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Spatial and geographic factors affecting the livestock production in the Rio Platano Biosphere Reserve

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Content

Table of Figures

Index of Tables

Abstract

Livestock production accounts for 30% of the world's land surface. In high to middle-income countries, livestock production has increased over the last 60 years. In Honduras, livestock represents 13% of annual GDP. Livestock production is affected by different factors, including geographic and spatial factors. This study was conducted to analyze how geographic and spatial factors affect livestock production in the Rio Platano Man and Biosphere Reserve (RPBR), Honduras. The geographical factors that affect the cadaster and intensification of the farms located in this area were analyzed. This study also used GIS-derived variables to explain, using econometric Logit and Tobit models, the cadaster and intensification of cattle farms. The results showed that the spatial factors that influence the probability that farms are cadastered or not are the distance to the core zone of the reserve and the distance to the marketplace. On the other hand, the factors that affect intensification are farm-specific factors such as area, number of cattle, forest area, and factors determined by climatic conditions such as rainfall. The study concludes that spatial and geographic factors influence some aspects of livestock production in the Rio Platano Man and Biosphere Reserve.

Keywords: Cadaster, cattle ranching, geographic analysis, intensification, Logit and Tobit models.

Resumen

La producción ganadera representa el 30% de la superficie terrestre del planeta. En países de ingresos altos a medios, la producción ganadera ha aumentado considerablemente en los últimos 60 años. En Honduras, la ganadería representa el 13% del PIB anual. La ganadería se ve afectada por diferentes factores, entre los cuales se encuentran los factores geográficos y espaciales. El presente estudio se realizó con el fin de poder analizar cómo los factores geográficos y espaciales afectan la producción ganadera ubicada en la Reserva del Hombre y de la Biosfera del Rio Plátano (RHBRP), Honduras. Se analizaron los factores geográficos que afectan el catastrado y la intensificación de las fincas ubicadas en esta zona. Este estudio utilizó variables derivadas de SIG para explicar, por medio de modelos econométricos Logit y Tobit, el catastrado y la intensificación de las fincas ganaderas. Los resultados sostienen que los factores espaciales que influyen en la probabilidad de que las fincas estén catastradas o no son la distancia a la zona núcleo de la reserva y la distancia al lugar del mercado. Por otra parte, los factores que afectan la intensificación son factores propios de la finca como el área, número de cabezas de ganado, área forestal, y factores determinados por las condiciones climáticas como ser la precipitación. El estudio concluye que los factores espaciales y geográficos sí ejercen influencia sobre algunos de los aspectos de la producción ganadera en la RHBRP.

Palabras clave: Análisis geográfico, catastro, crianza ganadera, intensificación, modelos Logit y Tobit.

Introduction

Livestock production has increased since the 1960s. As the years go by, the consumption of foods of animal origin has increased in both rich and poor countries. It is estimated that animal products, such as meat and milk, provide approximately 33% of the protein consumed worldwide (Thornton, 2010). In general, livestock is one of the fastest-growing sectors in developing countries. This growth trend is influenced by the constant and increasing demand for foods such as meat and milk (McGilloway, 2005). On the other hand, population growth increases the global demand for food every year. Studies by UNDP (2007) estimated that, by 2050, the world population will be 9.15 billion and that the increase will take place mainly in developing countries. This means that the global demand for food will increase dramatically.

Livestock production plays a significant role in the economic growth and social development in many countries (Herrero et al., 2013). Livestock products such as beef or milk are high-value products in the world market. Even though there is a high demand for livestock products in the world, the low accessibility to the world market for small cattle farms is a problem that affects the development and economic growth of low-income nations.

In poor countries, livestock farming is the livelihood of approximately 600 million people. It is estimated that about 38% of the global land surface is occupied by agricultural production systems; of these, 80% belong to livestock production (FAO, 2020). In Latin America, the land use in livestock systems lacks great advances in livestock technology that can increase the productivity of the sector. Therefore, production systems tend to be unsustainable and occupy large amounts of land (Thornton, 2010).

In Honduras, livestock production has increased in recent years. According to FAO (2021) livestock represents 13% of Honduran GDP, which translates into approximately 65,000 MT of meat and 700 million T of milk per year. However, it is estimated that the profitability and productivity of this sector are quite poor. The productivity and profitability of a livestock farm can be affected by several factors, among which are the geographical and spatial factors of the area in which this economic activity is developed.

Geographical factors are defined as those geographical circumstances that influence aspects such as elevation, climate, precipitation, location, etc. (Molina et al., 2020). On the other hand, spatial factors are defined as those aspects that are directly related to the geographical position of the object to be analyzed (Rigby et al., 2001).

Arias et al. (2008) determined that livestock productivity is affected by the conditions of the physical environment in which this productive activity takes place. Similarly, studies carried out in Costa Rica by Flores (2006) explain that various geographical and spatial factors affect aspects, such as market access and intensification of livestock farms. Thus, it is observed that, on multiple occasions, livestock production will be directly affected by the physical, geographic, and spatial characteristics of the site.

In Latin America, most agricultural products are transported from the place where the production unit is located to the final market by road. Therefore, the distance of livestock farms from their final market is a key factor to consider in the costs of access to the market (Zimmerer, Carney, & Vanek, 2015). On the other hand, Von Thünen argues that the level of market access that the most important sectors of the economy have is directly related to their distance from the main marketplace (Beckmann, 1972). In general terms, Von Thünen states that the level of access to the market and the distance to it are directly proportional. Therefore, the productive sectors closer to the market will have greater accessibility to it. This relationship is given in terms of market accessibility costs, this means that those economic productions that are farther away from the market will have higher market access costs, due to their distance from the market. This relationship is linked to the geographical location of the productive sectors. Conversely, Von Thünen argues that the closer the land is to the market, the more expensive it tends to be, due to its geographic location and its high accessibility to the market.

Nowadays, to technically analyze how geographic and spatial factors can affect the profitability and productivity of the most important economic sectors of a region, tools such as Geographic Information Systems (GIS) can be used. GIS is defined as a computer system for capturing, checking, and displaying data related to geography, in order to perform different analyses that help to make informed decisions (Boone et al,2008). GIS is a tool to help better understand spatial and geographic patterns in different thematic areas.

On the other hand, multiple factors can explain the market access of livestock farms. On the one hand, the type of production of a livestock farm can define the level of market access it has. Studies conducted in Nicaragua by Rodriguez et al, (2016) demonstrate how the intensification of a farm can affect its market access, input acquisition, and competitiveness. Rodríguez (2014) determined through economic analysis that farms producing under an intensive system have more access to the market.

A tool that can help to understand the physical characteristics of a site is the cadaster. In general terms, the cadaster is an analytical census of real estate assets and properties, which aims to locate, describe and record the physical characteristics of sites (Palma Herrera, 2008). Similarly, the cadaster allows the establishment of a database of physical and spatial characteristics, the calculation of its value, and the determination of the owners of the properties of a territory (Mihaela, 2019).

In Honduras, the cadaster was introduced between 1964 and 1970, through the resolution of the Central American countries approved by the national government (Cruz, 2010). However, a cadaster was legally introduced by Decree No. 933 ''Cadaster Law'' of 1980, which establishes the basis for a general inventory of the country's real estate wealth. This decree established that the cadaster would be developed in all the areas involved, including the agricultural and livestock sector.

The real estate registration process first began through a Demonstrative Cadaster Program, which included the department of Olancho, where the study's cattle farms are located.

This program was financed by a loan agreement signed between the governments of Honduras and the United States of America. This program was contemplated to register around 66,000 km^2, but due to economic problems, the area was reduced to 22,000 km^2, concentrating in the valleys and densely populated areas (Cruz, 2010). In the beginning, the institution in charge of controlling and managing the cadaster of the nation was the Executive Directorate of the Cadaster, which later became part of the Property Institute, currently the institution in charge of handling this instrument.

This study was developed to explain the influence that exists between geographic and spatial factors, cadaster, and the intensification of cattle farms located in the buffer zone of the Rio Platano Man and Biosphere Reserve, Honduras (RPBR). Through the development and analysis of these factors, how various geographic factors can influence cattle farms to be cadastered and the type of intensification was determined. The Rio Platano Man and Biosphere Reserve are considered one of the most important regions for the ecology and biodiversity of Honduras (Cruz et al., 2016). However, as it is registered under the category of Man and Biosphere Reserve, it is not considered a protected area in its entirety territory. In general, biosphere reserves are divided into three zones: buffer zone, cultural zone and core zone, the latter of which is considered a strictly protected area. Nevertheless, it is home to multiple plant and animal species that provide a high diversity and biological wealth to the region. In general, biosphere reserves are divided into three zones: buffer zone, cultural zone and core zone, the latter of which is considered a strictly protected area.

