International Journal of Engineering and Geosciences– 2022; 7(3); 283-293

International Journal of Engineering and Geosciences

https://dergipark.org.tr/en/pub/ijeg

e-ISSN 2548-0960

LiDAR modeling to determine the height of shade canopy tree in cocoa agrosystems as available habitat for wildlife

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Keywords
Conservation
Canopy Height
Humid Tropics
Point Cloud
Model

Abstract

Agrosystems have different canopy strata due to shade trees that serve as available habitats for endangered species such as birds, reptiles, and mammals. LiDAR is a technology used to assess habitat quality as a support for designing conservation strategies. The objective of this research was to develop a model with data derived from LiDAR to obtain the height of the shade canopy in cocoa agrosystems, as a habitat available for wildlife species. Through the data of the height of the vegetation taken in the field and the data obtained from a LiDAR point cloud, the Canopy Height Model was generated. The data from the mapping of the canopy height model of the agrosystems taken as study sites were validated using the coefficient of determination (R^2), mean absolute error (MAE), and the RMSE. The mean canopy height at the study sites was 14.63, 13.84, and 13.95 m, and the results of the validation using the model predicted canopy height shows good agreement with the actual value with an R^2 of 0.86, and very low values of MAE=1.88, MSE=5.64, and RMSE=2.37, which indicates that they have an acceptable degree regarding the canopy height model between the LiDAR data and the data taken in the field. Research using LiDAR provides useful information to determine the height of the canopy, in the cocoa agrosystems up to 3 strata are found, this is due to the diversity of tree species used as shade, ranging from timber, fruit, ornamental, which are used as feeding, nesting, and resting of wildlife, in the study area populations of howler monkey species that are listed as endangered by the International Union for Conservation of Nature (IUCN), in addition to other species such as bats and birds, with the presence of these species indicate that the cocoa agrosystems, serve as a habitat for a diversity of species, which is why it is important to conserve these agrosystems in the humid tropics.

1. INTRODUCTION

Tropical forests support a large proportion of plant and animal species, many of them are threatened or endangered by the increased deforestation and change in land use caused by human activities (Cottontail *et al.*, 2009; Raghubanshi and Tripathi, 2009). Therefore, some wildlife species in the Mexican humid tropics such as bats (Oporto *et al.*, 2015) and the endangered tree mammal *Alouatta palliata* (Sanchez-Gutiérrez *et al.*, 2016a) have sought refuge in shade-grown agrosystems, such as cocoa and coffee plantations. These agrosystems are important for maintaining vertebrate diversity in tropical landscapes modified by humans since they can provide temporary or permanent habitat, function as stopover sites, increase tree cover and the availability of potential resources, for isolated wildlife populations (Rice and Greenberg, 2000; Estrada and Coetes-Estrada, 2002; Daily *et al.*, 2003; Harvey *et al.*, 2004). Besides, these agrosystems favor carbon sequestration, water

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Cite this article

Sanchez-Diaz B, Mata-Zayas E E, Gama-Campillo L M, Rincon-Ramirez J A, Vidal-Garcia F, Rullan-Silva C D, Sanchez-Gutierrez F (2022). LiDAR modeling to determine the height of shade canopy tree in cocoa agrosystems as available habitat for wildlife. International Journal of Engineering and Geosciences, 7(3), 283-293

Research Article / DOI: 10.26833/ijeg.978990

Received: 05/08/2021; Accepted: 14/09/2021

capture, soil conservation, and other ecosystem services (García-Mayoral *et al*., 2015; Alexander *et al*., 2018a). Trees that provide shade have different canopy height strata and a great diversity of species (Somarriba *et al*., 2004; Salgado-Mora *et al*., 2007; Villavicencio-Enriquez, 2013). Therefore, shade-grown agrosystems such as cocoa and coffee play an important role as available habitats due to their complex structure and high diversity, becoming important spaces in conservation strategies in mega-diverse countries such as Mexico, Brazil, Colombia, India, Indonesia, and Malaysia (Bisseleua *et al*., 2009).

