Forest Ecology and Management 473 (2020) 118294

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Economic valuation of ecosystem services from secondary tropical forests: trade-offs and implications for policy making

Julia Naime[a,b,*], Francisco Mora[b], Mauricio Sánchez-Martínez[b], Felipe Arreola[b], Patricia Balvanera[b,c]

[a] School of Economics and Business, Norwegian University of Life Sciences (NMBU), PO Box 5003, 1432, Ås, Norway
[b] Instituto de Investigaciones en Ecosistemas y Sustentabilidad (IIES), Universidad Nacional Autónoma de México, Antigua Carretera a Pátzcuaro No. 8701, Morelia, Mexico
[c] Unidad Académica de Estudios Territoriales, Universidad Nacional Autónoma de México, Reforma s/n Centro, Oaxaca 68000, Mexico

ARTICLE INFO

Keywords:
Payment for Ecosystem Services
Economic valuation
Natural regeneration
Secondary forests
Contingent valuation

ABSTRACT

Natural regeneration of secondary forests can be an important source of recovery of ecosystem services (ES) critical for humanity, especially for climate change mitigation and adaptation goals. However, natural regeneration entails synergies and trade-offs across ESs and across stakeholders. To evaluate these trade-offs, we assessed the economic value of four ESs along the course of a natural regeneration process of tropical dry forests of the Pacific Coast of Mexico, and examined how this can inform the design of Payment for Ecosystem Services (PES) schemes incentivizing forest restoration. We estimated the monetary value of two provisioning ESs –forest products and fodder for calves–, using contingent valuation and direct market valuation methods, and two regulating ESs –carbon stocks and carbon sinks– using the voluntary carbon market prices and the social cost of carbon. We assessed these ESs in four natural regeneration stages: pasture, young secondary forest (0 to 12 years of natural regeneration), intermediate secondary forest (between 12 and 25 years of natural regeneration), and old-growth forest (more than 25 years of natural regeneration or primary forests).

Results indicate that throughout the course of the natural regeneration process, there are changes in the magnitude of the trade-offs between regulating and provisioning ESs. We find a clear trade-off between regulating and provisioning ESs in the early stages of natural regeneration. However, as secondary forests grow older provisioning ESs recover, creating synergies rather than trade-offs in later stages of natural regeneration. Our results suggest a PES aiming to increase climate regulation services should focus on the carbon sink potential of young and intermediate secondary forests, as this would provide the greatest additionality and mitigation. We also showed the relevance of using a portfolio of economic valuation methods that can include a wider range of values for understanding landholders' preferences. While with direct market valuation methods we found that young secondary forests have the lowest economic value as compared to other natural regeneration stages, contingent valuation showed that landholders value young secondary forests the most because of their potential – *future* – land use (i.e. the possibility of converting it back to pasture).

1. Introduction

The world today is struggling to keep global temperature rise below the 1.5 °C target. Natural Climate Solutions are the set of available practices to mitigate climate change by increasing carbon sinks and reducing greenhouse gas emissions from the agriculture, forestry and land use sector (Griscom et al., 2017). These solutions comprise conservation, restoration, and improved land management activities and are increasingly perceived as necessary to meet climate change targets because of their carbon dioxide removal potential (Chazdon et al., 2017; Seddon et al., 2019). Indeed, all the pathways proposed by the Intergovernmental Panel on Climate Change (IPCC) to meet the 1.5 °C target require carbon dioxide removal strategies (IPCC, 2019a).

Natural regeneration is a restoration strategy that includes the spontaneous recovery of forest cover in abandoned cropland and pastures (Crouzeilles et al., 2017), and resulting in the development and expansion of secondary forests. Natural regeneration has an important role among the set of restoration strategies available to mitigate climate change: forests that develop following the total or partial abandonment of human activities – secondary forests – can have a net carbon uptake

* Corresponding author at: School of Economics and Business, Norwegian University of Life Sciences (NMBU), PO Box 5003, 1432, Ås, Norway.
E-mail address: junaime@nmbu.no (J. Naime).

https://doi.org/10.1016/j.foreco.2020.118294
Received 19 April 2020; Received in revised form 24 May 2020; Accepted 27 May 2020

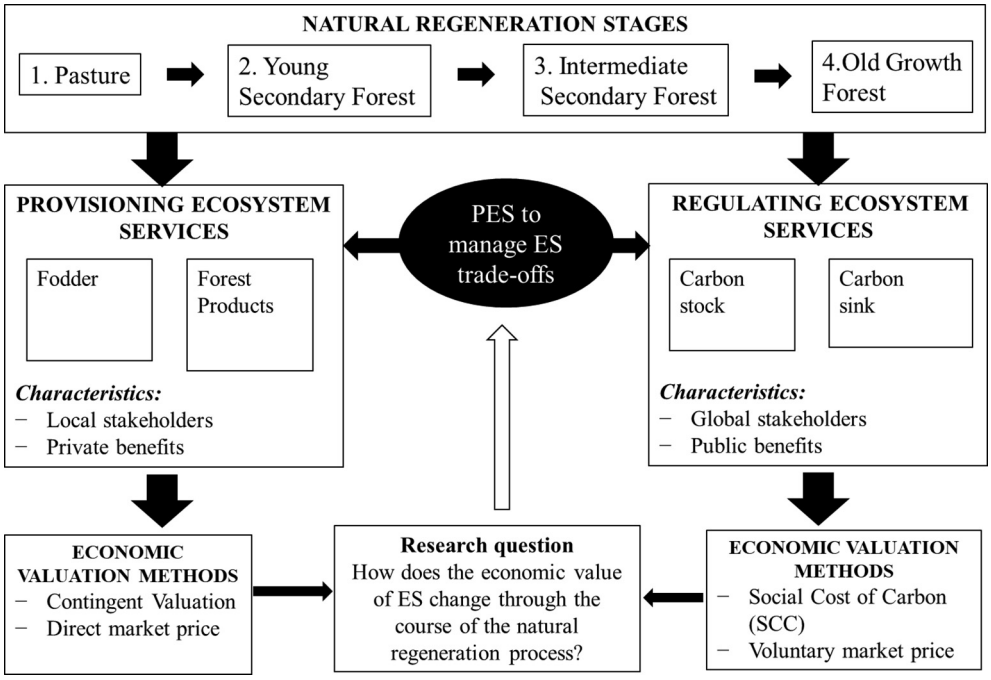

Fig. 1. Conceptual framework for the economic valuation of four ecosystem services along the course of natural regeneration of tropical dry forests.

of 3.05 Mg C ha^{-1} yr^{-1}, eleven times more than old-growth forests (Poorter et al., 2016). In addition, it potentially offers a low cost and effective solution to forest scarcity, biodiversity conservation, and land degradation (Rey Benayas et al., 2009; Chazdon and Uriarte, 2016; Chazdon et al., 2016; Meli et al., 2017) as it often requires little or no human intervention and has higher ecological success than active restoration (Crouzeilles et al., 2017). Furthermore, secondary forests emerging from natural regeneration provide ecosystem services (ESs) to local stakeholders, including provisioning, cultural and regulating services (Lazos-Chavero et al., 2016; Wilson et al., 2017; Tauro et al., 2018). Thus, natural regeneration and secondary forests provide benefits at the global, public level as well as at the regional and local scale.

Given that natural regeneration results in the establishment of tropical secondary forests at the expense of croplands and pastures, there are potential trade-offs between the public benefits received from increasing climate regulating services and the private losses of provisioning services. Indeed, natural regeneration can involve costs to local stakeholders if they lose the provisioning ESs that they receive from agricultural land uses (Chazdon and Guariguata, 2016; Lazos-Chavero et al., 2016; Wilson et al., 2017; Kearney et al., 2017). In such cases, a policy intervention is needed to manage the trade-offs and incentivize natural regeneration. Among the set of policies for managing ESs trade-offs, Payment for Ecosystem Services (PES) can be an effective tool (Bullock et al., 2011; Miteva, Pattanayak and Ferraro, 2012). Broadly defined, PES is a "positive economic incentive where environmental services providers can voluntarily apply for a payment that is conditional either on ES provision or on an activity clearly linked to ES provision" (Engel, 2016). PES has been the cornerstone policy goal of Reduced Emissions from Deforestation and forest Degradation (REDD +) strategies across the world. Most PES and REDD+ schemes have focused on reducing deforestation, while there has been much less attention for incentivizing forest enhancement strategies such as natural regeneration (Skutsch et al., 2017). Efficient and effective PES policies for natural regeneration require a clear understanding of the magnitude and nature of the ES provided and their potential trade-offs (Naeem, et al. 2015; Alexander et al. 2016; Guariguata and Balvanera 2009).

