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The ecology and ecosystem services of native trees: Implications for reforestation and land restoration in Mesoamerica

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ABSTRACT

Tropical forests provide a variety of goods and services to humanity. Although efforts to protect and manage these forests have increased in recent decades, forest loss continues. The last decade and a half has seen considerable research on reforestation with native species in Mesoamerica, including both biophysical and social aspects. Advances in knowledge have led to increasingly sophisticated reforestation treatments as well as novel ways of deriving forest goods and services from human dominated landscapes.

This Special Issue includes articles produced as the result of a conference held in Panama City, Panama in January 2010 with the goal to summarize the state of knowledge of native species reforestation and associated ecosystems services in Mesoamerica. The introduction concludes with a call for continued research, including a mechanistic understanding of tree interactions with the biophysical environment in order to advance or knowledge of ecosystem services and their interactions. Results from these and other studies aimed at socioeconomic aspects of reforestation are critical to land use planning.

1. Introduction

Tropical forests provide a wide variety of goods and services to humanity (Millennium Ecosystem Assessment, 2005). Conservationists have long highlighted the threat of biodiversity loss resulting from land use policies favoring fragmentation (Laurance et al., 2002) and extensive forest conversion to agriculture and other uses (Butler and Laurance, 2008; DeFries et al., 2010). More recently foresters, scientists and policy makers have focused on the role these forests play in sequestering carbon and thus impacting the global carbon cycle (Brown, 2002; Asner et al., 2010; Malhi et al., 1999; Lewis et al., 2009). The role of tropical forests in influencing regional hydrology and climate has also received attention. They influence local and regional weather patterns (Bruijnzeel, 1990, 2004), mitigate flooding (Bruijnzeel, 1990, 2004), reduce landslides (Larsen and Roman, 2001), and may prolong wet season storage and lengthen flow into the dry season (Bruijnzeel, 1990, 2004; Malmer et al., 2010). Other values include production of timber and non-timber forest products, wild game and cultural and spiritual values to local and indigenous people (Laurance, 1999).

In spite of the recognition of the importance of tropical forests, deforestation continues (FAO, 2006). Human population continues to grow and is not expected to level off for decades (United Nations, 2004). Given these trends, there is concern as to where the goods and ecosystem services derived from mature tropical forests will come from. A number of authors have suggested that these services could be obtained from naturally regenerating secondary forests or plantations (Oliver and Mesznik, 2005; Lamb et al., 2005; Chazdon, 2008; Benayas et al., 2009).

Foresters have planted trees in plantations in the tropics for more than a century (Troup, 1921; Brandis, 1990); however, most efforts in the last fifty years have been dominated by planting a relatively few, well known species with strong global timber markets (FAO, 2000). This trend is driven by the need to generate an economic return on reforestation and land restoration efforts, as well as by a lack of knowledge about how to manage native species (Condit et al., 1993; Wishnie et al., 2007).

Because they are perceived to produce an increased diversity of socially sensitive goods and services, interest in using native species for reforestation and restoration is increasing (see e.g., Butterfield, 1995; Montagnini et al., 1995; Haggar et al., 1998; Garen et al., 2011). Research in Mesoamerica with native species started with the first trial plantings of native species to evaluate establishment and growth rates on open pasture lands (Gonzalez and Fisher, 1994; Butterfield and Mariano, 1995; Butterfield, 1995). Trial mixtures of native species were tested in comparison with single species

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to examine species effects on soil and biomass (Montagnini and Sancho, 1990; Guariguata et al., 1995; Stanley and Montagnini, 1999). Other studies focused on the potential to develop successional models of mixtures that were hypothesized to be more productive than single species plantations (Hart, 1980; Haggar and Ewel, 1997; Menalled et al., 1998). All of this work was done in Costa Rica.