Forest vertical stratification can be classified into four levels: emerging layer, canopy, undergrowth, and soil layer (Pelt and Franklin, 2000; Minton, 2003), while the vertical stratification of cocoa agrosystems has been classified as high, medium, low, and floor (Somarriba *et al*., 2004). The knowledge of the different layers of the shade canopy, as well as the diversity that constitutes it, helps to understand the value that agrosystems have as a habitat. This information in turn allows agrosystems to be included in conservation strategies for threatened species (Alexander *et al*., 2018b). Different studies have shown the importance of forest agrosystems as a habitat for the survival of species. For example, at the local level in the municipality taken as a case study in this project, it has been reported that the richness of birdlife in the cacao groves is associated with the structure of the vegetation and its diversity of trees (Ibarra *et al*., 2001). In coffee agrosystems in India, the presence of wild species such as palm civet Paradoxurus hermaphroditus and the jungle palm squirrel Funambulus tristriatus has been reported (Caudill *et al*., 2014). In Mexico, in coffee agrosystems of the State of Chiapas, species such as naked-eared deer mouse *Peromyscus gymnotis*, yaguarundi or eyra wild cat *Puma yagouaroundi*, and white-nosed coati Nasua narica (Cassano *et al*., 2014) have been observed. In cocoa agrosystems like the ones in Brazil, species in danger of extinction have been found according to the International Union for the Conservation of Nature (IUCN), such as the golden-headed lion marmoset *Leontopithecus chrysomelas*, the Brazilian rabbit *Sylvilagus brasiliensis*, and the yellow-breasted capuchin *Sapajus xanthosternos* (Cassano *et al*., 2014). In Mexico, in the state of Tabasco, the mantled howler monkey *Alouatta palliata mexicana* has been studied in cocoa agrosystems (Valenzuela-Córdova *et al*., 2015; Sanchez-Díaz *et al*., 2019), in addition to a great diversity of birds (Ibarra *et al*., 2001).

In Mexico, most cocoa production takes place in the humid tropic, mainly in the states of Tabasco and Chiapas, and to a lesser extent in Oaxaca, Veracruz and Guerrero (Espinosa-Garcia *et al*., 2015). In the cocoa agrosystems in Tabasco, the most common tree species are: guácimo (*Guazuma ulmifolia*), ceiba (*Ceiba pentandra*), moté or colorín (*Erythrina americana*) and saman (*Samanea saman*) (Muñoz *et al*., 2006; Valenzuela-Córdova *et al*., 2015; Sanchez-Díaz *et al*., 2019; Sanchez-Gutiérrez *et al*., 2016b). These tree species are very tall and with a large canopy diameter, therefore, it is important to estimate dendrometry variables derived from the vertical structure of these agrosystems.

Conventional methods for estimating quantitative forest variables are based on field measurements and are generally limited in terms of spatial and temporal sampling (Funes *et al*., 2017). On the other hand, remote sensing provides methods to generate information on the vegetation structure, characterization, monitoring, and mapping of changes in land coverage at local, regional and global scales (Funes *et al*., 2017; Giri, 2012). LiDAR is an airborne or terrestrial remote sensing technology, which uses light as laser points to measure the distance between the sensor and a target surface and enables three-dimensional information to be generated about the shape of the earth and its surface characteristics (Bombi *et al*., 2019). This allows obtaining a point cloud to calculate Digital Surface Models (DSM), Digital Terrain Models (DTM), and Canopy Height Models (CHM). The CHM model is obtained by subtracting the DTM from the DSM (Park *et al*., 2015; Marcu *et al*., 2017), and three-dimensional information is generated on the characteristics of different classes of land coverage and vegetation structure (Parent *et al*., 2015). This type of technology has been used to estimate quantitative forest variables such as canopy height, coverage, and structure, to describe the vertical structure of forests in studies on biodiversity conservation (Lefsky *et al*., 2002).

LiDAR technology has been used for different studies, for example, in Brazil to detect coconut plantations (*Cocos nucifera*) (Mohan *et al*., 2019a), in Spain to estimate the vertical canopy structure of wild pine (*Pinus sylvestris*) (Fidalgo-González *et al*., 2019), in Indonesia and Malaysia to characterize the vertical structure of tropical rainforests, using a canopy height model (Alexander *et al*., 2018a; Wassihun, 2019), and in Mexico to estimate dendrometry attributes and variables such as canopy height, basal area and crown diameter in forests (Ortiz-Reyes *et al*., 2015). In the United Kingdom, they have used LiDAR technology to estimate habitat suitability in planning conservation areas for the red squirrel *Sciurus vulgaris* an endangered species (Flaherty *et al*., 2014). This technology has been recommended for studies on habitat structure (Bombi *et al*., 2019), as canopy height is an important attribute for evaluating the quality of habitat and for modeling ecological niches for birds, reptiles, and trees mammals (Lesak *et al*., 2011).

The objective of this study was to develop a model based on vegetation height data taken in the field and data obtained from a LiDAR point cloud to determine the canopy height and strata of shade trees in cocoa agrosystems as available habitats for the wildlife.

2. METHOD

To develop the canopy height model, the following stages were considered: 1) field measurement of dendrometry variables (normal diameter, canopy coverage and height), 2) generation of digital models of terrain, surface and vegetation height from LiDAR data, 3) adjustment of canopy height model using regression analysis, considering the data obtained in the field with the LiDAR data, 4) validation of canopy height predicted by the model with data observed in the field, 5) statistical analysis and evaluation of the Adjusted Model of canopy height, 6) correlation between the height of the trees and the presence of wildlife. Finally, the cartographic representation of the canopy height model was generated (Figure 1).

