

Identifying priority conservation areas for above-ground carbon sequestration in Central Mexico

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Identifying forest ecosystems with significant ecological, social, and/or economic values is an important first-step in conserving landscape function. Here, we identify priority conservation areas in the municipalities of Chignahuapan and Zacatlan, Puebla (Mexico), based on: (i) their capacity to sequester atmospheric CO₂; and (ii) risk of future deforestation. We also explore management strategies for priority-lands conservation in the Mexican context. Above-ground C sequestration was estimated using wood density and biomass expansion-factor data available from local forestry sources. Deforestation risk was estimated by a probabilistic model of land use change using socioeconomic and biophysical variables. Carbon sequestration estimates ranged from 14 to 531 Mg ha⁻¹ for Chignahuapan and Zacatlan, respectively. An estimated 11,746 and 4,406 ha of forest was determined to be at risk of deforestation in each municipality. Of these at-risk lands, 2,421 and 1,798 ha were determined to be at high risk. In combination, we determined that 10,687 and 4,319 ha, respectively, are priority lands for carbon sequestration in Chignahuapan and Zacatlan, of which 628 and 310 ha were determined to have high conservation priority. Identifying priority conservation areas through the integrated assessment of carbon sequestration and deforestation risk can enhance efforts to target land management strategies to mitigate climate change impacts. This approach can serve as a model for other forested regions in Mexico and other countries.

Keywords: Forest Carbon Sinks, REDD, Climate Change, Deforestation Risk, Priority Conservation, Probabilistic Model, Land Use, Development

Introduction

The role of forests in mitigating climate change has taken on increased attention in recent years. Initially, international efforts focused on reducing greenhouse gas (GHG) emissions from industrialized countries (e.g., Kyoto Protocol, Paris COP). Early work sought to establish baseline GHG inventories under the Intergovernmental Panel on Climate Change (IPCC). Data show that from 1970 to 2014, emissions increased by 90% (49 MMTCO₂ yr⁻¹ – Boden et al. 2017). More recently, efforts have broadened to include a portfolio of mitigation strategies, including flexible mechanisms such as emissions trading, clean development, and carbon accounting, the latter of which seeks to quantify the amount

of carbon absorbed by forests and other natural carbon sinks (Caballero et al. 2007).

Mexico emits more than 553 million tons per year of greenhouse gases (GHG) as a result of industry, farming, and forest degradation and deforestation. This total represents 1.5% of global emissions. Of this, degradation and deforestation account for 12.4% of Mexico's total GHG emissions. In response, Mexico pledged in 2009 to limit 2050 GHG emissions to 50% of year 2000 emissions through its newly established Special Climate Change Program or PECC, for its Spanish acronym (IICA 2012).

To reduce emissions, governmental and non-governmental institutions initiated various measures, such as sustainable forest management, Reducing Emissions from

Deforestation and forest Degradation (REDD) pilot projects, payment for environmental services, wildlife management units, protected natural areas in forest ecosystems, sustainable planned grazing, and commercial forest plantations (Greenpeace Mexico 2010, CONAFOR 2011, 2014).

To optimize resources and ensure effectiveness, a strategic forest planning approach is needed to identify and protect forested areas with high carbon sequestration (García & Lagares 2011). These priority conservation areas are spatial representations of the territory defined by environmental, social and cultural characteristics whose presence is threatened by human activities, natural causes, or both (Collins et al. 2001, Morgan et al. 2005). The designation of priority conservation areas for carbon sequestration have already been used to promote the reduction of high rates of deforestation and restore degraded areas (Saavedra et al. 2011, Alvarez & Rubio 2013) – a strategy that arose from collaboration between foreign research groups and Mexican researchers (Cantú et al. 2004, Riemann & Ezcurra 2005).

Here, we develop an integrated methodology to quantify both existing forest-level carbon sequestration, and risk of deforestation. This combination is then used to identify priority conservation areas for natural resource protection.