In addition to making progress towards understanding the autoecology of a large number of native species and ecological interactions, their potential for providing ecosystem services under a wide variety of land management scenarios – from naturally regenerating forest (Marin-Spiotta et al., 2007), timber plantations (Petit and Montagnini, 2004; Calvo-Alvarado et al., 2007; Piotto et al., 2009), ecological restoration efforts (Rodrigues et al., 2009), to their use in agroforestry systems (Diemont et al., 2006; Andrade et al., 2008; Harvey et al., 2008; Vieira et al., 2009) where a major goal is to generate income and improve the well being of rural farmers – is an active area of research. Advances have also been made towards understanding how people use and value trees across a mosaic of land uses in Mesoamerica (Aguilar and Condit, 2001; Fischer and Vasseur, 2002; Barrance et al., 2003). Indeed, a critical mass of information has been generated from a variety of fields of inquiry in Mesoamerica such that complex, interdisciplinary projects can be designed with the goal of producing different goods and services. Thus, in January 2010, the Environmental Leadership Training Initiative (ELTI) and the native species reforestation project, PRORENA, both joint initiatives of the Yale School of Forestry and Environmental Studies and the Smithsonian Tropical Research Institute, held a two day conference in Panama to review the scientific data and experiences relating to the ecology and management of native tree species in order to inform reforestation and land restoration activities in the region. The conference targeted land use managers throughout Mesoamerica. This special issue is organized around the four conference panels and includes articles that synthesize research from long term experiments, geographical areas, or specific topics as well as results of experiments aimed at improving our knowledge of the management of native species for the production of ecosystem services. Below we introduce the articles within each panel section followed by a discussion of future research directions.

2. Native species reforestation: when, where, why and how?

It can be extremely expensive to restore an ecosystem and it may not make sense to do so when natural processes could also do the job. Holl and Aide (2011) introduce this section by examining when and where ecosystems need to be actively restored. These authors introduce a simple decision framework that managers can use to decide if they should actively intervene. Dry forests are one of the most threatened forested biomes in the world (Murphy and Lugo, 1986; Janzen, 1988). Griscom and Ashton (2011) review the history of land conversion and ecosystem services provided by dry forests of Mesoamerica. They adapt the Ashton et al. (2001) framework for restoration pathways for Southeast Asia to this forest type with the goal of guiding land managers and practitioners in the decision making process depending upon social and biological site conditions.

Three manuscripts in this section describe experimental studies undertaken to test hypotheses related to species growth under different conditions and potential approaches to restoration techniques. Celis and Jose (2011) test the early growth performance of six native tree species on pastures dominated by two different grass species. van Breugel et al. (2011) describe a large scale project in Panama (PRORENA) to assess the growth of 49 species (47 native and 2 exotics) in a rainfall-soil fertility matrix. As the authors point out, with the publication of these data, survivorship and early growth data are available for over 130 species in Mesoamerica (also see Hall et al., 2011). Cole et al. (2011) describe an experiment that tested the survivorship and growth performance of five native species using direct seeding methods in abandoned pastures, plantations, and secondary forest as a way of incorporating late successional species into these tree planting schemes. They found significantly higher survival and better growth for seedlings seeded into plantations as compared to the other two land uses and recommend direct seeding as a complimentary technique to planting fast growing and nitrogen fixing trees to restore a landscape.

3. Native species reforestation: restoring ecosystem services

While much is known about the growth and management of a few species planted for timber production (e.g., Forrester et al., 2010) and, to some extent, carbon sequestration (e.g., Kraenzel et al., 2003), we are only now gaining a better understanding of these products or "services" for a wide variety of native species (see above). Much less, however, is known about a broad array of other ecosystem services. Rodrigues et al. (2011) present a large scale restoration program they have developed in Brazil over a 10 year period with the goal of informing large scale ecological restoration of high diversity forests.

Authors have used different approaches to assess growth and development of trees planted in monocultures and mixtures. In an assessment of the effects of diversity on ecosystem function, Potvin et al. (2011) analyze above-ground and total ecosystem Net Primary Productivity (NPP) for different levels of tree diversity in a plantation setting in rural Panama. Although this experiment is designed to isolate the effect of diversity on productivity by assessing changes in both pools and fluxes, the authors note that one of the most interesting findings presented in the study is the continued loss of soil carbon over the lifetime (8 years) of the plantation (Potvin et al., 2011). This result is consistent with other studies (see e.g.,Guo and Gifford, 2002). Interestingly, Neumann-Cosel et al. (2011) found no change in soil carbon over 12 years of secondary succession on cattle pasture. Albeit in close proximity to the Potvin et al. (2011) study site, the two studies were conducted on different soil types, a factor that may confound direct comparisons (Neumann-Cosel et al., 2011). While carbon credits are traded based on aboveground carbon in the biomass, changes in soil carbon can have an important impact on total ecosystem carbon sequestration (Potvin et al., 2011; Neumann-Cosel et al., 2011).