Man and Biosphere Reserves are defined as sites for testing interdisciplinary approaches to understanding and managing changes and interactions between social and ecological systems, including conflict prevention and management of biodiversity (Batisse, 1982). These types of areas are directly managed by the governments of the countries that decide to register regions under the MAB Programme. The Rio Platano Biosphere Reserve (RPBR) is managed directly by the Forest Conservation Institute of Honduras. Biosphere reserves, allow the development of livestock and agricultural activities within their limits. This is because these spaces are intended for the proper and sustainable management of natural resources, so it is not managed as strict natural reserves (Mollett, 2010). The core zone of the reserve is the area that is protected. Core zones are defined as strictly protected areas, aimed at the long-term conservation of ecosystems (Iñiguez et al, 2014). The activities allowed in these areas are those related to environmental conservation, research, and education. On the other hand, the cultural zone of the reserve is intended for the use of natural resources in a sustainable manner and for the action of Indigenous groups, their culture, and beliefs.

On the other hand, the buffer zone is defined as the area adjacent to the core zone and acts as a barrier against external influences to minimize the impact of human activities that put pressure on natural resources (Prévélakis, 2020). The buffer zone has the function of regulating the progress of mining activities towards sustainable development. In other words, the natural resources of protected areas can be used and exploited as long as they are not lost or degraded (Abanto, 2003). Activities such as livestock, fishing, and agriculture are developed in the buffer zone of the RPBR. The cattle farms analyzed in this study are specifically located in the southern region of the reserve's buffer zone.

The main objective of this investigation is to analyze the influence exerted by spatial and geographic factors on livestock production in the aspects of intensification and cadastral registration in the Rio Platano Man and Biosphere Reserve, Honduras. For the development of the study, the following specific objectives have been defined: 1) Evaluate geographically how different spatial characteristics and market access can explain the cadaster of cattle farms; 2) Analyze how different geographic and cattle management factors influence the type of intensification of livestock production farms.

Methodology

General Description

The Rio Platano Biosphere Reserve is located northeastern region of Honduras, centered at approximately 15.5329°N, and 84.7788°W. It was declared a World Heritage Site in 1982 by the United Nations Educational, Scientific and Cultural Organization (UNESCO), for its unparalleled natural and cultural wealth (Glick & Betancourt, 1983). The Rio Platano Biosphere Reserve covers an area of 830,000 hectares, approximately 7% of the total extension of Honduras (Wade, 2007). The reserve spans six different municipalities in three departments: Brus Laguna, Wampusirpi, and Juan Francisco Bulnes in Gracias a Dios; Dulce Nombre de Culmí, which is part of Olancho; and Iriona, located in Colon. Gracias a Dios is the department that has the largest area of the reserve within its limits. Table 1 details the area of the reserve included in each municipality and department.

Table 1

Rio Platano Biosphere Reserve area distribution by municipalities

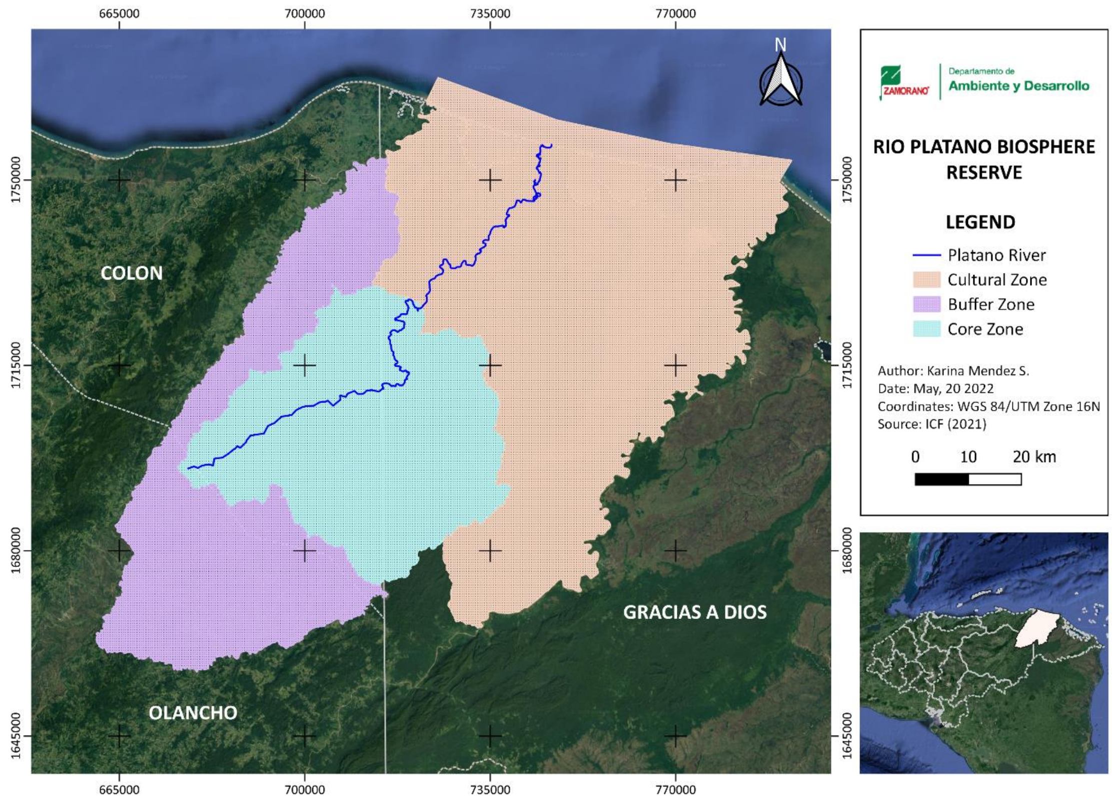
Department	Municipality	Area (ha)	Percentage (%)
Gracias a Dios	Brus Laguna	321,282.7	38.6%
	Wampusirpi	91,557.3	11.0%
	Juan Francisco Bulnes	55,766.7	6.7%
	Maritime area	51,605.0	6.2%
Colon	Iriona	194,767.3	23.4%
Olancho	Dulce Nombre de Culmí	116,527.4	14.0%
Maritime Zone	-	832.3	1.0%
Total		832,338.7	100%

Note. Adapted from Cerrato (2013).

This region is divided into three areas, known as macro zones: core zone, buffer one, and cultural zone (Figure 1). Of the total area of the biosphere, 196,000 hectares belong to the buffer zone, the cultural zone extends to 390,000 hectares, and the core zone has an area of 210,000 hectares. These regions were established and delimited in 1997, based on the United Nations Man and Biosphere (MAB) models. The MAB is an intergovernmental science program that aims to establish the scientific basis for improving the relationship between people and their environment. The program combines natural and social sciences to improve human livelihoods and protect natural and managed ecosystems, promoting innovative economically, socially, culturally, and ecologically sustainable development approaches. The reserve shares its name with the river that runs through it, *Río Plátano*. This watershed extends approximately 100 kilometers in length. It is joined along its course by the Wampu, Paulaya, and Sicre rivers. The Wampu river is located in the reserve's southern boundary, while the Paulaya and Sicre rivers are part of the northwest boundaries.

Figure 1

Rio Platano Biosphere Reserve by macrozones map



Most of the ecosystem types in Honduras can be found within the reserve. Among them are the rainforest, pine savannah, mangrove, cay, humid tropical forest, subtropical wet forest, and coastal savannah (Claudino-Sales, 2019; Wade, 2007). Because of the diversity of its ecosystems, the reserve is home to a wide array of animal species. The rich diversity of species present in the reserve is considered by the government of Honduras as one of the main reasons for the conservation of the natural habitat (Wade, 2007). According to Richards (1996), 130 species of mammals, representing 63% of the total mammal species of Honduras, 377 species of birds, and 126 species of reptiles and amphibians have been found in the reserve. Many of these animals are classified as endangered species, and some of them have been exploited by different indigenous groups for illegal purposes (Richards, 1996).

The main economic activities are carried out in the reserve's buffer zone because and is governed by a management plan developed by the Forest Conservation Institute (Cerrato, 2013). Some of the economic activities conducted in this region include raising livestock, such as poultry, pigs, and cattle. Some crops grown in the area include coffee, bananas, cassava, rice, beans, cocoa, and maize. There is also timber extraction by agroforestry cooperatives.

Moreover, this region is home to four ethnic groups which are: The Miskitos, Tawahkas, Pech, and Garifunas, which add a high cultural value to the area. Likewise, this region is home to several archaeological and cultural sites, such as various petroglyphs and the archaeological city *Ciudad Blanca*. According to a 2013 census, the Rio Platano Biosphere Reserve has a population of approximately 70,000 inhabitants in 120 towns, villages, and hamlets located within the reserve's boundaries. It is estimated that 35% of this population lives in the municipality of Dulce Nombre de Culmí.

