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Research Article

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Monitoring the Deforestation Rate and its Impact on Wild Bee Populations (Apidae: Meliponini) in the Chaco Serrano Ecoregion, Itapochi Community of the Serranía del Iñao National Park and Integrated Management Natural Area – Bolivia

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ABSTRACT
The research project, titled "Impact of Deforestation on Populations of (Apidae: Meliponini) in the Iñao Protected Area," aims to contribute to the understanding of the impact of deforestation on wild bee populations. The study methodology is based on multi-temporal analysis using remote sensing and geographic information systems (GIS) to determine the location and extent of vegetation cover changes associated with deforestation, based on Landsat satellite imagery from 2004–2019. The resulting temporal maps allowed for the georeferencing of transects for field monitoring and the observation of wild bee nest density. The deforestation rate results showed that deforested areas increased over 14 years. According to the multi-temporal analysis of Landsat images, starting with the year 2004 when the Serranía del Iñao National Park and Integrated Management Natural Area (PN ANMI Serranía del Iñao) was established, the deforested area was 156.26 hectares. By 2019, this figure had risen to 258.62 hectares, representing an increase of 93.36 hectares. This increase is primarily associated with the expansion of the agricultural frontier, which is one of the most significant threats to biodiversity in the Serranía del Iñao National Park and Integrated Management Natural Area. The fragmentation of natural habitats has irreversible effects that consequently lead to a loss of wild bee populations due to the destruction of their food sources and nesting sites. The density obtained from wild bee populations in natural forest areas adjacent to deforested areas was 10.26 hives per hectare made up of 5 species.

Keywords: Iñao Protected Area, Chaco Serrano Ecoregion, Deforestation, Impact, Populations, Wild Bees

Problem Statement

Problematic Situation

One of the most significant threats to Bolivia's biodiversity, including that conserved within its protected areas, is the change in vegetation cover, primarily associated with deforestation caused largely by the expansion of the agricultural frontier and land-use change. This phenomenon is the main cause of forest loss, which has irreversible effects on the modification and destruction of natural habitats, consequently leading to a loss of biodiversity and ecosystem and environmental functions [1].

Of the 22 protected areas of national interest, 16 safeguard 22% of Bolivia's forests, totaling 12,385,025 hectares. Between 1990 and 2010, approximately 77,801 hectares of forest, representing 0.63% of the total, were lost, mainly due to deforestation. Within

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protected areas, deforestation is observed; however, the affected areas are minimal or smaller compared to unprotected areas, which exceed 7.36% according to 2010 data [1].

Regarding pollinators, there are three critical aspects to consider when analyzing threats to bee populations and, consequently, to the pollination service they provide in a given region: a) availability of food sources, b) availability of nesting sites, and c) exposure to pesticides. According to these criteria, deforestation causes a decrease in nesting sites because bees use cavities in tree trunks to build their nests, and these trees are also food sources. Therefore, natural tree cover is key to sustaining wild bee populations [2].

In this context, the study for the creation of the Iñao Protected Area, conducted by the Chuquisaca Prefecture in 2001, recommended more intensive assessments of the groups already studied and other bioindicators, such as bees (Apoidea), which are still in their early stages of development [3]. Given the importance of wild pollinators in ecosystems and the environmental services they provide to humanity, it was decided to study the impact of deforestation on wild bee populations (Apidae: Meliponini) within the Iñao Mountain Range Protected Area.

Problem Formulation

The declaration of a protected area does not always result in adequate protection. Thus, the program for the protection, conservation, research, and knowledge management of the natural and cultural heritage of the Serranía del Iñao Protected Area is limited to protection and surveillance by its protection force. A protected area without a biodiversity research and monitoring system cannot guarantee its integrity and sustainability, and evaluating the effectiveness of such systems is fundamental. Scientifically demonstrating the area deforested between 2004 and 2019 and how many beehives are eliminated per hectare deforested is crucial. What is the impact of deforestation on wild bee populations?

Justification of the Research

Wild bees are considered the most efficient pollinators of higher plants inhabiting all tropical and subtropical regions of the globe, making them of great economic and ecological importance in the country's agroecosystems. In fact, a large portion of the food consumed and traded on a massive scale today depends directly or indirectly on pollination by bees. For example, it is estimated that in the United States, bees are responsible for nearly $3 billion worth of fruits and vegetables produced each year [4].

Some studies have estimated that a rapid decline in the number of pollinators, such as the one reported in recent decades, threatens global food security. It is estimated that without pollinators, one of the three daily meals would be lost, and fruits of low nutritional quality would be produced. For this reason, the Convention on Biological Diversity (CBD) (2000) highlighted the importance of pollinators and established the International Initiative for the Conservation and Sustainable Use of Pollinators. Within this context, the FAO established the Global Action Plan on Pollination Services for Sustainable Agriculture as a guide for member countries. This plan provides a list of tools necessary for the use and conservation of pollination services and assists in the formulation of policies that ensure the sustainability of these ecosystem services [4].

Some elements of this action include monitoring, research, and assessment of threats, along with their status and trends, in order to identify the likely causes of the decline in pollinators and their habitats in all regions, as well as addressing knowledge gaps, for example, by promoting relevant Research [5].

Research objectives

General Objective

Contribute to the knowledge of the impact of deforestation on the populations of Wild Bees (Apidae: Meliponini) in the Chaco Serrano Ecoregion, Itapochi community of the Serranía del Iñao National Park and Integrated Management Natural Area [6].

Objetivos Específicos

The specific objectives are as follows:

- To apply remote sensing techniques and geographic information systems (GIS) to analyze deforestation from 2004 to 2019.
- To monitor the relative density of wild bee colonies in natural forest areas adjacent to deforested areas.
- To determine the number of wild bee colonies eliminated per hectare of deforested forest.

Theoretical Framework

Background of the Problem

Over the past few decades, a marked decline in some pollinator taxa has been observed, although data on the status and trends of wild pollinators are limited and largely restricted to certain regions of Europe and the Americas. Risk assessments of the status of wild pollinating insects, such as bees and butterflies, are also geographically restricted, but indicate high levels of threat, with the proportion of threatened species often exceeding 40% [5].

