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Assessing ecosystem services in Neotropical dry forests: a systematic review

THEMATIC SECTION
Forest Ecosystem Services

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SUMMARY

There is an increasing consensus on the importance of understanding ecosystem service (ES) provision in order to facilitate decision making and the sustainable management of Neotropical dry forests (NTDFs), yet research on the ESs provided by NTDFs is limited. We identified the main existing gaps and trends in the quantification of provisioning, regulating and supporting ESs in NTDFs. Systematic web-based searches showed that research has been increasing in recent decades in NTDFs, supporting greater ES knowledge and assessment. Carbon storage and biodiversity are the main subjects under study, while ESs relating to water and soil lack investigation. The most common approaches for assessing ES were fauna and plant inventories, carbon dynamics and ecological processes.

Keywords: ecosystem services, Millennium Ecosystem Assessment, Neotropical dry forests, carbon storage, biodiversity, water, soil

INTRODUCTION

Neotropical dry forests (NTDFs) are considered to be the first frontier for economic development in Latin America. Early Mesoamerican cultures and later Spanish and Portuguese conquerors selected this ecosystem when creating their first human settlements (Murphy & Lugo 1986; Sanchez-Azofeifa *et al.* 2005). Today, the economic and anthropogenic pressures on NTDFs have made them one of the most deforested and the least protected forest ecosystems of the Americas (Janzen 1988; Sanchez-Azofeifa *et al.* 2005; Calvo-Alvarado *et al.* 2009; Portillo-Quintero & Sanchez-Azofeifa 2010). Tropical dry forests are broadly defined as a vegetation type dominated by deciduous trees (at least 50% of the trees are drought deciduous), with an annual average temperature of 25°C or higher, annual precipitation of 700–2000 mm per year and a dry season (precipitation of less than 100 mm) of 3 or more months (Sanchez-Azofeifa *et al.* 2005).

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The current extent of NTDFs in the Americas is 519 597 km^2, or 34% of their potential biogeographic distribution. NTDFs are highly fragmented, and just 4% of their current extent is protected, in contrast with 24% of protection in tropical rainforests (Portillo-Quintero & Sanchez-Azofeifa 2010; Scharlemann *et al.* 2010). NTDFs usually develop on the best agricultural soils and thus are under great pressure from population growth, land use and future climate change (Farrick & Branfireun 2013). According to Miles *et al.* (2006), more than 30% of the global tropical dry forests are at risk of decline under a climate change scenario of a 2.5°C increase. This estimate has significant implications for the functioning of NTDFs and jeopardizes the livelihoods of the communities that rely on them (Maass *et al.* 2005; Farrick & Branfireun 2013).

NTDFs provide a wide variety of ecosystem services (ESs) that are crucial for human well-being. Balvanera *et al.* (2011) have identified food (from agriculture and cattle ranching), timber, non-timber forest products, biofuels and germplasm as key contributions of NTDFs to humankind. Other ESs include soil erosion control, regulation of soil fertility, improvement of water quality, carbon storage and control of carbon emissions and climate (Balvanera *et al.* 2011). Linares-Palomino (2011) indicated that South American NTDFs are important above- and below-ground carbon reservoirs and help with the protection of soil and water. Global dry forests, their ESs and research that could contribute to their long-term sustainability have been reviewed (Sunderland *et al.* 2015). Maass *et al.* (2005) identified fresh water, agricultural and pastoral goods, preservation of biodiversity, climate regulation, maintenance of soil fertility, flood control and scenic beauty as key contributions of the Chamela–Cuixmala NTDFs to local communities.

Current governmental land management policies and regulations in Latin America are still based on the misconception that NTDFs are not important for biodiversity conservation (Portillo-Quintero *et al.* 2014), which has resulted in the absence of explicit policies for their preservation and management (Quesada *et al.* 2009). Moreover, tools to assess ESs in NTDFs are scarce, scattered and sometimes unsuitable. For example, some frameworks to evaluate ESs at a global scale include NTDFs under the general category of tropical forest, assuming that dry and humid/wet forests provide the same benefits (e.g. de Groot *et al.* 2012), but NTDFs differ markedly from wet forests in several ecological conditions (Quesada *et al.* 2009; Portillo-Quintero *et al.* 2014). Research on ESs in NTDFs has thus lagged behind research on wet forests (Quesada *et al.* 2009) and it has been difficult to develop sound policies (Portillo-Quintero *et al.* 2014). To date, a review of the provision of ESs by NTDFs is lacking, specifically one that identifies key approaches in order to assess ESs in NTDFs and the gaps in information at geographic scales.