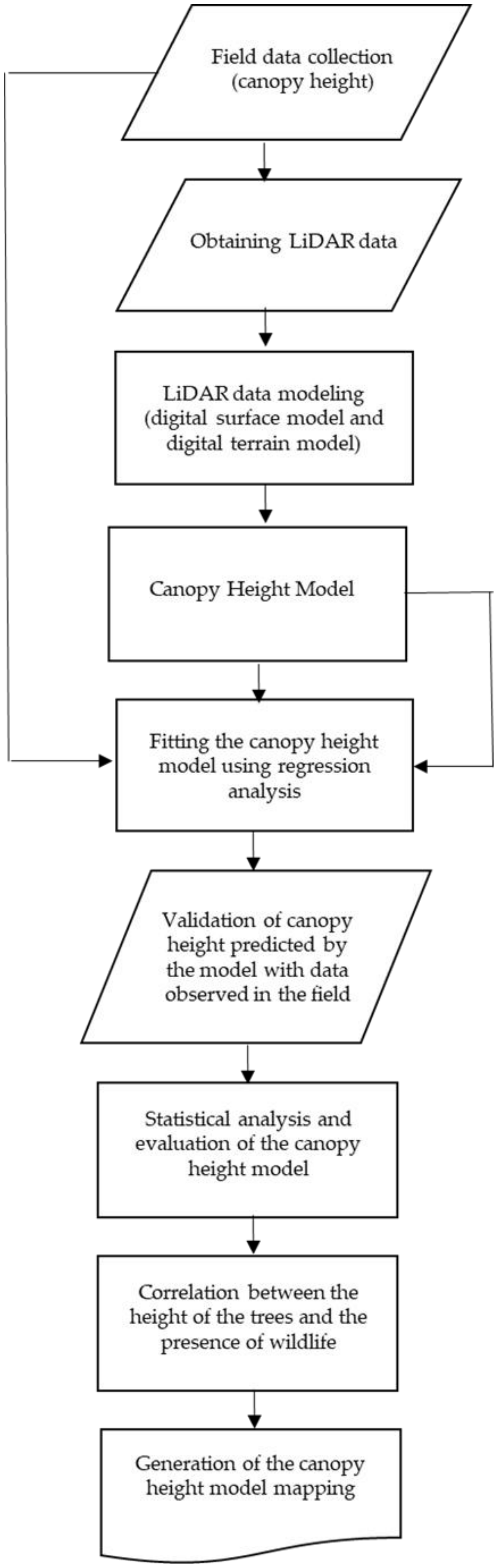

Figure 1. Flowchart each step of the study plan

2.1. Study Area

The study was carried out in three cocoa agrosystems, located in the municipality of Comalcalco, Tabasco, Mexico (Figure 2). The sites were selected from previous studies where it has been documented they are used as wildlife habitat (Table 1), particularly for howler monkeys A. palliata. At each site, 10 plots of 10 × 25 m were established (Rugnitz *et al*., 2009), for a total of 26 temporary sampling plots (TMP).