Despite the growing literature on ESs and their trade-offs (Howe, 2014; Raudsepp-Hearne et al., 2010), the empirical, 'on-the-ground' knowledge of how to manage ESs trade-offs during restoration practices is still scarce (Chazdon and Guariguata, 2016; Chazdon et al., 2017). Few studies have coupled the analysis of ESs trade-offs to their economic valuation and the specific policies to manage them at the local level (Pandeya et al., 2016; Cord et al., 2017; Marre and Billé, 2019). Such knowledge can contribute to adequately managing and leveraging the associated trade-offs, and the identification of suitable policies or compensation schemes. A useful research tool to evaluate ESs trade-offs is economic valuation (De Groot et al., 2010; Pandeya et al., 2016; Müller, Knoke and Olschewski, 2019), which consists of assigning a monetary value to the services supplied by an ecosystem.

This paper examines the ESs trade-offs that emerge during the process of natural regeneration on former pastures of a tropical dry forest (TDF), focusing on conflicts between climate regulating ESs that provide public, global benefits, and provisioning ESs that provide local, private benefits. We valued ESs at four distinct stages of the natural regeneration process of a tropical dry forest on the Pacific coast of Mexico, using multiple economic valuation methods to better capture different components of the Total Economic Value (TEV) of an ES (Pearce, Atkinson and Mourato, 2006). We consider two provisioning services locally relevant to the landholders –forest products and fodder for calves –, and two regulating services critical for climate change mitigation, globally relevant – carbon stocks and carbon sinks –. Each ES was valued at each of four stages of a natural regeneration process: pasture, young secondary forest (0 to 12 years of natural regeneration), intermediate secondary forest (between 12 and 25 years of natural regeneration), and old-growth forest (secondary forest older than 25 years or primary forests). Considering the findings, we discuss the implications of the economic valuation for the management of ESs trade-offs, focusing on the design of a PES program aiming to incentivize natural regeneration. The conceptual framework followed for the study is summarized in Fig. 1.

2. Methods

2.1. Site description and natural regeneration stages

The study was carried out in six localities, or *ejidos*, of the municipality of La Huerta, in Jalisco, Mexico, where the dominant vegetation is tropical dry forest (TDF). The region has a marked seasonality of

rainfall and water availability, where mean annual rainfall is 800.4 mm and 86.8% of yearly precipitation occurs between the months of June and October (Maass et al., 2018). An important land cover change process has occurred in the region during the last decades, with an overall reduction of 22% for TDF and 45% for tropical semi-deciduous forest (TSDF) between 1970 and 2012. As a result, by 2012 about 49% of the land was covered by old-growth TDF, 11% by secondary TDF, 9% by TSDF and almost 20% were pastures or croplands (Flores-Casas and Ortega-Huerta, 2019).

Three reasons make this region relevant to the study of natural regeneration. First, as a result of the land cover change process there is diversity of land uses, ranging from croplands and pastures to secondary forests and primary forests (Flores-Casas and Ortega-Huerta, 2019). Second, the site has been studied for more than 30 years and there is extensive ecological but also socioeconomic information regarding secondary forest succession and ES provision (Maass, 2005, 2016, Maass et al., 2018). Third, the rate of deforestation in the area is low and has been decreasing over time (Sánchez-Azofeifa et al., 2009; Flores-Casas and Ortega-Huerta, 2019) and natural regeneration has been identified by local stakeholders as one of the most feasible reforestation strategies available (Lazos-Chavero et al., 2016).

Based on previous research about tropical secondary forest succession on former pastures in the site (Mora et al., 2015, 2016), the process of natural regeneration was classified into four distinct stages: pasture, young secondary forest, intermediate secondary forest, and old-growth forest. Each natural regeneration stage differs in its ecology as well as in its management and use by local landholders. *Pasture* is the most intensively managed land use, dominated by planted grass for the production of fodder for cattle (Trilleras et al., 2015), and has the least biodiversity, plant and tree cover as compared to the other natural regeneration stages (Mora et al., 2016). Landholders in the region practice rotational grazing and have on average 2 or 3 animals per hectare. The main livestock income of landholders comes from the sale of calves to larger enterprises for fattening purposes (Trilleras et al., 2015, Ugartechea 2015). *Young secondary forests* are fallow lands undergoing secondary forest regrowth for up to 12 years. They are characterized by shrubby vegetation, generally thorny bushes, and show the highest rates of aboveground biomass growth and carbon capture in the region (Mora et al., 2018). These forests are also a potential source of forest grazing by livestock and extraction of forest products (Trilleras et al., 2015; Cortés-Calderón, Sánchez-Romero). *Intermediate secondary forests* are the fallow lands undergoing secondary regrowth for more than 12 years and up to 25 years. Its species richness is slightly lower or comparable to that of the old-growth forests but with a different composition (Cortés-Calderón). These forests are an important source of firewood, fencing posts and, to a lesser extent, can provide fodder (Cortés-Calderón). *Old-growth forests* are the ones that have never been deforested or in which there is no evidence of intensive management in the last 25 years. They have the highest biodiversity and the largest carbon stock compared to the other natural regeneration stages (Mora et al., 2018). Landholders recognize that they are a source of multiple useful forest products as well as regulating services (Sánchez-Martinez, 2016; Tauro et al., 2018).

2.2. The ecosystem services

In each natural regeneration stage, we assessed four ESs: two provisioning services, 1) forest products and 2) fodder for calves, and two regulating services, 3) carbon stocks and 4) carbon sinks. *Forest products* include all the products from the ecosystem that can be used by landholders, including medicinal, edible, fuel, or construction uses (Cortés-Calderón). Given that the most common forest products are firewood and wood for fencing posts (Rendón-Carmona et al., 2009; Godinez, 2011; Cohen, 2014; Ugartechea, 2015; Sánchez-Martinez, 2016), we only used those for the economic valuation. *Fodder* includes all the plant tissues of aerial biomass that are edible for livestock (Trilleras et al., 2015), whether leaf, seed, or stem, from grass or woody species (Cortés-Calderón et al.). We consider the yearly benefits of the fodder for calves only, and not livestock in general, given calves constitute the main source of income from livestock activities. *Carbon stock* was defined as the amount of CO_2 equivalents (CO_2-eq) stored in tree aboveground biomass, per hectare. *Carbon sink* refers to the average change in the amount of CO_2-eq stored in the aboveground biomass per hectare and per year. Both carbon stocks and carbon sinks are global ESs, providing climate regulation and climate change mitigation benefits that are non-excludable. The distinction between carbon stocks and carbon sinks is key for effective and efficient REDD + and climate mitigation projects. Carbon sinks relate to 'negative emissions', i.e. carbon dioxide removal from gases that are already in the atmosphere, while carbon stocks relate to reducing emissions as compared to a baseline projected deforestation. The drivers of change, the monitoring and baseline procedures, as well as the policy strategies to conserve carbon stocks or enhance carbon sinks are different (Herold and Skutsch, 2011; Skutsch et al., 2017).

We selected these four ESs based on theoretical as well as methodological considerations. First, the main trade-off in ES provision in the region occurs between biomass for regulating services, such as carbon regulation, and biomass for provisioning services, mainly fodder for cattle production (King et al., 2015; Mora et al., 2016; Cortés-Calderón et al.). Second, fodder and the forest products related to cattle activities are the two provisioning ESs that are most commonly recognized by landholders (Castillo, 2005; Maass, 2016; Sánchez-Martinez, 2016; Tauro, 2018). Third, long term studies in the region provide high-quality data for the supply of all four ecosystem services (Cortes-Calderon et al.) as well as the management practices associated to their use (Maass et al., 2005; Cohen, 2014; Trilleras et al., 2015; Ugartechea, 2015; Sánchez-Romero et al.). While there is information about how other ecological and biodiversity attributes change along the course of natural regeneration in the region, such as fungal or insect diversity (Boege et al., 2019; Carrillo-Saucedo et al., 2018), functional diversity (Gei et al., 2018), or species richness and composition (Rozendaal et al., 2019), there is less understanding about how they impact human well-being and thus are not included in this study.

2.3. Economic valuation methods

The choice of the economic valuation method depends on both the type of ES considered as well as on the objective of the valuation (De Groot, Wilson and Boumans, 2002). We used two complementary approaches for assessing the economic value of ESs. These were different for regulating and provisioning services.