The interplay of biophysical and social systems is extremely complex, and defining conceptual approaches is useful for the prioritization and identification of interactions and trade-offs among different ESs (Maes *et al.* 2013; Díaz *et al.* 2015). Recognizing these approaches along with scientific knowledge gaps and geographical gaps can assist decision makers in identifying priority areas for conservation and in constructing relevant policy measures, including the improvement in measuring and demonstrating or evaluating the benefits of ESs in relation to costs (Maes *et al.* 2013). ES frameworks for biodiversity conservation and sustainable development are becoming increasingly prominent in national and international environmental agendas, influencing policy elaboration at multiple levels (MEA 2005; Carpenter *et al.* 2009; Díaz *et al.* 2015; Wilcove & Ghazoul 2015).

In this paper, we analysed the different approaches for assessing ESs in NTDFs in order to quantify the best-known ESs and their geographic areas of production and to propose strategies in order to optimize policy-relevant research efforts. We focused on ESs characterized by the Millennium Ecosystem Assessment (MEA 2005) and the Common International Classification of Ecosystem Services (CICES 2013). Specifically, we identified approaches for evaluating services related to water, soil, carbon and biodiversity. Our main questions were: (1) what are the most studied types of ESs in NTDFs? (2) Does the knowledge on ESs vary across scales and between countries in the Americas? (3) What are the most common approaches used to assess ESs in NTDFs and what is the level of integration of these approaches across different ES types?

METHODS

Classification of ecosystem services

ESs have been defined in many different ways in the literature (e.g. de Groot 1992; Daily 2008). Thus, we used the concept of ESs as defined by the MEA in order to standardize our work. Since our main objective was to identify key indicators in order to evaluate and quantify ESs related to water, carbon, biodiversity and soils, we focused on provisioning, regulating and supporting services, excluding cultural services. Although cultural services may play an important role in managing ESs in NTDFs, our main purposes were describing the biophysical characteristics of the services provided by NTDFs and identifying research priorities and key knowledge gaps for future studies, thus providing baseline information that can be used for future studies that can incorporate cultural services and the perceptions of local communities that rely on service provision by NTDFs.

Data acquisition

We conducted several systematic web-based searches using keywords and Boolean operators in the Web of Science and Scopus databases. The Boolean search was built on the following keywords: tropical dry forest AND ecosystem services OR greenhouse gas regulation OR climate regulation OR carbon storage OR soils OR biodiversity OR carbon stocks OR watersheds OR biomass OR forest productivity OR water quality OR water quantity OR water supply OR fuel-wood OR non-timber forest products OR genetic resources OR flood regulation OR erosion regulation OR medicinal plants OR land use change OR land cover OR phenology OR flowering OR growth rates OR allometric equations OR pollination. The time period of publications collected was established between 1970 and 2015.

To capture relevant information that could not be tracked in the Web of Science or Scopus databases, we conducted additional searches of government publications, agency reports, non-Institute for Scientific Information (ISI) papers, websites and databases of ongoing projects, book chapters, synthesis papers or published manuals or guidelines. We searched within the results for specific NTDF terms including 'tropical dry forest', 'dry tropical forest' and 'seasonally dry tropical forest'. The abstracts and the methodologies of each publication were reviewed in order to identify the country or countries where the research took place. In this way, studies not conducted in the Americas were filtered out. Once the database with all of the studies was built, we classified each study within the categories of biodiversity, carbon, soils and water and the specific approach used in each study (Table 1). We then classified these same studies within the categories of provisioning, regulating or supporting services and their subcategories according to the ESs assessed in each study (MEA 2005).

