Present forest management structures and policies in temperate forests of Mexico: Challenges and prospects for unique tree species assemblages

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ABSTRACT

The temperate forests of Mexico are important economically for many small communities as they provide numerous essential ecosystem services. They also contain the highest biodiversity of oak and pine species in the world. Yet they have not been discussed and investigated as much as other temperate forests. This paper presents these unique temperate forests, the particularities of Mexico's forest management and forestry policies, and some of the main challenges and opportunities forest management poses to Mexican society today. Approximately 80% of the forests are under some form of collective property called *comunidades* or *ejidos*, which means that most forest management is based on small community enterprises and small-scale management. However, all forest management activities are regulated by the federal government through the Ministry of Environment and Natural Resources (SEMARNAT). Although the management of these forests shares many of the current challenges affecting all temperate forests, we discuss three challenges that appear to be unique to Mexico: (1) the difficulties in managing such a high number of pine and oak species; (2) the lack of a well-organized and integrated forest industry sector; and, (3) the high level of illegal logging thought to be responsible for almost 50% of the total harvest.

Key words: Mexican temperate forests, oak-pine forest, national park, conservation, PES system, community forest management, ecosystem management, biodiversity

RÉSUMÉ

La forêt tempérée du Mexique, de par les services écosystémiques qu'elle engendre, contribue de manière importante à l'activité économique de nombreuses petites communautés. Cette forêt arbore aussi la plus grande biodiversité de chênes et de pins au monde. Pourtant, celle-ci a fait l'objet de peu d'études comparativement aux autres forêts tempérées du monde. Cet article présente cette forêt tempérée unique, les particularités de la politique de gestion des forêts ainsi que les défis et opportunités actuels de la foresterie mexicaine. Approximativement 80 % des forêts du Mexique sont gérées sous différentes formes de propriétés collectives, appelées "Comunidades" ou "Ejidos", où la gestion de la foresterie est opérée à petite échelle par les communautés et leurs entreprises. Néanmoins, l'ensemble des activités d'aménagement de la forêt sont réglementées par le gouvernement fédéral, par l'intermédiaire du Ministère de l'environnement et des ressources naturelles (SEMARNAT). Bien que la gestion de la forêt mexicaine partage plusieurs des défis actuels qui touchent les autres forêts tempérées du monde, nous portons notre attention sur trois d'entre eux qui semblent uniques au contexte mexicain: (1) le défi posé par la gestion d'une telle diversité spécifique de chênes et de pins; (2) le défi relié à l'absence d'un secteur industriel intégré et bien organisé; et (3) le défi relié à l'exploitation illégale, qui serait responsable de près de 50 % de la récolte totale.

Mots-clés : Forêts tempérées mexicaines, forêt de chêne-pin, parc national, conservation, paiement pour services des écosystèmes: PSE, gestion forestière communale, aménagement écosystémique, biodiversité

Introduction

The temperate forests of Mexico represent 17% of the country's land area and are situated in the mountain ranges of the *Sierra Madre Occidental* (or Western Mother Mountains, the area of greatest concentration of forest ecosystems in the country); in the Eastern, Southern, and Chiapas *Sierras Madres*; in the Trans-Mexican Volcanic Belt, in the Northern Oaxaca Mountains; and in the Chiapas Highlands and in various isolated mountains of the Mexican Plateau (Challenger and Soberón 2008; Fig. 1). They are composed mainly of pine and pine-oak species at 1800 m to 4000 m elevation, and har-

bor broad ecological, faunal and floristic diversity (Rzedowski 1981). In fact, these temperate forests contain the greatest diversity of pine and oak species in the world with 42% and 33% respectively, in addition to other many important species from the *Juniper* and *Abies* genera (Rzedowski 1993, Valencia 2004, Rzedowski 2006). The mega biodiversity of Mexico's temperate forests is derived from the presence of a varied topography and geology, combined with a vast range of climatic conditions across the territory (González-Espinosa *et al.* 2004) and the mixing of Nearctic and Holarctic realms (Rzedowski 1981). It is also the result of various disturbances

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Fig. 1. The distributions of *Pinus*, *Quercus*, *Abies* and other *spp.* within the temperate forest range.

created by indigenous communities that have historically managed the land using a variety of cultures and systems (Maffi 2005). This rich biodiversity combined with a limited knowledge of the forest species and ecosystem dynamics increases the difficulties forest managers face in protecting and managing these areas.

This paper is the result of a graduate course that included a 10-day visit to Mexico in May, 2014. During the course, the students investigated the ecology, management and conservation of the temperate forests and assisted with a series of conferences by researchers working on these forests. We provide an overview of the main factors and conditions affecting forest management in Mexico. Overall, we focus on the general structure of the country's forestry sector from federal government to local communities. Mainly, we aim at describing: (1) the unique tree species assemblage of these forests; (2) the particularities of Mexico's forest management and forestry policies; and finally, (3) the main challenges and opportunities forest management poses to Mexican society, policy as well as research. We discuss all of these issues based on a review of the recent literature and in light of our trip to Mex-

ico and particularly, on our discussions with Mexican professors, forest engineers, park guardians, governmental actors, and investigators.

