD+ initiatives. Here, we identify the 36 participant countries of the World Bank's Forest Carbon Partnership Facility (FCPF) that we selected for content analysis. Third, we present our findings of the analysis. Results demonstrate that drivers of deforestation and forest degradation identified in the 36 countries lack consideration of the dynamic character of ecosystems and the potential role of natural disturbances in maintaining those dynamics. We discuss these findings and compare them to other studies (Angelsen et al., 2012; Kissinger et al., 2012) of these 36 countries that have drawn similar conclusions. Based on our analysis, we argue that the ecological stage on which REDD+ initiatives are implemented might be based on incomplete understanding of the dynamic character of forest ecosystem, which may raise concerns related to the effectiveness, efficiency and equity of the initiatives. Finally, in the fourth section, we propose four strategies of incorporating studies on natural disturbances in current and future REDD+ initiatives.

2. Forest ecology and management

2.1. *Contemporary theory and practice*

It is important to briefly examine contemporary ecological thought in order to appreciate its relevance for natural resources management practices. Current theoretical perspective on sustainable resource management are the result of an important paradigm shift in ecological literature in which, a stable and mechanistic worldview, which used to provide the foundation for much of the past strategies for natural resource research and management, has been replaced by a more dynamics view of ecosystems (Botkin, 1990; Kulakowski and Veblen, 2006; Morgan et al., 1994). Earlier works that analyzed the classical models and methodologies of ecological stability theory are well summarized in May (1971, 1972). A substantive review of contemporary forest ecology and management, landscape ecology, and conservation biology literature suggests that natural disturbances are fundamental to the structure and function of many forest ecosystems, and thus sustainable forest management should be based on the ecological understanding of the processes that drive periods of gradual and relatively rapid change, the latter being driven by disturbances (Moore et al., 2008; White and Jentsch, 2001). As the recognition of the dynamic character of ecosystems and the important role of disturbances in driving these dynamics has been an important shift in perception over the past several decades among scientists and resource managers (Botkin, 1990; Pickett and White, 1985), it is important to assure that modern initiatives aiming at sustainable management of natural resources are based not only on the best possible socio-economic understanding, but also on the best available ecological understanding.

Studies of natural disturbances have a long history in vegetation ecology. Research had focused on the importance of disturbance as an ecological factor in various habitats and communities (Pickett and White, 1985), disturbance regimes (Kulakowski and Veblen, 2006; Turner et al., 1993), functional adaptations of plants (Walker et al., 1999), responses of ecosystems (Johnson et al., 1998), and restoring disturbance as an ecosystem process (Covington et al., 1999). It should be acknowledged that disturbance has been defined variously in different context. For Pickett and White (1985), a disturbance is defined as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment". We adopted this definition of disturbance in this paper. Disturbances in forest communities include fires, insect outbreaks, storms, floods, and other events that alter demographic processes or resource availability (Hobbs and Huenneke, 1992). Pickett and White (1985) also recognized that some natural disturbances, such as fires and landslides, might have their origins in human activities. Recent studies have generally made the distinction between human-induced and natural disturbances based on the origin of the disturbance (Dale et al., 2001; Raffa et al., 2008). For example, while fire caused by lightening is considered as a natural disturbance, fire used for agricultural activities might be considered as an anthropogenic disturbance.

2.2. *Natural disturbances: importance and application*

There are several reasons for the importance of understanding natural disturbances and theirs relevance to sustainable forest management initiatives such as REDD+. First, natural disturbances are a primary cause of spatial heterogeneity in

ecosystems, influencing competition, substrate and resource availability (White et al., 2000). Second, disturbances often influence ecosystem composition and structure long after their occurrence, and thus understanding ecosystems requires an understanding of their disturbance history (White and Jentsch, 2001). Third, natural disturbances have been important in maintaining biotic diversity by acting as evolutionary forces that have contributed to adaptations in the biota exposed to them (Christensen et al., 1989). As such, ecologists no longer consider natural disturbance as extraordinary and merely destructive forces; instead they acknowledged the generality of the occurrence of disturbances and the significance of their influence on normal ecosystem development (White and Jentsch, 2001). Furthermore, natural and human disturbances interact (Kulakowski and Veblen, 2006), so studying the impact of disturbances on both natural and cultivated landscapes must take into account the synergistic effects of both natural and human-induced disturbance regimes.

The recognition of the importance of natural disturbance regimes in shaping ecosystem structure and function has been incorporated into basic applications of ecological restoration (Swetnam et al., 1999) and the design of nature reserves (Baker, 1992). In both cases, it was recognized that natural disturbances are so central to basic ecological function that their occurrence and effects must be explicitly considered in any restoration or conservation initiative. Drawing from the concepts and studies in island biogeography theory (MacArthur and Wilson, 1969), Pickett and Thompson (1978) suggested the explicit consideration of disturbance regime and patch dynamics in the design of nature reserves. Pickett and Thompson (1978) argued that this integrated knowledge provides the fundamental background information to determine the ''minimum dynamic areas,'' or an area large enough to contain within it multiple patches in various stages of disturbance or recovery such that internal recolonization can contribute to the maintenance of the overall ecosystem. Based on a computer simulation study, Shugart and West (1981) suggested that disturbances could be incorporated within land areas about 50 times the size of disturbances. Baker (1992) also suggested that reserve should be placed in such a way that both the disturbance initiation zones and disturbance export zones are contained within the reserve. Moreover, reserves should include some of the spatial variation in the disturbance regime such that topographic and other variation enables species with a variety of life history strategies to persist (Baker, 1992). We emphasized these classic studies not because we believe all REDD+ initiatives are based on the design of nature reserves, but instead because the incorporation of natural disturbances into the design of nature reserves was a major advancement that brought these conservation efforts into alignment with the best available science. As such, these examples provide precedents to REDD+ policymakers on how knowledge of ecosystem dynamics and especially natural disturbances could be integrated into the design of REDD+ initiatives.

3. REDD+ initiatives

Given the importance of natural disturbances and the dynamic character of ecosystems in contemporary ecological thinking and management, it is essential to examine the degree to which these concepts are incorporated into the design of REDD+ initiatives.