Data analysis

We organized the information collected and classified publications by country according to the place where the research was conducted. We then evaluated whether the research was carried out at a local, national or regional scale in order to assess how studies change across spatial scales and to identify geographic gaps. Next, we obtained the percentage of publications carried out at each scale and the number of publications per country. From the total number of publications found for each country, we also determined the percentage of publications evaluating biodiversity, carbon, soils and water within each country.

A network analysis using the software Gephi (Bastian *et al.* 2009) was performed in order to reveal the general patterns and trends in the data collected (e.g. which approaches for

Table 1 Approaches used in NTDFs in order to quantify ESs related to water, carbon, soils and biodiversity.

Approach	*Biodiversity*	*Carbon*	*Soil*	*Water*	*Measurement*
Watershed				X	Nutrient load, sediment load, water quantity, hydrological modelling, land use change
Carbon gain/loss	X	X	X	X	Root biomass, carbon stocks, soil carbon stocks, growth rates, carbon dynamics
Disturbance and recovery of soil properties	X	X	X		Soil biodiversity, soil erosion, nutrient dynamics, root biomass, soil properties, soil carbon stocks, germination, seed bank
Ecological processes	X	X		X	Ecosystem functioning, plant functional groups, pollination, flowering, reproduction, germination, herbivory
Fauna inventory	X		X	X	Composition and diversity, population dynamics, changes in community, habitat selection, distribution of species, DNA barcodes
Habitat disturbance, fragmentation and recovery	X	X			Effects of forest fragmentation, restoration, succession and management, regeneration, deforestation, land use change
Land cover	X	X	X	X	Forest distribution and extent, species distribution, forest detection, monitoring deforestation, conservation areas, forest fragmentation, land use change
Mycorrhizae dynamics		X	X		Disturbance and seasonal dynamics, diversity, influence and effect on biomass
Nutrient dynamics		X	X		Nutrient availability, nutrient limitation, effects of fertilization, slash-and-burn effects, nutrient cycling (phosphorus, carbon, nitrogen, calcium, potassium and magnesium)
Plant inventory	X	X	X	X	Composition and diversity, population dynamics, changes in community, habitat selection, distribution of species, medicinal plants, non-timber forest products, plant reproduction, regeneration, seed diversity
Primary productivity		X	X	X	Photosynthesis and phenology, net primary production
Water cycling			X	X	Rainfall interception by canopy, annual rainfall, seasonality and patterns, infiltration and soil water dynamics, responses to disturbance and drought, hydraulic conductivity

ES evaluation had been used most). The main output of this analysis was a plot of the number of publications for each of carbon, biodiversity, soil and water (Table 1). Eigenvectors (K_n) were calculated for each node in the network analysis in order to assess the centrality of each node ($K_n = 1$ is the highest centrality). Eigenvectors in matrices are useful as measures of centrality or of status inside the network (Bonacich & Lloyd 2001). The K_n values allowed us to identify which of carbon, biodiversity, soil and water had the most approaches for the evaluation of their ESs (higher centrality equates to more approaches) according to all of the publications found. In the network analysis, thicker lines represented a greater number of publications using a specific approach (e.g. the plant inventory approach has a strong connection with biodiversity, meaning many publications had used this approach in order to determine biodiversity). Fine lines represented few publications found using a specific approach.

RESULTS

In total, 536 studies were identified, with 248 (46%) quantifying one or more ES related to biodiversity, 140 (26%) to carbon, 87 (16%) to soils and only 61 (11%) to water. As expected, the number of studies that quantified or measured one or more variables in order to determine ESs in NTDFs has increased over time (Fig. 1(*a*)), from 10 studies per decade (1970–1980) to more than 250 (2000–2010), although the