Deforestation is among the main causes of biodiversity loss on the planet. The main land uses contributing to deforestation, and their relative impact, are: livestock grazing on sown pastures (50%), mechanized agriculture (30%), and small-scale agriculture (18%). The most affected areas are located in the Yungas forest ecoregion; the southwestern Amazon rainforest; Chiquitano Dry Forest and Chaco [7].

Deforestation reports applied to protected areas and Indigenous Peasant Territories (TIOCs) indicate that deforestation levels in both areas are significantly lower than outside them, suggesting that TIOCs could contribute significantly to the conservation of biological diversity as well as to the maintenance of their livelihoods through the management and governance of their territories [7].

In 2000, the Convention on Biological Diversity highlighted the importance of pollinators and established the International Initiative for the Conservation and Sustainable Use of Pollinators. Within this context, in 2014 the FAO established the Global Action Plan on Pollination Services for Sustainable Agriculture as a guide for member countries, which also provides a list of tools needed for the use and conservation of pollination services and helps in the formulation of policies that ensure the sustainability of these services for ecosystems.

Theoretical Framework

Monitoring Biodiversity in Bolivia's National Protected Areas

The Biodiversity Monitoring Protocols in National Protected Areas have the primary purpose of guiding the development of this research. The audit report on environmental performance regarding the management of National Protected Areas K2/AP11/Y14-E1, presents some indicators of interest regarding the development of specific standards for biodiversity monitoring and their implementation for monitoring and evaluating the conservation status of biodiversity in National Protected Areas in Bolivia [8].

First indicator: Special standards for biodiversity monitoring in National Protected Areas have been developed and issued. SERNAP reported that they have not yet developed or issued special standards for biodiversity monitoring in National Protected Areas.

Second indicator: Instruments and mechanisms for monitoring and evaluating the conservation status of biodiversity in the National Protected Areas (APNs) were implemented: SERNAP reported that they have developed Monitoring Programs for 19 of the 22 APNs (Apolobamba, Madidi, Pilón Lajas, Eduardo Avaroa, Iñao, Palmar, Toro Toro, Cotapata, Sama, Tariquía, Kaa Iya, San Matías, Amboró, Manuripi, Tipnis, EBB, Sajama, Carrasco, and Otuquis).

Regarding the implementation of the Monitoring Programs, they indicate that they are carried out differently in each protected area.

The implementation of monitoring activities involves: patrols along specific routes, data collection on conservation targets defined in the Monitoring Programs, generation of patrol and monitoring reports by park rangers, systematization and creation of local databases, and generation of monitoring reports. All of this is contingent upon the capacity of the park rangers or the availability of technicians assigned to this activity. The execution of these activities is conditioned upon the availability of financial resources.

The difficulties identified by SERNAP suggest that they have not fully implemented the instruments and mechanisms for monitoring and evaluating the conservation status of biodiversity in the National Protected Areas (APNs). These actions are subject to the availability of resources to have personnel and/or trained personnel to generate monitoring reports. This situation affects the management of the APNs, since monitoring is an activity that must be carried out periodically and continuously to obtain valid information for the stated purposes.

Third indicator. Coordination of biodiversity monitoring activities: SERNAP reported that monitoring activities are coordinated from the Central Unit, but operationally carried out within each protected area, where defined protocols exist for monitoring activities. They also indicated that these activities are conducted semi-annually by technicians or heads of protection in each protected area. The Directorates that have implemented Monitoring Programs send reports generated with the data, which are then systematized and analyzed at the SERNAP Central Unit (in this regard, it is worth recalling what SERNAP stated).

Fourth and fifth indicators: Whether there are periodic monitoring activities in the National Protected Areas (NPAs). Whether biodiversity monitoring provides information for achieving the objectives of the NPAs: SERNAP indicated that the activities carried out in the protected areas are entirely synergistic with each other and are not specific lines of action to achieve a specific objective. This is due to the complex characteristics of territorial and environmental management in protected areas. In this sense, the monitoring or monitoring coordination activities carried out in the NPAs are detailed in the Annual Operating Plans (AOPs), and there are no periodic monitoring activities as such. They did not refer to whether biodiversity monitoring provides information for achieving the objectives of the NPAs.

Geographic Information Systems and Remote Sensing

Remote sensing and geographic information systems (GIS) are used to acquire and process spatial data that allow us to address a wide variety of important issues related to aspects such as: the management of environmental and natural resources, food production and food security, coastal zone monitoring, desertification, biodiversity, energy, and the impact of climate change, among many others [9].

Landsat Satellites

Since 1972, Landsat satellites have continuously acquired space-based images of the Earth's surface, providing data that serve as valuable resources for land use/land change research. The data are useful for various applications, including environmental monitoring, deforestation, forestry, agriculture, geology, regional planning, and education [10].

Landsat 4-5 Thematic Mapper (TM) Level-1

The Landsat Thematic Mapper (TM) sensor was carried aboard Landsat 4 and 5 from July 1982 to May 2012 with a 16-day retake cycle, referenced to World Reference System-2. Very few images were acquired from November 2011 to May 2012. The satellite began decommissioning activities in January 2013. The approximate scene size is 170 km north-south by 183 km east-west. Landsat 4 and 5 followed the same orbit as Landsat 7 and 8 at an altitude of 705 kilometers [10].

Landsat 8 OLI/TIRS C1 Level-1

Landsat 8 was launched on February 11, 2013. The Landsat 8 payload consists of two scientific instruments: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). Landsat 8 (OLI/TIRS) images comprise nine spectral bands with a spatial resolution of 30 meters for bands 1 through 7 and 9. The ultra-blue band 1 is useful for coastal and aerosol studies. Band 9 is useful for detecting cirrus clouds. It is similar in size to the Landsat 4-5 thematic mapper scenes [10].

Bolivia's Spatial Data Infrastructure

Technologically, GeoBolivia is a computer platform of the Spatial Data Infrastructure of the Plurinational State of Bolivia

(IDE-EPB), which allows for the storage, search, and publication of the country's geographic information (GI) through a web portal: http://geo.gob.bo [11]. This portal provides access to relevant, harmonized, and high-quality geographic information to support decision-making and the country's social, economic, and environmental development.