3.1. *The state of REDD+ negotiations*

Since its inception, REDD+ has evolved as a concept that means different things to different countries, organizations, and individuals. For its policy proponents, REDD+ is based on the simple notion that countries that are willing and able to reduce emissions from deforestation and forest degradation by strengthening or establishing new forest conservation institutions and policies, should be financially compensated for doing so (UN-REDD Programme and UNEP-WCMC 2010). Overall, REDD+ represents a form of global environmental governance that transcends multiple structures of decision-making and organizations, assembles actors with diverse interests, and translates into numerous implementation procedures. Angelsen et al. (2009) further argued that across and within the REDD+ participating countries, the forest, socio-economic and policy contexts vary significantly, leaving project proponents and participants in a complex world that defies simplistic explanation, and yet requires clear and simple policies. Even though deforestation and forest degradation are often combined together as the acronym REDD+ suggests, they have distinct drivers and result in different forest conditions making the processes of identifying and abating deforestation and forest degradation very different (Myers Madeira, 2008; White and Minang, 2011). Hence, it is important to clarify the differences. The Intergovernmental Panel on Climate Change (IPCC) defined 'deforestation' as the permanent removal of forest cover and withdrawal of land from forest use, whether deliberately or circumstantially. Forest conversion to pasture, cropland, or other managed uses is considered the same as deforestation unless noted otherwise. The UNFCCC and IPCC employ a minimum crown cover criterion of 10–30 percent to differentiate between forests and non-forests. If crown cover is reduced below this threshold, deforestation has occurred (Myers Madeira, 2008). Forest 'degradation', in the context of REDD+ project, is the result of selective logging, grazing within forests, understory fires, and over-cutting for fuelwood and subsistence agriculture (Myers Madeira, 2008). Forest degradation can lead to cumulative thinning of some forests which can then result in deforestation (Asner and Broadbent, 2006).

It is essential to distinguish between REDD+ initiatives that follow the UNFCCC's decisions and are supported through the start up funding from the World Bank's FCPF and the UN-REDD Programme from other REDD+ initiatives that are established outside the auspices of the UNFCCC, and are funded through voluntary market mechanisms. This paper focuses on examining drivers of deforestation and forest degradation identified in the World Bank's FCPF's REDD+ participating countries. The FCPF was launched at COP 13th in Indonesia, and became operational as the global partnership on REDD+ in June 2008 (Bosquet and Aquino, 2011). As a major stakeholder in the REDD+ institutional landscape, the FCPF has created a normative framework that requires each of its 36 participant countries (13 in Africa, 15 in Latin America and the Caribbean, and 8 in Asia-Pacific) to propose the Readiness Plan Idea Note,

which will then be developed into the REDD+ Readiness Preparation Proposal (R-PP). The proposal specifies the necessary policies and systems, in particular by adopting national strategies; developing reference emission levels; designing measurement, reporting and verification systems; and setting up REDD+ national management arrangements, including the proper safeguards (UNFCCC, 2012). Each of the proposals also provides an analysis of the historical and contemporary drivers of land-use and land-cover change that have promoted deforestation and forest degradation within the given country.

3.2. *Content analysis of the 36 REDD+ countries*

Here, we examine what have been identified as the drivers of deforestation and forest degradation in the World Bank FCPF's REDD+ participant countries, and whether those identified drivers are consistent with contemporary understanding of dynamic forest ecosystems and the associated roles of natural disturbances. To do so, we conducted a content analysis of the national documents that countries have submitted to the World Bank. National policy documents of the 36 countries are openly available from the Bank's website (see http://www.forestcarbonpartnership.org/fcp/node/203). The participant countries vary in their geographical distributions and the stages of REDD+ participation. For example, some countries have just completed their Readiness Plan Idea Notes, while others have finished their Readiness Preparation Proposal (Table 1). We drew upon literature on land-use and land-cover change to code drivers of deforestation and forest degradation in the 36 countries into two broad categories: proximate and underlying (Geist and Lambin, 2002). Proximate causes include human activities or immediate actions at the local level, such as agricultural expansion, that originate from intended land use and directly impact forest cover. Underlying driving forces on the other hand are fundamental social processes, such as human population dynamics or agricultural policies, which underpin the proximate causes and either operate at the local level or have an indirect impact from the national or global level (Geist and Lambin, 2002). We paid particular attention to the identification and description of natural disturbances that were identified and discussed in the 36 policy documents (e.g., insect outbreaks, fires, and other factors identified in Section 2.1). Coding and analysis was done using *Nvivo 10*. software.

3.3. *Findings*

We summarized all the drivers that were identified in each of the 36 REDD+ countries (Table 2) and further categorized these drivers into thematic groups (Table 3). Ecological factors, in particular natural disturbance regimes, were rarely identified as one of the factors that lead to deforestation and forest degradation in the 36 countries (Tables 2 and 3). In most cases, there is no mentioning of this topic in the reviewed national documents. This is alarming because, as argued in the introduction section of this paper, natural disturbances have increasingly been recognized by forest ecologists and conservation biologists as critical ecosystem processes that shape landscapes, accentuate the inherent complexity in patterns of landscape cover, and create habitats for species (Lindenmayer and Hunter, 2010; Moore et al., 2008). These results are consistent with other recent studies that have suggested that the drivers of deforestation and forest degradation identified in REDD+ participating countries lack considerations on natural disturbances (Angelsen et al., 2012; Kissinger et al., 2012). Therefore, while REDD+ initiatives might have promising implications that are based on a nuanced understanding of the dynamic interactions of socio-political and economic variables, it is less clear that the understanding underlying these projects takes into consideration the potential importance of knowledge on the structure and function of the ecological systems in which the projects are proposed, in particular natural disturbances.