A unique tree species assemblage: High oak, pine and fir diversity

The genus *Quercus* is well-represented in Mexico with 81 species of white oaks, 76 species of red oaks and four species of golden cup oaks of the 490 species of oak found worldwide (Pérez-Olvera and Dávalos 2008, Bacon *et al.* 2011). These species are part of different plant communities such as the deciduous oak forests of low altitude in dry climatic areas or the dense evergreen oak forests in more humid areas (Chalenger and Soberón 2008). Oaks in temperate forests occur at altitudes between 1 800 m and 3 200 m and are commonly found with *Pinus* and *Abies* species (Valencia 2004). Oaks create a considerable challenge for taxonomists when classifying certain groups (Manos *et al.* 1999) because of the convergent evolution of many tree characteristics (at the interspecific level), high intraspecific trait variation (at the species level), as well as high species similarity among closely related species (Tovar-Sanchez and Oyama 2004, Gonzalez-Rodriguez and

Oyama 2005). This partly results because oaks frequently undergo hybridization, as this genus is highly outcrossing, wind-pollinated and long-lived (Coart *et al.* 2002, Dodd and Kashani 2003). New genetic and microscopic technologies such as micromorphologic keys will hopefully clarify taxonomic discrimination in the near future (Scareli-Santos *et al.* 2013). Oak-forest habitat provides a critical ecosystem for Mexico given that it harbors unique species diversity, constituting one of the most important hotspots for oak diversity in the world (Pérez-Olvera and Dávalos 2008). However, a rapid reduction of this habitat has been observed in recent years as a result of harvesting in some regions of southern Mexico (Wood 1981, Spector and Putz 2006), conversion of forests to cropland (Boucher 1983), pathogen outbreaks such as *Ceratocystis fagacearum*, known as oak wilt (Appel 1995), and canopy crowding due to fire suppression strategies that favor more shade-tolerant species (Putz *et al.* 1984). In addition, when oak forests are harvested, early successional pine species rather than oak are increasingly replacing oak forests, and this is especially the case in the southern tropical mountains. This ecological phenomenon is scarcely investigated yet it is overall understood to greatly decrease the biodiversity of these areas (Dr. Leopoldo Galicia, Pers. Comm.). This issue needs further research and discussion (González-Elizondo *et al.* 2012).

Pinus in Mexico represent two subgenera—*Pinus*: hard pines and *Strobilus*: soft pines. Of the 110 *Pinus* species worldwide, 43 are present in Mexico (Styles 1993). This genus also has high intraspecific variation (Hall *et al.* 2000) which may be attributed to its large populations, processes of speciation and diversification, hybridization with conspecifics and frequent colonization events of new habitats (Barry 1983, Axelrod 1986, Millar 1993). The species is important economically and socially for Mexico, given that it accounts for the majority of the timber produced (Bray and Merino 2005, Merino-Pérez and Segura-Warnholtz 2007). Coherent with how an increase in the occurrence of extreme climatic events and perturbations such as wildfires and bark beetle outbreaks exerts greater stress on species fitness and recruitment in north-western temperate forests (Návar 2014), researchers are working towards developing better tools to assist migration of pine species for successful colonization, many of which are at risk or threatened. Detrimentially, knowledge of each tree species genetic distribution across the latitudinal gradient is scarce (Návar-Cháidez and González-Elizondo 2009, González-Elizondo *et al.* 2012). New tools forest managers aspire to develop aim at strengthening a species genotype by increasing the expression of frost and drought tolerant genes. However, many pine species have large genomes with long repetitive sequences which are cumbersome and complicates the genome-sequencing task (Kriebel 1985, Wakamiya *et al.* 1993, Elsik and Williams 2000).

Abies is represented by 10 species of the 50 existing worldwide. The most common is *Abies religiosa* (Ferrusquia-Villafraña 2007), which mainly occurs in the Trans-Mexican Volcanic Belt's high mountains regions (Sánchez-Velásquez *et al.* 1991, Jaramillo-Correa *et al.* 2008). The most well-known forest is the Monarch Butterfly Biosphere Reserve where the firs serve as a migratory destination and repository for the monarch butterfly (Anderson and Brower 1996, Oberhauser and Peterson 2003). Of the dominant, long-lived tree species

of temperate forests in Mesoamerica, *Abies* is among the most under studied. Yet data on *Abies religiosa* has demonstrated that, since 1971, its distribution has suffered a 55% reduction in area which is alarming (Rzedowski 2006, SEMARNAT 2008). This tendency is increasing and predicted to reach as high as 92% within the next 50 years (Rehfeldt *et al.* 2012). This recent and drastic loss is suggested to result from extreme temperature and/or precipitation events due to large-scale climatic variability (Sáenz-Romero *et al.* 2010, Návar 2014). The loss of the *Abies religiosa* forest is a threat to monarch butterflies which utilize the trees but also jeopardizes the livelihoods of the people that depend on these forest resources.