ASTER Digital Elevation Model (30 meters) for Bolivia

This map presents the distribution of scenes from the ASTER Global Digital Elevation Model (GDEM) covering Bolivian territory. These scenes were created with a spatial resolution of 30 meters from images captured by the Japanese Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER GDEM), operated by NASA and the Japanese Ministry of Economy, Trade and Industry (METI). The images are available for download in GeoTIFF format with latitude/longitude coordinates from the Thematic Maps section of the GeoBolivia website.

Stingless Wild Bees

The tribe Meliponini belongs to the group of corbiculate bees in the subfamily Apinae and includes all those bees known as "stingless bees." They are found in all tropical and subtropical areas of the world [12]. They build very distinctive nests to house their young, with generally conspicuous entrances, which, in some cases, serve to identify the species. Stingless bees, along with honeybees (Apis mellifera), are the only ones that exhibit highly social behavior and live in permanent colonies [13]. They are mainly characterized by having a reduced stinger, wings with weak or reduced venation and bare eyes (without hairs), known as "corbiculate bees" characterized by the presence in females of a corbicula, a structure that serves for the collection and transport of pollen [14].

Nesting Habits

According to Roubik, bees carefully choose their nest location and are specially adapted to minimize vulnerability to natural enemies, intraspecific competition, and theft [15]. Unlike honeybees, queens mate only once. Stingless bees do not form free-ranging flocks, and we can predict a colony lifespan of 24 years. Regarding community dynamics in natural vegetation, the stingless bee community, in terms of active nests, can number approximately 150 colonies per square kilometer (100 ha), with a known range of 15 to 1500 colonies. However, colony biomass and bee size vary considerably, as even slight disturbance can alter the species composition. The characteristics of the nest entrance, the nesting substrate, and the defense behavior of Meliponini species provide a field identification key based on these characteristics [15].

Taxonomic Position of Stingless Bees

The taxonomic system used in this work is that proposed by Moure's bee catalog. The electronic database http://moure.cria.org.br provides information on the distribution and taxonomy of different Meliponini species. This catalog recognizes 33 exclusively Neotropical genera and lists a total of 641 names for the taxa of this species group, of which 417 are considered valid [16].

Ecoregions of the (PN - ANMI)

The World Wide Fund for Nature (WWF) presents a map distinguishing 17 ecoregions in Bolivia. Within the Serranía del Iñao area, three ecoregions are identified: the Dry Chaco, the Southern Andean Yungas, and the Bolivian Montane Dry Forest.

Protected Areas and the Convention on Biological Diversity (CBD)

The Convention on Biological Diversity is the first multilateral instrument to address biodiversity as a matter of global importance, demonstrating concern about its decline and recognizing its role in the viability of life on Earth and human well-being [5]. Its objectives are: the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of the benefits arising from the utilization of genetic resources.

Protected areas are an integral part of the Convention on Biological Diversity (CBD) and are central to a number of thematic areas and cross-sectoral issues addressed by the Convention. Article 8 defines the guidelines for in-situ conservation through the establishment of a system of Protected Areas or areas where special measures must be taken to conserve biological diversity.

Legal Framework for Protected Areas in Bolivia

Within the framework of the Convention on Biological Diversity (CBD), Bolivia is obligated to comply with the provisions of Article 8, in-situ conservation. This article stipulates that each party commits to establishing a system of protected areas to conserve biological diversity in situ. Similarly, mechanisms or measures should be established for the proper management of protected areas.

The Political Constitution of the Plurinational State of Bolivia (CPE) defines Protected Areas as a common good that forms part of the country's natural and cultural heritage and fulfills environmental, cultural, social, and economic functions for sustainable development. The CPE, promulgated on February 7, 2009, states in Article 385:

 Protected Areas constitute a common good and form part of the country's natural and cultural heritage; they fulfill environmental, cultural, social, and economic functions for sustainable development.

Where there is an overlap between Protected Areas and Indigenous Peasant Territories, shared management will be carried out in accordance with the norms and procedures of the Indigenous Peasant Nations and Peoples, respecting the purpose for which these areas were created.

Article 108, paragraph 15 of the Political Constitution of the Plurinational State of Bolivia (CPE) establishes the duties of Bolivians to protect and defend natural resources and contribute to their sustainable use, in order to preserve the rights of future generations. Paragraph 16 reaffirms the duty to protect and defend an environment suitable for the development of living beings.

Law No. 300 of October 15, 2012, in its article 16 establishes that the Plurinational State of Bolivia will promote the integral and sustainable management of the components, zones and life systems to guarantee the maintenance of the regenerative capacities of Mother Earth [17]. Subsection 4 emphasizes respect for the purposes and objectives of protected areas. Subsection 6 of article 23 expresses the bases and guidelines of the living well of the national, departmental, and municipal protected areas system defined in the Political Constitution of the State, as one of the main instruments for the defense of Mother Earth.

Specific Regulations of the National System of Protected Areas in Bolivia

Law No. 1333 of April 27, 1992, in its Article No. 60, establishes: Protected Areas constitute natural areas, with or without human intervention, declared under the protection of the State through legal provisions, for the purpose of protecting and conserving wild flora and fauna, genetic resources, natural ecosystems, watersheds, and values of scientific, aesthetic, historical, economic, and social interest, with the aim of conserving and preserving the country's natural and cultural heritage.

The Supreme Decree Decree No. 24781 of July 31, 1997, approves the General Regulations for Protected Areas, which aim to regulate the management of Protected Areas and establish their institutional framework, in accordance with the provisions of Law No. 1333 on the Environment of April 27, 1992, and the Convention on Biological Diversity, ratified by Law No. 1580 of June 15, 1994.

Decree No. 25158 of September 4, 1998, establishes the organization and operation of SERNAP, institutionalizing it as a "decentralized body of the Ministry of Sustainable Development and Planning (currently the Ministry of Environment and Water) with its own structure, national jurisdiction, and administrative, financial, legal, and technical independence, with functional dependence on the Vice-Ministry of Environment, Natural Resources, and Forestry Development" (Art. 2, Decree No. 25158).

Legal Basis for the Creation of the (PN ANMI)

The Serranía del Iñao National Park and Integrated Management Natural Area (PN ANMI) is one of the 22 Protected Areas established at the national level and is part of the National System of Protected Areas, which is under the jurisdiction of the National Service of Protected Areas (SERNAP) [6].