4. Discussion

Thus far, we examined factors that were identified as the drivers of deforestation and forest degradation within the context of the World Bank's REDD+ initiatives from the perspective of contemporary forest ecology. While much literature argues that natural and human disturbances interact to pose important problems for natural resources management projects (Holling and Meefe, 1996; Rudel et al., 2009), REDD+ initiatives – an ideal example of contemporary forest management projects – do not pay adequate attention to these dynamic interactions. Ecological literature has long recognized that the continued existence of particular species or communities often requires disturbance of some sort, and consequently, disturbance regimes must be integrated with management policies (White and Jentsch, 2001). This contemporary understanding of dynamic ecosystems and the importance of natural disturbances in driving those dynamics, we argue, must be utilized to improve the design of the REDD+ initiatives because the stage upon which REDD+ initiatives unfold is an active and ever-changing one due to the dynamic character of ecosystems and naturally induced disturbances.

Disturbance frequency, extent, and severity vary across biophysical settings and geographic gradients such that some ecosystems may be subject to large and/or infrequent disturbances, while others may be subject to smaller and/or more frequent disturbances. Natural disturbances vary from the removal of a single plant to the synchronous death of the whole forest (Peet, 1991). We argue that it is essential to correctly understand the disturbance regime of an ecosystem in designing and managing areas for REDD+ initiatives just as it is for other forms of ecological management (Baker, 1992; Pickett and Thompson, 1978). Ignoring the potential role natural disturbances may play in a given system might lead to an implicit assumption that natural disturbances are not important and that, in effect, ecosystems are static. Such oversights may lead to unforeseen surprises because forest disturbances affect regeneration, carbon dynamics, and other aspects of structure and function and because they can compound the effects of anthropogenic disturbances (McKenzie et al., 2004). Indeed, from this alone, it follows that it is impossible to realistically plan likely carbon emissions or future forest conditions without understanding the natural and anthropogenic disturbance regime of a given ecosystem. While we acknowledge that it is important that REDD+ initiatives address the institutional policies, political–economic contexts,

Table 1 – Participant countries of the World Bank FCPF's REDD+ initiatives sources: to download the following documents, visit http://www.forestcarbonpartnership.org/fcp/node/203.

Regions	Countries	Documents	Dates
Africa	1. Cameroon	Readiness Plan Idea Note	July 2008
	2. Central African Republic	Readiness Preparation Proposal	September 2011
	3. Congo, Democratic Republic of	Readiness Preparation Proposal	July 2010
	4. Congo, Republic of	Readiness Preparation Proposal	April 2010
	5. Ethiopia	Readiness Preparation Proposal	May 2011
	6. Gabon	Readiness Plan Idea Note	May 2008
	7. Ghana	Readiness Preparation Proposal	December 2010
	8. Kenya	Readiness Preparation Proposal	August 2010
	9. Liberia	Readiness Preparation Proposal	May 2011
	10. Madagascar	Readiness Preparation Proposal	October 2010
	11. Mozambique	Readiness Preparation Proposal	March 2012
	12. Tanzania	Readiness Preparation Proposal	October 2010
	13. Uganda	Readiness Preparation Proposal	May 2011
Asia-Pacific	1. Cambodia	Readiness Preparation Proposal	March 2011
	2. Indonesia	Readiness Plan Idea Note	May 2009
	3. Lao People's Democratic Republic	Readiness Preparation Proposal	December 2010
	4. Nepal	Readiness Preparation Proposal	September 2010
	5. Papua New Guinea	Readiness Plan Idea Note	July 2008
	6. Thailand	Readiness Plan Idea Note	March 2008
	7. Vanuatu	Readiness Plan Idea Note	July 2008
	8. Vietnam	Readiness Preparation Proposal	November 2011
Latin America and the Caribbean	1. Argentina	Readiness Preparation Proposal	June 2010
	2. Bolivia, Pluri-national State of	Readiness Plan Idea Note	March 2008
	3. Chile	Readiness Plan Idea Note	January 2012
	4. Colombia	Readiness Preparation Proposal	September 2011
	5. Costa Rica	Readiness Preparation Proposal	August 2010
	6. El Salvador	Readiness Plan Idea Note	February 2009
	7. Guatemala	Readiness Preparation Proposal	January 2012
	8. Guyana	Readiness Preparation Proposal	March 2010
	9. Honduras	Readiness Plan Idea Note	February 2009
	10. Mexico	Readiness Preparation Proposal	February 2010
	11. Nicaragua	Readiness Plan Idea Note	July 2003
	12. Panama	Readiness Plan Idea Note	April 2008
	13. Paraguay	Readiness Plan Idea Note	July 2008
	14. Peru	Readiness Preparation Proposal	March 2011
	15. Suriname	Readiness Preparation Proposal	January 2009

and social settings that drive deforestation and degradation, we argue that sufficient attention on the natural disturbance regimes of the proposed REDD+ project area – which might include fires, droughts, hurricanes, pathogen and insect outbreaks – is also required.

4.1. *Research directions*

We therefore propose that REDD+ initiatives incorporate, as part of their foundation, studies that examine and describe the history of and likely future trajectory of natural disturbance regimes in the potential areas for the projects. One of the ways to describe the disturbance history of a particular landscape is to describe the dimensions of disturbance regimes relative to the spatial and temporal dimensions of the ecological units in question (White and Jentsch, 2001). In other words, we suggest incorporating into REDD+ policy planning the concept of ''disturbance regime'', which Pickett and White (1985) advocated as a conceptual framework for considering the characteristics and consequences of disturbances, of the coordination of spatial and temporal characteristics of disturbances in a particular landscape. According to Pickett and White (1985), the key potential descriptors of a disturbance regime include: spatial distribution; frequency (mean number of events per time period; size of the area disturbed; frequency; predictability; rotation period (time required to disturb an area equivalent to the study area once)); magnitude or severity; and the synergistic interaction of different kinds of disturbances and their driving factors (e.g., climate or human ignition sources). We anticipate that the integration of an understanding of disturbance regimes to the reconceptualization of the drivers of deforestation and degradation within a REDD+ country would require the following:

1. Identification of literature on natural disturbances in the potential REDD+ countries; and description of those disturbance regimes. The amount of such literature varies across countries and regions. For example, substantial ecological research on fires, insect outbreaks and other natural forest disturbances has been conducted in Argentina and Mexico but much less in Cambodia or Ethiopia. Thus, new empirical research would be required for some countries where previous research on natural forest disturbances or historical range of variability is lacking.