2.3.1. Economic valuation of regulating ecosystem services

We first calculated the carbon stock and carbon sink of young secondary forests, intermediate secondary forests, and old-growth forests as the key input to assessing their economic value. We excluded pastures in our carbon measurements since we considered that they have negligible aboveground biomass (Mora et al., 2016). To calculate the carbon stock and carbon sink, the diameter at breast height (DBH) of trees with a diameter higher than 5 cm was measured in 50 plots of secondary and primary forests. Sites were selected across the study region to represent major gradients in biophysical and land use conditions known to cause major variations in aboveground carbon stocks and species diversity: forest age (5–45 years of abandonment), topographic position (hills and valleys), and previous land use (from clearing without use to use as pastures for several years). See Mora et al. (2015) and Mora et al. (this issue) for further details. Tree aboveground biomass was calculated using an allometric equation specific to the region (see Bojórquez et al.) and re-scaled to provide an estimation in hectares. The carbon stock in each plot was calculated by multiplying the biomass by the carbon coefficient specific to the region (Jaramillo et al., 2003) and transforming it to CO_2-eq following IPCC guidelines

Table 1
Mean economic value of carbon stock (USD ha^{-1}) and carbon sink (USD $ha^{-1}yr^{-1}$) across natural regeneration stages. Letters indicate statistical differences among categories from Bonferroni post-hoc tests. Standard errors are shown in parenthesis.

Ecosystem service	Valuation method	Young secondary forest	Intermediate secondary forest	Old-growth forest
Carbon stock (USD ha^{-1})	Voluntary carbon markets	210.99^{a} (38.75)	438.46^{b} (39.02)	682.60^{c} (30.97)
	Social Cost of Carbon (SCC)	$1,982.5^{a}$ (364.1)	$4,119.8^{b}$ (366.7)	$6,413.6^{c}$ (290.9)
Carbon sink (USD $ha^{-1}yr^{-1}$)	Voluntary carbon markets	42.09^{ab} (8.82)	44.59^{a} (3.46)	29.69^{b} (1.97)
	Social Cost of Carbon (SCC)	221.2^{ab} (46.4)	234.3^{a} (18.2)	156.1^{b} (10.4)

(IPCC, 2006, 2019b). A detailed description of carbon measurements is found in the Supplementary Materials (section SP1).

To calculate the carbon sink, the CO_2-eq stock of each plot was divided by the respective age of the plot. This represents the average rate of CO_2-eq sequestration. This method may overestimate the carbon sink potential - in particular for old-growth forests - since it assumes that CO_2-eq sequestration is linear and constant over time. While stock change methods would be more precise because they measure the change in carbon stocks between two time periods (IPCC 2006), we believe we have a good approximation for the purposes of our study, as they are comparable with those obtained from long term carbon sink measurements (see Cortés-Calderón et al.).

We used two prices to assign an economic value of regulating services because we consider they are complementary in nature. First, we considered the average selling price reported in the voluntary carbon markets in 2016 for the forestry and land use sector, in particular the prices reported for avoided unplanned deforestation and reforestation/afforestation projects (Hamrick and Gallant, 2017). Second, we considered the social cost of carbon estimated by the Environmental Protection Agency (EPA). All prices were adjusted for inflation to 2019 prices.

The advantage of using the carbon price from the voluntary markets is that it is based on observed market behaviour and reflects the average economic income that forest owners could obtain from selling carbon offsets in the market, assuming there are no transaction costs. To value the carbon stocks, we used the average price for avoided deforestation projects, equal to \$4.2/tCO_2-eq and to value the carbon sinks, we used the average price for afforestation and reforestation projects, equivalent to \$7.5/tCO_2-eq (Hamrick and Gallant, 2017). The voluntary carbon market price does not reflect the social value and benefits of avoiding carbon emissions, but is rather dependent on voluntary commitments or policy goals (Convery and Redmond, 2007; Wegner and Pascual, 2011; Hamrick and Gallant, 2017). The social cost of carbon can better capture the marginal value of the societal damage from carbon dioxide emissions since it is estimated using integrated assessment models. Thus, we consider that it is a better welfare measure than the voluntary carbon market price. However, the social cost of carbon is highly sensitive to assumptions and parameters selected for the model -such as discount rates, damage functions, or the projected emissions (Tol, 2009; Pezzey, 2019). The social cost of carbon estimated by the EPA is \$42/tCO_2-eq (EPA, 2016). This value is in the lower range of the estimates of the social cost of carbon, which can reach values higher than \$200/tCO_2-eq (Pindyck, 2019).

2.3.2. Economic valuation of provisioning ecosystem services

To value provisioning ESs, we used two methods: direct market prices and contingent valuation. The direct market approach relied on existing markets and prices for valuing the ESs. Contingent valuation elicited people's Willingness to Accept (WTA) monetary compensation for the loss of an ES (Pearce, Atkinson and Mourato, 2006; Pascual et al., 2010). Our survey asked respondents to state their WTA a compensation for the loss of the provisioning ESs provided by secondary forests.

The main advantage of direct market price valuation is that it is relatively easy and direct to implement, while its main drawback is that when markets are distorted, prices do not reflect the true or 'shadow' value of the ES (Pascual et al., 2010). In this case, the economic values will be biased. On the other hand, the strength of the contingent valuation method is its flexibility: it is applicable to practically all non-marketed and marketed goods, and it allows capturing of all types of benefits from an ES, including 'option values' and 'non-use values' (Pascual et al., 2010). Option value refers to the *future* use value of an ES (Díaz et al., 2015; IPBES, 2015), and non-use values refer to the preference towards an ES, without having to use it or experience it (Pascual et al., 2017). The weakness of contingent valuation is that it is highly sensitive to the survey design and implementation, and it can entail a hypothetical bias, limiting the generalizability of the results (Pearce, Atkinson and Mourato, 2006).

Both economic values were obtained by conducting a survey structured in three parts. The first part consisted of hierarchical preference questions (Chambers, 1985; Klain and Chan, 2012; Rey-Valette, Mathé and Salles, 2017) to obtain the quantity extracted of each ES in each natural regeneration stage, along with its market value. The second part consisted of the contingent valuation, and the final part contained follow-up and sociodemographic questions. The survey was carried out with 30 landholders practicing rotational grazing and interchanging grazing in the pasture with short periods of grazing in the forest (Trilleras et al., 2015; Ugartechea 2015). The sample was designed to include the greatest possible differences among individuals, in terms of age, education, occupation, and quantity of cattle. Survey pilots were conducted in January 2014 and final surveys were conducted in June 2014 (see Supplementary Materials SP2 for the entire survey and summary statistics of landholders in Table 1 of SP3).

a) Market value elicitation survey

Hierarchical preference methods were used to obtain the quantity of fodder for calves and forest products obtained from each natural regeneration stage. First, we asked the respondent to draw a schematic map of his plots and indicate to which natural regeneration stage they belonged to. During the survey, we used a visual support –a photograph– for each natural regeneration stage (see Supplementary Materials SP4) which helped minimize possible errors regarding different perceptions of natural regeneration stages across respondents. Second, we asked for the total quantity of forest products and fodder. In the case of fodder, our indicator variable was the total number of calves sold in the previous year, and their average weight[1]. In the case of forest products, we asked landholders for the total amount of firewood and fencing posts they extracted during the year, in kg and units, respectively. After this, we asked the respondent to distribute 50 beans in the schematic map, considering how much were forest products extracted and fodder grazed from each natural regeneration stage (see Supplementary Materials SP5 for illustrative pictures). The proportion

[1] Given that fodder is an input to livestock production, it cannot be directly measured or valued (Boyd and Banzhaf, 2007), so its economic value was determined from the economic value of the final product (Yahdjian, Sala and Havstad, 2015), which is the price of one kilogram of calf. This is the type of livestock that is most commercialized in the region (Cohen 2014; Ugartechea 2015).

of beans placed in each natural regeneration stage determined the total quantity of each provisioning ES (see further details in Sánchez-Martinez, 2016).

The economic value of the two ESs was obtained by multiplying the quantity extracted by the reported price in the local markets. Firewood is seldom exchanged in the local market, as it is mostly used for domestic consumption. When traded, it is usually sold in large quantities. The price of the firewood registered was $16.12[2] for 500 kg. For fencing posts, the average price was $2.8 ± 0.6 per post[3]. As for fodder, at the time of the study the regional price of a calf was $2.85 per kg, according to the regional union of cattle ranchers[4]. All prices were adjusted for inflation to 2019 prices.

b) Contingent valuation survey

To obtain the WTA of landholders, we presented the following hypothetical scenario: each *ejidatario* was asked to imagine that a non-governmental organization was interested in giving him a yearly financial compensation for every hectare he decided to enrol in a PES program[5]. The non-governmental organization would offer him a payment depending on the natural regeneration stage enrolled (e.g. pasture, young secondary forests, intermediate secondary forests, or old-growth forests). Similar to PES programs in Mexico, we specified that for five years this organization would give an annual cash payment for each hectare of land they chose to enrol in the program. There was no minimum land requirement to participate in the program. We also emphasized that they would not incur the costs of monitoring and infrastructure (i.e. fences). To incentivise interviewees to reveal their true preferences, we asked them to imagine that the funds available were limited and that only landholders offering the best price would receive the payments.