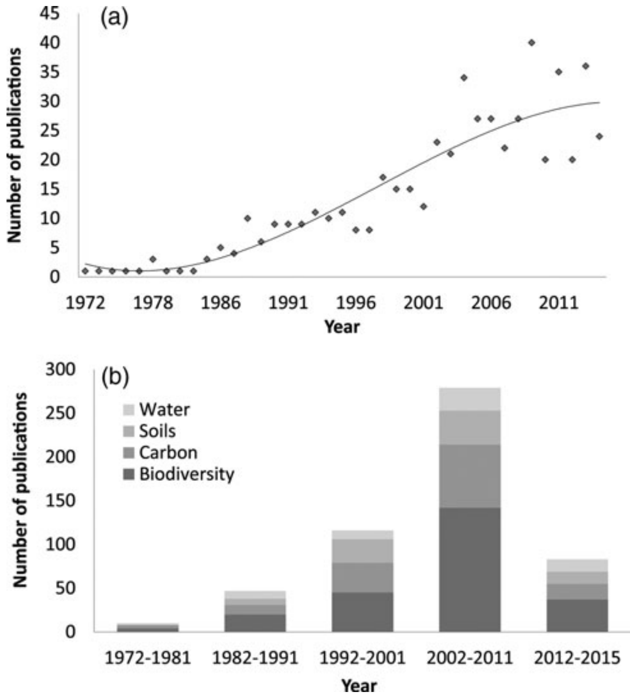

Figure 1 Number of publications found per year that evaluated an ESs in NTDFs (*a*). Number of publications found per decade that evaluated and quantified biodiversity, carbon, soils or water in NTDFs (*b*).

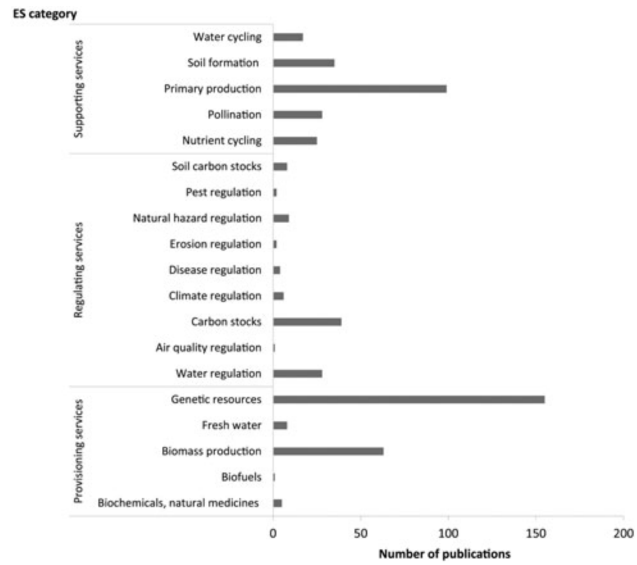

Figure 2 Number of publications found in each ES category and subcategory. Primary production is the major subcategory for supporting services; carbon stocks is the major subcategory for regulating services and genetic resources for the provision of services category.

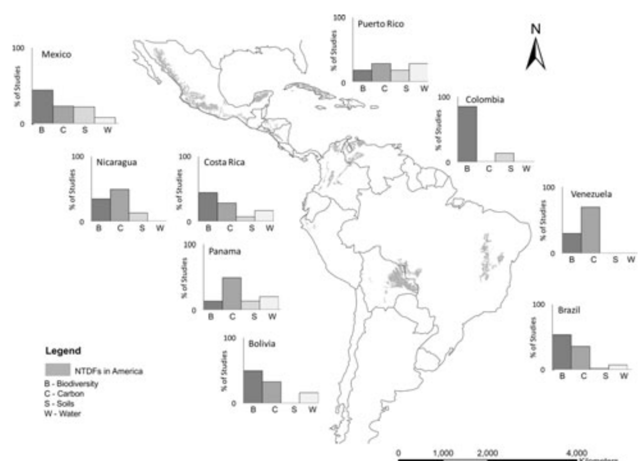

Figure 3 Distribution of NTDFs in the Americas, the number of publications per country evaluating one or more ES in NTDFs and the percentages of those publications relating to biodiversity, carbon, soils and water.

number may have tended to stabilize after 2006. Studies evaluating soils and water have increased in recent decades (Fig. 1(*b*)); however, these are still few in comparison with those evaluating carbon and biodiversity.

In general, the category of supporting services included a greater number of studies quantifying primary production (99 studies or 48%). Under regulating services, most studies focused on carbon stocks (39 studies or 39%) and water regulation (28 studies or 28%). In the provisioning services category, which is the one with the greatest number of studies (233), most of them focused on genetic resources (155 studies or 68%) and biomass production (63 studies or 27%) (Fig. 2). Regulation of air quality, pests and erosion were the least studied services in NTDFs (five studies in total).