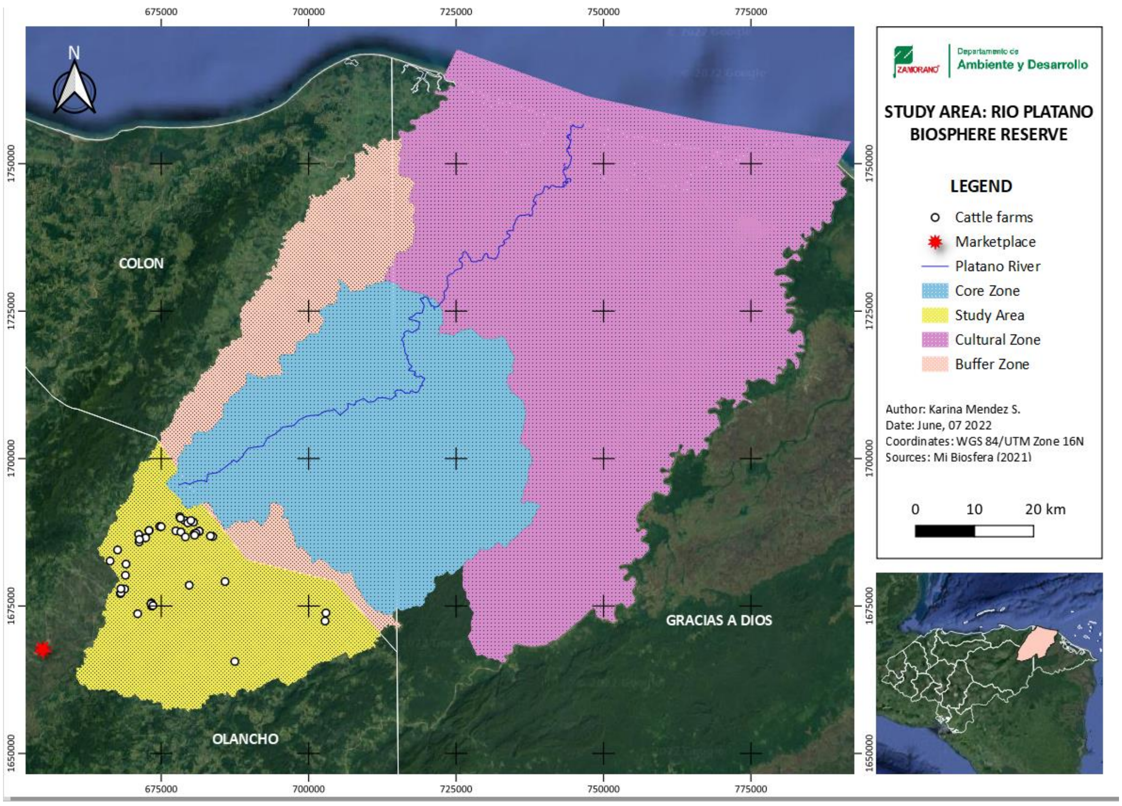
The rainfall in the reserve ranges from 2,000 to 4,000 mm. Most of the rain falls between May and November, which is the time when tropical air predominates. The driest season of the year occurs between February and April, under the influence of the trade winds from the northeast. The average annual temperature is 23°C and the average elevation is below 1,000 masl (Glick & Betancourt, 1983).

Study Area Description

The study was conducted in the southern region of the buffer zone of the Rio Platano Biosphere Reserve (Figure 2). The Rio Platano Biosphere Reserve is under the category of a biosphere reserve. A Biosphere reserve is not designated to protect the total area of the territory under this category. Instead, these regions designate an area in which the territory and its natural resources can be used sustainably. In other words, economic and productive activities can be carried out under certain regulations and parameters. This area is known as the buffer zone of the biosphere reserve.

Figure 2

Study area map: Southern region of the Buffer Zone



Productive and resource exploitation activities can be carried out within the buffer zone. These activities are specified in the Management Plan for the Rio Platano Man and Biosphere Reserve (2013-2025). The allowed economic and productive activities are specified in Table 2.

Activities such as establishing monocultures, land-use change, livestock, or agricultural activities on steep slopes, burning and open-pit mining are prohibited within the buffer zone.

Table 2

Productive activities allowed in the buffer zone of the RPBR

Permitted activity	Specification/regulation
Sustainable agriculture	Under soil conservation practices
	Agroforestry systems
Sustainable livestock	Silvopastoral systems
	Under the river protection strips
Community-based tourism	Ecotourism only
Subsistence hunting	Family consumption only
Building materials extraction	Family consumption only
Sustainable forest use	Family consumption only
Gold mining	Artisanal and no open-pit mining
Sustainable fishing	Family consumption only
Scientific research	-

Note. Adapted from Cerrato (2013).

This investigation was based on the methodology proposed by Flores (2006). This research studied different spatial and geographic factors in the region of Guanacaste, Costa Rica, and analyzed geographically and econometrically how these affect forest cover and livestock production systems. It also explained how the location and productivity of different cattle production systems, rather than land use, are influenced by site characteristics and the cost of access to cattle and dairy markets.

The methodology for this investigation includes two phases. Phase 1 was the spatial geographic analysis. By using Geographic Information Systems (GIS), market access of the farms located in the Rio Platano Biosphere Reserve region was analyzed. Phase 2 included an econometric analysis using Logit and Tobit models. These models were used to explain how each farm's internal geographical and spatial factors can define the cadaster and intensification of the ranches.

Geographic data was obtained by the Geoportal of the Forest Conservation Institute (ICF) and the GIS database from the Mi Biosfera Project collected in November 2021. The Mi

Biosfera project is directed towards the development of a land management plan, biodiversity, and halting deforestation in the Rio Platano Biosphere Reserve, as well as the evaluation and implementation of agroecological practices such as agroforestry systems. The project's overall objective is to reduce deforestation, protect biodiversity, and improve the food security situation of the local populations in the area of the Rio Platano Biosphere Reserve. This project is led by the European Commission, Zamorano, and the Forest Conservation Institute. The European Commission is the organization that finances the project. On the other hand, Zamorano and the Forest Conservation Institute are the institutions in charge of executing the project.

The database used for the econometric analysis was provided by the Mi Biosfera Project. the data was collected by surveys conducted by technicians who work for the project in November 2021.

The database contained information for 91 cattle farms located in the study area. However, only the farms that contained the necessary information regarding the objectives defined for this research were selected. Therefore, the sample size for the study was 42 ranches, located and distributed throughout the study area. Thus, the farms selected for the study belong to a larger population.

After defining the study sample number, a verification process of the information previously collected in the surveys was conducted. This verification was performed by consultation with technicians and experts of the Mi Biosfera project. This process was required to corroborate the information and complete some missing data.

Phase 1: Spatial and Geographic Analysis

The Spatial and geographic analysis was based on Von Thünen's original hypothesis of land rent established in the Model of Agricultural Land Use. In the Model of Agricultural Land Use, Von Thünen explained how spatial factors can affect the rent of different economic areas. Thus, this model tries to explain how accessibility and ease of transportation are factors that significantly impact land rent and its use. In other words, it explains how the location of extensive or intensive farms influences the rent through transportation costs. Therefore, farms located close to the marketplace have a higher land rent because they have lower transportation costs (Flores, 2006).

For the geographic analysis, vectorial information of spatial site factors such as farms and market location, roads, rivers, soil type, aquifers, land cover information, and Rio Platano Biosphere Reserve macrozones were used. The purpose of analyzing these site factors was to explain and link them with the market access of each farm, according to the distance from the ranches to the main marketplace, which is Dulce Nombre de Culmí. This data was also used to determine if the cadastral registration and type of intensification of each farm influenced its market accessibility.

Raster information was used to better understand the spatial and geographic context. This information was obtained through different open-access databases such as the United States Geological Survey (USGS) ''Earth Explorer'' and the Earth Data Science NASA Giovanni. The QGIS® v3.16.3 and the ArcGIS® v. 10.5 programs were used for the analysis of both formats.

Market Distance Calculation

To establish a distance between the cattle farms and the marketplace, a distance matrix was created using the QGIS program (Liu & Zhu, 2004). The UTM coordinates (x, y) of the farms selected for the study, as well as of the marketplace, which is Dulce Nombre de Culmí, were needed to carry out this process.

A distance matrix is a tool for vector analysis of layers in this format (vector). This tool calculates the distance from a reference point to a point of interest (Flores, 2006). For the study, the point of interest is the marketplace. Therefore, the distance in meters from the cattle farms to Dulce Nombre de Culmí was calculated. This information was required for the methodology's second Phase.

Calculation of Marketplace Accessibility

To establish the cost of access to the market through transportation costs, vector layers (shapefile) from the Forest Conservation Institute's geoportal and information on the coordinates of the farms selected for the study were used. The vector layers used were the road systems within the study area, the location of the farms, and the location of the marketplace, which is Dulce Nombre de Culmí.

The cost of transportation was established by a time variable. This means that, for the study, transportation costs were expressed in terms of the time it takes for each of the farms to reach the marketplace, depending on their geographic location.

In 2005, the Honduran Transit Law established that the maximum speed on national roads was 40 km/h (Ley de Transito, 2005). This law does not specify a difference between the minimum and maximum speed on roads of a different material. Speed information was converted into minutes/meter, which resulted in 0.0015 min/m. This information was required to be combined with a cattle farm and marketplace location to generate a friction map surface using a Euclidian distance tool (Gonçalves et al., 2014). The program used for this analysis was ArcGIS.

