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The range of Nahuelbuta has an outstanding biogeographic importance and high endemism of flora and fauna. In this range, the Valdivian temperate forest extends north along the maritime watershed, while the sclerophyllous forest extends south along the continental slope and northern coastal plain. The L. fulvipes that inhabits this habitat is considered at high extinction risk due to both demographic and ecological factors, such as disease, predation by cougars or other fox species. Our study was conducted in Caramávida using camera traps (N = 84) during October 2011-March 2012 to observe L. fulvipes, this information was correlated with LIDAR data to generate: elevation model, forest height; and the raw data were used to estimate the vertical vegetation coverage for seven different layers of height, cover, leaf area index and vertical complexity index. Our results indicate the presence of 17 positive results with L. fulvipes watch. The values of occupancy, occupancy corrected for detectability, and detectability, indicate that the proportion of stations where the species was recorded was 20%, but the actual ratio would reach 25% after correcting for detectability. The presence data and vegetation analyzes indicate correlations with tree cover larger than 20 meters high and with a high diversity of vegetation in the vertical profile, which may propose the presence of sites with potential presence and corridors for this species. We conclude that this methodology can generate highly accurate and relevant vegetation variables that may provide some guidance regarding which are the areas where a species is potentially distributed and the design of corridors that may enrich their habitat.

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ABSTRACT

The range of Nahuelbuta has an outstanding biogeographic importance and high endemism of flora and fauna. In this range, the Valdivian temperate forest extends north along the maritime watershed, while the sclerophyllous forest extends south along the continental slope and northern coastal plain. The *L. fulvipes* that inhabits this habitat is considered at high extinction risk due to both demographic and ecological factors, such as disease, predation by cougars or other fox species. Our study was conducted in Caramávida using camera traps (N = 84) during October 2011-March 2012 to observe *L. fulvipes*, this information was correlated with LIDAR data to generate: elevation model, forest height; and the raw data were used to estimate the vertical vegetation coverage for seven different layers of height, cover, leaf area index and vertical complexity index. Our results indicate the presence of 17 positive results with *L. fulvipes* watch. The values of occupancy, occupancy corrected for detectability, and detectability, indicate that the proportion of stations where the species was recorded was 20%, but the actual ratio would reach 25% after correcting for detectability. The presence data and vegetation analyzes indicate correlations with tree cover larger than 20 meters high and with a high diversity of vegetation in the vertical profile, which may propose the presence of sites with potential presence and corridors for this species. We conclude that this methodology can generate highly accurate and relevant vegetation variables that may provide some guidance regarding which are the areas where a species is potentially distributed and the design of corridors that may enrich their habitat.

Subjects: Conservation biology, Applied Remote Sensing.

Key words: LIDAR, Camera-trap, *Lycalopex fulvipes*, suitable habitat, Caramavida.

INTRODUCTION

The biogeographic situation of Nahuelbuta Range and its geomorphological and climatic characteristics have given rise to environmental heterogeneity establishing a wide variety of habitats (Mardones 2005, Luebert & Pliscoff 2005). Its peaks higher than 1,200 masl are covered by *Araucaria araucana* and *Nothofagus pumilio* forests, as well as wetlands. Both of the areas protected by the State in Nahuelbuta Range, the Nahuelbuta National Park (PNN) and the Contulmo Natural Monument (MNC), besides the protected area Piedra del Águila, are clearly insufficient to preserve this biodiversity, due to their small surface and location in high regions, above 600 masl (Contulmo with 82 ha) and above 1,000 masl (Nahuelbuta with 6,800 ha) (Ibarra-Vidal et al. 2005, Ortiz & Ibarra-Vidal 2005).

Lycalopex fulvipes (Martin, 1837) is an endemic canid of Chile at high extinction risk (Cofré & Marquet 1999, Sillero-Zubiri *et al*. 2004). This species was originally considered Vulnerable (Glade 1993) and then as Endangered (MINSEGPRES 2007) and Critically Endangered at global level by IUCN (Jiménez *et al*. 2008, IUCN 2012). It is included in Appendix II of CITES, being considered as one of the canids with most serious conservation problems (Sillero-Zubiri *et al*. 2004).