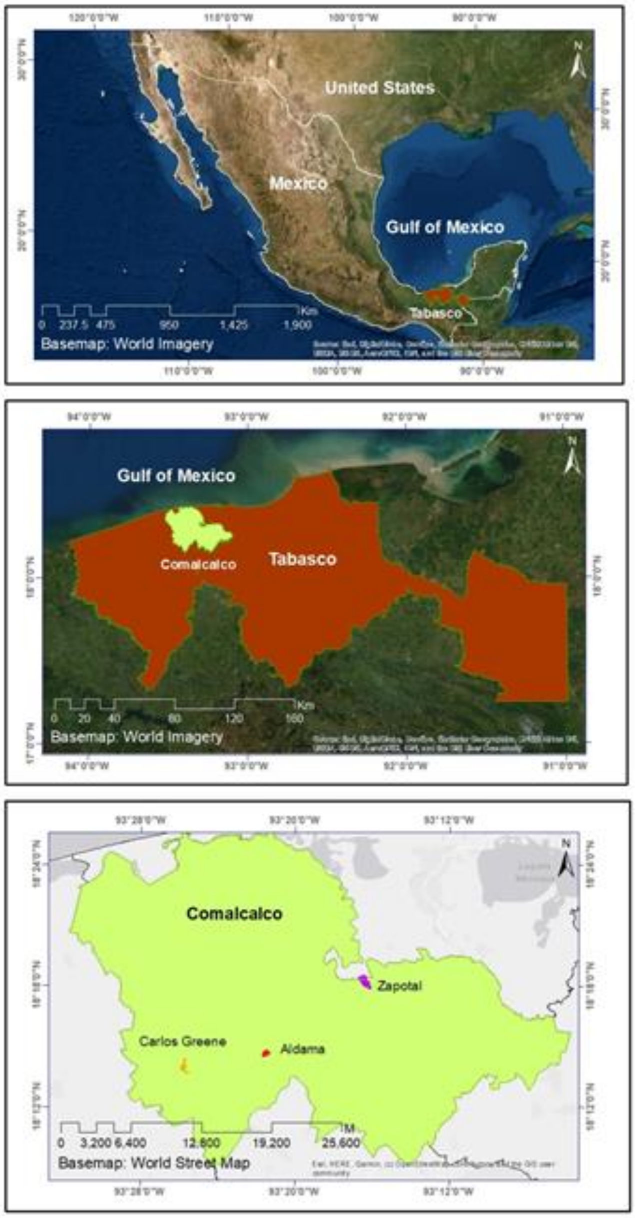

Figure 2. Location of cocoa agrosystems used as study sites at the Municipality of Comalcalco, state of Tabasco, Mexico.

2.2 Collection of Field Data

In each temporal sampling plot (TMP), dendrometry variables on the field of all trees were measured: canopy cover and height (Figure 3, Table 2).

Table 1. Cocoa agrosystems sites are used to generate canopy height models

Site	Location	Latitude	Length	Surface	Source
SA1	Carlos Greene	18°13'59.20"N	93°25'52.19"W	49.59 ha	(Valenzuela, 2018)
SA2	Aldama	18°14'37.56"N	93°21'39.81"W	21.08 ha	(Sanchez-Díaz *et al*. 2019)
SA3	Zapotal	18°17'58.98"N	93°16'22.00"W	57.82 ha	(Vidal-García and Serio-Silva, 2011)

Figure 3. Collection and measured of field data

Table 2. Dendrometry variables

Variable	Measurement Description	Equation
Canopy Height	The angles of the tree base (θ), the canopy (ρ) and the horizontal distance (hd) were measured using a clinometer.	$Ht = hd (\tan \rho + \tan \theta)$
Canopy cover	The projection was measured in two directions on the ground, North - South and East - West	$Dc = (dc1 + dc2) / 2$

2.3 Obtaining and Modeling LiDAR Data

The aerial LiDAR point cloud used was provided by INEGI of an overflight carried out in 2012, with a point density on the ground, for one swath, was of 0.47 points/m^2 for the first return, 0.20 points/m^2 for the second return, 0.02 points/m^2 for the third return, and 0.0001 points/m^2 for the fourth return. To process the LiDAR point cloud, an analysis was performed with the tool Insights and the LASTools module through the ArcGIS v9.2 software. Once this information was processed, the Digital Terrain (DTM) and Surface (DSM) Models were generated. Subsequently, the Model of Canopy Height (CHM) was developed, which was obtained by subtracting the DTM from the DSM (Park *et al*., 2015; Marcu *et al*., 2017; Mohan *et al*., 2019b). A Canopy Height Model (CHM) was generated for each site.

2.4 Model Adjustment to Estimate Vegetation height

Because the LiDAR data is from 2012, the CHM was updated. To obtain the updated canopy height, the CHM was fitted with a regression model (Martin-Garcia *et al*., 2017; Zuazo *et al*., 2017). For this, the height data were taken in the field (dependent variable Y) was related to the height data derived from LiDAR (independent variable X). To analyze the goodness of the adjusted model, the coefficient of determination statistic (R2) was used.

2.5 Statistical Analysis and Validation of the Canopy Height Model (CHM)

The statistical parameters of the Canopy Height Model were calculated in the three cocoa agrosystems, these statistics were: minimum and maximum height, a mean and standard deviation of the canopy height. The canopy height predicted by the model was validated with data observed in the field, so a sample size was calculated with a reliability level of 90% (z = 1.645) and a confidence interval of 10% (Aguilar-Barojas, 2005). Three statistical measures were used to assess model performance: the coefficient of determination (R2), mean absolute error (MAE), and the RMSE.

2.6 Analysis of the correlation between the height of the trees and the presence of wildlife

To detect whether the presence of primates such as Alouatta palliata and height were related, a correlation and regression analysis was performed. This made it possible to identify if there was any association between them. The analysis was performed using SAS software.

2.7 Mapping Generation

With the information obtained from LiDAR data, the Canopy Height Model mapping was generated. The classification proposed by Somarriba *et al*. (2004) was adopted to determine the canopy height of cocoa agrosystems: floor, low, medium and high. Likewise, a topographic profile was developed for each study site, where, along a transect, the evolution of altimetry is shown. The mapping was developed in ArcGIS v9.2 software.

3 RESULTS

3.1 Mapping Generation

Models generated from the LiDAR point cloud are shown below (Figure 4). The Digital Terrain Model (DTM) shows the three-dimensional representation of the terrain surface. The Digital Surface Model (DSM) shows the representation of the elevations above sea level of the reflective surfaces of trees on the ground.