We presented landholders with two PES conditions. The first condition was that the landholder could continue to use his land for livestock grazing, but that if enrolled, he would not be able to extract any product from the forest, including firewood and fencing posts. The second condition was more restrictive. In addition to not being able to extract any forest product, the landholder could no longer introduce his livestock. Thus, the first condition elicited the WTA of forest products, while the second condition elicited the WTA for the bundle of provisioning services, both fodder and forest products.

For each enrolment condition and natural regeneration stage, we presented a set of prices to which the landholder had to give a dichotomous answer (yes/no). The set of prices presented was (in USD ha^{-1} $year^{-1}$): $12.5, $25, $40, $50, $75, $100, $125, $150[6]. The minimum price was chosen based on the minimum payment offered by the national PES program, which is $16 (Pronafor, 2013), and the maximum payment was chosen considering yearly cattle earnings. The bidding always started at the price of $12.5 to avoid starting point bias. During the survey, there was a visual support for each price. Qualitative answers and justifications for their answers were recorded.

In the follow-up questions of the survey we asked respondents what they were planning to do with their plots in the next five years and why. In particular, for each natural regeneration stage, we asked if they were planning to: 1) deforest their plots and transform them into pasture (in the case of young secondary forest, intermediate secondary forest, and old-growth forest), 2) conserve it as it is, or 3) allow the forest to regrow (in the case of pasture), and why. These answers were used to understand differences in the economic values of ESs across natural regeneration stages.

2.4. Data analysis

To assess how economic values of ESs vary in relation to the natural regeneration stage, we conducted one-way ANOVA tests for the regulating services and Kruskal-Wallis tests for the provisioning services. For the provisioning ESs we conducted additional multivariate regressions that allowed us to control for socio-economic covariates of the landholders, as robustness tests to our estimations. We complemented the statistical analyses with the qualitative answers obtained during the survey.

To examine ESs trade-offs, we evaluated the relative importance of each ES in each natural regeneration stage, focusing on the ESs that provide yearly benefits: fodder for calves, forest products, and carbon sinks. We also compared the average economic values of the carbon sink – obtained with both voluntary carbon market prices and the social cost of carbon – with the median WTA obtained from the contingent valuation survey. The median WTA is the value at which the majority of the landholders would be sufficiently compensated to allow for natural regeneration to take place, which is a more useful indicator for policy making than the mean WTA (Pearce, Atkinson and Mourato, 2006). We considered only carbon sinks since it is the ES relevant for the purposes of negative emissions and natural regeneration.

3. Results

3.1. Economic value of regulating ecosystem services

We found significant differences across natural regeneration stages for both carbon stocks ($F_{(2,47)} = 35.81$, $p < 0.001$) and carbon sinks ($F_{(2,47)} = 3.39$, $p = 0.04$). Young and intermediate secondary forests offer the largest carbon sink benefits, while old-growth forests were the ones offering the largest carbon stock benefits (Table 1). This indicates that there is a complementary relationship between natural regeneration stages for providing carbon stocks and carbon sinks. The carbon dioxide removal services (i.e. carbon sinks) are mostly provided by secondary forests, while old-growth forests are the most important for reducing emissions from deforestation.

The economic value of the carbon stocks and sinks was higher when using the social cost of carbon than when using the voluntary carbon market price (Table 1). Bonferroni post-hoc tests indicated that there were significant differences in the economic value of carbon sinks between intermediate secondary forests and old-growth forests only. We note that for carbon sinks, the variation within stages is higher for secondary forests than for old-growth forests (Supplementary Materials SP6, Fig. 1). For carbon stocks, we found significant differences between every natural regeneration stage.

3.2. Economic value of provisioning ecosystem services

We found significant differences in the value of provisioning ESs across natural regeneration stages (Table 2), but the trend differs depending on the ES considered and the economic valuation method. The highest economic value for fodder was obtained in pastures, equivalent to $165.98 ha^{-1} yr^{-1} with direct market method and a corresponding mean WTA of $111.52 ha^{-1} yr^{-1}. Landholders confirmed that there is little fodder in young secondary forests: "*no animal enters here, it is only thorny bushes*", while intermediate secondary forests and old-growth

[2] Exchange rate of 20 MXN/USD is used for all prices (December 2019).

[3] The variation in the price of the fencing post depended on its biological characteristics. For example, the minimum sale price was $1.88 USD, however a good quality fencing post (straight and from dense timber) could cost up to $3.7 USD.

[4] Unión Ganadera Regional de Jalisco, accessed December 2018 (http://www.ugrj.org.mx/index.php?option=com_content&task=view&id=167&Itemid=325)

[5] The framing was done with a non-governmental organization in order to reduce institutional uncertainty and bias: pilot surveys indicated that previous negative experiences with government agencies could bias the willingness of participants to participate and respond.

[6] In MXN, this corresponds to 250, 500, 800, 1000, 1500, 2000, 2500, 3000, at an exchange rate of 1 USD = 20 MXN

Table 2
Mean economic value of forest products (USD $ha^{-1}yr^{-1}$) and fodder (USD $ha^{-1}yr^{-1}$) and Willingness to Accept (WTA) across natural regeneration stages. Standard errors are shown in parenthesis. P-values correspond to a Kruskal-Wallis rank test with $\chi 2_{(3,27)}$.

Ecosystem service	Valuation method	Pasture	Young secondary forest	Intermediate secondary forest	Old-growth forest	p-value
Forest Products (USD $ha^{-1}yr^{-1}$)	Direct market prices	2.51 (1.46)	2.25 (1.17)	7.59 (2.79)	49.55 (19.93)	< 0.001
	Contingent Valuation (WTA)	19.20 (2.45)	21.76 (2.89)	23.50 (2.89)	32.39 (7.15)	0.063
Fodder (USD $ha^{-1}yr^{-1}$)	Direct market prices	165.98 (21.86)	14.24 (6.42)	24.71 (6.40)	29.99 (9.37)	< 0.001
	Contingent Valuation (WTA)	111.52 (9.72)	69.07 (10.46)	51.73 (9.84)	51.12 (9.87)	< 0.001

forests, provide fruits and seeds for cattle: "*There are little fruits that cattle eat, and people say they are good for proteins*". In turn, old-growth forests were the most important source of forest products, providing an average value of \$49.55 ha^{-1} yr^{-1} and a corresponding mean WTA of \$32.39 ha^{-1} yr^{-1}. In general, landholders recognized the greater importance that old-growth forests have in providing fencing posts, as shown by this quote: "*I am keeping old-growth forests to get fencing posts from there*" or "*you have to have old growth forest for when it is needed, so you can find a pole or some timber to make a house*".

Furthermore, when considering the bundle of provisioning ESs, the results of the market price valuation indicate that young secondary forests provide the lowest benefits, but as natural regeneration progresses, provisioning ESs recover. This is mainly driven by an increase in the value of forest products (Table 2 and Fig. 2). However, the contingent valuation indicated the opposite pattern. Young secondary forest was the stage with the highest WTA, second only to pastures, while intermediate secondary forests and old-growth forests had the lowest mean WTA. This contrasting pattern between economic valuation methods originates from the fact that the contingent valuation survey is able to capture the option value of an ES, while market prices captured the actual use value only. Indeed, when asked about their deforestation plans in the next five years for each of the natural regeneration stages, *all* of the respondents answered that they were planning to clear their young secondary forests to transform them into pasture, while only 31.8% were planning to clear the intermediate secondary forests, and *none* were planning to clear old-growth forests. This is compatible with the existence of a higher option -*future use*-value of young secondary forest as opposed to intermediate secondary forests and old growth forests. Our results are consistent even after controlling for socioeconomic characteristics of landholders (see Supplementary Materials SP7).