It was considered that its distribution was restricted to the west part of the Great Island of Chiloé and Nahuelbuta National Park located at approximately 600 km from Chiloé Island. This disjoint pattern is now being questioned because of the recent finding of individuals using camera traps in the Alerce Costero National Park, Valdivian Coastal Reserve, Oncol Park and Chanchan near Valdivia, as well as the presence of a dead specimen in Lastarria, near Gorbea (Medel *et al*. 1990, Jaksic *et al*. 1990, Jiménez *et al*. 1990, Vilà *et al*. 2004, D´elía *et al*. 2013, Farias *et al*. 2014). This evidence leads to the hypothesis that the Darwin fox distribution may be more continuous, associated with the remaining coastal forests.

The biological information about this species is scarce, it is found mainly in studies conducted in Chiloé Island (McMahon 2002, Jiménez & McMahon 2004, Jiménez 2007, Jiménez *et al*. 2008). On this regard, Yahnke *et al*. (1996) describe home ranges and they inform a population of 500 individuals for Chiloé. Jiménez & McMahon (2004), based on intensive capture inside the Nahualbuta National Park (PNN), made a population estimate of 78 individuals by extrapolating from a density of 1.14 ind/km^2. This estimate is based on captures in the southeast section of the PNN (sectors: Pehuenco, Piedra del Águila and Coimallín). This scenario has become more complex because in general the areas adjacent to the PNN have high degradation and human impact levels (Armesto et al. 2010) turning them unsuitable for the *L. fulvipes* to have a viable population (Shaffer1981, Mella 1994).

The species distribution is mathematically or statistically associated with different independent variables that describe the environmental conditions. If it is so, this relationship is extrapolated to the rest of the study area and then a value is derived for each place which is usually construed as the presence probability of the species in that spot. The "presence probability" is, therefore, an abusive interpretation of the environmental similarity measure which should be construed, at the most, as a suitability value for the species to develop. These models use variables and among them the forest variables are widely used; however, they are often estimated categorically.

Using the LIDAR technology (*Light Detection and Ranging*) and some process algorithms vegetation variables can be generated (e.g. coverage, leaf area index, vertical profile and height) with high precision. Aerial LIDAR is a sensor installed in an airplane that emits pulses while flying and these pulses hit an object (*e.g.* bare ground, building, stone, vegetation, water). Part of this energy is reflected by the ground or the objects on the surface and this energy is detected by the sensor. The sensor calculates the distance to the ground or object; and each one of these pulses is stored together with coordinates by means of the differential GPS system and the inertial navigation system installed in the airplane, so that the position of a spot can be determined in three dimensions with high precision (Dubayah & Drake 2000). When these points hit the vegetation, they can be intercepted at different heights and if the pulse density is high (around 4 pulse/m^2) the vertical structure of vegetation can be determined very precisely by means of a set of algorithms (Ko 2012, McGaughey 2007, McGaughey 2003). And there are several applications of this technology used in conservation of birds habitat (Goetz et al. 2010, Seavy *et al*. 2009) and coral reef (Burns *et al*. 2015).

The purpose of this study is to use a methodology associated with the LIDAR technology in order to generate variables intended to be used in the biodiversity area and applied to endangered species such as *L. fulvipes*.

MATERIALS AND METHODS

Study Area and Data.

The study area is located in the Nahuelbuta Range in the central zone of Chile, in the sector called Caramavida, characterized by temperate forest vegetation and the presence of a wide animal diversity. The area is topographically steep and scarped with 900 m mean height above sea level, and the range going from 500 to 1200 m.

In 2010, flights were performed over the area among the activities of a cartographic improvement project of Forestal Arauco and the study area surface is 500 km^2. The data were collected using the LIDAR Optech sensor, the scanning angle was ± 15º and the footprint was around 0.5 m. The final pulse density was 3.5 pls/m^2. The data were processed by the owner company of the flight producing a high-resolution digital elevation model (1x1m resolution), surface model and orthorectified images (0.5x0.5 m resolution). The raw data were gathered in LAS format including X, Y, Z coordinates and intensity.

Determination of distribution range.

To estimate the quantity of stations, the monitoring information of Quebrada Caramávida perfomed by Forestal Arauco was used (Zuñiga 2012, Briones *et al*. 2011), based on which a minimum number of spots was determined in order to have significant estimates of the parameters being studied (standard error lower than 0.04; see Mackenzie *et al*. 2005), using the native forest registry (CONAF-CONAMA-BIRF, 1999). Within each coverage, the stations will be randomly distributed at a distance of ≥ 0.3 kilometres to promote spatial independence (based on the home range radius by Jiménez 2007). The proportion of sampling units in each coverage was related with the size of each coverage, and the design was balanced in order to minimize variance in the results, which might occur in a coverage with small surface.