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Materials and methods

Our research comprised three stages: (1) determining carbon sequestration; (2) estimating risk of deforestation; and (3) delineation and comparative analysis of priority conservation areas for carbon sequestration. We focus on the Chignahuapan-Zacatlan region because it represents the primary forest area of the Sierra Norte mountain range of the State of Puebla (Mexico).

Study area

The municipalities of Chignahuapan and Zacatlan are located in the Sierra Norte de Puebla, a mountainous, upland region of Central Mexico (19° 39' 42" - 20° 08' 12" N and 97° 51' 06" - 98° 18' 06" W). The 1250 km² study area is part of the Trans-Mexican volcanic belt composed of rugged mountain ranges with some intermediate plains. Peaks range from 2300 to 4200 m. The study area has a cold, temperate climate, with annual precipitation ranging from 600 to 1500 mm (Cruz-Huerta et al. 2015). The region is dominated by pine-oak forests, with 27.2% covered by coniferous forests.

The combined population in both municipalities is 115,456 inhabitants, of which 15% belong to an ethnic indigenous group that generally reside within areas of mountainous forest. The two municipalities include 289 discrete settlements, of which five are considered urban areas. The marginalization and human development indices for the study area are 0.16 and 0.74, respectively, indicating limited social capital and opportunities, and low levels of education, income, and life expectancy (CONAPO 2010). For comparison, at the State level, these indexes are 0.71 and 0.77, respectively. Agriculture and forestry are dominant land uses, comprising the bulk of economic activity. Most agricultural and forest lands are under *ejido* tenure regimes. At the State level, Chignahuapan accounts for 45% of total timber harvests, while Zacatlan contributes another 9%. Combined, the two municipalities support over half of the forest sector, including many jobs.

Tab. 1 - Wood density of timber species in the municipalities of Chignahuapan and Zacatlan, Puebla (Sources: Goche et al. 2000, Honorato & Fuentes 2001, CONAFOR 2011, Arredondo & Nívar 2012).

Species	Density (kg m ⁻³)
<i>Abies religiosa</i>	380
Broadleaf species	600
<i>Pinus pseudostrubus</i>	550
<i>Pinus patula</i>	430
<i>Pinus ayacahuite</i>	340
<i>Pinus montezumae</i>	460
<i>Pinus hartwegii</i>	496
<i>Pinus leiophylla</i>	485
<i>Pinus teocote</i>	480
<i>Pinus rudis</i>	530
<i>Quercus</i> spp.	760

Timber harvests in the study area were prohibited by federal law from 1947 to 1975. The policy was intended to limit deforestation and protect important environmental functions. Unfortunately, in the absence of management, deforestation rates increased, although data for the region from that era are lacking. After 1975, forests were managed under two systems to meet multiple use objectives including timber production: the "Mexican Method of Forest Regulation" (MMOM), and the "Method for Silvicultural Development" (MDS - SMRN 2007). Management led to reduced deforestation rates, estimated at around 3.3% per year today (for comparison, deforestation at the country level is 0.24% per year). Deforestation pressures are greatest near existing settlements, where forests are cleared for agriculture and residential use.

Determining carbon sequestration

Above-ground carbon sequestration in the forests of the study area was determined using forest inventory data from lands with forest management programs, avoiding the need for primary data or destructive sampling (Masera et al. 2000, Ordoñez & Masera 2001, Fonseca et al. 2009). Inventory data on 24 and 28 Chignahuapan and Zacatlan forest lands covering an area of 20,187 and 6,124 ha, respectively, was collected. Most lands were covered by pine forests dominated by *Pinus patula*, although forests included sacred fir (*Abies religiosa*), mixed pine-oak (*Pinus* spp. - *Quercus* spp.), and oak forests.