These unique pine, oak, and fir assemblages are the basis of timber production in Mexico. For example, 4.6 million m³ of pine (79.0 %), 500 000 m³ of oak (8.7 %), and 160 000 m³ of fir (2.9 %) were harvested in 2013. Of the total production of timber, conifers (mostly pine and fir) represented 82.4%, while deciduous species (mostly oak) represented 12.2%. The most harvested species are *P. engelmannii*, *P. montezumae*, *P. ayacahuite*, *P. patula*, *P. oocarpa*, *P. pseudostrobus*, *P. herrerae*, *P. leiophylla* and *P. arizonica* (Perry 1991, Le Maitre 1998, Ramírez-Herrera *et al.* 2005). At a local level, trees provide firewood and timber to build houses and furniture. For example, in northern Mexico *P. cembroides* is used to produce firewood, charcoal, and to a lesser extent, timber (Sánchez-González 2008).

Mexico thus offers an exceptional playground for studying the ecology of oak, pine and fir forests, along with processes such as species diversification to better account for their preservation. Considering the importance of these species ecologically, and bearing in mind that many oaks, pines and firs are key species in different types of economic activities in the country, the identification and protection of these temperate species and their habitats is crucial for future economic and overall social well-being.

Particular forest management structures and policies

Mexican temperate forests are managed by either the federal government for parks and national forests, or by local communities. However, many federal organizations are involved in providing regulation, guidelines and assistance to local communities. This section describes the parks and national forests, the forestry structure and management and the unique community-based forest management systems of Mexico. It then discusses one of the first and most successful incentives for payments for ecosystem services in the world, developed to safeguard water supply.

Parks and national forests

The Mexican government has created 176 "Natural Areas" which are 12 % of the nation's land area (CONANP 2012). These areas comprise the System of Natural Protected Areas. While most of the parks are not federally owned, the protection of these areas has been consolidated and coordinated by the National Commission of Protected Natural Areas (*Comisión Nacional de Áreas Naturales Protegidas*, CONANP). CONANP is a federal, decentralized agency of the Ministry of Environment and Natural Resources (*Secretaría del Medio Ambiente y Recursos Naturales*, SEMARNAT). The agency is responsible for providing protection to parks as

Fig. 2. Reforestation and restoration strategies: (a) nursery at Izta-Popo Zoquiapan National Park; (b) pine seedlings raised in a local nursery; (c) lupin-nurse plant shrub; and, (d) soil removal procedure to permit recruitment of pine after volcanic eruptions have left tephra deposits.

well as overseeing its rapid expansion, as parks are continuously created and added to the network. CONANP is also concerned with maintaining the living conditions of people in the park vicinities as well as providing opportunities for increasing their livelihoods. Parks are thus simultaneously managed from a conservationist – restorative approach while providing some basic ecosystem services and employment for local people.

The Natural Areas are further classified by CONANP into National Parks, Biosphere Reserves, Protected Flora and Fauna Areas, Nature Sanctuaries, Protected Natural Resource Areas, and Natural Monuments. In this discussion we will focus on National Parks and Biosphere Reserves as these areas were originally designed to conserve Mexico's highland forests where temperate forests are found. The following is based on our visit and personal exchanges with SINAP (*El Sistema Nacional de Areas Naturales Protegidas*) officials at three protected areas: the Izta-Popo Zoquiapan National Park; the National Park of La Malinche; and, the Monarcha Butterfly Sanctuary (Fig. 1). While visiting these parks, we discussed management strategies and observed various techniques implemented by Mexican officials to protect these areas from disturbances, over-grazing, and harvesting.