Law 2727 of May 28, 2004, provides the legal basis for the creation of the Protected Area, coinciding with its creation date. This Law consists of 12 articles, which were drafted based on the technical data and recommendations of the Justification Study of the same year. The following articles are considered of particular importance for this contextualization of the Protected Area:

Article 1. The area known as the "Serranía del Iñao" in the Department of Chuquisaca, with a surface area of 2,630.9 km², is hereby declared the "Serranía del Iñao" National Park and Integrated Management Natural Area.

Article 2 presents the objectives for the creation of the National Park and the Integrated Management Natural Area:

a. To conserve the biological diversity of the ecosystems within the Integrated Management Natural Area – Serranía del Iñao.
b. To conserve outstanding values and a wealth of fauna, flora, genetic resources, and endangered wildlife species.
c. To preserve natural areas for the development of scientific research and environmental education.
d. To protect the Serranías del Iñao, Ñahuañanca, and Khaska Orqo mountain ranges, as these are areas of production of environmental goods and services.
e. To safeguard and contribute to the preservation of scenic, landscape, archaeological, and historical sites within the area, which have potential for the development and implementation of ecotourism activities.
f. To restore fragile and/or degraded areas, reconciling conservation with the economic development of the communities involved in the area, within a participatory management framework.

Article 3 mentions the location of the Protected Area "Park and Integrated Management Natural Area – Serranía del Iñao" as being located within the Department of Chuquisaca, in the municipal jurisdictions of: Villa Vaca Guzmán, Luís Calvo Province; Monteagudo, Hernando Siles Province; Padilla, Tomina Province and the Municipality of Villa Serrano, Belisario Boeto Province.

Management Categories (PN - ANMI)

According to the law establishing the park, the Serranía del Iñao Protected Area belongs to the categories of National Park and Integrated Management Natural Area. The management categories were determined based on the specific characteristics, natural values, and potential identified in the 2001 Justification Study.

The "National Park" category was defined based on the presence of intangible areas, the scenic beauty of its landscapes and geomorphological formations, the representativeness of its ecosystems, and the uniqueness and endemism of its flora and fauna, all of which possess ecological and scientific values that deserve special attention. In this category, the extractive or consumptive use of renewable or non-renewable resources and infrastructure projects are prohibited, except for duly qualified and authorized scientific research, ecotourism, environmental education, and subsistence activities of Indigenous communities.

In contrast, the category of "Integrated Management Natural Area" aims to reconcile the conservation of biological diversity with the sustainable development of the local population. It comprises a mosaic of units that include representative samples of ecoregions, biogeographic provinces, natural communities or species of flora and fauna of singular importance, areas of traditional land-use systems, areas for multiple uses of natural resources, and core areas of strict protection (Art. 25, Supreme Decree No. 24781, of July 31, 1997). Within this category, prohibitions, restrictions, and regulations on use may be imposed, as well as incentives established to ensure the perpetuity of the area and its resources.

Hypothesis And Variables

Research Hypothesis

Based on both theoretical knowledge and empirical data, and considering the proposed answer to the research problem, the following hypothesis is proposed:

Alternative: Changes in vegetation cover associated with deforestation affect the relative population density of wild bee species (Apidae: Meliponini).

Null: Changes in vegetation cover associated with deforestation do not affect the relative population density of wild bee species (Apidae: Meliponini).

Variable Identification

According to the quantitative paradigm of scientific research described by Hernández, R. & Coello, S, variables are the qualitative and quantitative aspects or characteristics of an object or phenomenon that take on different values with respect to the units of study. There are different criteria and terminology for defining variables [18]. Following the methodological approach, we identified two study variables:

- **Independent variables:** These are the characteristics that the researcher observes or manipulates to understand their relationship with the dependent variable. They are the cause of the phenomenon.
- **Dependent variables:** These are the characteristics of the phenomenon that appear or change when the researcher applies, removes, or modifies the independent variable.

Table 1: Variables by specific objectives

Specific objective	Number of variables
1. Apply remote sensing techniques and geographic information systems (GIS) to analyze deforestation from 2004 to 2019.	2
2. Monitor the relative density of wild bee colonies in natural forest areas adjacent to deforested areas.	1
3. Determine the number of wild bee colonies that are eliminated per hectare of deforested forest.	1
Total	4

Source: Own elaboration.

Operationalization of Variables

Operationalization characterizes variables and makes them measurable based on the behavior of indicators, enabling their evaluation. This is why operationalization allows the transition from theory to empirical data, which is crucial for testing hypotheses and solving the research problem (Hernández & Coello, 2008).

Table 2: Observable indicators for each variable

Conceptual variable	Dimension	Indicators	Index
Geoprocessing of the study area	Map of the Iñao Protected Area	Polygon	Hectares
	Map of the Chaco Serrano Ecoregion		
Monitoring the rate of deforestation	Multi-temporal analysis year 2004	Polygon	Hectares
	Multi-temporal analysis year 2019	Polygon	Hectares
Wildlife monitoring	Sampling using transects	Density	n/area

Source: Own elaboration.

Research Methodology

Methodology

This study is based on a multi-temporal analysis, using remote sensing and geographic information systems (GIS), of vegetation cover changes associated with deforestation. The analysis determines the location and extent of these changes using Landsat satellite imagery from 2004 to 2019. The resulting temporal maps will allow us to georeference transects for field monitoring, thus enabling us to determine the relative density of wild bee colonies targeted in this research study.

This research is framed within the quantitative paradigm of scientific research, with a value-free positivist approach. It recognizes that the research process is a historically determined social practice influenced by changes in reality, the object of study, and the circumstances under which the academic research is conducted (Hernández, R. & Coello, S. 2008).

The research is positivist because it has a predominantly quantitative methodological approach, which studies the objective and singular reality independent of the object of study and allows us to organize and classify the quantitative indicators obtained in empirical research, determining through them the properties, relationships and trends of the phenomenon to then be processed statistically.

Determination of the Study Area

It was determined that the study would be conducted in one of the three ecoregions present within the spatial boundaries of the Serranía del Iñao National Park and Integrated Management Natural Area (PN-ANMI), as defined by WWF [6,19]. The purpose of this study was to obtain a sample of the Chaco Serrano ecoregion. Some general descriptions, based on Ibisch & Mérida, are presented below [20].