Table 2 – Drivers of deforestation and forest degradation in the 36 FCPF's participant countries.

Countries	Drivers of deforestation and forest degradation	
	Proximate	Underlying
Argentina	Unsustainable logging, plantations replacement and small farmers plantations Urban development Human-induced forest fires Unsustainable activities of small and medium farmers, specially livestock grazing Soybean cultivation and infrastructure development	Insufficient coordination and alignment of public policies that affect forests Historic implementation deficit in the forest sector and implementation of land planning tools Insufficient allocation of resources and institutional capacities for monitoring and forestry development High opportunity cost of land and insufficient incentive to conserve and sustainable use of forests land uses The value of standing forest is very low Lack of regularization of land tenure and related conflicts
Bolivia	Advancement of agricultural frontier Slash and burn practices caused by migrants and colonists Forest fires for forest clearance in agricultural expansion and slash and burn practices Infrastructure development – roads and gas pipelines Mining activities	Low prices of land in Bolivia Increases in the price of soy and bio-energy market dynamics Weaknesses in the governance of forest and agricultural sectors Migration to lower lands due to food insecurity Forest road development that leads to further colonization and deforestation
Cambodia	Unsustainable and illegal logging Unsustainable wood fuel collection Clearance for agriculture Expansion of settlements	Population increases Migration into forest areas Social norms (claiming land through utilisation) Increasing accessibility of forest areas Regional demand for resources Weak forestland tenure Lack of a fair and transparent conflict resolution mechanism Insufficient implementation of land-use planning Low economic benefits provided by forests at the national level in comparison with alternatives Low awareness of environmental roles of forests
Cameroon	Development of agricultural activities Illegal exploitation of timber Exploitation of fuelwood System of industrial exploitation in Forest Management Units Numerous projects linked to the development of the mining sector	Demographic growth Framework of the Strategic Document concerning the growth and reduction of poverty Anthropogenic uses of fires (hunting, grazing areas) Cultural causes – the system of inheritance in the forest zones
Central African Republic	Unsustainable extensive livestock farming Slash and burn agriculture Development of cash crops (rubber tree, cotton, coffee) Uncontrolled harvest of timber and NTFPs Development of Infrastructure (roads/bridges, mining, housing)	Lack of policy coordination and weak institutional capacities Lack of dissemination of technical tools Weak economy largely based on the exploitation of natural resources High population growth and rural exodus Lack of understanding of the notion of environmental common good Insecurity and political/military conflicts
Chile	Over extraction of high-value logs and fuel wood Livestock grazing	Poverty of small landowners Lack livelihood alternatives
Colombia	Extension of agricultural and livestock frontier Illicit crops Settlement/displacement of populations Infrastructure – energy-related activities, roads, etc. Mining activities Removal of timber for sale or personal consumption	Demographic, economic, political/institutional, technical, environmental, or cultural factors Expansion of the agricultural frontier and colonization, Development of illicit crops
Congo, Democratic Republic of	Infrastructures extension Transportation development (road, railway, river road) Settlements – migration toward forest Public services (water lines, electrical grids, fuel wood, charcoal) Mining exploitation (informal vs. formal) Private infrastructure (hydropower, oil exploitation)	Demographic factors (natural increment, migration, and population density and distribution) Economic factors (market growth and commercialization, economic structures, urbanization and industrialization) Technological factors (agro technical changes, techniques in the wood-energy sector) Policy and institutional factors (corruption, mismanagement, land tenure issues and property rights Cultural factors (public attitudes, values and beliefs, individual and household behaviors seeking short-term immediate gains)

Table 2 (*Continued*)

Countries	Drivers of deforestation and forest degradation	
	Proximate	Underlying
Congo, Republic of	Unsustainable slash-and-burn practices Unsustainable production and consumption of fuelwood Unsustainable or even illegal logging; and Urban development	Absence of a national land-use plan: Low access to inputs (credit, improved seeds, fertilizers) Population growth creating a higher need for cultivated food Poverty: Lack of alternative energy sources adapted to low incomes Weak forest governance by the state, the local collectivities and their agents Proximity of consumption and export areas Operation of logging concessions without a preliminary management plan Infringement of low impact logging regulations Absence of a national study on growth and recovery of tree species Lack of promotion and market opportunities for the so-called secondary species Absence or lack of respect of urban planning master plans
Costa Rica	Establishment and expansion of agriculture and livestock Promotion of commercial crops such as coffee and sugar cane Rural settlement policies	Opening of the meat markets in the United States, Macroeconomic, especially political, demographic or technological elements
El Salvador	Expansion of agricultural frontier Logging to obtain firewood and timber Construction of shrimp and salt Illegal logging for timber, and Establishment of salt and small shrimp Urbanizations and housing development	Lack of approval by the Executive of the Forest Policy Lack of managerial, technical and administrative capacity Lack of knowledge, information and awareness by civil society leading to continue illegal harvesting in forested areas Unclear political commitment to define the limits of protected areas and mangroves Low land productivity within small properties schemes Lack of adequate coordination among related entities, particularly Ministries of Agriculture, Environment and local governments (municipalities) and civil society Lack of conditions that ensure private investments in the forestry sector and integrate forestry production into broader productive chains Lack of a strategic framework that considers the role of the forest sector into national development strategies
Ethiopia	Expansion of traditional agriculture Expansion of large scale development activities Settlement programs Wood extraction & other forest products collection Human-induced forest fires	Deficiencies in the regulatory and institutional environment Inappropriate regulation, or the absence of means of implementation, combined with the absence of a strong, dedicated forestry institution Unclear, uncoordinated and overlapping roles and responsibilities of relevant institutions
Gabon	Development of agricultural activities Settlement of populations near urban areas and Development of a blooming industrial mining activity and infrastructure Illegal logging for timber and construction	Demographic pressure Improvement of communication networks leading to development of new mining activities (gold, manganese, iron), Price increase on agricultural markets and development of biofuels
Ghana	Timber harvesting – industrial and chainsaw logging Non-mechanized agriculture and agricultural practices Agricultural expansion, land conversion for beverage, oil and other crops Small-scale agriculture and pastoralism Energy – firewood and charcoal Mining – large-scale and artisanal	Weak regulatory and enforcement mechanisms and rights regimes Imbalances in forest exploitation, in favor of large-scale timber industry Population growth and urban expansion Limited technology development in farming systems High international prices for primary products (wood, agricultural and minerals) Policy and market failures in timber pricing Low local purchasing power within agricultural economy Natural causes – wind, natural fire events, floods, pests and diseases