Following the documentary and spatial identification of forest types, the carbon in the above-ground biomass was calculated as follows (Masera et al. 2000 - eqn. 1):

$$C_{AB} = V \cdot WD \cdot BEF \cdot CF \quad (1)$$

where C_{AB} is the carbon content in above-ground biomass (Kg CO₂ ha⁻¹); V is the wood volume (m³ ha⁻¹); WD is the wood density (Kg m⁻³); BEF is the biomass expansion factor; and CF is the carbon fraction.

Eqn. 1 is conservative in its estimates of carbon because it only includes volume from tree species with marketable timber diameters, excluding aboveground biomass from unmerchantable species, trees with diameters less than 15 cm DBH, brushwood, and foliage (Di Matteo et al. 2014). Other important forest compartments not considered include deadwood, litterfall, below-ground plant biomass and soil carbon (Wegglar et al. 2012, Ruiz-Peinado et al. 2013).

The expansion factor, BEF , was used to represent biomass components that were difficult to obtain from direct measurement (e.g., branches and leaves). The BEF reference values, based on previous studies by Caballero et al. (2007) and Silva & Nívar (2010), were as follows: *Pinus* spp. (1.38), *Quercus* spp. (1.5), *Abies* spp. (1.3),

and broadleaf species (1.3). Wood density (WD) for each species in eqn. 1 was obtained from a variety of sources reported in Tab. 1 (i.e., Goche et al. 2000, Honorato & Fuentes 2001, CONAFOR 2011, Arredondo & Nívar 2012).

As the dry weight of carbon in biomass ranges from 0.45 to 0.55 (IPCC 1996), our research used a mid-range value of carbon fraction (CF) of 0.50 (Houghton et al. 1999). However, this default value could underestimate the overall carbon fraction (Jones & O'Hara 2012). Finally, carbon values were then converted to CO₂ using the conversion factor (44/12). Once above-ground biomass by species was established, it was expressed as carbon units per hectare by municipality using Microsoft Office Excel®.

The Mg CO₂ database was joined to the polygon database of forest lands using the Join command in ArcGIS® ver. 9.3; it was deployed in ArcGIS ArcMap™ ver. 9.3 and interpolated to the total forest area of Chignahuapan (29,401 ha) and Zacatlan (28,039 ha) using the Kriging method (Murrillo et al. 2012). The magnitude of the stored carbon was categorized into three intervals or classes using the Reclassify command located in the Spatial Analyst module within ArcGIS ver. 9.3. The final product was a map with average carbon sequestration categories: (1) high (from 218 to 531 Mg CO₂ ha⁻¹); (2) medium (from 96 to 218 Mg CO₂ ha⁻¹); and (3) low (from 0 to 96 Mg CO₂ ha⁻¹). These categories were established according to the data distribution without using thresholds criteria.

Estimating risk of deforestation

A probabilistic model of land use (eqn. 2) was used to estimate deforestation risk (dependent variable) based on 21 socio-economic and biophysical variables (independent variables, see Tab. S1 in Supplementary material - González 2000, Montgomery 2004). These variables were selected based on their importance as drivers of land use change between 1986 and 2011 in the study area (Cruz-Huerta et al. 2015 - eqn. 2):

$$\hat{Y}_i = \frac{1}{1 + e^{-(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_{21} X_{21})}} \quad (2)$$

where \hat{Y}_i is the probability that a hectare (100 × 100 m) changes from forest use to another use; i = forest, agriculture, livestock or residential use; e is the base of the natural logarithm; β_0 , β_i are intercept and estimators of the independent variables (X_i); and X_i are independent variables (X_1, X_2, \dots, X_{21}).

The stepwise procedure of SAS® ver. 9.0 was used to construct the model. Once the probabilistic model was specified, it was used to estimate (in maps) the probabilities of land-use changes for the forest area of 2011 in each municipality.