A total of 84 sampling stations were installed being made up by a camera trap. They were deployed in micro-habitat conditions suitable for *L. fulvipes*, as close as possible to the selected spot, but considering the following restrictions: ≥ 300m from houses, and ≥ 50m from trails and roads. The cameras were installed at 0.5 m high and they remained active during 15 consecutive days in each station. Considering that detection rates could be low for this species, baits will be used to attract them (synthetic urine and jack mackerel). The camera trap study was carried out in spring and summer (from October 2011 to March 2012). Both seasons are critical periods after winter for recovering the energetic demands and reproduction, increasing the carnivore activity (Jiménez *et al*. 1990, Jaksic *et al*. 1990, Muñoz-Pedreros *et al*. 1995). On the other hand, the previous study with cameras conducted between 2009 and 2011 in the study area confirms a higher activity of *L. fulvipes* in spring-summer, compared to autumn-winter (Zuñiga 2012)(Fig. 1b).

Determination of Core Patches.

With the elevation model (bare land) and the surface model, the crown height model was calculated using the difference between both surfaces (Fisk *et al*. 2009). After that, the surface with a vegetation height above 4 m was identified, in order to get the core patches in the area;

subsequently, the patches with a surface larger than 100 ha. were isolated since these are the areas that may potentially support a sustainable habitat (Santos & Tellería 1998).

Additionally, a model of morphology patterns (Vogt *et al*. 2007) was used to classify the patches in 7 shape classes in order to determine which patches are actual patches or which participate in other connectivity functions.

Processing raw LIDAR data.

The data were processes with the software program FUSION (McGaughey 2007) and the Gridmetrics algorithm. The resolution or cell size for calculation was 20x20 m (container) since at lower resolution the process tends to identify trees and generate gaps in the vegetation coverage and therefore the coverage estimate of the area cannot be determined. The points intercepted at seven height ranges were obtained (0 – 2, 2 – 4, 4 – 8, 8 – 12, 12 – 20, 20 – 32 and >32 m.), which are those used by the national registry of native forest (CONAF-CONAMA-BIRF 1999).

The coverage (Cob) was estimated for each height range as follows:

$$\mathbf{Cob} = \frac{\sum \mathbf{x}_{\mathbf{int\ veget}}}{\sum \mathbf{x}_{\mathbf{totales}}}$$

$\sum x_{\text{int veget}}$ stands for the pulses intercepted by vegetation and $\sum x_{\text{totales}}$ is the total pulses intercepted in that height range. Based on this, the vegetation coverage for each layer could be

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estimated. Besides, the total coverage for the entire vertical profile was estimated. The effective leaf area index (LAI) is calculated with the Beer law equation:

$$\mathbf{LAI = -\ln x\,(1 - Cob)}$$

The LIDAR system is classified as an active remote sensing system, that is, it emits its own light source. This characteristic means that vegetation can be illuminated by means of pulses or infrared light beams and comparing the light that is intercepted with the light that reaches the forest ground it is possible to apply the Beer law in order to estimate the area where light was intercepted; and that area is then the effective leaf area.

The vertical complexity index (VCI) is based on diversity measurement indexes that measure the heterogeneity within a specific system (Van Ewijk *et al*. 2011) in this case, the vertical structure of vegetation.

$$\mathbf{VCI = \left(-\sum_{i=1}^{HB}\left[\left(p_i * \ln\left(p_i\right)\right)\right]\right)/\ln\left(HB\right)}$$

Where HB is the total number of pulses in the container and p_i is the pulse ratio in the container at height i.

Statistical Analysis

There is a variety of models in order to predict the potential habitat of species; however, a logistic regression model was selected due to the nature of the dependent variable and also because these models can provide a probabilistic prediction of *L. fulvipes* presence and in this way our analysis with LIDAR can be prioritized. Additionally, unlike most of the multivariate procedures, it does not require variables to be normally distributed. The logistic function is expressed as:

$$\mathbf{P = e^{u}/(1 + e^{u})}$$

Where P is the estimated probability of occurrence of an event, e is the inverse of the natural logarithm and u is the linear model:

$$\mathbf{u = b_0 + b_1X_1 + b_2X_2 + \dots + b_nX_n}$$

Where b_n is the regression coefficients and X_n is the independent variables.