Table 2 (*Continued*)

Countries	Drivers of deforestation and forest degradation	
	Proximate	Underlying
Guatemala	Land use change Firewood consumption Human-induced forest fires Illegal logging with industrial purposes	High unemployment rate in the rural area Corruption Culture of clean crops Institutional weakness in monitoring and control Flaws in market intermediation Financial market Inefficient public policies
Guyana	Forest land conversion for agriculture – livestock, crops, and aquaculture Forest land conversion for mining Logging activities Forest land conversion for roads Forest land conversion for urban development (housing) Forest land conversion for energy development Fires (agricultural fires and accidental burning of forest)	Lack of security on land tenure, user rights are disincentives to land and user rights Mangrove improvement for sea defense purposes Limited utilization of NTFPs and Environmental services Benefits sharing – lack of benefits sharing systems for REDD+ practices
Honduras	Forest fires impact Illegal logging	Inequitable distribution of productive land induces migratory flows to forest areas attractive for the apparent fertility of their soils Disputes over land use Poor planning and participative implementation of management plans in protected areas Government lack budget
Indonesia	Rapidly growing of forest plantation and pulp and paper industry Oil palm plantation Forest encroachment Unsustainable levels of logging from legally permitted forest concessions Illegal logging at small and large scales	Population increase and increasing demand for food Unplanned encroachment from communities of local people or other commercial forest users Insufficient incentives for communities and governments for maintaining protected areas Low capacity of institutions charged with managing the protected areas
Kenya	Allowing grazing in forest reserves Unsustainable charcoal production/large urban market for charcoal fuel Conversion of trust-land woodland to agricultural use for large-scale commercial production of bio fuel crops or other agricultural crops Other agricultural expansions Conversion of coastal forest to other uses Lack of knowledge and use of appropriate technology in tree growing, and nurseries production Lack of knowledge by the population about impacts of deforestation Improved saw milling technology Fires used in agricultural clearing, inadequate capacity to manage fires	Poor governance, including weak institutions, corruption, illegal logging, weak law enforcement Weak community participation in forest management Inadequate benefit sharing from forest resources (including revenue sharing) Local authorities do not value their forests Communal land systems – lack of private ownership of the resources/land Unclear tenure and access to forest resources (e.g., Local Authority forests) Agricultural policies urging farmers to produce more cash crops for export The focus on gazette forests has led to reduced attention on dry land woodlands and other types of forests including coast and riparian forests Harvesting ban in plantation forests Inadequate integration of the forest sector into the economy and national accounting High prices for agricultural products Subsidies/incentives – tax exemption for fertilizers, for farming tractors Fixing timber prices at too low levels Lack of security of supply of timber to the sawmilling industry (low investment in timber processing technology, poor timber conversion ratios)

Table 2 (*Continued*)

Countries	Drivers of deforestation and forest degradation	
	Proximate	Underlying
Lao People's Democratic Republic	Pioneering shifting cultivation Infrastructure/hydropower developments Unsustainable wood extraction Agricultural expansion and the establishment of industrial tree plantations	Weak control and monitoring of forest management activities Growing domestic/international demand Weak governance, insufficient capacities of local authorities Inadequate extension services, inadequate budget allocation Insufficient availability of information and appropriate technologies Consumption pattern especially in neighboring countries and overseas Weaknesses in regional/international rules and cooperation Insecure land tenure
Liberia	Commercial and chainsaw logging Shifting cultivation Plantation and permanent agriculture Charcoal production Development of onshore oil wells and pipelines Mineral extraction and mining	Overemphasis on commercial forest use over conservation and non-destructive uses Ineffective regulatory supervision Corruption of forest service Lack of capacity to implement sustainable forest management and prevent unsustainable or unregulated logging Lack of forest monitoring, evaluation and certification processes High international demand and prices Unsatisfied local markets (inadequate supplies at wrong prices) Excess processing capacity Unregulated cross border trade in forest products Impermanent agriculture comprising small plots without fixed investment in productivity Access to forest land enabled by forest roads and capacity for land clearance enhanced by chainsaw logging Lack of accessible markets to justify investment in productivity and larger production units Need to provide subsistence food requirements, particularly in response to internal migration and resettlement after war Need to meet deficit in domestic food production Lack of coordinated land use planning Inefficient cooking fuel for food preparation
Madagascar	Forest conversion for agriculture Unsustainable logging Livestock grazing Unsustainable consumption of fuel wood Land conversion for slash-and-burn subsistence and cash crop agriculture Uncontrolled trend of small-scale mining and illegal operations Strong dependence on wood for energy needs (fuelwood, charcoal) Non compliance with the provisions of the contract and PAG for legal operations Zebus penning in forests Fires for pasture renewal	Unsustainable agricultural and development policies Poverty and precarious livelihoods of households Lack of financial incentives for sustainable resources use Inefficient transformation industries Lack of diversification and professionalization actors Forest governance failure Unrestrained population growth and migration in forests areas Strong increase of the demand and prices of timber and relate products Poverty Poor command of harvesting, transformation, and carbonization techniques Governance failure and corruption
Mexico	Limited utilization of forested areas Uncontrolled livestock activities in forested areas Uncontrolled logging (over exploitation and/or illegal logging) Conversion to pasture land Slash-and burn agriculture	Lack of investment in forest related industries Low forestry related opportunity costs Lack of security on user rights Poverty and lack of forestry related income opportunities Government subsidy programs
Mozambique	Unsustainable agriculture practices throughout the country Unsustainable production of biomass energy and inefficient consumption Construction materials (poles in particular) Unsustainable and illegal logging Uncontrolled fires Infrastructure (settlements, roads, electricity transmission) Mining and settlements (horizontal expansion of urban areas)	Rapid population increase Limited extension network and limited access to technologies and markets Demand for commodities in international markets Investment policies and taxation including royalties Increasing large scale plantations Limited law enforcement capacity