The studies were located in 17 countries, including Mexico, Costa Rica and Brazil, which had the greatest numbers of publications (291, 96 and 39 respectively) (Fig. 3). From all of the studies evaluated, 88% focused on secondary NTDFs, 7% on old growth tropical dry forests and 5% on watersheds or streams. Mexico, the Caribbean Islands and Central America were the regions with the most studies, with Mexico and Costa Rica in the lead, followed by Nicaragua, Panama and Puerto Rico (Table 2). In South America, most of the studies that assessed ESs in NTDFs were conducted in Brazil, followed by Bolivia and Venezuela.

The knowledge of NTDF ESs in the Americas varies across scales and between countries. Countries with the greatest extents of NTDFs, with the exception of Mexico, are not those that are promoting and producing more knowledge for the assessment of ESs. For example, Bolivia, Colombia, Venezuela, Cuba and the Caribbean Islands have few such publications, in spite of their large potential and current extents of NTDFs. Also, Costa Rica, Bolivia, Cuba and the Caribbean Islands have the greatest percentages of NTDFs under protection; however, this is not reflected in more publications and studies on NTDFs. In fact, Mexico has the lowest percentage of NTDF protected areas (0.2%) and is the country with the most such publications. However, Mexico has the largest extent of NTDFs on the continent, comprising

Table 2 Potential and current extent of NTDFs in the Americas, the percentages under protection and numbers of publications evaluating ESs.

Country	*NTDF potential extent (km²)*	*NTDF current extent (km²)*	*Percentage under protection*	*Number of publications*
Mexico	625 038	181 461	0.2	291
Bolivia	216 031	118 940	8.9	6
Brazil	168 164	81 046	6.2	39
Venezuela	113 143	29 396	1	10
Colombia	92 664	30 713	5.1	7
Peru	48 914	2337	8.1	4
Nicaragua	32 277	7414	–	14
Honduras	26 582	6280	–	1
Ecuador	25 275	6443	2.3	1
El Salvador	11 291	3344	0.3	0
Guatemala	10 431	1463	–	0
Costa Rica	7559	1795	15.6	96
Panama	6160	2128	–	14
Cuba	109 879	36 996	10.9	1
Belize	8971	2002	0	1
Jamaica	3438	1585	25	2
Caribbean Islands	137 100	46 839	10.2	2
Continental	1 520 659	519 597	4.5	47

38% of all NTDFs in the Americas (Portillo-Quintero & Sanchez-Azofeifa 2010), with several consolidated research groups studying these ecosystems. Despite the fact that Costa Rica only possesses 0.4% of the NTDFs in the Americas, it has produced more studies than countries with much greater NTDF areas, such as Nicaragua (1.6%) and Honduras (1.3%). Other countries that contain NTDFs, such as El Salvador and Guatemala, had conducted almost no research relating to the ESs of NTDFs.

Most studies (62%) were conducted at the local scale and reported only one location, usually national parks, state parks, or nature reserves. Fewer studies (38%) focused on global, national or regional scales. The most studied locations were the Chamela–Cuixmala Biosphere Reserve (Jalisco, Mexico; n = 225), the Santa Rosa National Park (Guanacaste, Costa Rica; n = 42) and the Mata Seca State Park (Minas Gerais, Brazil; n = 18). The most studied regions were Jalisco state in Mexico (n = 232) and Guanacaste province in Costa Rica (n = 96).

From the 12 major approaches identified in the literature that were used to assess ESs (Table 1), only three have been used to assess ESs in the four categories of biodiversity, carbon, soils and water (e.g. plant inventory, carbon dynamics and land cover change). The network analysis showed that biodiversity and carbon had received more approaches for assessing ESs than water and soils (Fig. 4). Despite the number of publications on biodiversity being greater (more entries in the network, n = 248), carbon (n = 140) was the node with the highest centrality (K_n = 1.00), meaning that carbon received more approaches for assessing ESs than biodiversity. The node with the lowest centrality was water (K_n = 0.8), indicating that water received fewer approaches for studying and evaluating ESs. The most used approaches for assessing ESs for biodiversity were plant and fauna inventories