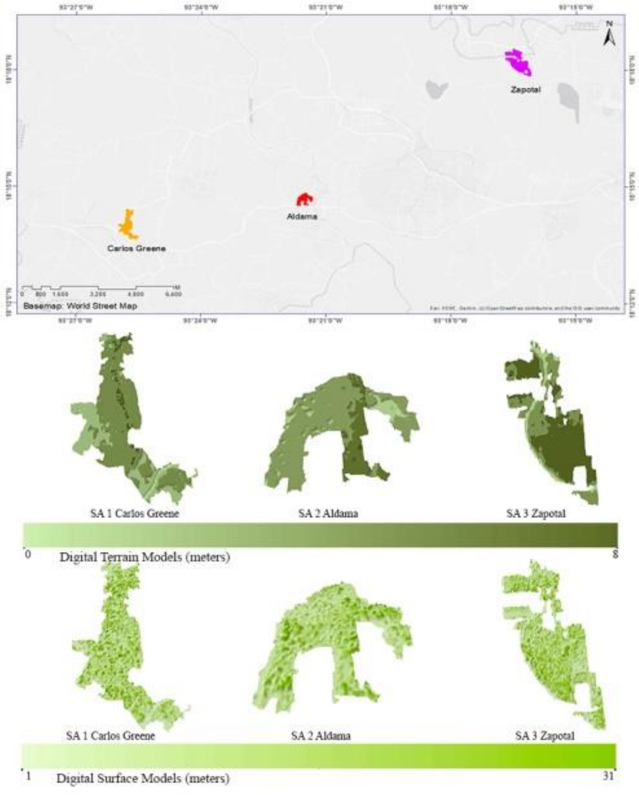

Figure 4. Digital Terrain Model (above) and Digital Surface Model (below) in three cocoa agrosystems in Tabasco, Mexico

3.2 Regression Analysis

The scatter diagram indicates that height data resulting from LiDAR (independent variable X) are strongly correlated with the height data taken in the field (dependent variable Y), where, there is a slope of 1.27 and an offset of -0.53m; the value of the coefficient of determination R2 was 0.991, therefore, there are no observed trends of overestimation or underestimation (Figure 5).

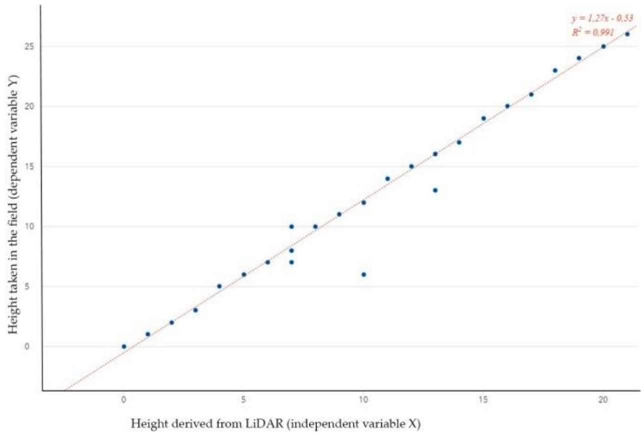

Figure 5. Scatterplot representing the fit of the independent variable (X) and the dependent variable (Y)

3.3 Statistical Analyzes of the Canopy Height Model

The site with the highest mean height canopy was SA 1 with 14.63, while the lowest value was SA2 with 13.84 m (Table 3). The range of canopy heights varied from 10 to 33 m.

Table 3. Mean height Canopy in cocoa agrosystems

LiDAR Variables	SA 1	SA 2	SA 3
Maximum height (m)	33	32	26
Minimum height (m)	10	10	10
Mean (m)	14.63	13.84	13.95
Standard deviation (m)	4.16	3.79	3.11

The model predicted canopy height shows good agreement with the observed values in the field with an R2 of 0.86. Analytically, MAE, MSE and RMSE have very low values (Table 4). This suggests that the developed model provides good performance results for the mapping of the canopy height in cocoa agrosystems.

Table 4. The values of validation measures between predicted and observed data

MAE	MSE	RMSE	R^2
1.88 (m)	5.64 (m)	2.37 (m)	0.86 (m)

3.4 Correlation between the height of the trees and the presence of wildlife

Pearson's correlation showed a high correlation of 0.95 between the height where the presence of wildlife species was recorded and the total height of the tree (Table 5). The height of the canopy predicted by the model shows a good agreement with the height where the wildlife species were observed with an R2 of 0.91. Analytically, MAE, MSE and RMSE have very low values (Figure 6).