Global changes are already affecting Mexican highland temperate forests. They include changes in regional climate and climate variability (temperature and precipitation pat-

terns), land use, deforestation, and effects from invasive species on native flora and fauna (Galicia *et al.* 2015). One of the alarming ramifications of these stresses is an adverse effect on forest regeneration and recruitment. In an attempt to mitigate this phenomenon, SINAP officials are transplanting young trees from areas of high to low areas of recruitment, collecting seeds from the forest to grow in nurseries (Fig. 2) and assist migration of the seedlings. Often seedlings with high survival potential are chosen or selectively bred and then planted in areas where high seedling mortality or low recruitment is occurring. However, following natural disturbances (e.g., wildfires, pests, diseases, climate-driven events) that open tree canopies, pines normally colonize these sites successfully (Návar-Cháidez and González-Elizondo 2009). Additionally, seed survivorship may depend on management practices. A widespread and often necessary method in Mexico to permit pine seedling survivorship is to plant seedlings where lupins, referred to as nurse plants, have occurred (Blanco-García *et al.* 2011). Lupins are legumes that fix nitrogen from the atmosphere into ammonia via a rhizobium-root nodule symbiosis (modulated by *Bradyrhizobium* soil bacteria), fertilizing the soil for other plants. This adaptation allows lupins to be tolerant of infertile soils and capable of pioneering change in barren and poor-quality soils, including re-establishment of pine habitat, especially at high elevations. Lastly, following volcanic activity, tephra deposits render soils

Fig. 3. Fire and water-scarcity management: (a) narrow “path-like” barriers for fire management; (b) aqueduct to provide water to local residents; (c) troughs to create watering hole for fauna and for water retention for forest management and physical structures are implanted in streams to create barriers to water flow using; (d) wood; (e) used-pneumatic tires; (f) cement or stone, or physical structures are imposed via excavation across the landscape in (g) troughs and/or (h) trenches.

incompatible with pine recruitment. Restoration practices to re-establish pine habitat on these soils include manually removing tephra deposits, followed by the application of pine-bark mulch (Blanco-García and Lindig-Cisneros 2005). Thus nurse plant effects have been used as an effective reforestation and restoration strategy, and mulching has also effectively ameliorated adverse soil conditions. However, the use of nurse plants is limited by the presence of suitable nurse species before trees are planted, and use of mulching depends on availability of appropriate materials (Fig. 2).

Another challenge linked to global change is the threat of invasive species (CONABIO and SEMARNAT 2009). For example, in the forests of Baja California Sur, feral pigs are causing soil erosion and affecting recruitment of oaks (*Quercus spp.*) due to their high predation of acorns and seedlings (Dr. Leopoldo Galicia, Pers. Comm.). Also at Izta-Popo Zoquiapan National Park, there is an ongoing invasive and abundant mole species which preferentially feeds on the roots of pine. It consumes the roots at such a rate that seedling

recruitment and adult survival are threatened. Park officials are investing great efforts to maintain a low mole population by cutting the damaged trees.

In addition, climate change is predicted to increase fire frequency and water scarcity (Galicia *et al.* 2015). These issues are already of concern in many areas during the dry season. At Izta-Popo Zoquiapan National Park, a preventative measure against the spread of fires consists in creating long and narrow strips devoid of vegetation, resembling a footpath within the grassland landscape. These strips act as fire barriers that reduce possible propagation of fire (Fig. 3).

Water scarcity is also a crucial problem that could intensify with climate change. To mediate this in terms of forest restoration measures, physical structures are implanted in streams to create barriers to water flow using wood, cement, stone or used pneumatic tires. These soil and water conservation practices have been funded by the federal government (CONAFOR) and, in some instances, by regional commercial enterprises (such as Coca-Cola and Volkswagen) as well as by

state governments. In the temperate forests in Central Mexico, thousands of troughs and trenches have been dug across the landscape to retain water (Fig. 2). Although this is an interesting idea, the efficiency of these trenches in affecting water movement has not been demonstrated (Cotler *et al.* 2013). To provide water for people living further below the high elevations where temperate forests occur, aqueducts run from high to low elevations, and to provide water for fauna, permanent concrete troughs are dug within the park (Cotler *et al.* 2013). Although these parks and national forests are protected, human-related disturbances still greatly affect these protected areas through both direct and indirect effects. For example, an important indirect effect is cattle grazing. In Mexico, cattle are abundant and are often free to roam or led to graze by individuals. Cattle affect park vegetation by eating or trampling seedlings, new shoots and young trees, thus disrupting forest growth, recruitment, and population dynamics. Cattle grazing and other livestock have been restricted from roaming freely on the landscape of Natural Protected Areas. However, many national parks, including La Malinche and Izta-Popo, have found it necessary to build extensive fences to keep out cattle from their periphery. Unfortunately parks do not always have the resources or financial support to construct these protective barriers nor do they have professionals to monitor livestock exclusion (Dr. Leopoldo Galicia, Pers. Comm.).

The most pervasive, human-related direct effect comes from the legal or illegal usage and exploitation of the protected area for its many resources. The extraction of various forest products is an important factor affecting the quantity and quality of biodiversity in protected areas. Illegal logging, conversion of forest timber into charcoal, and hunting all constitute recurrent problems in Mexico's parks and national forests for which park officials and rangers must patrol and fight against (Dr. Leopoldo Galicia, Pers. Comm.; Fig. 4).