Table 2 (*Continued*)

Countries	Drivers of deforestation and forest degradation	
	Proximate	Underlying
Nepal	Illegal and unsustainable harvest of forest products Human-induced forest fire Encroachment Overgrazing Infrastructure development Resettlement Expansion of invasive species	Inefficient forest product use Weak governance and governance vacuum Inefficient distribution mechanisms for timber and firewood Market failure Poverty and lack of livelihoods opportunities High cross border demand for forest products Insecure tenure Insufficient technical inputs Poverty and lack of livelihoods opportunities New economic growth prospects (e.g., oil and gas, transmission lines, cement factory, airport, hydropower dam, etc.) Poorly enforced planning regulations Lack of proven eradication practices
Nicaragua	Forest fires used for expanding the agricultural border Illegal logging Natural phenomena – hurricanes over the past 20 years Insecurity in land tenure	Forest sector has not been a matter of priority on the agenda of the Government Low valuation for environmental and economic services Severe budgetary constraints of the institution administering the forest scheme Weak institutional and inter-agency coordination Lack of market for financial compensation for environmental services
Panama	Irresponsibility uses of fires Traditional and mechanized agricultural practices Practices of extensive stockbreeding Taking advantage of forests in a disorderly and unsustainable manner Inadequate practices for the exploitation of the mining resources	Excessive development frameworks Extreme poverty Culture of the pasture and the incorrect appraisal of the forest resources Low level of education and environmental culture Badly planned urban development
Papua New Guinea	Shifting cultivation Commercial logging Large-scale commercial agriculture Human-induced forest Fires Mining and petroleum exploration and development Infrastructure development Settlements and urbanization Natural sources (Earth quakes, volcanic eruptions, tectonic movements, landslips, and flooding)	Not specified in the document
Paraguay	Slash and burn activities to open areas for agriculture and livestock Expansion of the agriculture frontier exacerbated by a steady increase on commodities prices such as soybean Road, dam and commercial fishing development projects Inadequate use of fire Unsustainable forestry activities	Competition from illegal forestry activities that pay little or no taxes and deal with little bureaucracy Few options for long-term financing of sustainable forestry operations or little knowledge of how to access them High perception of risk regarding products and companies of Paraguayan origin leading to lower prices or less potential for joint-ventures Little entrepreneurial culture to generate innovative ventures Insecurity with regard to land tenure and long-term ownership of forests Relatively inexpensive land Close proximity to Brazil Improved infrastructure through multilateral bank investments in the road system, Increased beef and milk processing capacity Reduced or total absence of social pressures from invasion and expropriation

Table 2 (*Continued*)

Countries	Drivers of deforestation and forest degradation	
	Proximate	Underlying
Peru	Expansion of agricultural and livestock-raising frontier Construction of road, and hydropower infrastructure Urban expansion Mining activities Inappropriate use of forest resources Unsustainable logging Forest fires for agricultural purposes	Poverty and inequity among forest residents Lack of skills and tools for appropriate forest use Population growth and greater access to forests Uncontrolled internal migration and greater access due to infrastructure Economic development programs without sufficient management of environmental impact assessment requirements Overlapping of land tenure categories Uncertain land tenure status of native communities Lack of understanding of forest management Lack of control and monitoring system Corruption, illegality and informality Unregulated domestic wood market Deficient institutional coordination Overlapping of responsibilities on forestry issue Lack of civil society participation in program development and decision making
Suriname	Mining – bauxite and gold Slash and burn agriculture Energy production Infrastructural developments	Weak enforcement and monitoring of mining activities Increased accessibility of the interior due to road building Development and accessibility to specialized mining methods Weak enforcement and monitoring mechanism on logging activities Insufficient awareness about REDD and the importance of sustainable forest management International demand for timber and timber products Increased accessibility of the interior Poor land use planning Increased housing construction projects (public grand private sector) Increased industrial activities excluding mining and agriculture Finance sources available that do not require ESIA Export Act regarding Agriculture and Forest products
Tanzania	Agricultural expansion and human settlements Overgrazing Timber extraction, firewood and charcoal production Uncontrolled fires during land preparation for shifting cultivation, collecting honey, making charcoal, hunting or livestock grazing Development of infrastructure/industry (road and railway construction, industries, hydroelectric projects and mineral and oil extraction) Land clearing for refugee campsites, construction material, fuelwood and agricultural crop production Bio-fuel production	Market failures Policy failures Rapid population growth and rural poverty
Thailand	Shifting cultivation and forest fires Land resettlement, dam and road construction and conversion to agricultural use Demand for land for subsistence farming, rubber plantation Commercial agriculture, physical infrastructure, land development for tourism	Not specified in the document
Uganda	Agricultural encroachment into forested land Unsustainable charcoal production Unsustainable firewood and timber harvesting Livestock grazing and bush burning Settlement and urbanization Oil exploration	Agricultural policies Population growth Uncertainty over access and use of forest resources Poorly defined modalities for stakeholder engagement Weak coordination among various actors in forestry management Weak institutional capacities for enforcing forestry policies and legislation

Table 2 (*Continued*)