Geographic Location (Political-Administrative Areas)

Chuquisaca (L. Calvo, H. Siles, B. Boeto, Zudañez, Sud Cinti), Santa Cruz (Cordillera), Tarija (Gran Chaco, O’Connor, Arce). Continues into Argentina.
Area (km²) 23,176

Altitudes 700-2,000 m above sea level
Average annual temperatures 18-22°C. Strong influence of cold southerly winds (surazos).
Average annual rainfall 700-1,000 mm.
Number of dry months 6-7
Landscape Low mountain ranges of the last foothills of the Eastern Cordillera of the Andes, low valleys, piedmont.

Vegetation Dry deciduous forest (-25 m). Important tree species include Anadenanthera colubrina, Astronium urundeuva, Lithraeaternifolia, Schinopsis haenkeana, Tabebuia impetiginosa, and Zanthoxylum coco. In more humid areas, Calycophyllum multiflorum and Schinopsis cornuta are among the notable species.

Monitoring the Deforestation Rate
Studying deforestation requires time-series images that allow for systematic comparisons over time. The ArcGIS program provides a wide and varied collection of analytical tools that can be used to work with and solve problems. Image analysis using the combination of several layers is one of the processing capabilities of today's intelligent analytical models (The ArcGIS Imagery Book, 2016). Therefore, this work focuses on the use of ArcGIS software (version 10.6.1), a computer program produced and marketed by ESRI.

Wildlife Monitoring
This study aligns with the wildlife monitoring approach proposed by Maza, M. & Bonacic, C, which employs the fixed-width transect survey method in natural hábitats [21]. This method allows for determining the relative density of wild bee colonies (Apidae: Meliponini) within a specific area of an ecosystem.

Several approaches exist for obtaining information on the presence and abundance of wildlife populations. Maza, M. & Bonacic, C. highlight the census and sampling method [21]. The sampling method involves counting only a portion of the individuals present to estimate the total population, taking into account the likelihood of detecting the species. The main sampling methods utilize transects, point counts, and capture-mark-recapture.

Transect Sampling
This method is commonly used for all vertebrate taxa, adapting the transect scale to each species and specific hábitat [21]. Therefore, the transect sampling method was adopted, and two sampling points were established in areas of natural forest. The fieldwork process is described below.

Fixed-Width Transect
The fixed-width transect measurements were established before monitoring: Length 130 linear meters. Width 60 meters, i.e., 30 meters on each side of the transect's centerline (Fig. 1). The transect area is 0.78 hectares. It is assumed that all individuals within the transect are counted. For this method to be valid for animals, it must be ensured that every individual will be found within the transect and that its presence along the transect will not affect the presence or absence of another individual [22]. The species density for each transect is calculated by dividing the total number of individuals recorded by the total transect area (length x width): Density = n / area (Length x Width) [21].

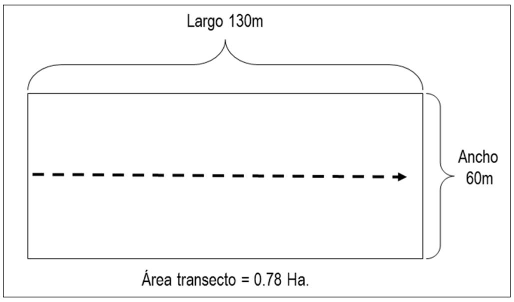


Figure 1: Schematic of a fixed-width transecto

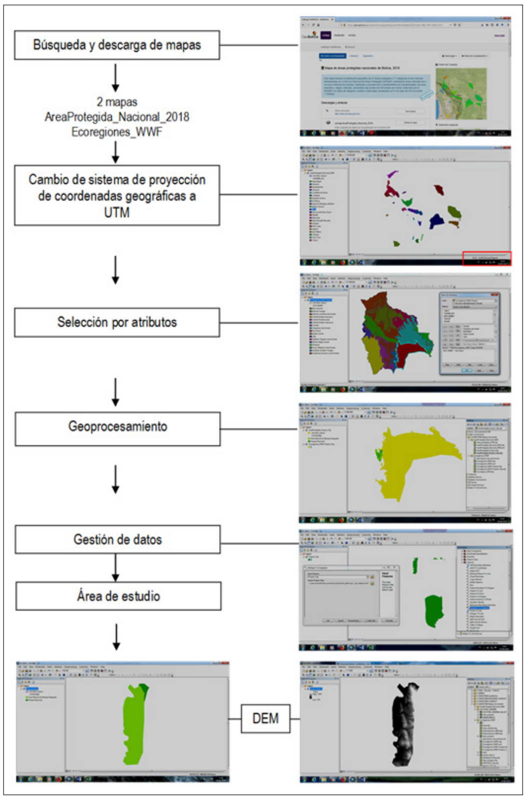
Source: Prepared by the author, based on information from [21]

Nest Sighting Record
According to Maza & Bonacic, for a wildlife sighting to have value as a scientific or wildlife monitoring record, it must include information beyond simply recording the observed species [21]. To give value to any wildlife sighting, the following must be recorded at a minimum during fieldwork:

a. Exact location of the sighting or monitoring site (mark GPS point): Without the exact location of the sighting, it is not possible to relate the presence of the species to specific habitat conditions where it was recorded.
b. Date and time of the sighting or the start and end of the monitoring: Wildlife activity varies significantly throughout the year (seasonality) and has periods of higher and lower daily activity.
c. The observer(s) who participated in the sighting or monitoring: The observer's experience influences the accuracy of the sighting and the possibility of errors in species identification. Furthermore, the publication of data must acknowledge the individuals who carried out the fieldwork.
d. Species sighted: A single sighting or a list of species sighted, the number of hives per species, and additional information about the animal's behavior or apparent health status, among other things, is always appreciated.

Photographic Record of the Entrance Structure
Photographic records are an important way to obtain information on species that could not be identified in the field or to record behaviors that may be relevant to researchers or have educational value. Therefore, creating image databases is also a useful way to monitor wildlife populations and can be included in monitoring plans [21].