Table 5. Correlation between the presence of wildlife and the height of the trees

Pearson correlation coefficient, N = 24 Prob > |r| suppose H0: Rho=0	PRESENCE_WILDLIFE	TREE_HEIGHT
PRESENCE_WILDLIFE	1.00000	0.95620 <.0001
TREE_HEIGHT	0.95620 <.0001	1.00000

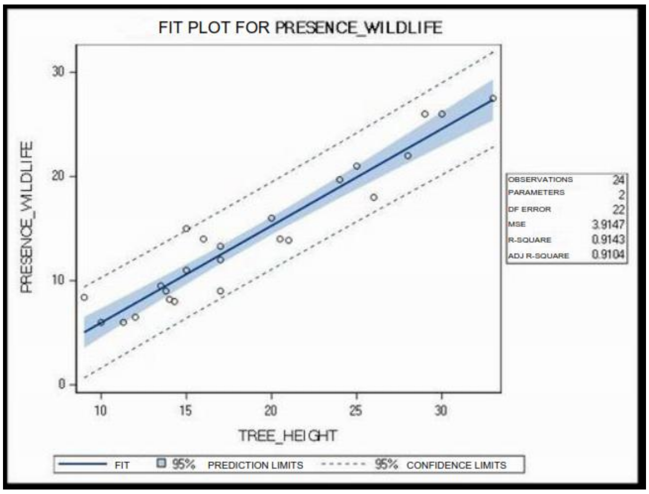

Figure 6. Regression of wildlife presence and tree height

3.5 Mapping

Vertical stratification of these agrosystems is classified as high, medium, low and floor (Somarriba *et al*., 2004). Shade trees in cocoa agrosystems used as study sites are found in the upper-middle strata (Figure 7).