Identification and comparative analysis of priority conservation areas for carbon sequestration

Priority areas for carbon sequestration were identified using the map algebra technique of the Spatial Analyst module and the Raster Calculator tool (Vargas et al. 2009). This technique allows calculating scenarios from two combined criteria. For example, a high-priority CO₂ conservation area results from combining an area that has high carbon sequestration and a high risk of deforestation. The normalized criteria for carbon sequestration were: (1) high (from 0.66 to 1); (2) medium (from 0.33 to 0.66); and (3) low (from 0 to 0.33). The same classes were used for categorizing deforestation risk (CORENA 2000, Cruz-Huerta et al. 2015), although remote areas without risk of deforestation were not considered in the model. Tab. 2 shows the different combinations obtained.

Finally, a comparative spatial analysis was conducted on deforestation risk area, carbon sequestration, and priority conservation areas for carbon sequestration in order to provide a quantitative overview for resource planners in our two study area municipalities.

Results and discussion

Estimating above-ground carbon sequestration

The municipality of Chignahuapan had CO₂ sequestration estimates ranging from 14 Mg ha⁻¹ to 410 Mg ha⁻¹. The highest estimates were found in areas with oak forests (*Quercus* spp.), not because they capture more carbon, but rather because of selective silvicultural practices (e.g., harvesting, thinning, etc.) in pine stands that decreased carbon content. While some authors suggest that carbon sequestration is mainly a function of forest composition and age (Ruiz-Peinado et al. 2013), we found no direct correlation (r = 0.049) between carbon sequestration and species richness (Tab. S2 in Supplementary material). This suggests that in our study area, carbon sequestration is dependent on tree age, size and volume rather than species. In Zacatlan, forests presented CO₂ sequestration estimates ranging from 41 Mg ha⁻¹ to 531 Mg ha⁻¹, with an average of 158 Mg CO₂ ha⁻¹ and standard deviation of 8.7 (Tab.

Tab. 2 - Prioritization matrix of deforestation risk, carbon, and conservation. Risk of deforestation: high (from 0.66 to 1), medium (from 0.33 to 0.66), and low (from 0 to 0.33); Current carbon sequestration: high (from 218 to 531 Mg CO₂ ha⁻¹), medium (from 96 to 218 Mg CO₂ ha⁻¹), and low (from 0 to 96 Mg CO₂ ha⁻¹). (‡): Conservation areas priority is derived from the risk of deforestation and current carbon sequestration levels.

Risk of deforestation	Current carbon sequestration	Conservation areas priority ^(‡)
High	High	High
High	Medium	High
Medium	High	High
High	Low	Medium
Medium	Medium	Medium
Low	High	Medium
Medium	Low	Low
Low	Medium	Low
Low	Low	Low

S2). Once again, the correlation between carbon sequestered and the number of species per management unit (Tab. S2) was low (r = 0.02).

An earlier study by Castellanos et al. (1996) used a series of allometric equations to estimate that forests of Chignahuapan and Zacatlan store on average 81 to 150 Mg CO₂ ha⁻¹. Ruiz-Peinado et al. (2013) estimated the total carbon present in the unthinned, moderately thinned and heavily thinned plots in Mediterranean maritime pines obtaining 317,256 and 234 Mg ha⁻¹, respectively, estimates consistent with our findings.

Above-ground carbon sequestration

In the municipality of Chignahuapan, there are 29,401 ha of forest area, of which 3,480 ha (11.8%) were determined to have high carbon sequestrations suitability, i.e., current carbon sequestered from 218 to 531 Mg CO₂ ha⁻¹ (Tab. 3, Fig. 1a). In contrast, 17.5% of the forested area (5,157 ha) held 96 to 218 Mg CO₂ ha⁻¹ and was classified as medium. The balance (70.6 % or 20,764 ha of the total) was classified as low and held on average 82 Mg CO₂ ha⁻¹. These results are consistent with previous research by Angeles et al. (2005) who found low carbon sequestration in forests with young trees and/or sparse vegetation, oftentimes as a result of harvesting activities (Fig. 1a).