Distance Calculation to the Marketplace, National Roads, and Rivers Distance

The Euclidean distance is a tool that describes the relationship of each cell to an origin or a set of origins, based on the distance established by a straight line. In other words, the Euclidean distance allows us to measure the distance between two points of interest through a straight line. To carry out this process, the geodesic coordinates of the livestock farms and the market point were needed to graphically represent the distance between the two. The distances obtained were then classified. This classification included eight categories, every 7,500 m. This process was conducted to calculate the accessibility to national roads and rivers. The classification made for national roads included six categories, every 4,000 m, and the classification for rivers was made every 1,000 m, in six categories as well.

To extract the distance values individually, that is, from each of the farms to the point of interest (roads and rivers), the vector tool ''NNJoin'' was used. This tool calculates the distance between one spatial object and another (Cillis et al., 2020). These data were necessary to carry out the second part of the methodology. After classifying the data obtained, the data were extracted for each of the farms.

Core Zone Distance Calculation

To determine the distance of the farms to the core zone of the reserve, different distance buffers were used (Table 3). In general, four categories were generated, each 10,000 m away from the core zone. Using the vectorial tool ‘’NNJoin’’, the distance values (m) from the core zone to each of the farms were extracted. This data was required to carry out the econometric analysis established for the second part of the methodology.

Table 3

Buffer classification for the RPBR core zone

Classes (by buffer)	Distance
1	0 – 10,000 m
2	10,000 – 20,000 m
3	20,000- 30,000 m
4	>30,000m

Elevation and Slope Calculation

To calculate the elevation and slope in the study area, it was necessary to have a digital elevation model (DEM). This model was acquired through the open-access "Earth Explorer" of the United States Geological Survey (USGS). The DEM was taken using the Shuttle Radar Topography Mission (SRTM), with a resolution of 10 x 10 m. Before starting the raster spatial analysis process, a reprojection of the DEM was carried out with the WGS 84 Zone 16N coordinates. Because the original DEM was in the coordinates EPSG:4326 - WGS 8.

Similarly, a cut was made in the DEM to work with the area of interest, which is the southern region of the buffer zone in the reserve. This process was carried out using the raster tool cut by a mask layer, which allows layer cuts in raster format taking a vector layer as a cut extension. In this case, a polygon of the study area selected for this investigation was used.

After the DEM was reprojected and clipped, an elevation classification was made. This classification was made every 150 masl, in eight different categories, registering a maximum elevation of 1,050 masl. Subsequently, slope analysis was performed using the ''slope'' tool using the DEM downloaded from USGS. The process that was followed to carry out this analysis was: Processes > raster terrain analysis > slope. In the same way, this process can be carried out by following the following steps: Raster > analysis > slope. As a result, a slope map in degrees was obtained. Next, the data obtained was classified. This classification was made in five different categories, with the following ranges: 0 - 19°, 20 - 29°, 30 - 39°, 40 - 49°, and > 50°.

Finally, to extract the slope and elevation data for each of the farms in a systematic way, the tool known as the Point Sampling Tool was used. The Point Sampling Tool allows the extraction of values from different geographical layers in raster format through another layer in vector format of interest, to locate the desired values (Escobar-Wolf et al., 2021). The result of this process is presented in vector format, which contains the values of interest in its attribute table.

Rainfall Calculation

To calculate the precipitation received by the farms in the study area, a satellite image was used. This process was required because, in the study area, there is no record of rain gauges that could provide more accurate data. The information obtained through the NASA Giovanni free access database was used. Giovanni is NASA's web interface that provides information from various satellites for all areas of the world. The data is already processed and can be downloaded on a required scale. In this case, the data was downloaded in terms of mm/year. Therefore, the precipitation data used were those accumulated during the year 2021.

The resolution of this satellite image is 1,000 x 1,000 m, which means that the information is not as precise. However, due to the low availability and accessibility of information of this nature, it was decided to work with these data. Using the QGIS program, extraction of the annual accumulated precipitation data was carried out for each of the farms individually. This process was carried out using the Point Sampling Tool, using the Giovanni satellite image and the coordinates of the farms in vector format.

Phase 2: Econometric Analysis

The second part of the methodology designed for this investigation involved an econometric analysis of cattle farms' cadaster and intensification. To analyze these factors, this investigation combines Logit and Tobit models to explain the factors influencing these two variables. Two statistical software were used to perform these analyses: SPSS® version 28.0.1.1 and STATA® version 16.0.

To evaluate the factors that the study explained, to evaluate the relationship that exists between the land registry of the farms and their geographic and spatial factors, a Logit Model was carried out. A Logit Model is a logistic regression that is considered that be one of the most promising state of the art discrete choice model currently available (Hensher & Greene, 2003).

In other words, a logistic regression evaluates the probability that an event occurs or not, that is, only two scenarios (0,1). On the other hand, a Logit model aims to establish the value of a binary variable (endogenous) based on the relationship that it has with other explanatory variables (exogenous).

To evaluate the intensification of a cattle farm, a Tobit model was analyzed. This type of regression performs a truncation for those data that are not possible to explain the influence that exists between the variables analyzed. Truncation limits the data by excluding observations that do not have values in the dependent variable. Similarly, truncation is an intrinsic characteristic of the distribution of the variable under study, from which the sample data is extracted.

Logit Model

Initially, the analysis of the cadaster of each of the cattle farms was developed. The after variable for this analysis was the cadaster. The explanatory or exogenous variables for this model were: 1) Slope, 2) Elevation, 3) Distance to rivers, 4) Distance to the core area, 5) Distance to the market point, and 5) Distance to highways. The endogenous variable was coded in terms of 0, 1 (0 = uncadastered, 1= cadastered).

The statistical software program that was used for this analysis was SPSS®. In general, the following steps were followed within the program when the necessary data for the analysis was entered: >Analyze > Regression > Binary Logistic. The cadaster coded in 0, 1 was selected as the dependent variable and the previously mentioned exogenous variables as independent variables.

Tobit Model

To carry out the analysis of the intensification of the farms, the stocking rate was used as an endogenous variable. The database provided by the My Biosphere project did not contain this information. However, it contained the necessary information to estimate it. As exogenous variables, the following were used: 1) Slope, 2) Elevation, 3) Total cattle head, 4) Farm's forest reserve area, 5) Farm area, 6) Distance to the core area, 7) Distance to rivers and 8) Rainfall.

Before analyzing the model, the calculation of the Animal Stocking (AS) was performed. To carry out this calculation, it was initially divided into cattle in different age ranges. These ranges were 0 – 1 year, 1 – 2 years, 2 – 3 years, and > 3 years. This process is carried out regardless of the cattle, that is, if it is female or male. Subsequently, a conversion to the Livestock Unit was estimated using a conversion factor. These conversion values are detailed in Table 4.

Table 4

Livestock unit conversion factors

Age rate	Conversion factor
0-1 year	0.25
1-2 years	0.50
2-3 years	0.75
>3 years	1.00

Note. Adapted from Ibrahim (2001).

By having the livestock units of each of the groups according to age range, a total sum was made to have the livestock units of the farms in general. This data is divided by the Farm Area, resulting in the Animal Load (AS) of each of the farms individually. In general, the stocking rate is related to the number of animals that a livestock farm has and to the total area of the farm. In Equation 1, the composition of the factors that make up the stocking rate is shown.

Animal Stocking (AS) calculation

$$Animal\ Stocking\ (AS) = \frac{\Sigma\,(LU)}{FA}\ [1]$$

Where:

LU is a Livestock unit

FA is a Farm area

This data was required to estimate the Tobit model. Having the complete database to analyze the intensification of the farms using a Tobit model, this procedure was carried out using the statistical software program STATA®. To carry out this process, the following steps were followed within the program: >Statistics > Linear and related models > Censored regression > Tobit regression.

Results and Discussion

Econometric analysis was carried out to determine the influence of various spatial factors by a binary logistic regression, known as the Logit Model. The dependent variable for this model was the cadaster registration of each farm. There are only two scenarios: Farms are either cadastered or uncadastered. The coding used for these two outcomes is detailed in Table 5.

Table 5

Codification for the dependent variable (Logit model)

Cadaster status	Internal codification	Farms
Uncadastered	0	18
Cadastered	1	24
Total farms		42

The factors that were analyzed through this process were slope, elevation, distance to the marketplace in terms of time (min), distance to rivers (m), distance to roads (m), and distance to the core zone of the Rio Platano Biosphere Reserve.

The program generated a model through five steps. In the first step, all explanatory variables were analyzed. In the following steps 2, 3, and 4, the program eliminated those exogenous variables that did not contribute to the significance. In step five, only those variables that contributed significantly to the model and that could explain the response variable were shown.

The results reflect that not all geographic factors affect whether farms tend to be cadastered, according to their spatial and geographic condition. The results obtained when carrying out the logistic regression (Logit) are detailed in Table 6.