3.3. Trade-offs and synergies between ecosystem services

We found that overall, the economic value of regulating services is higher than that of provisioning services in all stages except pastures (Fig. 3). This is mainly driven by the high social value of the carbon stock. Furthermore, while there is a strong trade-off between provisioning and regulating ESs in the transition from pasture to young secondary forests - as most of the fodder is lost -, provisioning ESs increase together with regulating ESs at later stages of the natural regeneration process. Thus, there is synergy rather than a trade-off between regulating and provisioning ESs. However, the value of provisioning ESs never reaches the initial value obtained in pastures (of \$168.49 $ha^{-1}yr^{-1}$). If only the ESs that provide a yearly flow are considered (i.e. leaving out the carbon stocks), the economic value of young and intermediate secondary forests is dominated by the carbon sink, while the carbon sinks of the old-growth forests are of secondary importance as compared to the provisioning ESs (Fig. 3). This highlights two important points. First, that natural regeneration stages complement each other for supplying provisioning and regulating ESs, and second, the need to conserve young and intermediate secondary forests to obtain the largest benefits from the carbon capture and removal provided by the carbon sinks.

Indeed, the public, global, benefits obtained from the carbon sinks of secondary forests outweigh the private costs borne by landholders for losing provisioning ESs. The value of the carbon sinks considering the social cost of carbon was always higher than the WTA demanded by landholders (Fig. 4). Furthermore, we found that the voluntary carbon markets can provide enough compensation to incentivize secondary

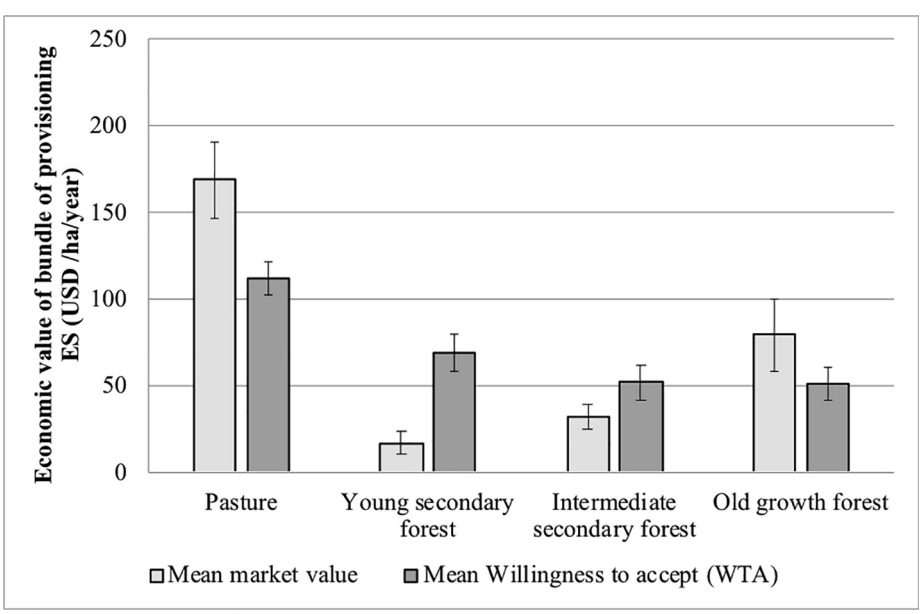

Fig. 2. Mean market value and mean Willingness to Accept (WTA) for the bundle of provisioning services (forest products and fodder) for each natural regeneration stage.

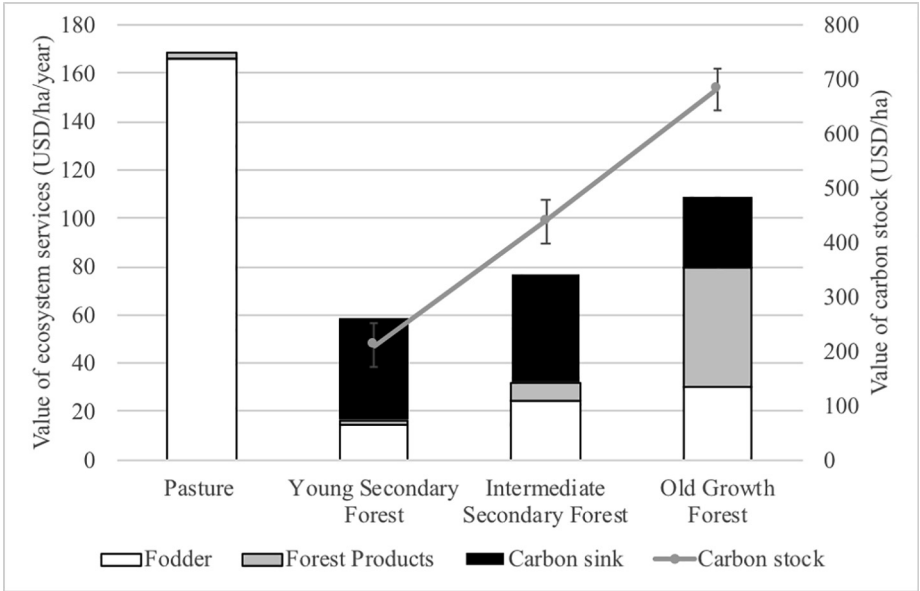

Fig. 3. The average economic value of provisioning services and regulating services obtained with direct market methods, for each natural regeneration stage.

forest conservation and the continuation of natural regeneration for the majority of the landholders. This is especially true for intermediate young secondary forests: the average compensation landholders would receive from the sale of carbon sinks in the voluntary carbon markets, equivalent to \$44.59 $ha^{-1}yr^{-1}$, is higher to the median WTA required to compensate for the loss of provisioning ESs, equivalent to \$30.25 $ha^{-1}yr^{-1}$. When considering the young secondary forests and old-growth forests, the compensation offered by the voluntary carbon markets is roughly the same as the compensation requested by the majority of the landholders (Fig. 4).

4. Discussion

4.1. Economic value of ecosystem services at different stages of the natural regeneration process

Our results indicate that the economic value of regulating ESs provided by secondary tropical forests comes at the expense of provisioning ESs, in particular, fodder. This is consistent with literature highlighting the existence of trade-offs between regulating and provisioning ESs (Howe, 2014; Mora, 2016; Pohjanmies, 2017; Polasky, 2011; Raudsepp-Hearne et al., 2010). Our study complements other studies identifying ESs trade-offs in the region (King et al., 2015; Mora et al., 2016), and contributes with the empirical quantification of these trade-offs throughout the course of the natural regeneration process of secondary forests.

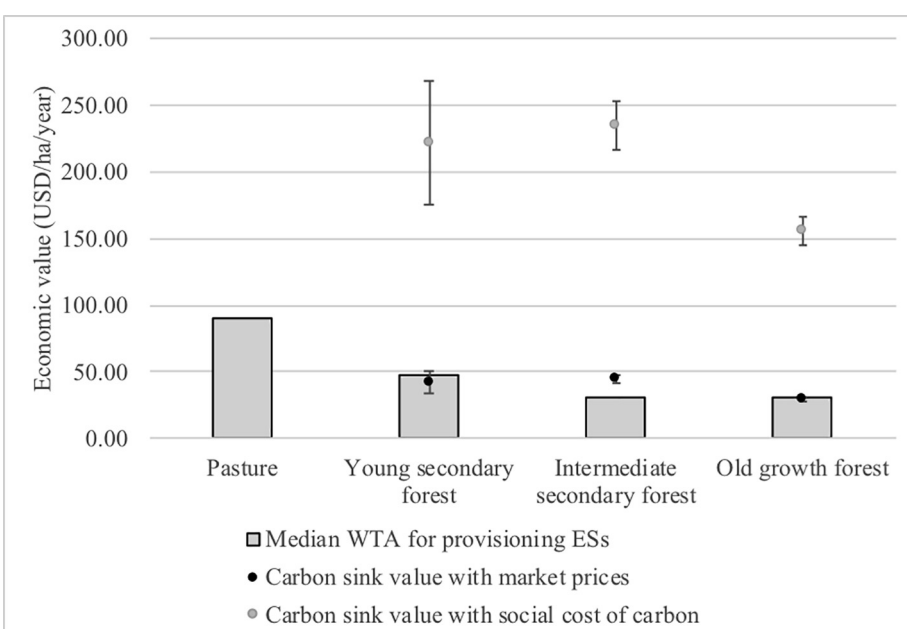

Fig. 4. Comparison of median Willingness to Accept (WTA) for the bundle of provisioning ESs and the economic value of the carbon sinks with market prices and with the social cost of carbon.