In Zacatlan, Fig. 2a shows that areas with high carbon sequestration are located in the north and center of the municipality, capturing around to 531 Mg CO₂ ha⁻¹. These

areas are covered by trees of the genera *Pinus* and *Quercus*. Species, age and density affect CO₂ sequestration rates; however, earlier research by Castañeda et al. (2012) found that *Quercus* spp. forests stores on average 664 Mg CO₂ ha⁻¹. This finding that oak forests hold greater levels of carbon than pine forests is not surprising given the silvicultural regimes applied, where oaks are not intensively managed due to low commercial value. Areas with low sequestration averaged about 68 CO₂ Mg ha⁻¹, while areas with medium sequestration captured 164 CO₂ Mg ha⁻¹, based on a 50-year-old stand. Figueroa et al. (2010) found that on average a 25-year-old stand of *Pinus patula* captures 86 CO₂ Mg ha⁻¹, which is similar to the values found in this study.

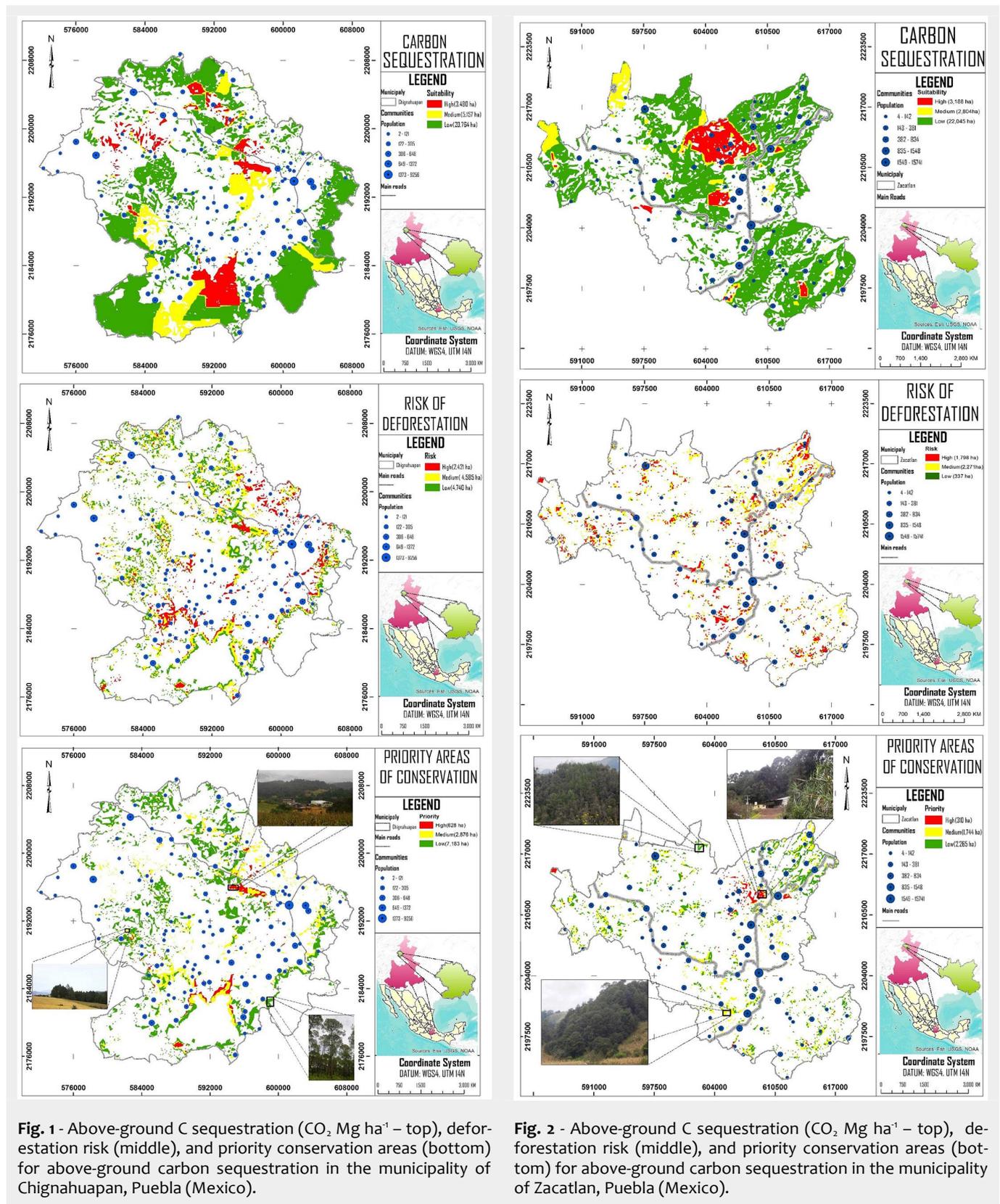
Based on our analysis, managed forests in Chignahuapan and Zacatlan can function efficiently as carbon sequestration lands (sinks), since 12% of the forest area is classified as high carbon sequestration and 73% as low-current carbon sequestration, ranging from 2.7 Mg CO₂ ha⁻¹ to 164 Mg CO₂ ha⁻¹ (Fig. 2a). Finally, although both municipalities include areas classified as high, medium and low current carbon sequestration, their current carbon levels exhibit a wide variation due to the structure, management and volume of present species (Tab. 3).