Forestry structure and management

Although most forestry activities are carried out in community forests, they are regulated by the federal government through the Ministry of Environment and Natural Resources (SEMARNAT). As part of the National Development Plan 2001–2006 (PND), the federal government establishes priorities, strategies and objectives related to the environment and promotion of sustainable development. The PND has provided short-term solutions for overcoming major challenges linked with the forestry sector, but also has provided a long-term vision with the establishment and implementation of the Strategic Forestry Program 2025 (PEF). This aims at promoting and strengthening the sustainable development of forest ecosystems until 2025, and is the first government-endorsed, long-term forest policy program for guiding forest activities.

SEMARNAT is responsible for ensuring forest policies for sustainable use, conservation, protection and restoration of resources and habitat. All legal logging in Mexico (landowners, communities, enterprises), must at all times be approved by SEMARNAT. For instance, it issues, suspends, revokes, invalidates or cancels authorizations for tree planting and exploitation of forest resources in order to ensure forest conservation and functioning ecosystems. Permits are usually valid for a period of 10 years. In 2000, SEMARNAT issued 2 616 permits, representing nearly seven million m³ of timber

(CONAFOR 2001), contributing to about 1.8% to the Gross Domestic Product (SEMARNAT/CONAFOR 2001). SEMARNAT also develops and evaluates programs for soil rehabilitation in non-forested areas (SEMARNAT/CONAFOR 2001).

CONAFOR is an independent organization from SEMARNAT and aims to promote and stimulate activities of production, conservation and reclamation of forested land. Jointly with SEMARNAT, it develops and implements federal forest policies, holding a key role for planning sustainable programs. CONAFOR has four main programs: commercial forest plantations; forest development programs; conservation and sustainable management of forest resources; and, a national reforestation program. It promotes the development of commercial forest plantations and mediates the establishment and management of forest species on agricultural land as well as on land that has become barren and devoid of endemic forest vegetation. Commercial plantations are established to secure the provision of wood and timber but also other non-woody materials. To develop a commercial plantation, any landowner or company with authorization to manage the land may apply to the program. However, an important difficulty must be overcome. The start-up cost is high for communities and thus most do not have the capital to make valid their application.

Overall, CONAFOR oversees the reforestation of approximately 20 000 ha/yr nation-wide (CONAFOR 2005). With reforestation programs, a major problem is becoming increasingly evident: seedling survival is low and there is a lack of monitoring after planting. Today, survival averages approximately 36% after the first year (Sheinbaum and Masera 2000). According to Saenz-Romero and Lindig-Cisneros (2004), this low survival is attributed to the seedling genotypes poor adaptation to local environmental and climatic conditions on the reforestation site. This is hardly surprising, considering that CONAFOR's protocol and methodological guidelines are executed uniformly across the country with little consideration for environmental variability (i.e., elevation, precipitation, soil type, temperature) among reforestation sites. This merits greater attention. Particularly, we suggest the protocol should be revisited because such a top-down, uniform approach is unlikely to bring better results in the future, given that overall environmental stress is increasing. Anthropogenic and climatic factors are creating more variation in environmental conditions at multiple spatial scales, which will further increase the need for a more flexible approach to reforestation.

CONAFOR is strongly promoting the sustainable management of temperate forests, and this is especially evident by its commitment to the country's ambitious Strategic Forestry Program 2025 (PEF) plan. Although some excellent examples of community-based forest management exist in *Comunidad Ejidal El Tarahumar y Bajíos*, *Comunidad Indígena de Nuevo San Juan Parangaricutiro Comunal*, *Comunidad Ixtlán de Juárez* and *Comunidad Santa Catalina Ixtepeji*, it is not the general rule at the national level. For example, only 30 community-based forest enterprises have recognized certification to harvest 2% of the forested areas of the country. However, many applied measures are not fully compatible with local communities' needs, particularly when considering the high start-up reforestation costs and high seedling mortality. Other

Fig. 4. Challenges for forest preservation: (a) a cow grazing in the Mariposa Monarch Sanctuary; (b) legal extraction of wood products by a local individual; (c) legal commercial wood extraction by selectively logging; (d) legal pine resin collection; (e) illegal extraction of resin covered wood chips to sell as fire starters; (f) illegal logging; (g) sequestered charcoal by park officials as a result of illegal charcoal production.

related social, cultural and economic issues are also restricting good management practices: land tenancy insecurity; poor organization of *ejidos* and *comunidades* as units of commercial forest production; a negative import-export balance of forest products; and, a deficient legal and institutional framework that truly promotes sustainable forest management (Bray *et al.* 2006). It appears that sustainable management of temperate forests requires the consideration and safeguard of local community livelihoods.