Table 6

Logit regression results

Variables	Unit	Coefficient	Standard Error	P-value
Market distance	minutes (min)	0.848	0.327	0.009
Core Zone distance	meters (m)	0.002	0.001	0.005
Constant	-	-47.530	17.868	0.008

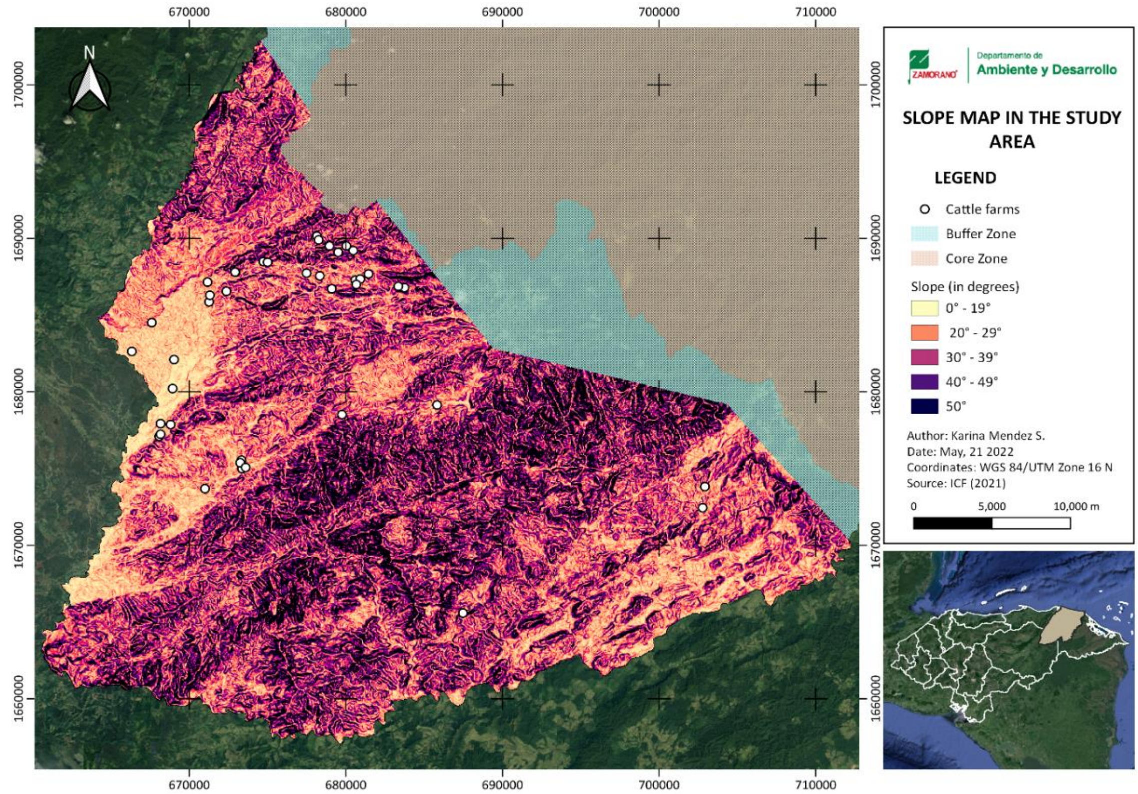
Note. P-value = 0.002, R2 = 0.644, Chi-squared = 21.24

The SPSS program analyzes the Logit model in steps. The program generated a model through five steps. In the first step, all explanatory variables were analyzed. In the following steps 2, 3, and 4, the program eliminated those exogenous variables that did not contribute to the significance. In step five, only those variables that contributed significantly to the model and that could explain the response variable were shown. The logit model reflects that the slope and the elevation are not factors that explain whether the farms had a greater probability of being cadastered. As can be seen in Figure 3, the farms located in the study area are in different slope conditions. The slope range in which the cattle farms selected for the study are located ranges from 1° to 35°.

Studies carried out in Costa Rica show that the slope is an important factor that could explain livestock production and its type, that is if the farms tend to be dairy or meat. Flores (2006), determined by a logit model that cattle farms located on low slopes tend to be dairy farms and that, in regions with steeper slopes, there is a greater probability of finding meat farms. However, the cattle farms selected for this study are entirely dual-purpose farms, that is, they produce both meat and milk.

Figure 3

Slope map in the Study Area

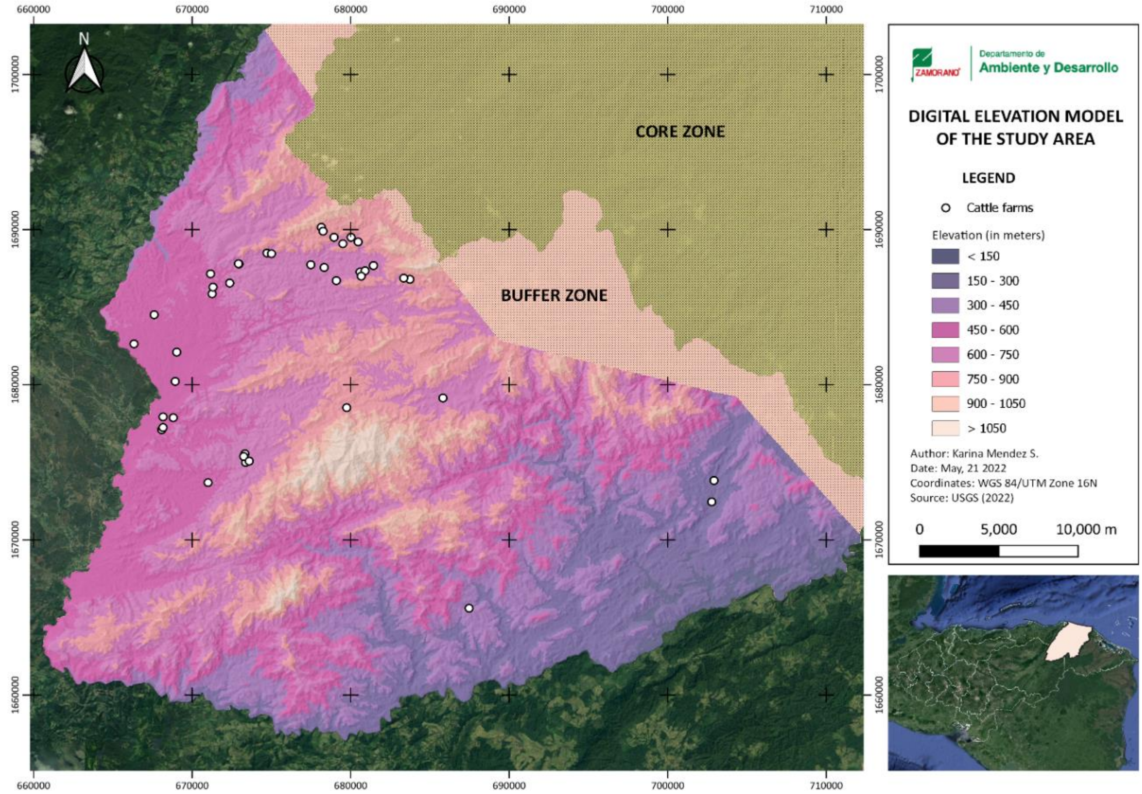


Cattle farms are located at different elevation ranges. The elevation range in which the farms are located is between 170 - 850 masl (Figure 4). In general, producers with dual-purpose farms have cattle that are adapted to different altitudes or elevations.

Similarly, the elevation is in an extremely low range, so it does not directly affect livestock production and its quality. Likewise, the p-value registered through the logit model shows that an increase or decrease in the elevation at which the cattle farms are located does not increase or decrease the probability that the cattle ranchers decide to register under the cadaster of the area.