Nine variables based on surfaces were used: understory vegetation coverage, mean, maximum and modal height of vegetation, total coverage, leaf area index, elevation and vertical complexity index. Since there are different scales in the variables, some of them were converted in order to generate a better adjustment ($\mathrm{elev_t = elev/1000}$). A stepwise process was performed to select the variables that generate the best estimate of the *L. fulvipes* distribution. The statistics used for the selection was the Chi-square test and the correct percentage of model classification (Felix et al 2007).

RESULTS

From the 84 sampling stations consisting of camera traps, 17 had positive results for the *L. fulvipes* presence (Fig. 1B). A total of seven carnivore species were found during the sampling period: *L. fulvipes*, *Lycalopex culpeus* (Molina, 1782), *Lycalopex* griseus (Gray, 1837), *Puma* *concolor* (Linnaeus, 1771), *Conepatus chinga* (Molina, 1782), *Galictis cuja* (Molina, 1782). The occupancy values, occupancy corrected for detectability and detectability of *L. fulvipes* show that the proportion of stations where the species was detected was 11%, but the actual proportion would reach 14% after correcting for detectability.

Figure 1: Study area in Caramávida zone located at 30 km from Cañete. The grey zone is the area that has raw LIDAR data and the hatched zone is Caramávida, the area with high conservation value belonging to Forestal Arauco. The points indicate the 84 cameras installed in the study area and those in red are the ones that detected the presence of *L. fulvipes.*

Table 1: Occupancy index, occupancy corrected for detectability (Ψ ± DE) and detectability (p ± DE) for *L. fulvipes*.

The stepwise process carried out by means of forward selection, backward elimination and subset selection, gave as a result that the best prediction model includes the following as main variables: modal height, vertical complexity index and elevation (Fig. 2). The chi-square value for the model is 49.60 (Table 2).

Figure 2: **A**) Modal height (m) which characterizes the most frequent height, indicating the homogeneous forest height. **B**) Vertical complexity index, derived from diversity indexes that allow characterizing the vertical structure of the forest. Closer to zero means that only a few

height layers have vegetation and closer to 1 means that all the height layers have the same quantity of vegetation or coverage, showing that there is a high diversity in the vertical profile of vegetation. **C**) Elevation above sea level. These three variables were selected as the best indicators or independent variables explaining the presence of *L. fulvipes*.

The probability of occurrence increases as long as there are core patches present and the most important predictor variables are the modal height, representing the most frequent height, that is the most homogeneous height of the core patch, and then the VCI variable that reflects the distribution of vegetation at different heights; closer to zero indicates areas where vegetation is concentrated at certain heights, such as the case of forest plantation, but when the value is near 1, vegetation is distributed homogeneously in the entire vertical profile, indicating the presence of forests with different composition or age, which show a high diversity in the zone. Subsequently, elevation indicates an altitudinal gradient for the presence of *L. fulvipes*.

Table 2: Parameters derived from the best predictor variables of the regression model.

The classification matrix (Table 3) shows that the model has a high prediction rate (79.07%), which means that from every 5 observation 4 are virtually successful, also, the *odds ratio* was

16, indicating that there is a high probability of occurrence or presence (16:1) of *L. fulvipes* in the zones shown by the model (Fig. 3).

Table 3: Error matrix or logistic regression classification. The correct classification percentage of the model was 79.07% and its *odds ratio* was 16.

Figure 3: Map showing the probability of *L. fulvipes* presence, derived from the output of the logistic model. The variables used in the model were modal height, VCI and elevation; the correct classification percentage was 79.07%.

DISCUSSION

The Caramavida cleft, Trongol and their surroundings are the most relevant areas in Nahuelbuta, since they still have primary and secondary forest fractions. These native forests, preserved in different degrees, constitute the laurifolia ecosystem in the Nahuelbuta Range (Pauchard *et al*. 2011). In its low areas *Gomortega keule* (Molina, 1782) Baill, 1869 and *Berberidopsis corallina* Hook, 1862, can be found, and in its high areas *Araucaria araucana* (Molina) K. Koch. dominating the landscape. The Caramavida ecosystems are considered as priority sites for regional preservation by the Chilean governmeantal bodies.