Countries	Drivers of deforestation and forest degradation	
	Proximate	Underlying
Vanuatu	Subsistence land use Conversion to agriculture and subdivisions Activities of international logging companies Urban and peri-urban infrastructure development	Need stronger link between forestry and agriculture, through agroforestry Institutions need to meet the development needs of the forest sector whilst allowing natural forests to remain protected where possible and appropriate
Vietnam	Forest conversion to agriculturally cultivated land Infrastructure development and hydropower plans Unsustainable and illegal logging Forest fires from slash and burn practices	National and provincial policies and plans for expansion of agriculture Forest classification systems and procedures Weak law enforcement and impunity for land encroachment Undervaluing forest goods and services Poverty alleviation Traditional agricultural practices Population growth and demand for energy Poor planning and consideration of environmental impacts Lack of appropriate mitigation and compensation measures Weak accountability mechanisms for planning and approval of development projects Lack of legal safeguards Poor awareness and knowledge and data gaps

2. Establishment of the spatial and temporal frame of reference to compare the different data sets by documenting how the observations within the existing literature and empirical fieldwork were conducted.
3. Utilization of the understanding of disturbance regimes to determine the appropriate size of areas to be set aside to account for natural disturbances of a given country or region. That size will vary spatially across ecosystems and biophysical settings and temporally with climatic fluctuations. For example, in regions in which natural disturbances are large, even if infrequent (for example, occurring on the order of centuries), areas set aside for REDD+ should

Table 3 – Thematic drivers of deforestation and forest degradation in FCPF's 36 REDD+ participant countries.

Proximate drivers	Underlying drivers
1. Agricultural encroachment into forested lands, e.g. - Shifting or slash-and-burn cultivation - Weak extension systems - Unsustainable activities of small and medium scale farmers - Soybean cultivation - Permanent cultivation (large-scale commercial agriculture) - Livestock grazing - Bush burning 2. High dependency on forests and forest products, e.g. - Unsustainable charcoal production, Limited access to alternative sources of energy - Poor conversion technology - Unsustainable firewood harvesting practices 3. Illegal logging and unsustainable timber harvesting 4. Wild fire by hunters and livestock herders 5. Infrastructure development, e.g. - Transportation (e.g., roads, railways, river roads) - Settlement - Urbanization 6. Mining and oil exploration, e.g. - Development of on-shore oil wells and pipelines - Mineral extraction and other mining activities	1. Demographic factors, e.g. - Population increase and distribution - Migration in forest areas 2. Economic factors, e.g. - Land speculation - Low economic benefits provided by forests at the national level in comparison with alternatives - Policies for market growth and commercialization - Unregulated cross-border trade in forest products - Poverty and precarious livelihoods of households 3. Technological factors, e.g. - Agro technical changes (in/extensification) - Poor agricultural practices and resultant soil degradation - Greater access to forest lands due to infrastructure development 4. Policy and institutional factors, e.g. - Unclear/weak forest tenure system - Deficient and insufficient coordination and alignment of public policies that affect forests - Insufficient allocation of resources and institutional incentive to conserve and sustainable use of forests land uses - Insufficient implementation of land-use planning - Corruption of forest service - Lack of civil society participation in program development and decision making 5. Cultural factors, e.g. - Public attitudes, values, beliefs (unconsciousness, mentality oriented on colonization of forest) - Individual and household behaviors (seeking short-term immediate gains) - Social exclusion of forest resident

also be large enough to minimize the possibility that a large portion of any given project area would be disturbed by a single event, which would clearly alter the efficacy of the project area in sequestering and storing carbon and otherwise meeting the stated needs of the initiative.

4. Determination of the spatial and temporal patterns of the dominant natural and anthropogenic disturbance regimes and the integration of this understanding with the institutional, political, economic and social causes of deforestation and degradation.

5. Conclusion

The World Bank's REDD+ initiatives have the potentials to deliver benefits to human societies and forest ecosystems. However, to ensure that those benefits are achieved, an improved understanding of how the drivers of deforestation and degradation are identified within the context of REDD+ is required. It should be acknowledged that the goal of this paper is not to comment on the validity or credibility of those political, social and economic factors identified as drivers of deforestation and forest degradation in the 36 national policy documents that we reviewed. Rather our main objective has been to draw attention to the lack of consideration of underlying ecosystem dynamics, in particular natural disturbance regimes, that may be driving and/or interacting with those identified drivers. It cannot be known "how important" natural disturbances are for a given REDD+ participating country, until research is conducted in that country – and this not knowing is a major vulnerability in the current design of REDD+ projects. Thus we suggest that there is an urgent need for more research in REDD+ participating countries on the roles of natural disturbances.

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REFERENCES

Angelsen, A. (Ed.), 2008. Moving Ahead with REDD: Issues, Options and Implications. Center for International Forestry Research, Bogor.

Angelsen, A., Brockhaus, M., Kanninen, M., Sills, E., Sunderlin, W.D., Wertz-Kanounnikoff, S. (Eds.), 2009. Realizing REDD+: National Strategy and Policy Options. Center for International Forestry Research, Bogor.

Angelsen, A., Brockhaus, M., Sunderlin, W., Verchot, L. (Eds.), 2012. Analyzing REDD+: Challenges and Choices. Center for International Forestry Research, Bogor.

Asner, G., Broadbent, E., 2006. Condition and fate of logged forests in the Brazilian Amazon. Proceedings of the National Academy of Science of the United States of America 103, 12947–12950.

Attiwill, P., 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. Forest Ecology and Management 63, 247–300.

Baker, W., 1992. The landscape ecology of large disturbances in the design and management of nature reserves. Landscape Ecology 17, 181–194.

Bosquet, B., Aquino, A.R., 2011. Brochure of the Forest Carbon Partnership Facility. The World Bank's Carbon Finance Unit, Washington, DC.

Botkin, D., 1990. Discordant Harmonies: A New Ecology for the Twenty-first Century. Oxford University Press, New York.

Christensen, N., Agee, J., Brussard, P., Hughes, J., Knight, D., Minshall, G., Peek, J., Pyne, S., Swanson, F., Thomas, J., Wells, S., Williams, S., Wright, H., 1989. Interpreting the Yellowstone fires of 1988. Bioscience 39, 678–685.

CIFOR, 2012. Forests and Climate Change: The Global Comparative Study of REDD+. http://www.forestsclimatechange.org/global-comparative-study-on-redd.html (accessed 10.06.12).