Community-based forest management

In Mexico, 12 million people live in forested areas and most are affected by extreme poverty (CONAFOR 2001). At present, 80% of forests are under some form of collective property, either as *comunidades* or *ejidos*, which are under an *ejidal* regime (Bray *et al.* 2003). These are the two main forms of forest-based communities with land tenure following the agrarian reform of the 1930s (Klooster 2003). *Comunidades* are pre-Hispanic agrarian communities that have demonstrated a long-term occupation of the land, while *ejidos* have their origins in the Mexican Revolution, and are communities of peasants that manage lands granted by the government. In northern Mexico, *ejidos* started managing forests in the early 1960s but national level forest-based communities have gained the rights for agroforestry exploitation of their lands since the mid-1980s, in turn taking on the responsibilities associated with the management planning of timber extraction (Bray *et al.* 2003). Because this requires a linkage to government authorities, Community-based Forest Enterprises (CFEs) were created, which are intercommunity organizations that negotiate on behalf of the communities with government authorities on funding, logging permits and timber

prices (Antinori and Bray 2005). Currently, the government legally recognizes over 2 400 CFEs and has constituted a community forest enterprise with 600 of them (Bray *et al.* 2006). Decisions regarding resource use and profit reinvestment are decided within the communities, while appointed managers make recommendations regarding silviculture options through the implementation of a forest management plan that requires the acceptance by SEMARNAT.

CFEs are involved in the support network and decision-making process of other secondary businesses that use forest resources—for instance, for furniture construction, refining high-quality resin and providing carpenter suppliers, which creates a linked network between industry players and local markets. The profits of the CFEs are reinvested into both the enterprise and the community itself, providing social benefits such as schools or medical centres. In well-developed communities, CFEs can even act as a funding entity for other smallholders and local economic activities. In Mexico, forest-based communities supported by CFEs have shown to be invaluable for creating fruitful economies, promoting individual engagement in community interests, and generating multiple benefits for livelihoods and cultural well-being (Molnar *et al.* 2011). In light of conservation and environmental benefits, the forests found within the forest-based communities are often perceived as an alternative scenario to the development of protected natural areas, which show lower deforestation rates (Porter-Bolland *et al.* 2012). Indeed, the overarching goal of reducing deforestation and increasing biodiversity conservation is shared among *ejidos*, *comunidades*, industries and the government (Alix-Garcia *et al.* 2005). For CFEs to contribute positively to forest and biodiversity conservation, a forest management plan designed by the community and approved

by the government has to be implemented in the long-term; logging operations need to be strictly controlled and legally-enforced protected areas need to be respected (Bray *et al.* 2006). While only 12% – 20% of *ejidos* have a forest management plan prepared by a forest technician (CONAFOR 2012), the majority of *comunidades* and *ejidos* develop some form of sustainable management plan for their forests to secure their place in the timber market (Bray *et al.* 2006). However, in many Mexican states, there are ongoing land tenure conflicts because of overlapping governmental reforms, which in turn has caused overwhelming litigation between government officials and private landowners. These conflicts tend to encourage deforestation, illegal logging and social degradation, thus impeding the sustainable use of forest resources (Klooster 2000, Honey-Rosés 2009).

The government recognizes that when communities manage their own forests, this creates employment and strengthens local economies and community well-being, while also maintaining biodiversity conservation. We suggest the government now should further recognize how the provision of technical support for forest management plans via CFEs is crucial, and has the power to benefit biodiversity conservation and community welfare.

Payment for ecosystem services

Payment for ecosystem services (PES) is defined as a voluntary transaction in which a user buys a specific ecosystem service or set of services from a provider for as long as the service is provided (Engel *et al.* 2008). Examples of this concept are hydrological services, carbon sequestration, and biodiversity conservation. Thus, this tool is used overall as a means for protecting and/or restoring natural resources. Its application is widespread, with many examples from Latin America (Mayrand and Paquin 2004).

In Mexico, the nation-wide PES program is arguably the government's most innovative environmental program. Launched in 2003 in collaboration with the World Bank, the Payment for Hydrological Services program (PSAH) was created and implemented in response to water scarcity and deforestation problems of the temperate forests surrounding Mexico City. Overexploited watersheds and high rates of deforestation threatened fundamental services. Thus, this program aimed at preserving and ameliorating water for consumption in urban areas. The targeted forests of the program were those found in the upper watersheds that supplied water to high-populated urban areas, but were susceptible of being converted into agricultural land or pastures (Muñoz-Piña *et al.* 2008). Following the implementation of this first PES scheme to regulate the water cycle through higher water recharge by forests, other PES schemes were developed for enhancing and securing carbon sequestration, habitat for biodiversity, and agroforestry services such the PSA-CABSA program (Corbera *et al.* 2009, Shapiro-Garza 2013). Given the efficiency of the program, some respective activities were consolidated. For example, the PSA-CABSA program was merged with the PSAH program under a unifying framework led by CONAFOR, ProÁrbol (Perevotchikova and Vázquez 2012).