Assuring access to fresh water is one of the biggest challenges faced by governments, urban planners, and development specialists in the 21st century (see e.g., Schiermeier, 2008). Although there is a popular perception that in a seasonal climate, tropical forest soils retain water that is slowly released in streams during the dry season (the "sponge" effect), empirical support is limited and it remains controversial (Malmer et al., 2010). One important parameter for gauging the sponge effect is infiltration – the rate at which water can be absorbed by the soil matrix. Hassler et al. (2011) measured infiltration across a young secondary forest chronosequence in rural Panama where forest established on cattle pasture. These authors found that infiltration can return to old secondary or mature forest rates in a decade; however, the depth at which a difference was detected was very shallow (see also Ilstedt et al., 2007).

One of the constraints to the use of a wide variety of native species in reforestation projects is the lack of autoecological information (van Breugel et al., 2011); given the high investment necessary to reforest, land managers are reluctant to risk planting species that may suffer high mortality rates or exhibit exceptionally slow growth rates. Craven et al. (2011) looked at plasticity in physiological traits related to photosynthesis and water use across seasons at a relatively wet and a drought stressed site for eight species to improve our understanding of the mechanisms plants use to overcome drought and recommend drought tolerance as a criterion for species in reforestation projects. Ultimately, species selected for drought tolerance and water use efficiency could potentially impact stand level water availability in the dry season in tropical plantations (Kunert et al., 2010), suggesting the potential to design plantations to maximize this ecosystem service.

4. Native species in agroforestry systems

Agroforestry, intentional integration of trees with agricultural crops and/or livestock, is a common land use practice in the tropics and is viewed as providing ecosystem services, environmental benefits, and economic commodities as part of a multifunctional working landscape (Jose, 2009). Cattle culture is ingrained in Mesoamerica (Murgueitio et al., 2011) and provides a source of income, food production, and often serves as a sort of bank account for rural farmers (Coomes et al., 2008). In a summary of research conducted on four landscapes in Costa Rica and Nicaragua, Harvey et al. (2011) point out that rural farmers have extensive knowledge of tree species on the land and often manipulate densities to favor those with particular uses (also see Garen et al., 2011). Murgueitio et al. (2011) describe a program of intensive silvopastoral system (ISS) that depends upon significantly increasing trees and shrubs on cattle farms (>10,000 individuals per hectare). Among other results, they report sustained beef and milk production for more than 20 years at sites in Mexico and Columbia. Harvey et al. (2008) have described how living fences and dispersed trees can play an important role as habitat and biological corridors for different taxonomic groups of animals. Harvey et al. (2011) document that while the number of tree species dispersed across cattle pastures within a landscape can be impressive (>100 species; also see Garen et al., 2011), most species are rare and at risk of disappearing from the landscape. Garen et al. (2011) and Harvey et al. (2011) point out that farmers can be open to technological innovations that increase cattle and crop production.

Hall et al. (2011) report on a six year study where selected timber trees were grown with farmers at two sites in rural Panama. Their study highlights the fact that trees grown on farms do not necessarily grow as well as they do on species selection trials, where tree species are grown to assess potential performance under different site conditions. Because the economic revenue generated by trees is years to decades off, it can be difficult for farmers to overcome the financial barriers to planting trees for this purpose (Coomes et al., 2008). However, by managing expectations and providing continued technical assistance, farmers can continue with tree planting initiatives (Hall et al., 2011). Given that farmers have consistently been shown to manage trees on their farms in Mesoamerica (Garen et al., 2011; Harvey et al., 2011; Love and Spaner, 2005), further diversification of tree planting initiatives to maximize farm production (e.g., ISS, Murgueitio et al., 2011) and other goods and services of more immediate interest to farmers holds promise to substantially increase carbon sequestration and biodiversity values.