Figure 4

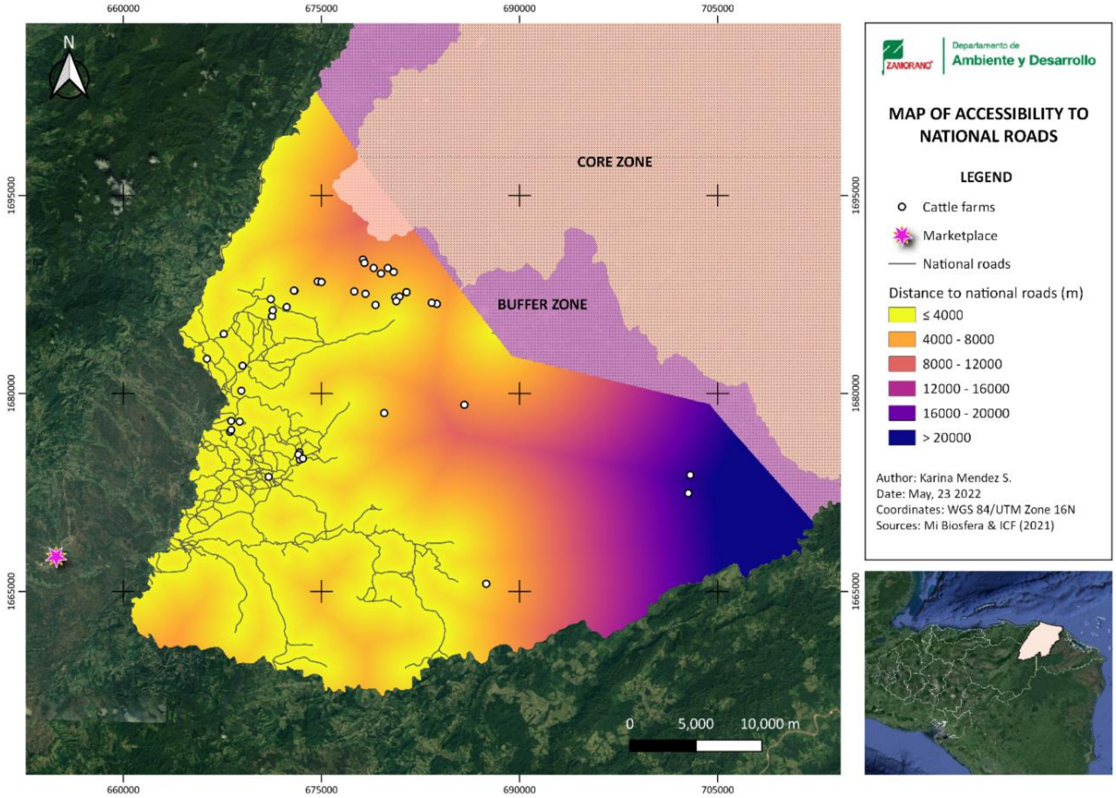
Digital elevation model (DEM)



The distance to roads and the distance to rivers are not factors that influence the cadaster of farms. When analyzing the distance to roads (m) and the distance to rivers, it was determined by the logit model that the accessibility to these two factors did not influence whether the farms were registered. The P-values recorded for the distance to roads and the distance to rivers are both above the margin of error (5%), which shows that they are not significant in explaining the dependent variable. The national roads within the study area are distributed throughout the zone. Therefore, there is a greater possibility of being able to access them. Figure 5 shows the distribution of the road network within the study area and its distance from the farms. Only two of the farms located in the zone have low accessibility to the road network due to their geographic location. These were the farms that are farthest from the roads.

Figure 5

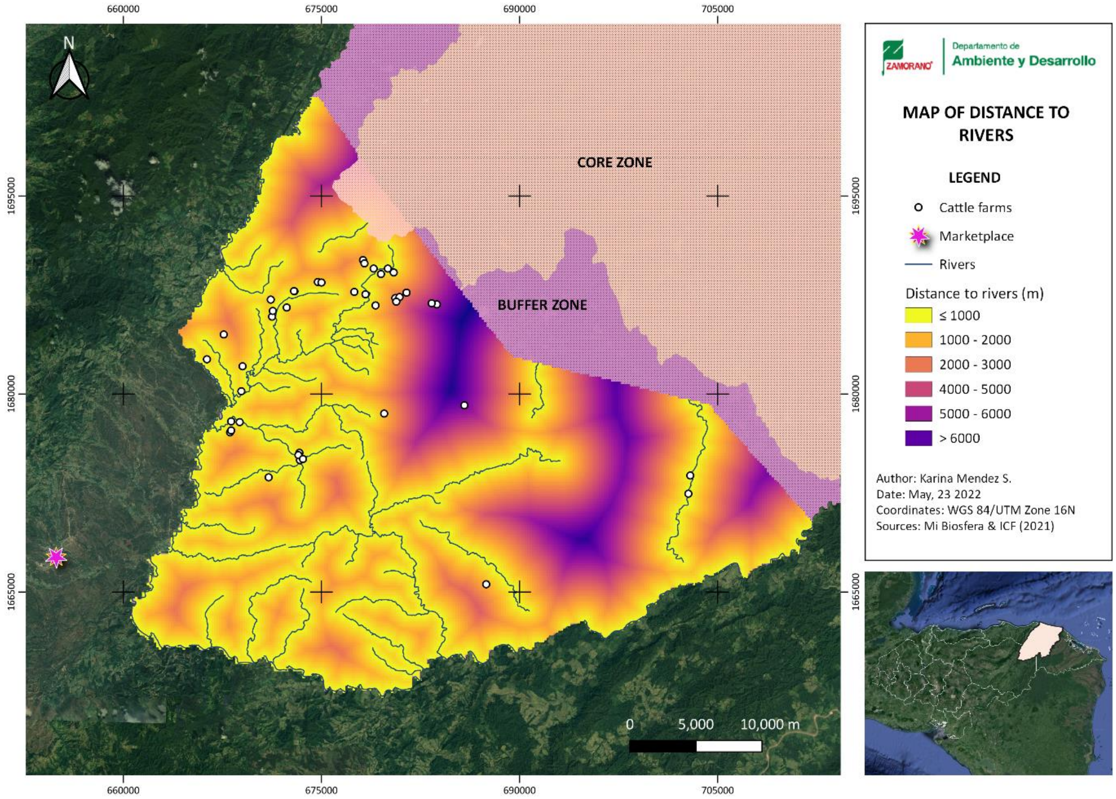
Map of the distance between the national road network and cattle farms



There are rivers distributed throughout the study area. Approximately 50 bodies of water have been registered in this region, of which 20 are rivers and 30 are streams. Therefore, the farms have greater access to these due to the distribution that they present throughout the study area. Studies conducted by Flores (2006) show that cattle farms, specifically beef farms, tend to be close to rivers because they tend to be less intensive than dairy farms. However, the farms studied for this research were farms dedicated to producing both milk and meat, which may help explain the difference with results from Flores (2006). Figure 6 presents the distribution of the rivers located in the study area. It shows that the distance to the rivers is not a factor that affects the farms, since most of them have medium to high accessibility to this resource.

Figure 6

Map of accessibility to the rivers

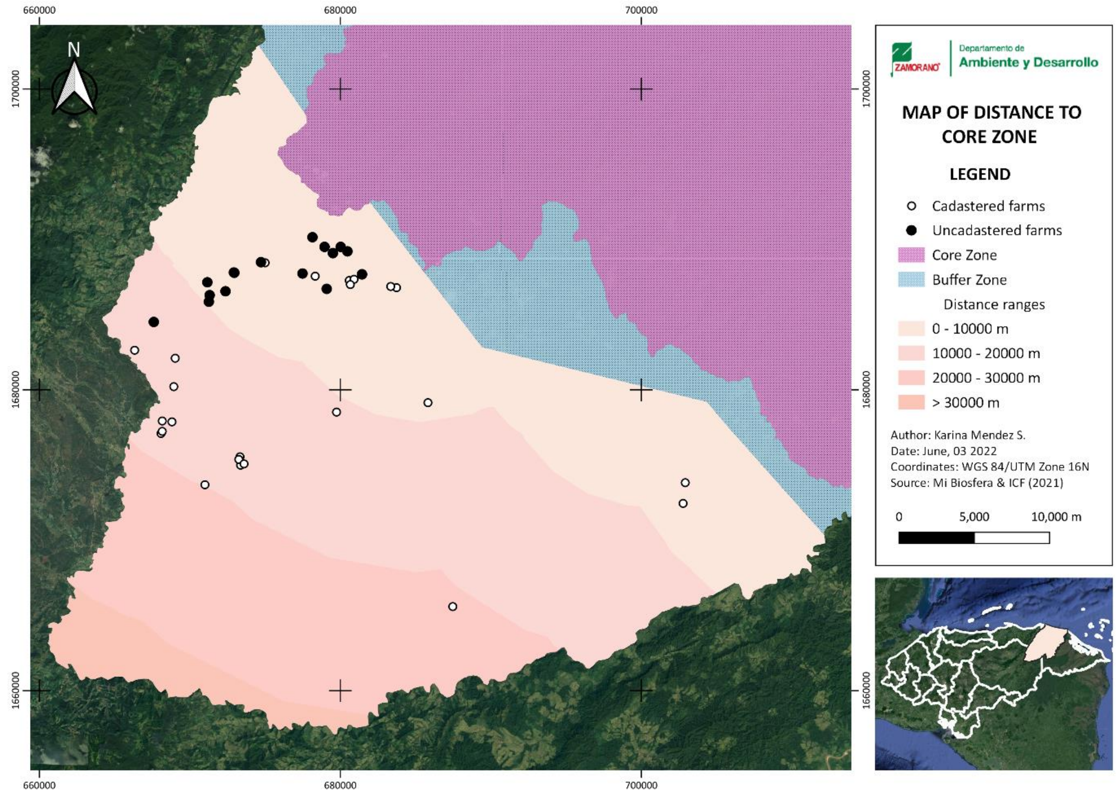


Nevertheless, the distance in terms of time (min) to the marketplace and the distance (m) to the core zone of the Rio Platano Biosphere Reserve from each of the farms are factors that increase the probability that the farms are cadastered. The distance to the core zone was considered because the farms are located within a region that was declared a protected Biosphere Reserve, and the different productive activities that are carried out nearby to it will have an impact on the health of the core area.