Deforestation risk

Deforestation risk in Chignahuapan and Zacatlan was determined by a probabilistic

Tab. 3 - Comparative data on current carbon sequestration, deforestation risk, and priority areas in the municipalities of Chignahuapan and Zacatlan, Puebla (Mexico). (‡): Differences between risk of deforestation and priority for CO₂ sequestration areas are due to the use of buffers in the processing and categorization of satellite images and the models. For example, remote areas without development pressure were not considered in the modeling.

Criteria	Chignahuapan Area (ha and %)			Zacatlan Area (ha and %)		
	High	Medium	Low	High	Medium	Low
CO ₂ sequestration	3,480 (11.8%)	5,157 (17.5%)	20,764 (70.6%)	3,188 (11.4%)	2,804 (10.0%)	22,045 (78.6%)
Deforestation risk ^(‡)	2,421 (8.2%)	4,585 (15.6%)	4,740 (16.1%)	1,798 (6.4%)	2,271 (8.1%)	337 (1.2%)
CO ₂ sequestration priority ^(‡)	628 (2.1%)	2,876 (9.8%)	7,183 (24.4%)	310 (1.1%)	1,744 (6.2%)	2,265 (8.1%)
Total forest area	29,401			28,039		



model of land-use change. The model for Zacatlan included 21 significant variables ($p < 0.05$), while Chignahuapan included 16 significant variables. Discarded variables included: population density, distance to trails, distance to low marginalization, and land tenure. It is important to note that within the two models, the independent variables have different relative impor-

tance, though for both municipalities the minimum distance to agricultural areas (+), elevation (-), and slope (-) had the greatest impact on deforestation (Tab. S1 in Supplementary material). There was no correlation between independent variables in the deforestation risk model, nor was the model affected by multicollinearity, having tolerances > 1 and vari-

ance inflation factors < 10. As a consequence, there is no linear relationship between the model's independent variables (Kutner et al. 2005). The adj-R² presented in the model was > 20%, which indicates a low amount of variance explained. However, on average, about 80 % concordant observations were obtained by the model (Tab. 4), indicating that the independent

and dependent variables are ordered in the same direction; therefore, the model is appropriate for predicting the phenomenon of interest (Gomben et al. 2012). Moreover, due to the broad inclusion of both biophysical and socioeconomic variables, we deemed the model's goodness-of-fit as adequate.