5. The use and management of native trees by rural landholders

Diemont et al. (2011), Garen et al. (2011), and Harvey et al. (2011) all document multiple and diverse uses of trees and forests by local people. Diemont et al. (2011) report on a study comparing agroforest management for food, raw materials, and animal products by five Mayan groups living in Mexico and Belize. The authors document the use of highly complex systems that includes enrichment planting to improve soils and establish target species where different fallow stages are managed for different products. In studies reported elsewhere (Diemont and Martin, 2009; Diemont et al., 2006) the authors have documented specific attributes of tree species actively planted by Lacandon Maya. Managing cultivation and different stages of forest regeneration within a forest matrix is important for biodiversity, particularly linking protected areas within the Mesoamerican biological corridor (Diemont et al., 2011).

Garen et al. (2011) assess the different tree species used by farmers and their motivations for doing so in a predominantly cattle and crop oriented regions of the dry arc of Panama. They emphasize the importance of building upon local knowledge in the design and management of projects aimed at improving livelihoods and the provision of ecosystem services (Garen et al., 2011). Thus advances in the acquisition of knowledge of how to manage an ever increasing number of tree species, traditional and novel ways to improve livelihoods through the incorporation of trees, and insights as to how to work with local communities suggests real progress for the design of conservation and development projects.

6. Future research directions

It is clear from the articles published in this Special Issue and elsewhere that considerable progress is being made in understanding the basic silvicultural characteristics of an ever increasing number of native tree species in Mesoamerica. However, the number of species studied remains a fraction of the flora such that continued research is necessary to increase the pool of species used in restoration and reforestation projects and avoid a problem parallel to that described by Harvey et al. (2011) for pasture dominated landscapes, where species diversity across the landscape is much reduced. In addition, further research needs to be undertaken like the work described by Cole et al. (2011) to assess the potential of direct seeding and enrichment planting schemes under different conditions to increase structural and functional diversity across the landscape. The relative efficiency of reforesting using a wide variety of species selected for their autoecology or other traits to jump start succession (Ashton et al., 2001; Elliott et al., 2003; Celis and Jose, 2011) versus large scale initiatives that maximize species diversity such as the research described by Rodrigues et al. (2011) deserve further consideration, as does the potential to favor restoration through the establishment of nuclei or islands within a deforested landscape (Holl et al., in press).

Comparably less effort has gone into understanding the ecosystem services provided by forests actively or passively reforested with native species than their silviculture. These land uses and silvopastoral systems like those described by Murgueitio et al. (2011) deserves more attention to better quantify ecosystem services such as carbon sequestration, biodiversity, and hydrological services across the landscape (Harvey et al., 2008; Canadell et al., 2009; Jose, 2009; Malmer et al., 2010). Local people should not be seen as the obstacle but rather researchers and land managers should seek to understand traditions and local knowledge (Garen et al., 2011; Diemont et al., 2011) and employ interdisciplinary techniques to project planning related to reforestation and restoration.

Recent work has gone into understanding tradeoffs between services (Bennett et al., 2009) and the extent to and conditions under which services are correlated and can be "bundled" for planning and management scenarios (Raudsepp-Hearne et al., 2009). Intriguing data that hints towards tradeoffs are published in different articles in this Special Issue. Understanding the mechanisms that lead to the provision of a given ecosystem service is prerequisite to understanding how services will correlate over time under different biophysical conditions and social scenarios. Such information is critical to informed land use planning with the objective of managing ecosystem services. It may be, for example, that because of site or other differences, the carbon accumulation trajectories described in Potvin et al. (2011) and Neumann-Cosel et al. (2011) cannot be compared, much less extrapolated to larger spatial scales.

Research is underway at a number of sites across Mesoamerica to understand how forests and land use change, including natural succession and active reforestation, impact the production of ecosystem services (e.g., Stallard et al., 2010). However, as asserted by Ewel and Mazzarino (2008) relating the productivity between monocultures and mixtures, without a mechanistic understanding, foresters and land managers will be resigned to endless trial and error to determine the best species and/or land use mix to optimize a suite of ecosystem services at a given site. Thus while it is important to continue avenues of research that document ecosystem services, a mechanistic understanding of plant–plant interactions within the biotic and abiotic environment is fundamental to proactive planning for the production of ecosystem services. Further, implementation of land management strategies requires an understanding of the social and political environment.

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