Generating reliable information about the geographic distribution of species is one of the main requirements to establish effective preservation policies. However, after decades of taxonomic and wildlife work, we only have approximate data about the total of species that inhabit Chilean lands and we do not have convincing information that enables us to know the current distribution of most species (Briones *et al*. 2012). These insufficiencies become evident when we include vegetable coverage in our study. For our study area we have generated information layers regarding the understory vegetation coverage, mean, maximum and modal height of vegetation, total coverage, leaf area index, elevation and vertical complexity index. This information gives us more variables making our analysis statistically more robust.

The species distribution models are in full development and expansion with new methods and strategies for their treatment and interpretation. Consequently, there is a large number of articles building up with significant methodological and theoretic contributions for the modelling of species distribution (Mateo *et al*. 2011). There are several information restrictions for these models, such as the lack of presence/absence data, cartography, and environmental variables. With this the predicting capacity of the models is affected.

The distribution range of a species is certainly determined by its environmental tolerance but also by the dispersion limitations. For this reason we evaluated the correlations between the presence of the species (preliminary presence/absence information) and the sturdy vegetation variables (analysis with LIDAR data).

The recent records of *L. fulvipes* achieved in the Valdivian Coastal Range and the placed called Lastarría (D' Elía *et al*. 2013, Farias *et al*. 2014), have given rise to a discussion about the real conservation state of this species. On this regard, although Caramavida has an approximate surface of 30,000 ha, our analysis shows that from that, less than a fourth of the surface is a potential habitat for the *L. fulvipes* presence. We must add to this the anthropogenic threats (Stowhas 2012), conflict with wild carnivores (e.g. competence with *L. culpaeus*, see Zuñiga 2012) and domestic carnivores (e.g. transmission of diseases by *Canis lupus familiaris* Linnaeus, 1758, see Jimenez *et al*. 2012). Finally, only comprehensive studies on distribution, potential habitat, population viability and threats may maintain or propose a change in the endangered state of this species.

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TABLE 1: Occupancy Rate, occupancy corrected by detectability (Ψ ± SD) and detectability (p ± SD) for *L. fulvipes*.

	Occupancy	**Ψ ± DE**	**p ± DE**
L. fulvipes	0.11	0.14 ± 0.004	0.22 ± 0.04

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TABLE 2: Parameters obtained from the best predictor variables of the logistic regression model and its significances.

Variable	Parameter	Chi-Square	Value - p
Constant	8.875		0.0000437
Modal Height	-0.194	29.75	0.0000004
VCI	-7.634	13.17	0.0140017
Elevation	-1.959	6.67	0.0154766

TABLE 3: Error matrix or classification of logistic regression. Correct percentage of model classification was 79.07 % and its odds ratio was 16.

Observed	Predicted		Correct
	Absence	Presence	Percentage
Absence	48	18	72.73
Presence	9	54	85.71