Before the PES policy, the country was delineated in areas of high necessity for forest conservation to regulate the water cycle through aquifer recharge. All *ejidos* that were part of

these delineated areas were considered for PES. These schemes were developed as models for market-based management to recognize the total value of forest and agroforestry ecosystems (SEMARNAT 2008, 2010). The functioning is fairly simple: an owner or a land user (usually an *ejido* or a *comunidad*) submits to the program an application that is in turn scored against 26 selection criteria (Romero 2012). Approved projects are registered under a five-year contract with the government. The landowner must then sequester the part of his land that he enrolled in the program to preserve its services, the landowner being paid a certain amount per year per hectare sequestered. Particularly at its onset, enrollment for participation in the PES program was very high, with demand exceeding initial budgets (Alix-Garcia *et al.* 2009, Corbera *et al.* 2009). In response, budgets were increased during the following years (González 2008) and the selection criteria were widened. However, even then not all *ejidos* and *comunidades* were allowed to apply for this program.

Some caveats were identified following implementation. One important issue was direct competition with other governmental programs, such as subsidies promoting agriculture expansion (Jack *et al.* 2008, Muñoz-Piña *et al.* 2008). Secondly, payments to landowners were also said to be too low, widening the economic gap between landowners and non-landowners (Landell-Mills and Porras 2002, García-Amado *et al.* 2011). Thirdly, PES schemes do not always sequester land that provides the greatest yield of ecosystems services. For instance, it would have been more profitable for Mexicans to sequester land where aquifers are overexploited, but this was not prioritized by the program (Alix-Garcia *et al.* 2009). On average, as of 2010, only a small fraction (e.g., 19 %) of the total possible points that can be given to a site submitted for approval to the program came from environmental criteria (Romero 2012). The other criteria were largely administrative (OECD 2013). This issue can trigger cascading consequences. For example, forests with a low risk of deforestation may be favored by private landowners for PES sequestration over those with high deforestation risks (Engel *et al.* 2008, Wunder *et al.* 2008, Alix-Garcia *et al.* 2012). Leakages, on the other hand, may occur intrinsically when providers chose to increase deforestation at other non-sequestered sites on their land to compensate for the lost opportunity due to their PES-sequestered land. In fact, *ejidos* as well as many other players see PES as additive sources of income and not as substitutive practices (Silva-Flores *et al.* 2010, Pérez-Verdín *et al.* 2011). All these issues mitigate the net reduction rate of deforestation (Wunder *et al.* 2008, Alix-Garcia *et al.* 2012). Even if the overarching goal of PES schemes is to foster the preservation of ecosystem services, they also helped reduce poverty (Pagiola *et al.* 2005, Pascual *et al.* 2010). And it is clear that forest owners that participate in a PES program are driven mainly by the opportunity costs of their land. One important question to ask: Is exploitation more profitable than participation in a PES program? (Pagiola *et al.* 2005, Wunder 2006). If this is the case, exploitation will continue and affect negatively other ecosystem services. It will also encourage plots with the lowest risk of exploitation to be sequestered for biodiversity conservation (Pagiola 2007, OECD 2013).

PES programs worldwide have been both praised and criticized (Mayrand and Paquin 2004, Jack *et al.* 2008, Corbera *et al.* 2009, Pattanayak *et al.* 2010). The Mexican PES program,

which has been going for more than ten years, provides an invaluable pilot study for discerning crucial forest uses and functions. We anticipate that Mexico will remain a leading country in the implementation of ecosystem-service programs, particularly if it can adapt its PES program such that benefits continue to outweigh its challenges. For instance, in Mexico, PES schemes allowed millions of people to have access to pure water for free, resolving a critical environmental, economic and health issue. Alternatively, there are a few key improvements that we believe could augment the efficiency of expenditure and reduce human labor invested into the program. A better evaluation and selection criteria for participation into the program could help avoid leakages and allow better use of the program's monetary resources (Landell-Mills and Porras 2002, Alix-Garcia *et al.* 2005, González 2008, Muñoz-Piña *et al.* 2008). The development of risk-assessment and service-monitoring schemes in the establishment of a stable and long-term financial framework could help define expected gross returns and build confidence between users and providers of forest services (Mayrand and Paquin 2004, Corbera *et al.* 2009, Muradian *et al.* 2010). Finally, the program could be improved if landowners were directly involved in the design of the program implemented on their land and their knowledge taken into account (Alix-Garcia *et al.* 2009).

Particular challenges and opportunities: Towards more sustainable management

The temperate forests and forestry sector of Mexico face many similar challenges and opportunities as other forests and regions of the world: (1) the need to adapt to climate and global changes and other human-induced modifications; (2) the increasing competition of fast-growing species coming from tropical countries or regions; (3) the increasing pressure to protect more forests from any type of exploitation; and, (4) the increasing awareness of the other important ecosystem services provided by forests. However, our review of the literature and visit made us aware of a number of challenges and opportunities particular to the temperate forests of Mexico that warrants further discussion.