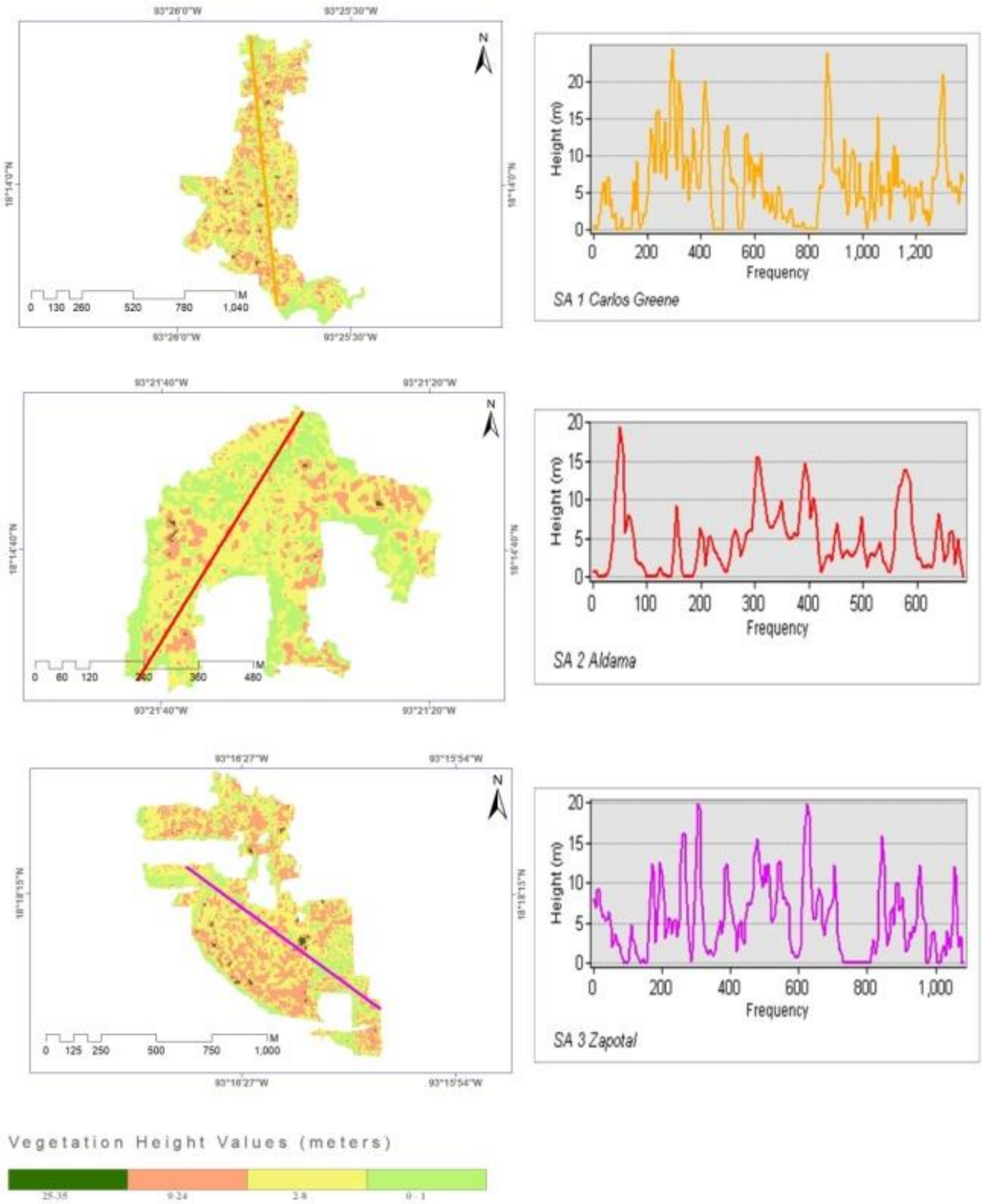

Figure 7. Canopy Height Model (CHM) and elevation profile for cocoa agrosystems

4 DISCUSSION

The loss of tropical forest cover generated by human activities has caused some wildlife species to seek refuge in agroforestry systems, such as cocoa and coffee (Cicuzza *et al*., 2011; Zarate *et al*., 2014). Although these systems do not replace the ecological complexity of forests, vertical stratification, as well as dominance, density and frequency of tree species is important since it favours the conservation of species in wildlife (Salgado-Mora *et al*., 2007). In the case of cocoa plantations in Tabasco, some reports indicate howler monkeys living there and using the native vegetation as a source of food (Valenzuela, 2018). Most of the activity of howlers is developed in the shadow vegetation because outside of the agrosystems there is not available vegetation. Both the vertical stratification and the diversity of trees present, favour their use as places of refuge, nesting and feeding among others, having the potential to provide habitats for wildlife. Some examples of species that use agrosystems are *Leontopithecus chrysomelas*, *Sylvilagus brasiliensis*, *Sapajus xanthosternos* and *Alouatta palliata mexicana*, considered as endangered according to IUCN (Bhagwat *et al*., 2008; McDermott *et al*., 2015).

In agrosystems of other countries such as Cameroon, Colombia and Brazil, it has been observed that species with higher height are *Mangifera indica* and *Spondias mombin* (Sambuichi *et al*., 2012; Mbolo *et al*., 2016; Salazar *et al*., 2018). Also, fruit trees such as *Citrus sinensis*, *Annona muricata* and *Persea americana* (Asase *et al*., 2010; Mbolo *et al*., 2016), and timber species such as *Tabebuia rosaea*, *Tabebuia guayacan*, were found at study sites, and *Swietenia macrophylla* (vulnerable species, IUCN 1998). All these tree species are used as shade trees in cocoa plantations and are important for native fauna, as they represent a source of food and shelter for endangered species. For example, in Colombia, the lazy bear (*Bradypus variegatus*) uses plant species such as *Spondias mombin* and *Bursera simarouba* (Ballesteros *et al*., 2009) in its diet, and the white-headed marmoset (*Saguinus oedipus*) uses *Tabebuia rosea* and *Cedrela odorata* leaves as food (De la ossa *et al*., 2014). In Costa Rica, the jabirú (*Jabiru mycteria*) uses *Ceiba pentandra* trees as a habitat to place their nests over 25 m high (Orias, 2009). In Mexico, in the municipality of Balancan, Tabasco, elements of *Mangifera indica* and *Tabebuia rosea* were recorded in the *Alouatta pigra* diet (Aristizabal-Borja, 2013); in Comalcalco, Tabasco howler monkeys were identified feeding on species like *Spondias mombin*, *Mangifera indica*, *Bursera simaruba* and *Erythrina americana* (Muñoz *et al*., 2005). These tree species are part of the structure and diversity of the species used as shade, which serve as food for wildlife because they offer food throughout the year according to the seasonal production of the different plant parts, they can consume new leaves (sprouts), fruits and flowers (Aristizabal-Borja, 2013). They also provide shelter between their branches with abundant leaves, which allow temperature regulation, aid in the digestion process and, at the same time, as a refuge for protection from predators (De la ossa *et al*., 2014). Therefore, diversification in agrosystems, through the rational incorporation of shade trees, to increase the overall production of the system, can be a strategy that allows producers to compensate for economic losses caused by price fluctuations and low production of coffee and cocoa (Alline *et al*., 2016); thus, promote shade trees in cocoa plantations as a way of preserving wildlife species (Cicuzza *et al*., 2011), such as insects, birds and mammals (Mbolo *et al*., 2016; Asase *et al*., 2010).