Our results further show that trade-offs change at different stages of the natural regeneration process. While we find a strong trade-off between regulating and provisioning services at the start of natural regeneration, since pasture clearly gives the farmer the greatest returns per hectare, in later stages provisioning ESs recover, creating synergies rather than trade-offs between regulating and provisioning ESs. Furthermore, there are complementarities between natural regeneration stages for overall ESs provision. Intermediate secondary and old-growth forests have the highest economic value for regulating ESs and forest products, which is associated with their higher biomass and diversity (Mora et al., 2018). Indeed, the higher diversity in the composition of species increases the number of useful species (Cortés-Calderón et al.). Young secondary forests are the ones providing the lowest economic benefits. The high prevalence of thorny bushes in early stages of natural regeneration (Mora et al.) make young secondary forests difficult to access and manage (Burgos and Maass, 2004), which explains why landholders gain little in the way of provisioning services. However, in this study we argue they are most important because of their carbon sink potential.

In addition, our results highlight the importance of using a portfolio of methods to provide sound estimations for the valuation of nature. Focusing only on single-value and direct use value methodological approaches can provide an incomplete and erroneous picture of the overall value of an ecosystem (Jacobs et al., 2016; Pascual et al., 2017). Our economic values obtained with contingent valuation were in general higher than the ones obtained with market methods, given that this method can encompass a wider range of values. Their difference was particularly relevant for understanding the value of young secondary forests: direct market methods showed that they provided the lowest economic benefit, while contingent valuation showed that they were the most valued by landholders, second only to pasture. We argue that the differences in the economic valuations stem from the existence of a higher option (i.e. future use) value of young secondary forests, while recognizing that option values and non-use values are hard to measure precisely (Pascual et al., 2010). To our knowledge, this is the first study to directly compare two economic valuation methods on the same ecosystem service, showing the relative advantages for policy making of using economic valuation methods that include a wider range of use and non-use values. By using such a portfolio of methods, we could identify different facets of the trade-offs at stake.

4.2. Payments for ecosystem Services: A policy tool for natural regeneration?

Our results have two implications relevant to policy making. First, in spite of the fact that the carbon stocks are likely to be underestimated in this study since we only considered aboveground biomass, the high economic value obtained for carbon stocks indicates that avoiding the deforestation of secondary and old-growth forests is necessary to obtain the largest societal benefits in land use management activities. Other important carbon pools like litter, topsoil or tree roots would increase the carbon stocks of secondary and old-growth forests (Mora et al., 2018; Quijas et al., 2018).

Second, the economic value of carbon sinks shows that there are potentially large societal benefits from promoting natural regeneration. However, the spontaneous development of secondary forests is hindered because it involves a loss of provisioning ESs obtained from pastures (of \$168.49 $\pm$ 22.07 ha^{-1} yr^{-1}) – which were similar to the opportunity costs estimated in the region (Borrego and Skutsch 2014) – and because landholders receive few benefits from the conservation of young secondary forests. Thus, to promote natural regeneration, PES can be useful policy to compensate the landholders losing provisioning ESs (Montagnini and Finney, 2011) and fill the mismatches between the private loss of pastures and the public gains of regulating ESs from the secondary forests. We found that current voluntary carbon market prices could offer enough economic compensation to landholders. Such a program could involve government, individuals, or private enterprises compensating the landowners who allow natural regeneration, but it would involve various challenges. First, the trends in livestock and CO_2-eq prices suggest that incentivizing natural regeneration and secondary forest conservation can be hard to maintain over time: the price of cattle in the region has been rising since 2009, while the price of CO_2-eq tends to decrease (Hamrick and Gallant, 2017). This hints at the necessity of government intervention, rather than a PES involving only 'market' actors. Second, such a PES is likely to have high transaction costs in terms of monitoring and enforcement, particularly given the high variability we found in the carbon sinks of secondary forests (see also Cortés-Calderón et al.). Transactions cost could decrease by involving local stakeholders in the monitoring process: participative monitoring can be easy to implement and a reliable source of information (Danielsen et al., 2011; Skutsch et al., 2017). Third, our results showed that few landholders plan to deforest intermediate secondary forests or old-growth forests in the next five years, which means a PES payment targeting avoided deforestation of old-growth forest – as they are often implemented – would have little additionality and moreover, it could crowd out their intrinsic motivation to conserve these forests (Muradian et al., 2013; Rode, Gómez-Baggethun and Krause, 2015). Rather, our results suggest that a PES scheme focused on the conservation of young and intermediate secondary forests based on their carbon sink potential would provide the greatest additionality and thus the largest climate benefits. Our results show that shifting the focus of PES program to carbon sinks, rather than the loss of carbon stocks, could be enough to provide the necessary incentives for the conservation and regeneration of tropical forests. While the REDD + strategy has been devoted to the issue of reducing the loss of carbon stocks (Herold and Skutsch, 2011; Skutsch et al., 2017), strategies focusing on carbon sinks may be more relevant. We note however that our results are contingent on the consideration of other carbon sink sources, such as heterotrophic respiration, which could mitigate the benefits considerably (Quijas et al., 2018).

5. Conclusion

Throughout the course of the natural regeneration process, there are changes in the magnitude of the trade-offs between regulating and provisioning ecosystem services. While there is a significant loss of provisioning services in the transition from pasture to young secondary forest, there are synergies between regulating and provisioning ESs at later stages of natural regeneration. Pastures provide the greatest economic benefits to landholders while the young secondary forests are the ones that offer the lowest benefits. Nevertheless, landholders' value young secondary forests because of their potential – future – land use and potential transformation into pasture. Old-growth forests are the most important to maintain carbon stocks, while young secondary and intermediate secondary forests are the most important for carbon sinks. Furthermore, we found that young secondary forests face a higher deforestation risk than old-growth and secondary forests. Taken together, these results suggest a PES aiming to increase climate regulation services should focus on the carbon sink potential of young and intermediate secondary forests, as this would provide the greatest additionality and mitigation. This is in contrast with the way REDD + strategies and PES payments have been designed in many tropical countries. For an effective PES design, our results suggest at least two areas requiring further research. One is the need to evaluate the equity implications of implementing a PES program targeted at young secondary forests. If the ownership of secondary forests amongst landholders is highly unequal, then negative distributional implications may arise. The second area for future research is to evaluate large-scale implications of incentivizing natural regeneration at the local scale. General equilibrium economic effects might entail leakage of cattle activities into other areas and mitigate the positive impacts of the local efforts to increase natural regeneration.

CRediT authorship contribution statement

Julia Naime: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Francisco Mora:** Methodology, Investigation, Supervision, Validation, Writing - review & editing. **Mauricio Sánchez-Martínez:** Validation, Investigation, Methodology. **Felipe Arreola:** Investigation, Data curation, Project administration. **Patricia Balvanera:** Conceptualization, Methodology, Validation, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was funded by the Mexican National Council for Science and Technology [grant numbers SEP-CONACyT/2009-129740 and SEP-CONACyT/2015- 255544] and by the Universidad Nacional Autónoma de México [grant numbers UNAM-DGAPA-PAPIIT IN211114 and PAPIIT-UNAM IN211417 2017]. Authors declare there are no conflicts of interest. Special acknowledgements to the landholders and ejidatarios who participated in our survey, and to the Biological Station Chamela of the Biology Institute of the National Autonomous University of Mexico (UNAM) who facilitated the fieldwork. We also thank Lucia Almeida, Sophia Avila Foucalt, Eduardo García-Frapolli, Julia Carabias, David Mitre, Michael Tanner and Santiago Izquierdo-Tort for their comments and suggestions to previous versions of this manuscript, and an anonymous reviewer for the valuable suggestions to the final version.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foreco.2020.118294.

References

Alexander, S., et al., 2016. The relationship between ecological restoration and the ecosystem services concept. Ecol. Soc. 21 (1). https://doi.org/10.5751/ES-08288-210134.

Bojórquez, A., et al. Improving the accuracy of aboveground biomass estimates for secondary tropical dry forests with allometric models. Forest Ecology and Management, this issue in revision.

Boege, K., et al., 2019. Temporal Variation in the Influence of Forest Succession on Caterpillar Communities: A Long-Term Study in a Tropical Dry Forest. Biotropica 514, 529–537. https://doi.org/10.1111/btp.12666.

Borrego, A., Skutsch, M., 2014. Estimating the opportunity costs of activities that cause degradation in tropical dry forest: Implications for REDD+. Ecol. Econ. 101, 1–9. https://doi.org/10.1016/j.ecolecon.2014.02.005.

Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecol. Econ. 63 (2–3), 616–626. https://doi.org/10.1016/j.ecolecon.2007.01.002.

Bullock, J.M., et al., 2011. Restoration of ecosystem services and biodiversity: Conflicts and opportunities. Trends Ecol. Evol. 26 (10), 541–549. https://doi.org/10.1016/j.tree.2011.06.011.

Burgos, A., Maass, J.M., 2004. Vegetation change associated with land-use in tropical dry forest areas of Western Mexico. Agric. Ecosyst. Environ. 104 (3), 475–481. https://doi.org/10.1016/j.agee.2004.01.038.