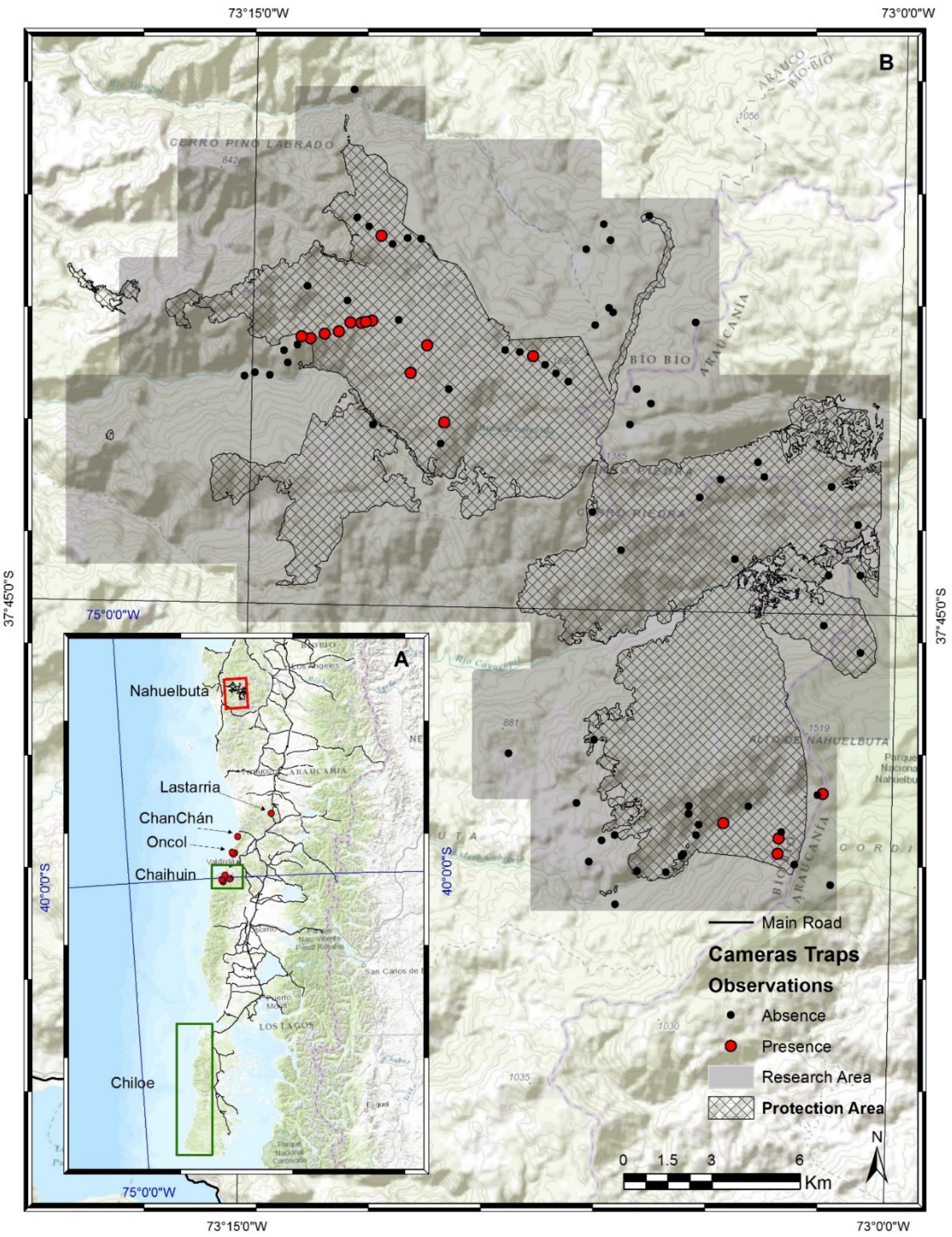

Figure 1: A) Current distribution of *L. fulvipes*. **B)** Study area in Caramavida. The grey area is the area that has raw LIDAR data and the hatched area to AAVC Caramávida. The points represent the 84 cameras within the study area and those selected in red are the ones that detected the presence of *L. fulvipes*.

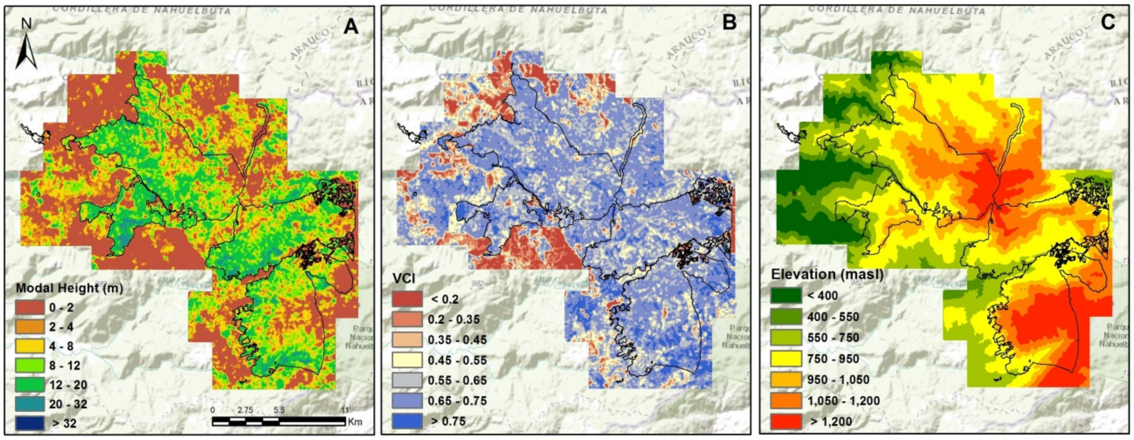

Figure 2: a) Modal height (m) characterized as the most frequent height, indicating the homogeneous forest height. b) Vertical complexity index, derived from diversity indexes that allow characterization of the vertical structure of the forest. Closer to zero indicates that only a few layers of heights have vegetation and closer to 1 indicates that all levels of height have the same amount of vegetation or cover, showing that there is a high diversity in the vertical profile of the vegetation. c) Elevation above sea level. These three variables are selected as the best predictors or independent variables that explain the presence of *L. fulvipes*.