The canopy height models in cocoa agrosystems were generated from the LiDAR point cloud of INEGI (2012), with a resolution of 0.47 points/m^2. However, to obtain better information such as the canopy diameter and identify tree species resulting from LiDAR data, it is recommended to work with a cloud of density points higher than 0.5 points/m^2 (Gonzalez-Ferreiro *et al*., 2013; Bujan *et al*., 2013). LiDAR technology has been used in studies of different plantations with a resolution higher than the one recommended. In a Cocos nucifera crop in Brazil, canopy cover was estimated with a resolution of 3 points/m^2 (Mohan *et al*., 2019a). In the United States, it has been used for the delimitation of individual deciduous trees, with a resolution of 2.3 points/m^2 (Shao *et al*., 2019). In Indonesia, the cover and height of the mangrove canopy were mapped, with a resolution of 4 points/ m^2 (Mahadi *et al*., 2018). In Malaysia, a model was developed to delineate individual trees in a tropical forest, with a resolution of 8.8 points/m^2 (Wan-Mohd *et al*., 2017). In Spain, the canopy has been outlined in Pinus radiata Don, with a resolution of 0.5 points/ m^2 (Gonzalez-Ferreiro *et al*., 2017). In Mexico, in the state of Hidalgo, a forest inventory was generated in a temperate forest, through a private LiDAR flight with a density of 5 points/m^2 (Ortiz-Reyes *et al*., 2015).

The updated shade canopy height model was adjusted with a regression model between the canopy height obtained in the field and the aerial LiDAR point cloud (Martinez-Tobon *et al*., 2013; Cabrera *et al*., 2014; Martin-Garcia *et al*., 2017; Zuazo *et al*. 2017). Calculation of coefficient of determination (R2), mean absolute error (MAE), and the RMSE, showed good performance results of the adjusted Model prediction. This allows reducing the costs of a LiDAR flight and space sampling when it is sought to update the canopy height of the shade trees in cocoa agrosystems. However, there are other models built using neural networks, a branch of Artificial Intelligence, which has obtained good results to classify the LiDAR point cloud over the air and to evaluate metrics derived from LiDAR technology with variables from different sensors (Funes *et al*., 2017; Zhao *et al*., 2019).

A statistical estimate of shade canopy height generated the mean and standard deviation values at the three study sites 13.84 ± 3.79, 14.63 ± 4.16 and 13.95 ± 3.11 respectively. This is important since the preferential use of the strata where habitats preferably used by species such as Alouatta palliata and Lagothrix poeppigii are found and canopies between 15-20 m have been reported (Pozo, 2009; Arcos *et al*., 2013). Data obtained in the analysis through LiDAR were validated in the field, using the coefficient of determination (R2), mean absolute error (MAE), and the RMSE, showing that the vegetation height values were good when adjusting the canopy height model between the LiDAR data and the data taken in the field, thus confirming the validity. LiDAR technology has also been used to estimate habitat suitability, to support the planning of conservation areas for threatened species (Flaherty *et al*., 2014). The use of remote sensors, both in natural vegetation and in agrosystems has evidenced the importance of knowing the vertical structural complexity of vegetation and terrain in general, and not only horizontal heterogeneity (Zamora-Martinez, 2017). The use of data derived from LiDAR technology to analyze habitat structure will help to strengthen the implementation of actions to contribute to biodiversity conservation (Bombi *et al*., 2019; Zamora-Martinez, 2017). For example, the preferred tree height for *Loris tardigradus* is between 6-14 m (Gamage *et al*., 2009), while *Trachypithecus pileatus* spends most of its time between the canopy height of 5-15 m, and Hoolock hoolock spends time between 6-20 m (Islam *et al*., 2014).

5 CONCLUSION

The use of data derived from LiDAR technology provided reliable information to generate the canopy height model. The application of the regression model with the data taken in the field allowed generating the cartography of the height of the canopy of the shade trees in the cocoa agrosystems, through LiDAR the analysis of the height can be facilitated in agroforestry plantations that can be used as available wildlife habitat. It is recommended that for future studies, a spatial resolution higher than 0.47 points per square meter be used; this resolution will allow extracting information such as the diameter of the canopy and identify tree species, important attributes in the habitat structure for the species. The canopy height of shade trees is an important attribute, since they are used as food, nesting and resting of wildlife, in particular for birds, bats and tree primates, and thus, supports decision-makers to generate conservation strategies.

ACKNOWLEDMENT

Authors thank the National Council of Science and Technology of Mexico (CONACYT), for granting the scholarship for the research work, and the National Institute of Statistics and Geography (INEGI) for providing the LiDAR data used in this research.

Author contributions

Baltazar Sanchez Diaz: Methodology, Visualization, Editing; Ena **Edith Mata Zayas**: Methodology, Writing-Original draft preparation, Editing; **Lilia Maria Gama Campillo**: Conceptualization, Investigation, Writing-Reviewing; **Joaquin Alberto Rincon Ramirez**: Statistical analysis Writing-Original draft preparation; **Francisca Vidal Garcia**: Visualization, Investigation, Writing-Reviewing and Editing; **Cristobal Daniel Rullan Silva**: Data curation, Visualization, Statistical analysis, Writing-Reviewing and Editing; **Facundo Sanchez Gutierrez**: Conceptualization, Investigation, Writing-Reviewing.

Conflicts of interest

The authors declare no conflicts of interest.

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