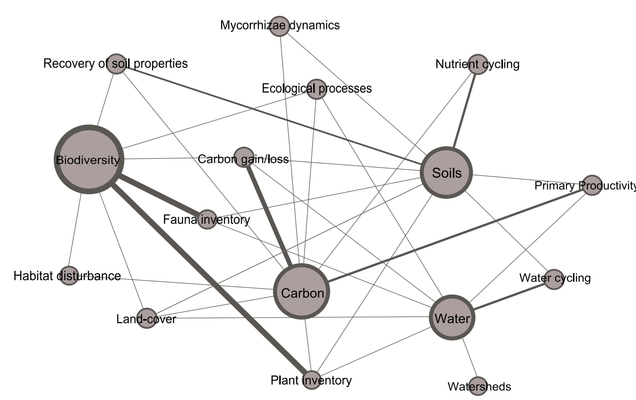

Figure 4 Network analysis of the most studied subjects in NTDFs in order to quantify ESs related to water, carbon, soils and biodiversity. Lines represent connections among nodes; the wider the line, the greater the number of publications found.

and studies on ecological processes (n = 93, 108 and 44, respectively). For carbon, the most common approaches were assessments of primary productivity (n = 33) and carbon dynamics (gain/loss) (n = 69). For soils, the nutrient cycling (n = 34) predominated, and for water, the approach that was most used was water cycling (n = 35) (Table 1 & Fig. 4).

For carbon quantification, the most common research approaches estimated biomass from measured organic matter in vegetation, soil and litterfall (n = 77). For land cover (change, quantification and classification) and primary productivity, a great number of studies employed remote sensing data (n = 46), which enables the acquisition of data for vast areas (e.g. satellite images and airborne LIDAR) and for continuous periods of time (e.g. carbon flux towers and optical phenology towers).

DISCUSSION

Main trends and gaps

The generation of quantitative data on biodiversity, carbon, soil and water related to ESs in NTDFs has increased significantly over the last 20 years.

Most research has been conducted in secondary forests, since they represent the largest natural land vegetation cover class in the agro-landscape (Quesada *et al.* 2009; Portillo-Quintero & Sanchez-Azofeifa 2010). This dominance of research output reflects a significant knowledge gap; there is little knowledge of ESs provided by mature tropical dry forests, but the extent of mature tropical dry forests in the Americas also remains unclear. Furthermore, most studies focused on local assessments, with few implemented at regional or global scales. Site-specific evaluations are of great importance for ESs because the functionality and value of an ecosystem is highly variable (Brauman *et al.* 2007), but scaling up ES assessments is needed for large national or international policy development.

Regulating services are the least studied at any temporal or spatial scale, and this gap is widened by the significant lack of methodologies for their evaluation. This generates significant challenges to generating sound conservation and management strategies in NTDFs. Climate regulation is not a local element, but rather a regional and global component of more complex land–atmosphere interactions. Lack of knowledge of climate regulation services therefore presents another significant challenge to developing short- and long-term government responses to events such as extreme droughts. The paucity of information on ESs for the Central American Dry Corridor ('Corredor Seco') is probably one of the most important examples of a lack of data to support national and international policy making.

Our results suggest that the majority of studies on NTDFs have been in countries where research groups have been consolidated; there is no correlation between the extent of NTDF and number of studies published. This is problematic for conservation planning at local and regional scales. Studies in areas where NTDF cover is high are needed in order to quantify the ESs there. For example, countries with the greatest percentages of their cities within dry ecoregions (Honduras 75%, Nicaragua 66%, Mexico 71% and Venezuela 63%) (Portillo-Quintero *et al.* 2014) should be priority areas for ES research in NTDFs because of the high pressure on natural resources.