Geoprocessing of the Study Area
This involves analyzing geographic data downloaded from the Spatial Data Infrastructure of the Plurinational State of Bolivia (IDE-EPB) and preparing maps with the layers of interest for the study area. This tool allows us to slice a portion of one feature class using one or more features from another feature class. This is particularly useful for creating a new feature class, also known as a study area or area of interest, that contains a geographic subset of the features in a larger feature class [23]. Figure 2 shows the geoprocessing for the study area.



Figurre 2: Methodological sequence for geoprocessing of the study area Source: Own elaboration

Land Cover Map Preparation for the Period 2004–2019

Temporary land cover maps were created by visualizing a multispectral and panchromatic image on screen. This involved digitizing polygons using an interactive selection of the Red, Green, and Blue (RGB) color fields, as these represent the features visible to the human eye on the Earth's surface. Figure 3 presents the methodological sequence for preparing temporary land cover maps and analyzing the regeneration process on Landsat satellite imagery.

Search and Download of Landsat 4-5 TM C1 Level-1 Scene

Based on the search criteria, 22 scenes were displayed for the study area, corresponding to the 2004 period. The product identified for this work is: LT05_L1TP_231073_20041201_20161128_01_T1. Acquisition Date: December 1, 2004, and download of the product: GeoTIFF Data Product (187.59 MB) [24].

Download Landsat 8 OLI/TIRS C1 Level-1 scene

Similarly, based on the search criteria, 10 scenes were displayed for the study area corresponding to the 2019 period. The product identified for this work is: LC08_L1TP_231073_20190125_20190206_01_T. Acquisition Date: January 25, 2019, and download of the product: GeoTIFF Data Product (938.26 MB).

Land cover change map preparation for 2004

The maps were created from the visualization of a multispectral image on screen by digitizing polygons using an interactive selection of the Red, Green, and Blue (RGB) color fields, as these represent the features on the Earth's surface visible to the human eye.

Land Cover Change Map Preparation for 2019

The maps were created by displaying a panchromatic image on screen through the digitization of polygons using an interactive selection of the Red, Green, and Blue (RGB) color fields, as these represent the features on the Earth's surface visible to the human eye. Panchromatic images have one of the highest resolutions and are created when the sensor capturing the images is sensitive to a wider range of light wavelengths, typically including the entire visible spectrum, which is stored and displayed as a single-band grayscale image. This allows for the creation of smaller pixels on the sensor and produces a sharper image than typical multispectral sensors of the same system (ESRI, 2016).

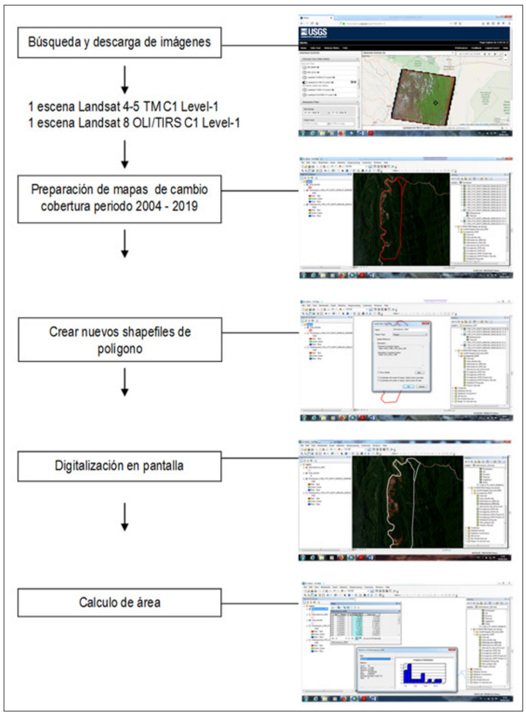


Figure 3: Methodological sequence for multi-temporal analysis

Source: Own elaboration.

Basic Cartography

Knowing our location relative to other spatial indicators within the study area is essential for fieldwork. For this purpose, two maps were used:

a. DEM reclassification to two values for the study area. This type of information is crucial for determining the maximum and minimum elevation of the terrain in the study area and observing the progression of deforestation in relation to elevation. Therefore, the DEM was reclassified to two values.
b. Titled lands and lands in the process of being titled. Based on information from the National Institute of Agrarian Reform (INRA) regarding the map of titled lands and lands in the process of being titled in Chuquisaca, the relevant attributes were extracted for the study area.

Results

This chapter describes the results of the research process that responds to the requirements of the three specific objectives, based on the methodological approach for each of them.

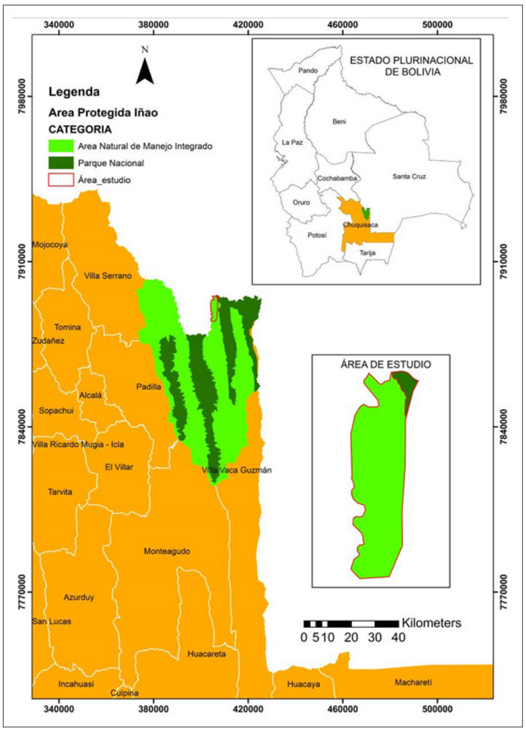


Figure 4: Location map of the study area
Source: Own elaboration.

Study Area

The study area has a total surface area of 26.30 km², within which the area corresponding to the National Park (PN) category is 1.23 km², and the area corresponding to the Integrated Management Natural Area (ANMI) category is 25.06 km².