First, the extremely high number of pine and oak species can be seen as both a curse and a blessing. With so many species having different ecological and silvicultural requirements as well as different wood chemical and physical properties, the accumulated knowledge for each and every species is obviously poor. This is particularly true for Mexico, where both forestry and ecological research for the temperate forest is lacking (Galicía and Zarco-Arista 2014). This means that only a few pine species are managed for high value-added products and that most oak species are used to make charcoal instead of high-quality timber that could be used for furniture making. On the other hand, with such a diversity of pine and oak species well-adapted to almost all possible climatic conditions, the potential for the temperate forests to adjust to global changes through natural or human-assisted means (such as assisted migration) is high.

Second, the lack of a well-organized and integrated forest industry sector means that no industry has the capability to invest money in research and development to develop the potential the region has to offer in terms of wood products. In most *ejidos* and *comunidades*, silvicultural activities (timber

harvesting and industrialization) result in part-time seasonal jobs done by non-professional workers. From cutting to transportation to transforming industries, all activities are done with insufficient and inappropriate machinery that negatively impact the environment and increase production costs (CONAFOR 2008). However, in northern Mexico, several forest industries that support research and alternative management practices have proliferated. This is particularly true for oak species, which have been traditionally used for charcoal instead of high-end products. The problem seems to stem from the difficulties of any large company to obtain any guarantee of a steady supply of timber, since production is divided among so many small communities that often lack proper forest management plans and social organization. Of course, the high number of species, each having different chemical and physical properties, makes it even more difficult for any large company to obtain a large volume of wood from the few desirable and well-known species they want.

Because most individual CFEs do not have the resources to do the necessary research and development or to buy sophisticated equipment needed for forest-product transformation (e.g., modern sawmills), increased cooperation between neighboring communities seems necessary to develop the required knowledge, strengthen the wood-supply chain and develop larger and more modern mills. But at the same time, there is a need to develop other new, alternative non-woody products such as edible and medicinal plants, mushrooms and resin (Bray and Merino 2005). We witnessed a perfect example of such new, alternative non-woody products when we visited the community of Nuevo San Juan (Michoacán). In addition to timber production, the community has developed a very lucrative pine resin harvest activity, adding an increased value to the standing forest and an important source of income for the community. To foster local economies as well as to maximize the benefits from forest management, products from the Mexican forest should be as diverse as possible and target strategic markets. For example, in northern temperate forests, other alternative management practices exist such as producing edible mushrooms for local and regional markets, wine from mushrooms, compost from pine bark, and bio-energy from forest residues and litter (CONAFOR 2008, SEMARNAT 2008).

A third and final particular challenge confronting forest managers is related to the high level of illegal logging that occurs in both national parks and communal forests. Officially, illegal logging is thought to be responsible for almost 50% of the timber harvested (Challenger 1998). Illegal timber harvesting is so uncontrolled that the volume illegally logged has not been totally quantified; but the Federal Office for Environmental Protection (PROFEPA) estimates that illegal logging accounted for about 3 495 000 m³ annually between 2007 and 2010. However, this amount may be largely underestimated given its clandestine nature (Dr. Leopoldo Galicia, Pers. Comm.). Illegal logging responds to multiple causes: land tenancy insecurity; deficient surveillance of forested lands; lack of job opportunities in some regions; predisposition of the forest industry to trade with illegal timber; corruption of authorities that allow these activities; as well as the existence of organized criminal groups (FAO 2004). Illegal logging is a primary threat to sustainable forest management, lowering community incomes from forest produce and dis-

couraging local communities to develop any formal management plan. Thus, stronger enforcement of regulations and independent solutions to illegal logging should be envisioned and local community ownership should be enforced. Moreover, it is imperative to implement the laws and regulations of the *La Ley General de Vida Silvestre* (The Wildlife General Law), as well as the Federal Penal Code that regulates environmental crime, promoting both wildlife and habitat conservation and sustainable management.

Conclusions

The high diversity, extent and particular socio-economic situations of Mexican temperate forests are still relatively unknown in the rest of the world. But with 42% and 33% of the world's pine and oak species, this forest needs to be better understood, studied and preserved. Although it shares many of the current global challenges affecting other forests and regions of the world, the particular environmental, social and economic conditions of this region and its forests demand new and novel approaches to insure its sustainable development. In our 10-day visit, we witnessed many new and innovative approaches that could benefit other forests and regions of the world, particularly regions with similar temperate forests such as Canada and Europe. We conclude by calling for more collaboration and exchanges among those regions that share the remaining temperate forests.

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