The map of deforestation risk for Chignahuapan (Fig. 1b) shows that 8.2% (2421 ha) of the total forest area (29,401 ha) in the municipality is at high risk of deforestation; these areas border agricultural and livestock areas (Fig. 1b). Also, 15.6% (4585 ha) of the total forest area was found to have medium risk, and just 16.1% (4740 ha) is at low risk. In Zacatlan, 1798, 2271 and 337 ha were assessed to be at high, medium and low risk of deforestation, respectively (Fig. 2b). The greatest deforestation threats are due to the conversion from forest to agriculture (forest-agriculture), grazing (forest-livestock), and development (forest-residential – Cruz-Huerta et al. 2015).

High-risk deforestation areas are located in the northwestern part of the municipality, while medium-risk areas are distributed throughout the municipality (Fig. 2b). In contrast, low-risk areas are located in the northern part of the municipality. This is likely due to forest fragmentation from agriculture and livestock activities, which increases the risk of increasing deforestation in the municipality. Finally, it is important to note that wildfire is a limited risk on managed forests within each municipality.

Priority areas for above-ground carbon sequestration

We integrated current carbon sequestration and deforestation risk to determine priority areas for conservation efforts (see Tab. 2). For Chignahuapan, we identified 628, 2876 and 7183 ha with high, medium and low conservation priority, respectively (Fig. 1c). Low-priority areas tended to be located in remote forest zones with little disturbance, while medium-priority areas were located near agricultural limits. High-priority areas are located in forest zones situated near livestock pasture, agricultural lands, and residential settlements. Our finding that the largest forest area is classified as having low conservation priority for carbon sequestration may be due in part to sound management practices by forest managers and their efforts to preserve healthy forests that provide sustained flows of environmental goods and services (SMRN 2007). As a result, both deforestation risk and current carbon sequestration are low or medium, largely due to periodic harvests which have reduced biomass levels.

In Zacatlan, 310, 1744 and 2265 ha were identified as high, medium and low conservation priority for carbon sequestration, respectively (Fig. 2c). These lands, distributed throughout the municipality, represent land areas that are roughly half in size of what we found in Chignahuapan (Fig. 1c).

Tab. 4 - Measures of association of predicted probabilities and observed responses for the deforestation risk model for both municipalities. (VIF): Variance inflation factor.

Variable	Parameter/ Index	Municipality	
		Chignahuapan	Zacatlan
Measures of association	Concordant	85.9	76.3
	Discordant	13.2	22.9
	Bound	0.9	0.8
Pairs	-	75,418,437	94,900,581
Correlation indices	Somers' D	0.72	0.53
	Gamma	0.73	0.53
	Tau-a	0.16	0.15
	c	0.86	0.76
Adj-R ² (%)	-	37.33	20.12
Multicollinearity	Tolerance	0.63	0.8
	VIF	1.6	1.25

Integrating current carbon sequestration and deforestation risk to identify conservation priority areas (Tab. 3) identified Chignahuapan as a focal region for conservation. This is due in part because forests in the municipality are at greater risk of deforestation due to high population densities for agricultural, livestock and residential uses to meet food, clothing, housing and future energy needs. For example, the population density (residents ha⁻¹) for Chignahuapan and Zacatlan in the agricultural, livestock and residential areas was 1.1, 90.3, 70.8 in 1985 and rose up to 4.5, 11.6, 327.5 in 2010, respectively. Zacatlan's population density is more than four times that of Chignahuapan, with the population of the former more concentrated (CONAPO 2010).

By analyzing the forest carbon sequestration data in relation to the total forest area of the two municipalities, the results were found to be very similar because stands under forest use were analyzed. However, areas with high conservation priority for carbon sequestration in the municipality of Chignahuapan occupy 628 ha, representing 2% of the forest area of the municipality (Tab. 3). For comparison, Zacatlan has 310 ha identified as high priority, accounting for only 1% of the forest area.