Our findings also provide insights into what is driving ES research on tropical dry forests in the Americas. Some of the most frequently studied services are associated with genetic resources, primary production, carbon stocks and biomass production. The selection of these variables is probably the result of the need for this kind of information in order to formulate decision-making policies associated with forest management, bioprospecting and carbon sequestration (Balvanera *et al.* 2012; Martínez-Harms & Balvanera 2012). Certainly, issues related to carbon receive great attention for economic reasons, not only for conservation purposes. For example, the issue of carbon is probably influenced by reducing emissions from deforestation and forest degradation in developing countries (REDD+) frameworks (Scharlemann *et al.* 2010), which are essential in NTDFs given the high levels of deforestation (Janzen 1988; Sanchez-Azofeifa *et al.* 2005; Calvo-Alvarado *et al.* 2009; Portillo-Quintero & Sanchez-Azofeifa 2010). However, since NTDFs are mostly unprotected (Portillo-Quintero *et al.* 2014), stronger policies may be required in order to manage the remaining dry forest patches so as to ensure ES provision in support of the human populations that rely on NTDFs.

Other ESs that are critical for the maintenance of ecosystems and human welfare, such as the protection and provision of freshwater, air quality regulation, pest regulation, disease regulation and erosion regulation, have rarely been addressed and represent significant knowledge gaps. Balvanera *et al.* (2012) stated that research on ESs is still limited to a few services, largely those of global impact (e.g. carbon storage), and less importance has been placed on regulating services (e.g. regulation of human diseases, microclimatic conditions and floods). Significant bias and limitations exist not only in terms of what has been studied, but also the different spatial and temporal scales at which these studies are conducted. Large international initiatives such as those of the International Platform on Biodiversity and Ecosystem Services (IPBES 2014) might foster the development of protocols and standards to be used in NTDFs.

What are the most common approaches for assessing ESs in NTDFs?

Common research approaches for carbon quantification include estimating biomass from measured variables in the field or from remote sensing data. Emerging environmental data sharing, remote sensing techniques and visualization tools and practices can support ES modelling with high accuracy and lower costs (Bagstad *et al.* 2013), although the time lag for the translation of these techniques to the decision-making process is significant. Maps are also very powerful tools for processing complex data and information of ES quantification at different spatial and temporal scales, and thereby supporting resource and environmental management and landscape planning (Crossman *et al.* 2012). Recent studies have also focused on the potential role of NTDFs in mitigating climate change through carbon sequestration from secondary forests in stages of regeneration and succession (Diaz-Gustavo *et al.* 2015; Chazdon *et al.* 2016; Poorter *et al.* 2016).

Biodiversity, on the other hand, is a more difficult resource to quantify, given the complexity of species dynamics and all of the variables that need to be taken into account. Most of the studies in this area are simple reviews or inventories

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of plants or fauna focusing on a specific genus (e.g. Janzen *et al.* 2005; Avila-Cabadilla *et al.* 2014). Although there is a great amount of available data, there is still a lack of consensus about what to analyse and evaluate for biodiversity services (Pereira *et al.* 2013). Pereira *et al.* (2013) considered that the most essential biodiversity variables to take into account for ecosystem evaluation are population dynamics, community composition and ecosystem structure and function.

Despite the vast amount of literature in the last two decades on the role of biodiversity in ecosystem functioning (Cardinale *et al.* 2012), forest ecosystems, including NTDFs, continue to be understudied. Thus, it is still unclear what key components of biodiversity are needed in order to maintain ESs in NTDFs. Recent techniques for assessing carbon storage and biodiversity are also based on plant functional traits (Lavorel *et al.* 2011; Duran *et al.* 2015). Abiotic variables and plant traits rather than land use alone provide a stronger link with ecosystem properties, and therefore could be used as functional markers of ESs (Lavorel *et al.* 2011; Ball *et al.* 2015). Functional traits, such as vegetation height, leaf dry matter content, leaf nitrogen and phosphorus concentration and flowering onset, can be used to map several services (Maes *et al.* 2013). Some of these initial efforts in NTDFs can be found in Alvarez-Anorve *et al.* (2008), Hulshof *et al.* (2013) and Powers and Tiffin (2010).

For water services, most of the studies used ground measurements in order to estimate hydrological parameters in watersheds or water cycling in forests. Most of this research involves long-term studies in watersheds being conducted in order to create more accurate models and to evaluate the behaviour of the resources at large temporal scales (e.g. Chapman & Kramer 1991; García-Oliva *et al.* 1991; Martínez & Díaz 2011; Maza-Villalobos *et al.* 2013). However, there is still a poor understanding of key hydrological processes in NTDFs, resulting in limited data availability for assessing water services in these areas (Farrick & Branfireun 2013). Other efforts have focused on communities' access to water in a specific area and have proposed management projects in order to help reduce threats (e.g. Pesenti & Dean 2003; Gutiérrez & Espíndola 2010; Heras *et al.* 2014). Given that most NTDFs occur in semi-arid regions, water scarcity and desertification are urgent issues for decision makers (Portillo-Quintero *et al*. 2014).