Carrillo-Saucedo, Silvia Margarita, et al., 2018. Arbuscular Mycorrhizal Fungal Spore Communities of a Tropical Dry Forest Ecosystem Show Resilience to Land-Use Change. Fungal Ecol. 32, 29–39. https://doi.org/10.1016/j.funeco.2017.11.006.

Castillo, A., et al., 2005. Understanding the interaction of rural people with ecosystems: A case study in a tropical dry forest of Mexico. Ecosystems 8 (6), 630–643. https://doi.org/10.1007/s10021-005-0127-1.

Chambers, R., 1985. Shortcut Methods of Gathering Social Information for Rural Development Projects. In: Cernear, M. (Ed.), Putting People First. Sociological Variables in Rural Development. Oxford University Press/The World Bank, Washington, D.C.

Chazdon, R.L., et al., 2016. 'Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. Sci. Adv. 2 (5). https://doi.org/10.1126/sciadv.1501639.

Chazdon, R.L., et al., 2017. A Policy-Driven Knowledge Agenda for Global Forest and Landscape Restoration. Conservation Lett. 10 (1), 125–132. https://doi.org/10.1111/conl.12220.

Chazdon, R.L., Guariguata, M.R., 2016. Natural regeneration as a tool for large-scale forest restoration in the tropics: prospects and challenges. Biotropica 48 (6), 716–730. https://doi.org/10.1111/btp.12381.

Chazdon, R.L., Uriarte, M., 2016. Natural regeneration in the context of large-scale forest and landscape restoration in the tropics. Biotropica 48 (6), 709–715. https://doi.org/10.1111/btp.12409.

Cohen, D., 2014. Estrategias de manejo de bosque tropical seco: un estudio de caso en Jalisco. Universidad Nacional Autonoma de Mexico (UNAM) Thesis.

Convery, F.J., Redmond, L., 2007. Market and Price Developments in the European Union Emissions Trading Scheme. Rev. Environ. Economics Policy 1 (1), 88–111. https://doi.org/10.1093/reep/rem010.

Cord, A.F., et al., 2017. Towards systematic analyses of ecosystem service trade-offs and synergies: Main concepts, methods and the road ahead. Ecosyst. Serv. Elsevier B.V. 28, 264–272. https://doi.org/10.1016/j.ecoser.2017.07.012.

Cortés-Calderón, S. et al. Recovery trends in the supply of ecosystem services and interactions in secondary tropical dry forests. Forest Ecology and Management, this issue in revision.

Crouzeilles, R., et al., 2017. Ecological restoration success is higher for natural regeneration than for active restoration in tropical forests. Sci. Adv. 3 (11), 1–8. https://doi.org/10.1126/sciadv.1701345.

Danielsen, F., et al., 2011. At the heart of REDD+: A role for local people in monitoring forests? Conservation Lett. 4 (2), 158–167. https://doi.org/10.1111/j.1755-263X.2010.00159.x.

Díaz, S., et al., 2015. The IPBES Conceptual Framework - connecting nature and people. Current Opin. Environ. Sustain. 14, 1–16. https://doi.org/10.1016/j.cosust.2014.11.002.

Engel, S., 2016. The Devil in the Detail: A Practical Guide on Designing Payments for Environmental Services. Int. Rev. Environ. Resour. Economics 9, 131–177. https://doi.org/10.2139/ssrn.2712376.

EPA Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866, Social Cost of Carbon Estimates for Regulatory Impact Analysis: Development and Technical Assessment, 2016.

Flores-Casas, R., Ortega-Huerta, M.A., 2019. Modelling land cover changes in the tropical dry forest surrounding the Chamela-Cuixmala biosphere reserve, Mexico. Int. J. Remote Sens. Taylor & Francis 40 (18), 6948–6974. https://doi.org/10.1080/01431161.2019.1597305.

Gei, Maga, et al., 2018. Legume Abundance along Successional and Rainfall Gradients in Neotropical Forests. Nat. Ecol. Evol. 2 (7), 1104–1111. https://doi.org/10.1038/s41559-018-0559-6.

Godinez, C., 2011. Plantas utiles y potencialmente utiles del bosque tropical seco presentes en Chamela, Jalisco. Universidad Nacional Autonoma de Mexico, Mexico.

Griscom, B.W., et al., 2017. Natural climate solutions. Proc. National Academy Sci. United States of America 114 (44), 11645–11650. https://doi.org/10.1073/pnas.1710465114.

De Groot, R.S., et al., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol. Complexity 7 (3), 260–272. https://doi.org/10.1016/j.ecocom.2009.10.006.

De Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecol. Econ. 41 (3), 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7.

Guariguata, M.R., Balvanera, P., 2009. Tropical forest service flows: Improving our understanding of the biophysical dimension of ecosystem services. For. Ecol. Manage. 258 (9), 1825–1829. https://doi.org/10.1016/j.foreco.2009.06.025.

Hamrick, K., Gallant, M., 2017. Fertile ground, State of Forest Carbon Finance 2017. Ecosystem Marketplace, Washington, DC.

Herold, M., Skutsch, M., 2011. Monitoring, reporting and verification for national REDD + programmes: Two proposals. Environ. Res. Lett. 6 (1). https://doi.org/10.1088/1748-9326/6/1/014002.

IPBES, Preliminary guide regarding diverse conceptualization of multiple values of nature and its benefits, including biodiversity and ecosystem functions and services (deliverable 3 (d)). Kuala Lumpur, 2015.

IPCC, Guidelines for National Greenhouse Gas Inventories, 2006.

IPCC, Climate change and land, Special report, 2019.

IPCC, Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, 2019.

Howe, C., et al., 2014. Creating win-wins from trade-offs? Ecosystem services for human well-being: A meta-analysis of ecosystem service trade-offs and synergies in the real world. Global Environmental Change 28, 263–275.

Jacobs, S., et al., 2016. A new valuation school: Integrating diverse values of nature in resource and land use decisions. Ecosyst. Serv. Elsevier B.V. 22, 213–220. https://doi.org/10.1016/j.ecoser.2016.11.007.

Jaramillo, V.J., et al., 2003. Biomass, Carbon, and Nitrogen Pools in Mexican Tropical Dry Forest Landscapes. Ecosystems 6 (7), 609–629. https://doi.org/10.1007/s10021-002-0195-4.

Kearney, S. P. et al. (2019) 'Evaluating ecosystem service trade-offs and synergies from slash-and-mulch agroforestry systems in El Salvador', Ecological Indicators. Elsevier, 105(August 2017), pp. 264–278. doi: 10.1016/j.ecolind.2017.08.032.

King, E., et al., 2015. Trade-offs in ecosystem services and varying stakeholder preferences: Evaluating conflicts, obstacles, and opportunities. Ecol. Soc. 20 (3). https://doi.org/10.5751/ES-07822-200325.

Klain, S.C., Chan, K.M.A., 2012. Navigating coastal values: Participatory mapping of ecosystem services for spatial planning. Ecol. Econ.. Elsevier B.V. 82 (December), 104–113. https://doi.org/10.1016/j.ecolecon.2012.07.008.

Lazos-Chavero, E., et al., 2016. Stakeholders and tropical reforestation: challenges, trade-offs, and strategies in dynamic environments. Biotropica 48 (6), 900–914. https://doi.org/10.1111/btp.12391.

Maass, J.M., et al., 2005. Ecosystem Services of Tropical Dry Forests : Insights from Long-term Ecological and Social Research on the Pacific Coast of Mexico. Ecol. Soc. 10 (1) 17 17\nArtn 17.

Maass, J.M., et al., 2016. Changes in biodiversity and trade-offs among ecosystem services stakeholders and components of well-being: The contribution of the International Long-Term Ecological Research network (ILTER) to Programme on Ecosystem Change and Society (PECS). Ecol. Soc. 21 (3). https://doi.org/10.5751/ES-08587-210331.

Maass, J.M., et al., 2018. Long term (33 years) rainfall and runoff dynamics in a tropical dry forest ecosystem in western Mexico: Management implications under extreme hydrometeorological events. Forest Ecology and Management 426, 7–17. https://doi.org/10.1016/j.foreco.2017.09.040.

Marre, J.B., Billé, R., 2019. 'A demand-driven approach to ecosystem services economic valuation: Lessons from Pacific island countries and territories. Ecosyst. Serv. Elsevier B.V. 39 (June), 100975. https://doi.org/10.1016/j.ecoser.2019.100975.