Since the cattle farms are located in a site that is considered a place this economic activity can only be conducted in the buffer zone. In general, all the farms selected for the study are located within this region. The most critical area for the Biosphere Reserve is the core zone. Therefore, all the economic activities that are conducted near it can generate negative effects on the health and well-being of the core zone. Figure 7 shows the distribution of the farms (cadastered and uncadastered) throughout the study site and their distance to the core zone of the Rio Platano Biosphere Reserve.

Figure 7

Map of the distance between cattle farms and RPBR core zone

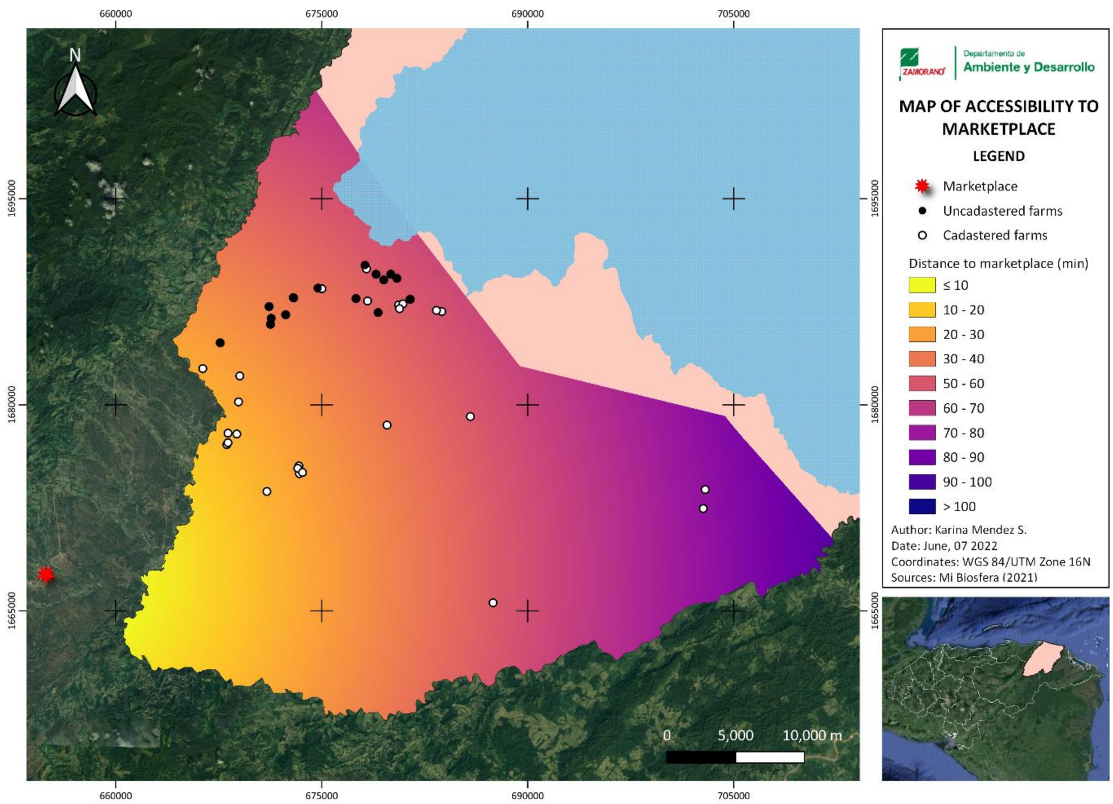


The results reflect that the distance to the core zone is a factor that increases the probability that the farms are cadastered or not. The p-value registered for this factor is 0.005, which is less than the margin of error established for the study (5%). The value of the coefficient recorded for this factor through logistic regression (coefficient = 0.002), reflects a positive relationship between the distance to the core area and the probability that the farms are registered. Farms that are further away from the core zone in terms of distance (m) have a higher probability of being cadastered. The management regulations for the Rio Platano Biosphere Reserve do not specify the distance from the core zone from where agricultural and livestock production activities can be conducted. These regulations only specify that productive activities will only take place in the reserve's buffer and cultural zones. It was found that there are farms located just a few meters from the border with the core zone.

Another factor that influences the cadaster registry is the distance to the market (Dulce Nombre de Culmí). The p-value registered for this factor is 0.009, which is less than the margin of error established for the study (5%). The value of the coefficient recorded for this factor through the logit model (coefficient = 0.848) reflects a positive relationship between the distance to the marketplace and the probability that the farms are cadastered. Therefore, this means that, as farms are located farther away from the marketplace, there is a greater probability that they are cadastered. Figure 8 shows the distribution of the farms (cadastered and uncadastered) throughout the study and the distance to the marketplace.

Figure 8

Map of distance to the marketplace in time (Dulce Nombre de Culmi)



Beckmann (1972) explained how distance to the market can define market access. An analysis conducted by the Territorial Cadaster in the Republic of Honduras determined that the properties that are registered, specifically those of a livestock nature, have greater access to the market. This analysis did not link distance to the market and accessibility to it, as proposed by

Von Thünen. However, the analysis carried out by Palma (2008) specifies that farms that are cadastered have greater commercial opportunities, regardless of whether they are located in urban or rural areas. However, in general, the main markets in Honduras are located in the country's cities, so farms located in rural areas will have higher market access costs in terms of time. This is supported by the distribution and perfect location of the most important economic sectors proposed by Von Thünen in the Model of Agricultural Land Use.

To analyze the cattle farms intensification, a Tobit model was estimated using the Animal Stocking (AS) as a proxy. Tobit model is also known as a censored regression model: truncated if observations outside a specific range are censored at least one exogenous variable can be observed (Albertini et al., 2021).

To better explain the intensification, The forest reserve area of each farm, the farm area, the total head of cattle, the rainfall on the farms, the slope, the elevation, the distance to rivers, and the distance to the core zone were used as explanatory variables. The results reflect a model with a p-value = 0.000, which shows that the model is highly significant. However, not all the variables selected for the estimation of the model can explain the level of intensification of cattle farms. The results of the Tobit Model are detailed in Table 7.

Table 7

Tobit model results

Variables	Unit	Coefficient	Standard Error	P-value
Farm's forest reserve area	Hectares (ha)	0.019	0.004	0.000*
Farm area	Hectares (ha)	-0.024	0.003	0.000*
Total cattle head	-	0.017	0.002	0.000*
Rainfall	mm/year	-0.004	0.001	0.002*
Constant	-	5.8229	1.5107	0.000

Note. P-value = 0.000, Pseudo R2 = 0.4548, Chi-squared = 48.46

Slope and elevation are not factors that can influence whether farms tend to be extensive or intensive. These explanatory variables showed a p-value of 0.917 and 0.731 respectively, which are above the margin of error stipulated for this model (5%). Due to the type of production conducted on the farms (dual purpose), the slope and elevation factors are not variables that can explain the intensification of the farms. In general, the maximum and minimum values that are represented in the slope and elevation study area do not significantly affect production, so ranchers do not pay attention to these factors when determining whether they are going to produce intensively or extensively. The trend that exists in developing countries is that producers are only guided by the value of the land and not by its physical and topographical characteristics (López-Feldman, 2015)

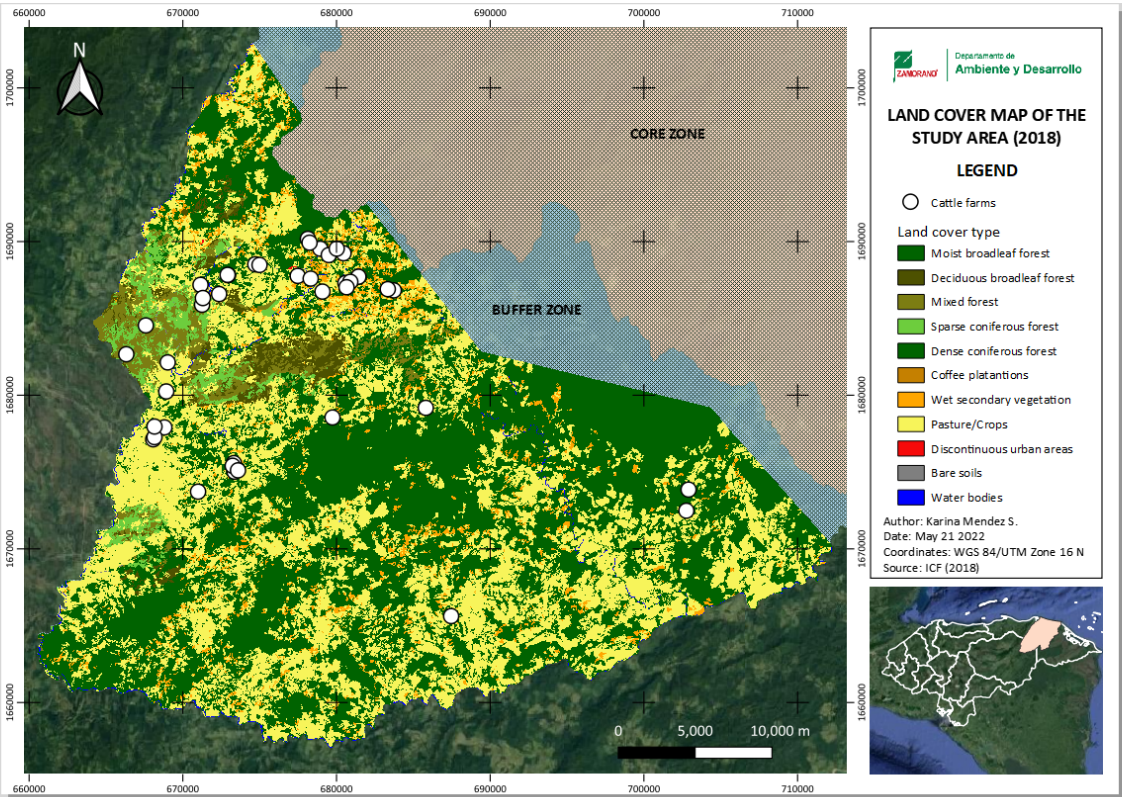
The distance to rivers and the distance to the core area are not factors that can explain whether the farms are extensive or intensive. When performing the analysis of the results, these factors turned out to be not significant to explain the model. With a p-value of 0.582 for distance to rivers and 0.67 for distance to the core zone, both factors are above the margin of error. Therefore, they did not influence the response variable. (Flores, 2006) determined by research conducted in Costa Rica, that dairy farms tend to be closer to rivers because they need a constant water supply. This is because dairy farms need large amounts of water to be able to conduct milking activities. In this study the opposite was determined for the beef farms; that is, they are located closer to the rivers. In general, cattle farms tend to be less intensive than dairy farms, and this is influenced by their distance from rivers. However, as mentioned above, this is not a factor that affects the intensification of the farms located in the Rio Platano Biosphere Reserve, since the farms studied are dedicated to producing both meat and milk.