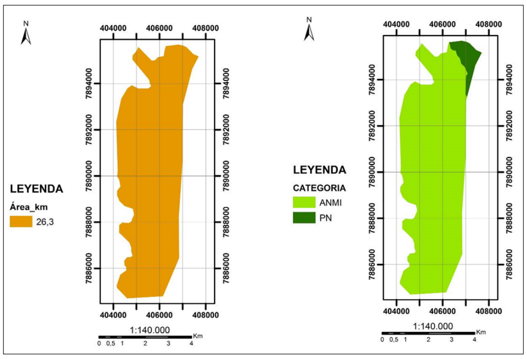


Figure 5: Surface area of study
Figure 6: Categories area of study
Source: Own elaboration

Elevation Values for the Study Area

Based on the digital elevation model (DEM) for the study area, the values are: Highest point 1207m and lowest point 575m. The corresponding map is shown below.

Temporal Maps of Vegetation Cover Change, 2004–2019

The Landsat images processed in the study for the period 2004–2019 are as follows:

The temporal maps of vegetation cover change associated with deforestation, corresponding to the period 2004–2019, are as follows: 2004: The deforested area is 165.26 hectares, distributed across 19 polygons. 2019: The deforested area is 258.62 hectares, distributed across 22 polygons.

The results of the vegetation cover change maps for the period 2004–2019 show that in 14 years there was a deforestation of 93.36 hectares.

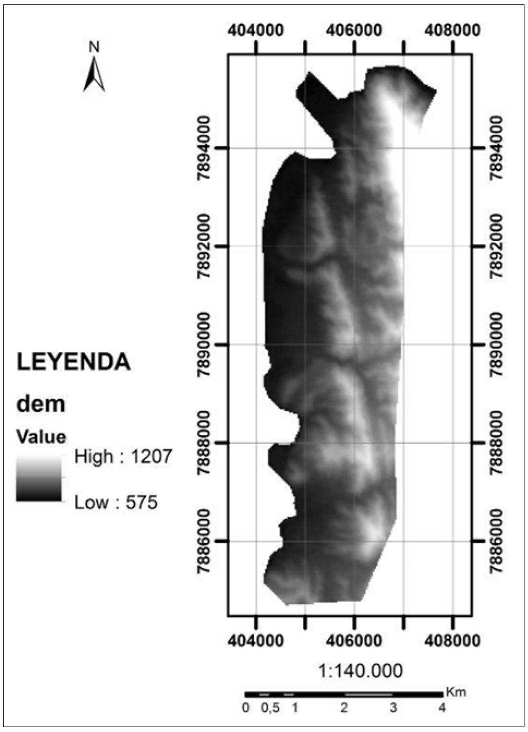


Figure 7: Values of the study area
Source: Own elaboration.

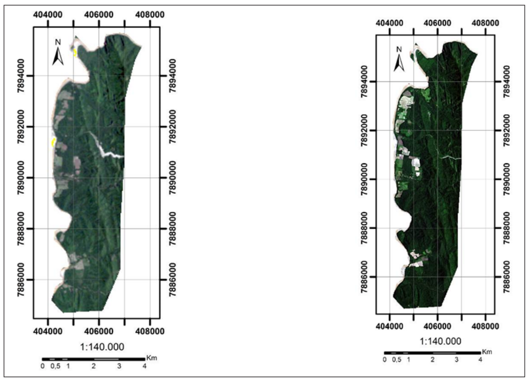


Figure 8: Landsat image from 2004
Figure 9: Landsat image from 2019.
Source: Own elaboration.

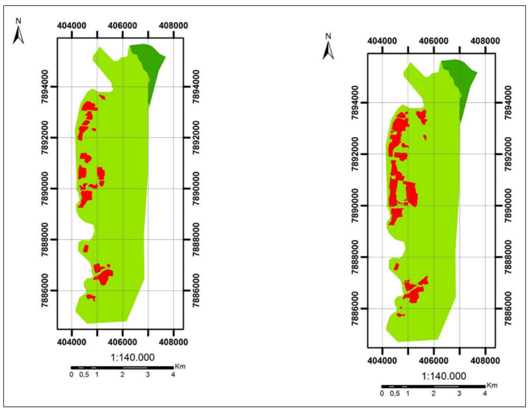


Figure 10: Deforestation 165.26ha year 2004
Figure 11: Deforestation 258.62ha year 2019
Source: Own elaboration.

DEM Reclassification of the Study Area

Overlaying the deforestation maps from 2014 and 2019 onto the reclassified DEM map (with two values) reveals that the deforested areas are located below 720 meters in altitude. Therefore, this serves as a reference for locating the study transects within these altitude parameters, considering the similarity of the floristic composition.

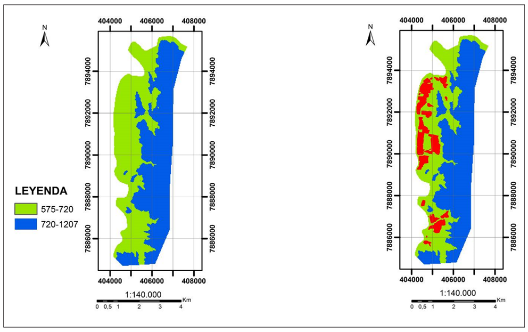


Figura 12: Reclasificación DEM a dos valores.
Figura 13: Deforestación según la altura.
Source: Own elaboration.

Lands with Ownership Rights

The spatial boundaries of lands with ownership rights or collective community areas provide us with geospatial reference information about our location.

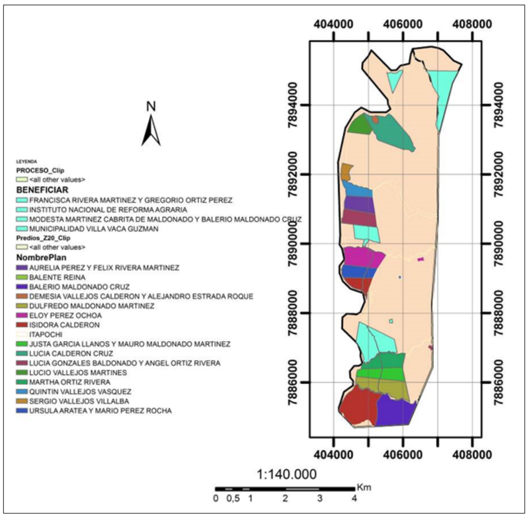


Figure 14: Location of areas with property rights
Source: Own elaboration

Monitoring of wild bee populations (Apidae: Meliponini)

The following shows the location of the monitoring transects and details of the field data sheets, code: T1-M1 and code: T2-M2.