Most of the approaches for assessing the ESs of soils are developed at local scales (e.g. Campo *et al.* 1998; Galicia & García-Oliva 2004; Powers & Perez-Aviles 2013), given the difficulty of scaling-up ecosystem processes to regional and national scales (Powers *et al.* 2011). Moreover, most methodologies are focused on nutrient cycling using soil samples collected in the field, with no linkages to ecosystem structure and composition or stage of ecological succession. These linkages are important for assessing and quantifying the ESs provided by soils because element cycling can be influenced by the dynamics of soil communities (e.g. mycorrhiza fungi) (Waring *et al*. 2016). Moreover, it is unclear how forest succession, land cover change, management and other disturbances can affect community dynamics and, at the same time, the magnitude and direction of soil carbon stocks (Powers *et al.* 2011).

Our results also demonstrated that the understanding of the ESs provided by soils is incomplete, despite a good understanding of soil formation and functioning (Daily *et al.* 1997; Dominati *et al.* 2010). Furthermore, the recovery of soil properties and soil erosion are less studied and often only assessed at local scales (García-Oliva *et al.* 1995; Ellingson *et al.* 2000; Diekmann *et al.* 2007). Methods used to extrapolate observations of plots or even small watersheds to large regions for determining average annual soil erosion rates are often controversial and criticized (Cotler & Ortega-Larrocea 2006). Given the high deforestation rate in NTDFs, it is surprising that few erosivity and sediment transport studies on NTDFs are currently available to the decision-making community (Farrick & Branfireun 2013; Portillo-Quintero *et al*. 2014).

Given that NTDF regions are located on areas under high land use/cover change pressures due to rapid population growth and agricultural development, the most significant challenge identified in this paper is to improve the evaluation of less understood provisioning and regulating services, such as air quality regulation, disease regulation and erosion regulation, among others. The socioeconomic and cultural evaluation must also be incorporated into these frameworks, although our research did not focus on these approaches.

To date, efforts have been made to document the roles that NTDFs play in biodiversity conservation and carbon sequestration (Portillo-Quintero *et al.* 2014). These ESs are the most commonly studied in NTDFs, and are assessed using a great number of methodologies at local, regional or global scales and with methods that are applicable to multiple ecosystems. However, regulating and provisioning the services of water and soil are addressed less often. Furthermore, interactions between NTDFs and these services are not well understood under climate change and land use change scenarios, which are expected to accentuate the crisis of accessibility to water resources. Hence, it remains essential to formulate better predictions of the impacts of climate change on the water resources of NTDFs in order to develop suitable strategies for adapting to future uncertainty (Ceballos *et al.* 2009).

Land use change impacts are expected to intensify the effects of climatic change on NTDFs (Portillo-Quintero & Sanchez-Azofeifa 2010; Meir & Pennington 2011). Increased regional atmospheric aerosol loading resulting from fire and land use change could cause reductions in precipitation (IPCC 2007). A higher proportion of NTDF areas are at risk of severe climate change in the Americas than in other regions, which will translate into either a temperature increase of at least 2.5°C or a precipitation decrease of at least 50 mm year^{-1} by 2055 (Miles *et al.* 2006). By mid-century, annual average river runoff and water availability are projected to decrease by 10–30% in dry regions at mid-latitudes and in the dry tropics, some of which are presently water-stressed areas (IPCC 2001).

Under the scenario of climate change, understanding the relationship of NTDFs with the conservation of water and soils is of vital importance. If these interactions are better defined and physically assessed in NTDFs, societies will be more willing to preserve these ecosystems by applying different strategies. However, our literature review showed that the ESs of NTDFs are the least studied, and thus their assessment should become a priority, given the high demands of society for fertile soils and the availability of fresh water in NTDF areas.

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CONFLICT OF INTEREST

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