The variables that contribute to the model and that can explain the intensification of the cattle farms selected for the study were the farm's forest reserve area, the farm area, the total number of heads of cattle, and rainfall. These variables presented a P-value lower than the established margin of error (5%). The farm area presented a p-value of 0.000 and a coefficient of -0.024. These values show that farm size can determine the type of intensification of cattle farms. The results of the Tobit model reflect that there is a negative relationship between both variables; that is, the behavior of one variable concerning the other is inversely proportional. This means that when one variable increases, the other will behave oppositely, and it will decrease. Therefore, the results obtained through Tobit regression indicate that as the size of the farm decreases in terms of area, the Animal Stocking (AS) will increase, and this will make the farm more intensive.

On the other hand, the total cattle head for each of the farms is a factor that is related to the response variable of the Tobit model. The total cattle head presents a p-value of 0.000, which makes it significantly high to explain the selected model. In the same way, it presents a coefficient of 0.017, which shows that there is a positive relationship between the stocking rate and the number of heads of cattle on each farm. This supports the conclusion that, as the number of livestock increases on a farm, the stocking rate will increase in the same way. As explained in the methodology, livestock units are calculated by dividing the livestock according to their ages and multiplying by a conversion factor. Subsequently, to calculate the total cattle units of the farm, a sum of the results is made, according to the ages of the cattle. This supports the relationship between the stocking rate and the number of heads of cattle. This can explain whether the farms are intensive or extensive. On the other hand, the farm's forest reserve area was a factor that can affect the intensification of the farms. Despite being in the buffer zone of the Rio Platano Biosphere Reserve, the presence of diverse types of cover, including various kinds of forests, Figure 9 shows the several types of coverage found in the study area, including distinct types of forests. The results show that this factor has a positive coefficient (0.019), and a p-value of 0.000, which indicates that the relationship between the Animal Stocking and the farm's forest reserve area is directly proportional. This means that, as the farms have a larger forest reserve area, the Animal Stocking will increase because the amount of productively active area is reduced. This makes farms more intensive.

Figure 9

Map of land use in the study area



Similarly, precipitation is a factor that can explain livestock intensification on farms located in the study area (p-value = 0.002). The results obtained through the Tobit regression show that there is an inversely proportional relationship between the rainfall recorded on the farms and their stocking rate (coefficient = -0.004). This translates into the fact that as the farms recently receive less rain, the stocking rate increased. Thus, it reflects that the farms turn out to be intensive.

Precipitation is a factor that is linked to the amount of pasture that can be produced within the farms. The farms selected for the study produce their pastures and forages internally, which serve as food for livestock. An analysis conducted by Lopez-Feldman (2015) determined that precipitation on cattle farms in Latin America is related to the quality and quantity of pasture that they can produce. In the same way, the study mentions that those agricultural or livestock farms that receive less rainfall tend to increase their productive pasture area, to complete the same amount of nutrients that a pasture that was developed with a good amount of water could offer. This behavior can be related to the findings found through the Tobit model.

On the other hand, some of the roads that allow farmers to transport their products are made of dirt, that is, they do not have any paving. As they receive more rainfall, these roads remain in unfavorable conditions for the transport of livestock products. Therefore, ranchers are less motivated to intensify their farms. On the other hand, the incidence of diseases such as mastitis is intensified by high rainfall. Mastitis is a disease that affects livestock production (Jingar et al., 2014). As a result, by having higher incidences of this disease in productive cows, farmers are less motivated to intensify their farms, because this disease represents great economic losses.

Conclusions

It is possible that not all geographic and spatial factors affect whether there is a greater probability that cattle farms located in the buffer zone of the Rio Platano Biosphere Reserve are cadastered. In general, the factors that can exert the greatest force on the cadaster of the farms are the distance to the core zone and the distance to the market. The establishment of these cattle farms is not determined by the conditions of the land, such as elevation or slope. If the producer considers the conditions favorable empirically, they will decide to start his cattle production at the site.

The distance to the core area that the farms possess concerning their geographical location is a factor is a factor that could increase or decrease the possibility that the farms have a cadaster. In general, the productive activities that are carried out closer to the core zone can have negative repercussions on the health of the reserve. Farms further away from the core zone have a greater probability of having a cadaster and livestock producers located a short distance from this area has a lower probability of having this instrument.

It is possible that some farms are not being cadastered due to different non-geographical aspects. Initially, some of the farms located in this area are productions that began after the cadaster was legally introduced in 1980. The farms that were established after the national registry were left out of this process. When the cadaster process of the country's real estate began, all the farms present at that time were registered. On the other hand, some cattle farms did not have the legal documentation requirements necessary to be registered under the real estate registry, so these farms get left out of this process.

The distance to the market that the cattle farms have from their location and the cadaster seems to be a factor that could determine the level of accessibility that they have to the market. The cadaster is a crucial factor that can open market opportunities for livestock producers. In general, the farms that have a cadaster are far from Dulce Nombre de Culmi, which is the market point, which increases their accessibility and transportation costs to it. However, the cadaster is a tool that allows ranchers to obtain better business opportunities for their livestock products.

The Tobit model shows that not all geographic and spatial factors can define the intensification of cattle farms. In general, slope, elevation, and distance from rivers and roads are not factors that significantly affect whether a farm is extensive or intensive. The factors that can explain this aspect are the internal factors of the farm. Except for the rainfall which is directly explained by the climatology characteristics of the site.

Recommendations

In general, cattle ranches should be completely registered. Since they are located in a zone of biological, ecological, and cultural interest, the government and competent institutions should have a complete record of all productive activities carried out in this region. The cadaster is a tool to establish control over the real estate present in a specific area. Therefore, it is recommended that the national government works directly on this issue to monitor economic activities such as cattle ranching and agriculture in order to adequate resource management and sustainable land use within the Rio Platano Man and Biosphere Reserve.

On the other hand, other geographical and spatial factors that were excluded in this study should be evaluated to know how they affect the cadaster and intensification of livestock farms. This would generate a more complete study to know how livestock production is affected by these types of factors. By knowing the effects that geographic and spatial factors have on livestock production, it will be possible to establish alternatives to support producers in establishing systems that use the land through sustainable production that ensures the well-being of the reserve.

It is recommended to evaluate other economic activities such as crop production, forestry, and fishing. These activities have a large presence in the area. It is suggested to evaluate how spatial geographic factors could affect how these productions are carried out, and how this relates to the well-being of the reserve.

In the same way, it is recommended to evaluate how geographic and spatial factors could affect the intensification of cattle ranches dedicated specifically to the production of meat and milk individually. By knowing how these aspects affect dairy and beef farms, sustainable management alternatives can be proposed for each of them, to ensure the well-being of the reserve and promote environmentally sustainable agricultural production.

It is recommended to start a new cadaster process for farms located in the Rio Platano Biosphere Reserve. Because many farms have been established in recent years, it is necessary to update the current real estate registry. In this way, it will be possible to have a more complete record of all the economic activities carried out in the reserve, in order to establish better management opportunities for the reserve.

It is recommended to work with a series of data from different years to analyze climatic conditions such as rainfall in this region and how they affect the factors analyzed in this study. It is necessary to increase the climatological information of the study site in order to reduce the statistical bias and have more robust and precise results.

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