N°	Species	Common Name	Number of beehives	Area T1 and T2 (ha)	Absolute density Number of species*ha	Relative density % species *ha
1	Scaptotrigonasp.	Donkey	1		0,64	6,25
2	Plebeiasp.	Old woman's mouth	2		1,28	12,50
3	Tetragoniscaangustula	Miss	6	1,56	3,85	37,50
4	Scaptotrigonasp.	Black	6		3,85	37,50
5	Cephalotrigonasp.	Mombucao	1		0,64	6,25
TOTAL			16	1,56	10,26	100

Source: Own elaboration.

Specimen Description

The following describes additional aspects of the specimens based on data collected in the field.

Scaptotrigonasp. (Moure, 1942)

A Scaptotrigona sp. hive, locally called the "burro" bee, was located inside the trunk of a Cebil tree (Anadenanthera colubrina). The hive entrance was 20 centimeters from the ground. The average DBH was 1.4 meters, and the tree was 9 meters tall. The host species was a living tree. According to Aguilera, F. (2019), the original "burro" bee is a Scaptotrigona, but this genus is commonly parasitized by kleptobiotic bees of the genus Lestrimellita, which invade their nests and remain there until the stored food is depleted. This is why confusion arises when identifying them at the collection site.

Description: Aguilera, F. 2019 Entrance mouth before the attack and possession of the original nest of Scaptotrigonasp.

Description: Aguilera, F. 2019 Entrance mouth after the attack with possession of the original nest carried out by Lestrimelittasp.). See the digitiform processes built around the original entrance mouth

Figure 17: Record Plebeiasp

Plebeiasp. (Schwarz, 1938)
Two Plebeias sp. hives, locally known as "old lady's mouth," were located in Anadenanthera colubrina trees. The average height of the hive entrance from the ground was 4 meters. The average diameter at breast height (DBH) was 1.67 meters, and the average tree height was 11 meters. The host tree was found to be alive.

Tetragonisca angustula (Latreille, 1811)
Six colonies of Tetragonisca angustula, locally known as "señorita," were located. They were found in five different tree species: Astronium undeuva, Anadenanthera colubrina, Tabebuia impetiginosa, Caesalpinia pluviosa, and two nests in Parapiptadenia excelsa. The average height of the hive entrance from the ground was 0.4 meters (ranging from 0.15 to 1 meter). The average diameter at breast height (DBH) was 1.4 meters, and the average tree height was 9 meters. Five trees were alive and one was dead.

Figure 18: Record Tetragonisca angustula

Scaptotrigonasp. (Moure, 1942)
Six colonies of Scaptotrigonas sp., locally known as "negro," were located. They were found in two different tree species: Anadenanthera colubrina and Caesalpinia pluviosa. The average height of the hive entrance from the ground was 3.6 meters (ranging from 0.20 to 7 meters). The average diameter at breast height (DBH) was 1.89 meters, and the average tree height was 10.3 meters. Two trees were alive and four were dead.

Figure 19: Record Scaptotrigonasp

Cephalotrigonasp. (Schwarz, 1940)
A colony of Cephalotrigona sp., locally known as "Mombucao," was located. It was found in the tree species Anadenanthera colubrina. The hive entrance was 0.2 meters above the ground. The average diameter at breast height (DBH) was 2.4 meters, and the tree was 12 meters tall. The host tree was alive.

Figure 20: Record Cephalotrigonasp

Sightings Related to the Research
The sightings described below were not found within the defined sampling transects, but they were within the spatial limits of the study area and were therefore recorded for informational purposes due to their relevance to the research topic. At a distance of 674 meters from transect No. 1, a Tetragonisca angustula hive was sighted and recorded. It had been removed from its nesting site, and there were also signs of removal from other tree species.

Figure 21: Record of sighting adjacent to transect one

During the 1500-meter stretch of transect No. 2, a sighting and recording of the harvesting of wood from the Astronium urundeuva species was made, and evidence of extraction in other tree species.

Figure 22: Sighting record adjacent to transect two

Conclusions and Recommendations
Conclusions
This research concludes as follows:
According to the multi-temporal analysis of Landsat images regarding the deforestation rate in the study area, it is evident that deforested areas increased over 14 years, starting from 2004, the year the Serranía del Iñao National Park and Integrated Management Natural Area (PN ANMI Serranía del Iñao) was created. In 2004, 165.26 hectares were deforested, while by 2019, the deforested area had reached 258.62 hectares, representing an increase of 93.36 hectares.

Regarding the cause of deforestation, it was observed that it is primarily associated with the expansion of the agricultural frontier, considered one of the most significant threats to biodiversity in the Serranía del Iñao National Park and Integrated Management Natural Area (PN ANMI Serranía del Iñao).

The fragmentation of natural habitats has irreversible effects on the biology and ecology of wild bee populations due to the destruction of food sources (pollen and nectar), resins, and nesting sites. For every hectare of deforested forest, 10.26 bee colonies are eliminated; that is, between 2004 and 2019, approximately 958 colonies were destroyed.

Regarding the density of wild bees, it is 10.26 colonies per hectare, comprised of 5 species. According to Roubik (2006), the density of stingless bee colonies can vary between 1.5 and 15 per hectare depending on environmental conditions.

Recommendations

Continue the line of research in the Bolivian Tucumano Forest and Bolivian Montane Dry Forest ecoregions, which form part of the special boundaries of the Serranía del Iñao National Park and Integrated Management Natural Area (PN ANMI), using the research conducted in the Chaco Serrano ecoregion as a baseline.

Strengthen research and monitoring of bee populations within the Protected Area, as the perpetuation of plant species in the region depends on them due to cross-pollination by wild bees.

If the authorities responsible for protecting biodiversity in the Iñao Protected Area do not act decisively and take the necessary protective measures to prevent deforestation and the excessive expansion of the agricultural frontier; They will experience in the short term a continuous displacement and irreversible loss of various species of wild bees (Apidae: Meliponini), causing at the same time a decrease in the quality and number of fruits produced by the plant species present in the area.

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