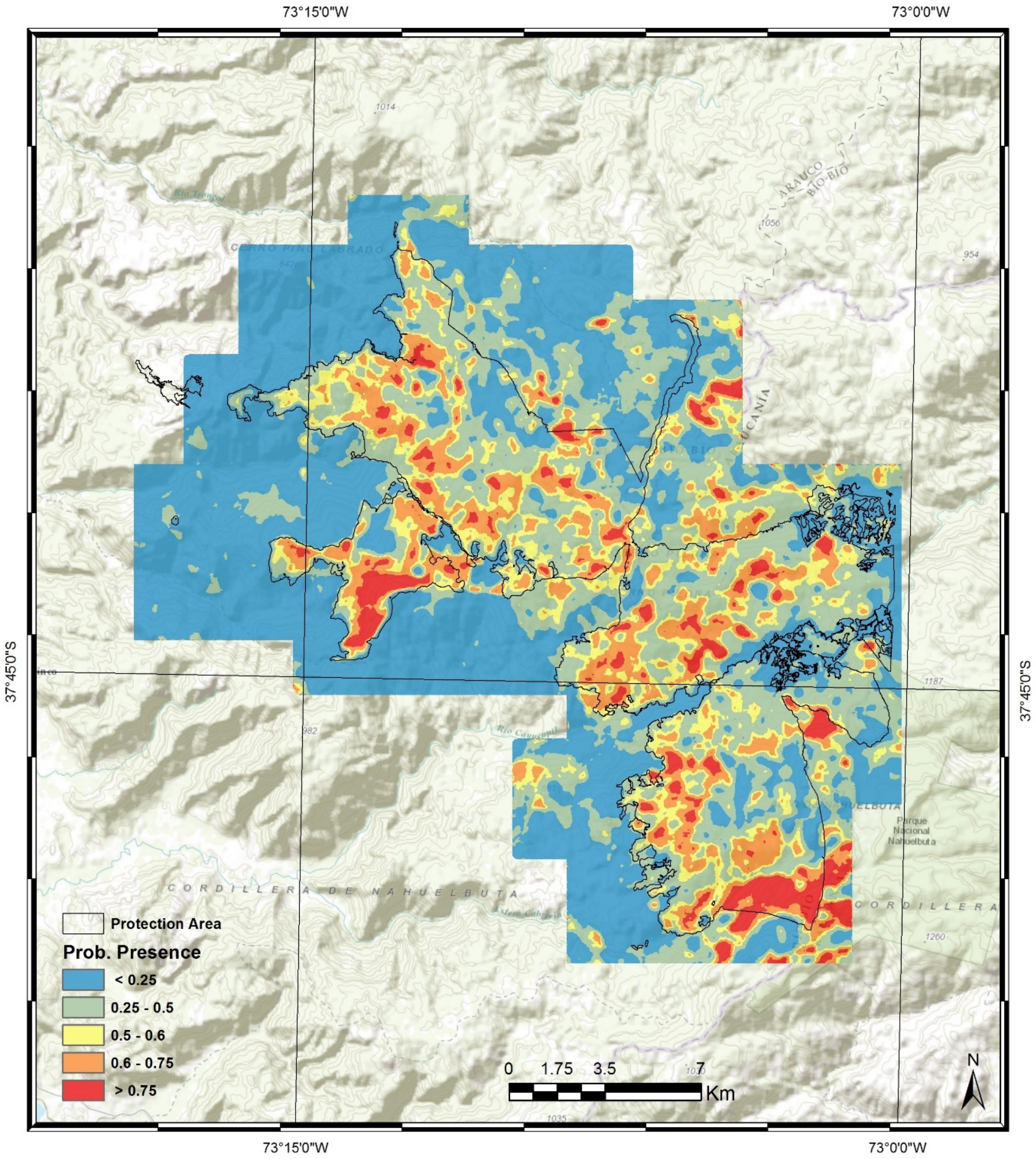

FIGURE 3: Map of presence probability of *L. fulvipes*, derived from the output of the logistic model. The variables used in the model were modal height, ICV and elevation; the percentage of correct classification is 79.07 %.