Covington, W., Niering, W., Starkey, E., Walker, J., 1999. Ecological restoration and management: scientific principles and concepts. In: Johnson, N., Malk, A., Sexton, W., Szaro, R. (Eds.), Ecological Stewardship: A Common Reference for Ecosystem Management. Elsevier Scientific, Ltd., Oxford.

Dale, V., Joyce, L., McNulty, S., Neilson, R., Ayres, M., Flannigan, M., Hanson, P., Irland, L., Lugo, A., Peterson, C., Simberloff, D., Swanson, F., Stocks, B., Wotton, B., 2001. Climate change and forest disturbances. BioScience 51, 723–734.

Geist, H., Lambin, E., 2002. Proximate causes and underlying driving forces of tropical deforestation. BioScience 52, 143–150.

Hobbs, R., Huenneke, L., 1992. Disturbance, diversity, and invasion: implications for conservation. Conservation Biology 6, 324–337.

Holling, C., Meffe, G., 1996. Command and control and the pathology of natural resource management. Conservation Biology 10, 328–337.

Johnson, E., Miyanishi, K., Weir, J., 1998. Wildfires in the western Canadian boreal forest: landscape patterns and ecosystem management. Journal of Vegetation Science 9, 603–610.

Kissinger, G., Herold, M., De Sy, V., 2012. Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers. Lexeme Consulting, Vancouver.

Kulakowski, D., Veblen, T., 2006. Historical Range of Variability for Forest Vegetation of the Grand Mesa National Forest. USDA Forest Service, Boulder, CO.

Lindenmayer, D., Hunter, M., 2010. Some guiding concepts for conservation biology. Conservation Biology 24, 1459–1468.

Long, J., 2009. Emulating natural disturbance regimes as a basis for forest management: a North American view. Forest Ecology and Managament 257, 1868–1873.

MacArthur, R., Wilson, E., 1969. The Theory of Island Biogeography. Princeton University Press, Princeton.

May, R., 1971. Stability in multi-species community models. Mathematical Biosciences 12, 59–79.

May, R., 1972. Will a large complex system be stable? Nature 238, 413–414.

McKenzie, D., Gedalof, Z., Peterson, D., Mote, P., 2004. Climatic change, wildfire, and conservation. Conservation Biology 18, 890–902.

Moore, S., Wallington, T., Hobbs, R., Ehrlich, P., Holling, C., Levin, S., Lindenmayer, D., Pahl-Wostl, C., Possingham, H., Turner, M., Westoby, M., 2008. Diversity of current ecological thinking: implications for environmental management. Environmental Management 43, 17–27.

Morgan, P., Aplet, G., Haufler, J., Humphries, H., Moore, M., Wilson, W., 1994. Historical range of variability: a useful tool

for evaluating ecosystem change. Journal of Sustainable Forestry 2, 87–111.
Myers Madeira, E., 2008. Policies to Reduce Emissions from Deforestation and Degradation (REDD) in Developing Countries: An Examination of the Issues Facing the Incorporation of REDD into Market-Based Climate Policies. Resource for the Future, Washington, DC.
Oliveira, P., Asner, G.P., Knapp, D., Almeyda, A., Galván-Gildemeister, R., Keene, S., Raybin, R., Smith, R., 2007. Land-Use Allocation Protects the Peruvian Amazon. Science 317, 1233–1236.
Parrotta, J., Wildburger, C., Mansourian, S. (Eds.), 2012. Understanding Relationships between Biodiversity, Carbon, Forests and People: The Key to Achieving REDD+ Objectives. Global Forest Expert Panel on Biodiversity, Forest Management and REDD+: A Global Assessment Report.
Peet, R.K., 1991. Case studies in natural systems: lessons from nature. In: Real, L., Brown, J. (Eds.), Foundations of Ecology: Classic Papers with Commentaries. The University of Chicago Press, Chicago.
Pickett, S., Thompson, J., 1978. Patch dynamics and the design of nature reserves. Biological Conservation 13, 27–36.
Pickett, S., White, P., 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press, London/New York.
Raffa, K., Aukema, B., Bentz, B., Carroll, A., Hicke, J., Turner, M., Romme, W., 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. BioScience 58, 501–517.
Rudel, T., DeFries, R., Asner, G., Laurance, W., 2009. Changing drivers of deforestation and new opportunities for conservation. Conservation Biology 23, 1396–1405.
Shugart, H., West, D., 1981. Long-term dynamics of forest ecosystems. American Scientist 69, 647–652.
Swetnam, T.W., Allen, C.D., Betancourt, J.L., 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications 9, 1189–1206.
Turner, M., Romme, W., Gardner, R., O'Neill, R., Kratz, T., 1993. A revised concept of landscape equilibrium: disturbance and stability on scaled landscapes. Landscape Ecology 8, 213–227.
UN-REDD Programme and UNEP-WCMC, 2010. Beyond Carbon: Ecosystem-based Benefits of REDD+. , Geneva, Switzerland.
UNFCCC, 2012. REDD Web Platform: Demonstration Activities. United Nations Framework Convention on Climate Change. , Bonn.
Verchot, L., Petkova, E., 2010. The State of REDD Negotiations: Consensus Points, Options for Moving Forward and Research Needs to Support the Process. The Center for International Forestry Research, Bogor.
Walker, B., Kinzig, A., Langridge, J., 1999. Plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. Ecosystems 2, 95–113.
White, D., Minang, P. (Eds.), 2011. Estimating the Opportunity Costs of REDD+: A Training Manual. Forest Carbon Partnership Facility and Carbon Finance Assist. Washington, DC.
White, P., Harrod, J., Walker, J., Jentsch, A., 2000. Disturbance, scale, and boundary in wilderness management. In: Cole, D., McCool, S. (Eds.), Proceedings: Wilderness Science in a Time of Change. Proceeding RMRS-P-000. Utah US Department of Agriculture Forest Service Rocky Mountain Research Station. United States Department of Agriculture, Washington.
White, P., Jentsch, A., 2001. The search for generality in studies of disturbance and ecosystem dynamics. Progress in Botany 62, 399–450.

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