Meli, P., et al., 2017. A global review of past land use, climate, and active vs. passive restoration effects on forest recovery. PLoS ONE 12 (2), 1–17. https://doi.org/10.1371/journal.pone.0171368.

Miteva, D.A., Pattanayak, S.K., Ferraro, P.J., 2012. Evaluation of biodiversity policy instruments: What works and what doesn't? Oxford Rev. Economic Policy 28 (1), 69–92. https://doi.org/10.1093/oxrep/grs009.

Montagnini, F., Finney, C., 2011. Payments for environmental services in latin America as a tool for restoration and rural development. Ambio 40 (3), 285–297. https://doi.org/10.1007/s13280-010-0114-4.

Mora, F., et al., 2015. Testing Chronosequences through Dynamic Approaches: Time and Site Effects on Tropical Dry Forest Succession. Biotropica 47 (1), 38–48. https://doi.org/10.1111/btp.12187.

Mora, F., et al., 2016. Trade-offs between ecosystem services and alternative pathways toward sustainability in a tropical dry forest region. Ecol. Soc. 21 (4). https://doi.org/10.5751/ES-08691-210445.

Mora, F., et al., 2018. Carbon Accumulation in Neotropical Dry Secondary Forests: The Roles of Forest Age and Tree Dominance and Diversity. Ecosystems 21 (3), 536–550. https://doi.org/10.1007/s10021-017-0168-2.

Mora, F. et al. Resprouting contribution to tropical dry secondary forest regeneration is mediated by previous land use intensity, Forest Ecology and Management, this issue in revision.

Müller, A., Knoke, T., Olschewski, R., 2019. Can existing estimates for ecosystem service values inform forest management? Forests 10 (2), 1–17. https://doi.org/10.3390/f10020132.

Muradian, R., et al., 2013. Payments for ecosystem services and the fatal attraction of win-win solutions. Conservat. Lett. 6 (4), 274–279. https://doi.org/10.1111/j.1755-263X.2012.00309.x.

Naeem, S., et al., 2015. Get the science right when paying for nature's services. Science 347 (6227), 1206–1207. https://doi.org/10.1126/science.aaa1403.

Pandeya, B., et al., 2016. A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data scarce regions. Ecosyst. Serv. 22 (October), 250–259. https://doi.org/10.1016/j.ecoser.2016.10.015.

Pascual, U. et al., 'Chapter 5. The economics of valuing ecosystem services and biodiversity', in The Economics of Ecosystems and Biodiversity. Ecological and economic foundations, 2010, Available at: http://africa.teebweb.org/wp-content/uploads/2013/04/D0-Chapter-5-The-economics-of-valuing-ecosystem-services-and-biodiversity.pdf.

Pascual, U., et al., 2017. Valuing nature's contributions to people: the IPBES approach. Current Opin. Environ. Sustainability 26–27, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006.

Pearce, D., Atkinson, G. and Mourato, S., Cost-benefit analysis and the environment: Recent developments, Cost-benefit analysis and the environment: Recent developments, 2006, doi: 10.1787/9789264010055-en.

Pezzey, J.C.V., 2019. Why the social cost of carbon will always be disputed. Wiley Interdiscip. Rev. Clim. Change 10 (1), 1–12. https://doi.org/10.1002/wcc.558.

Pindyck, R. S., The social cost of carbon revisited, Journal of Environmental Economics and Management. Elsevier Inc., 94, 2019, pp. 140–160. doi: 10.1016/j.jeem.2019.02.003.

Pohjanmies, T., et al., 2017. Conflicting objectives in production forests pose a challenge for forest management. Ecosyst. Serv. 28, 298–310. https://doi.org/10.1016/j.ecoser.2017.06.018.

Polasky, S., et al., 2011. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the state of Minnesota. Environ. Resour. Econ. 48 (2), 219–242. https://doi.org/10.1007/s10640-010-9407-0.

Poorter, L., et al., 2016. Biomass resilience of Neotropical secondary forests. *Nature*. Nature Publishing Group 530 (7589), 211–214. https://doi.org/10.1038/nature16512.

PRONAFOR (2013) Programas de Servicios Ambientales. Available at: https://snigf.cnf.gob.mx/apoyos-pronafor-2013/ (Accessed: 20 September 2012).

Quijas, S., et al., 2018. Modelling carbon stock and carbon sequestration ecosystem services for policy design: a comprehensive approach using a dynamic vegetation model. Ecosyst. People 15 (1), 42–60. https://doi.org/10.1080/26395908.2018.1542413.

Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M., 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proc. Natl. Acad. Sci. 107 (11), 5242–5247. https://doi.org/10.1073/pnas.0907284107.

Rendón-Carmona, H., et al., 2009. Selective cutting of woody species in a Mexican tropical dry forest: Incompatibility between use and conservation. For. Ecol. Manage. 257 (2), 567–579. https://doi.org/10.1016/j.foreco.2008.09.031.

Rey-Valette, H., Mathé, S., Salles, J.M., 2017. An assessment method of ecosystem services based on stakeholders perceptions: The Rapid Ecosystem Services Participatory Appraisal (RESPA). Ecosystem Services Elsevier B.V. 28, 311–319. https://doi.org/10.1016/j.ecoser.2017.08.002.

Rey Benayas, J.M., et al., 2009. Enhancement of Biodiversity and Ecosystem Services by Ecological Restoration: A Meta-Analysis. Science 325 (August), 1121–1125.

Rode, J., Gómez-Baggethun, E., Krause, T., 2015. Motivation crowding by economic incentives in conservation policy: A review of the empirical evidence. Ecol. Econ. Elsevier B.V. 109. https://doi.org/10.1016/j.ecolecon.2014.11.019.

Rozendaal, Danaë M.A., Frans Bongers, T., Aide, Mitchell, Alvarez-Dávila, Esteban, Ascarrunz, Nataly, Balvanera, Patricia, Becknell, Justin M., et al., 2019. Biodiversity Recovery of Neotropical Secondary Forests. Sci. Adv. 5 (3). https://doi.org/10.1126/sciadv.aau3114.

Sánchez-Azofeifa, G.A., et al., 2009. Land cover and conservation in the area of influence of the Chamela-Cuixmala Biosphere Reserve, Mexico. For. Ecol. Manage. 258 (6), 907–912. https://doi.org/10.1016/j.foreco.2008.10.030.

Sánchez-Martinez, M., 2016. Uso de servicios ecosistémicos en el bosque tropical seco secundario de la región Chamela- Cuixmala, Jalisco. México, Thesis, UNAM.

Sánchez-Romero, R. et al. Management strategies, regional drivers and adaptive learning in traditional silvopastoral systems in dry tropical forests of Jalisco, México: An integrated socioecological analysis. Forest Ecology and Management, this issue in revision.

Seddon, N., et al., 2019. Grounding nature-based climate solutions in sound biodiversity science. Nat. Clim. Change 9 (2), 84–87. https://doi.org/10.1038/s41558-019-0405-0.

Skutsch, M., et al., 2017. Adapting REDD+ policy to sink conditions. Forest Policy Economics 80, 160–166. https://doi.org/10.1016/j.forpol.2017.03.016.

Tauro, A., et al., 2018. Unraveling heterogeneity in the importance of ecosystem services: Individual views of smallholders. Ecol. Soc. 23 (4). https://doi.org/10.5751/ES-10457-230411.

Tol, R.S.J., 2009. The Economic Effects of Climate Change. J. Economic Perspect. 23 (2), 29–51.

Trilleras, J.M., et al., 2015. 'Effects of livestock management on the supply of ecosystem services in pastures in a tropical dry region of western Mexico'. Agri. Ecosyst. Environ. Elsevier B.V. 211, 133–144. https://doi.org/10.1016/j.agee.2015.06.011.

Ugartechea, O., 2015. Valor economico y disyuntivas ambientales en el manejo del bosque tropical seco en Chamela. Thesis, Universidad Nacional Autonoma de Mexico (UNAM), Jalisco. MSc.

Wegner, G., Pascual, U., 2011. Cost-benefit analysis in the context of ecosystem services for human well-being: A multidisciplinary critique. Global Environ. Change 21 (2), 492–504. https://doi.org/10.1016/j.gloenvcha.2010.12.008.

Wilson, S.J., et al., 2017. Forest ecosystem-service transitions: the ecological dimensions of the forest transition. Ecol. Soc. 22 (4), p. art38. https://doi.org/10.5751/ES-09615-220438.

Yahdjian, L., Sala, O.E., Havstad, K.M., 2015. Rangeland ecosystem services: Shifting focus from supply to reconciling supply and demand. Front. Ecol. Environ. 13 (1), 44–51. https://doi.org/10.1890/140156.