The high, medium and low conservation priority categories for different forest management units were validated through field trips and consultation with Technical Forest Service Providers. Some authors agree that validating priority conservation areas requires considering specific mapping points and then undertaking field visits (Lasso et al. 2011). Our field verification and consultation with forest managers revealed that our high-priority conservation areas have a high probability of deforestation since they are surrounded by agricultural and livestock areas, as well as small patches of urban areas. In fact, areas with high conservation priority for carbon sequestration were located in forest clusters with mature trees, fragmentation by agricultural areas with corn crops, livestock areas, and urban areas, which are all indica-

tors of high carbon sequestration and high deforestation risk. Areas identified for medium conservation priority were typically pine-oak forest, with small patches of farmland within the forest area. Finally, low-priority areas showed little fragmentation by any land use. These areas were generally located away from the agricultural frontiers, or were located in managed forest areas.

Conservation strategies for priority areas

The identification and management of priority conservation areas must consider economic, social and environmental factors to ensure sustainability (Sánchez et al. 2008). Tab. S3 (Supplementary material) outlines some key management strategies and responsible implementing agencies for the study area. The development of management strategies at different administrative and geographic levels has been considered to foster efficiency in conservation programs and actions, seeking to obtain maximum impact with the resources available in the study area (Kristensen & Rader 2001, March et al. 2009).

Future studies should focus on a thorough quantification of both above- and below-ground carbon components in order to better determine total carbon sequestration and how these levels are affected by various forest management regimes. To better understand deforestation risk, we suggest the development of a series of future scenarios of land use change. These could serve as the basis for analyzing the impacts and opportunity costs of carbon sequestration and other ecosystem services. For priority carbon areas, we recommend to test various forest management practices designed to both protect stored forest carbon and facilitate future carbon sequestration at the forest level. These practices should carefully consider both conservation and management goals, seeking to provide a blueprint for mitigating climate change impacts on Mexico's forest resources.

Conclusions

We estimated above-ground carbon sequestration in forests of Chignahuapan and Zacatlan municipalities, Puebla (Mexico) using volume information from forest management programs and the kriging interpolation method. Our results showed that both municipalities have similar current carbon sequestration, with carbon estimates ranging from 14 to 531 Mg CO₂ ha⁻¹. Based on this, we classified areas as high current carbon sequestration (218 to 531 Mg CO₂ ha⁻¹), medium (96 to 218 Mg CO₂ ha⁻¹), and low sequestration (from 0 to 96 Mg CO₂ ha⁻¹). Next, we applied a probabilistic model of land use in order to identify future risk of deforestation based on a host of socioeconomic and biophysical variables. Combining current carbon sequestration with deforestation risk allowed to identify priority lands for conservation. In Chignahuapan and Zacatlan, 628 and 310 ha, respectively, were determined to have high priority for carbon sequestration.

It is important to note that in this study the potential of forests to sequester additional carbon in the future was not considered. For example, a young forest on a productive site may have little stored carbon today, but may sequester large quantities in the future. In contrast, an older stand comprised of many large trees may have high levels of stored carbon, but may not store much additional carbon in the future as stand growth slows. In fact, age- or density- induced mortality could transition the stand into a net carbon emitter as large trees die and decompose.

Despite this, the approach developed here represents an important first-step in identifying priority conservation areas through the integrated assessment of carbon sequestration and deforestation risk. This knowledge can enhance efforts to efficiently target land management strategies aimed to mitigate climate change impacts. In doing so, the approach can serve as a model for other forested regions in Mexico and other countries.

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Supplementary Material

Tab. S1 - Dependent and independent variables included in the deforestation risk probabilistic model.

Tab. S2 - Relationship between carbon content and the number of existing species per forest management unit and municipality.

Tab. S3 - Management strategies for the protection of priority conservation areas for carbon sequestration and responsible Agencies and Partners to apply them.

Link: Cruz-Huerta_1980@suppl001.pdf