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AN INTEGRATED METHODOLOGICAL APPROACH FOR THE BALANCE BETWEEN CONSERVATION AND TRADITIONAL USE IN A PROTECTED AREA: THE CASE OF THE PICO AZUL-LA ESCALERA ENVIRONMENTAL PROTECTION ZONE

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ABSTRACT. Protected Natural Areas often impose restrictions that require a delicate balance between conservation and the traditional uses upheld by local communities. This study presents a novel integrated methodological approach using anthropo-natural landscapes as the primary unit of analysis. The methodology evaluates natural suitability for various appropriate uses within the protected area, considering legal compatibility, environmental sustainability, socioeconomic benefits, and technical-financial feasibility. Our case study of the Pico Azul – La Escalera Environmental Protection Zone reveals that 59.2% of the territory is primarily suited for conservation activities, 38.3% for the rehabilitation of degraded areas, and only 2.5% for extensive livestock farming and rainfed agriculture. Additionally, 24% of the area, comprising mainly non-degraded sectors, is designed for the sustainable use of non-timber forest resources. Furthermore, alternative tourism is identified as a viable secondary use in 10.2% of the most preserved landscapes. This research underscores the importance of a comprehensive and balanced approach to managing protected areas, ensuring both conservation goals and the livelihoods of local communities are met.

Aproximación metodológica integrada para el balance entre conservación y uso tradicional en un área protegida: el caso de la Zona de Protección Ambiental Pico Azul-La Escalera

RESUMEN. Las áreas naturales protegidas a menudo imponen restricciones que requieren un delicado equilibrio entre la conservación y los usos tradicionales defendidos por las comunidades locales. Este estudio presenta un nuevo enfoque metodológico integrado que utiliza los paisajes naturales antropógenos como unidad principal de análisis. La metodología evalúa la idoneidad natural para diversos usos dentro del área protegida, considerando la compatibilidad legal, la sostenibilidad ambiental, los beneficios socioeconómicos y la viabilidad técnico-financiera. Nuestro caso de estudio, la Zona de Protección Ambiental Pico Azul-La Escalera, revela que el 59,2% del territorio es apto para actividades de conservación, el 38,3% para la rehabilitación de áreas degradadas y solo el 2,5% para la ganadería extensiva y la agricultura de secano. Además, el 24% de la superficie, que comprende principalmente sectores no degradados, está destinado al uso sostenible de recursos forestales no madereros. Además, el turismo alternativo se considera un uso secundario viable en el 10,2% de los paisajes más preservados. Esta investigación subraya la importancia de un enfoque integral y equilibrado para el manejo de las áreas protegidas, asegurando tanto los objetivos de conservación como los medios de vida de las comunidades locales.

Keywords: protected natural areas, environmental management, landscape approach, land use suitability, Mexico.

Palabras clave: áreas naturales protegidas, gestión ambiental, aproximación al paisaje, uso sostenible del suelo, México.

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1. Introduction

Protected natural areas (PNAs) are defined geographical areas aimed at achieving specific conservation objectives (Maldonado *et al*., 2020). According to the International Union for Conservation of Nature (IUCN, 2020), they form the basis of biodiversity conservation, and aim to safeguard nature and cultural resources, improve the livelihoods of resident communities, and promote balanced development between nature protection and the needs of the people living there.

Although PNAs restrict and regulate certain traditional activities, they also open up new avenues for development. If carefully planned and managed, these areas can contribute to economic growth and enhance the well-being of local communities (Botana, 2022). The declaration of a PNA in a territory entails a series of protocols to be followed, primarily aimed at restricting land uses through increased limitation and monitoring of traditional activities previously carried out, upon which local communities often depend for their subsistence (Rienmann *et al*., 2011; Engen *et al*., 2019).

Faced with this issue, specialists suggest that organizing a territory based on its potential suitability allows for long-term growth and development opportunities for rural communities (Lee-Cortés and Delgadillo-Macías, 2018). Rezende *et al*. (2017) and Sosa-Montes *et al*. (2012) highlight the need for residents in PNAs, regardless of conservation objectives, to have spaces to develop their economic activities without affecting the conservation of protected areas, or even participating in the rehabilitation of degraded areas essential for maintaining ecosystem services.

Consistent with these above considerations, in Mexico, there is a recognized need to establish an integrated methodology that considers the social and environmental needs of these territories (Espinoza and Bollo, 2015; Pablo and Hernández, 2016; Azuela de la Cueva *et al*., 2019). The lack of Management Plans (MPs) and Zoning schemes is recognized in about 62 Federal PNAs, accounting for 34.1% of those in the country (CONANP, 2024), which are under various land tenure regimes. This leads to incompatible land uses with the natural suitability of the soils, resulting in degradation and loss of conservation attributes and characteristics which led to their categorization as PNAs.

The natural suitability of a territory is framed within the conceptual and methodological contributions made by the FAO (1993) to define the analytical process that allows the selection of optimal land use forms based on their natural characteristics (Pablo and Hernández, 2016). The potential of the landscape, derived from its natural suitability, is defined by Bollo *et al.* (2010) and Pablo and Hernández (2016) as the set of natural, socioeconomic, and cultural conditions suitable for the development of a particular activity within a territory space called a landscape. The term "landscape" refers to a territorial system integrated by natural and anthropic elements socially conditioned, where the original properties of the landscape are modified (Mateo, 2011; Martínez and Bollo, 2023).

The use of these landscape units as a foundation for environmental research (Izakovicová *et al*., 2019; Martínez and Bollo, 2023) has been demonstrated to be applicable in planning. They serve as environmental management units in zoning exercises across various scales, given their nature as anthropo-natural systems (Fry *et al*., 2009; Skřivanová, 2014; Cirer *et al*., 2009; Mejías, 2015; López, 2019; Martínez and Bollo, 2023).

Maldonado *et al*. (2020) point out that local communities present in a PNA can interact with their natural resources and use them sustainably. In addition to tourism, activities linked to maintenance, rehabilitation, and utilization can establish other sources of economic income. Thus, the identification of the natural potential of landscapes and their compatible activities may constitute the fundamental approach for proper planning in these protected spaces and avoid their degradation.

In this context, the study aims to evaluate the natural potential of landscapes within the Pico Azul-La Escalera Environmental Protection Zone in Michoacán, Mexico, for various uses. The assessment will consider legal compatibility, environmental feasibility, socioeconomic factors and the technical-financial viability of land use. This approach aims to promote sustainable practices that conserve natural resources while benefiting local communities engaged in socioeconomic activities.

2. Methodology

2.1. Study Area

The Pico Azul-La Escalera Environmental Protection Zone (Fig. 1) was declared in 2011 as an Environmental Protection Zone due to its physical, climatic, and conservation characteristics. It provides a series of environmental services focused on regulating water flow, purifying and retaining water, and infiltration for aquifer recharge. Additionally, it contributes to flood control and prevention, as well as sediment regulation and climatic regulation in the region. Furthermore, it offers areas with scenic beauty for recreation, which is of great importance to the population of the city of Morelia (Official Newspaper of the Constitutional Government of the State of Michoacán de Ocampo, 2011).

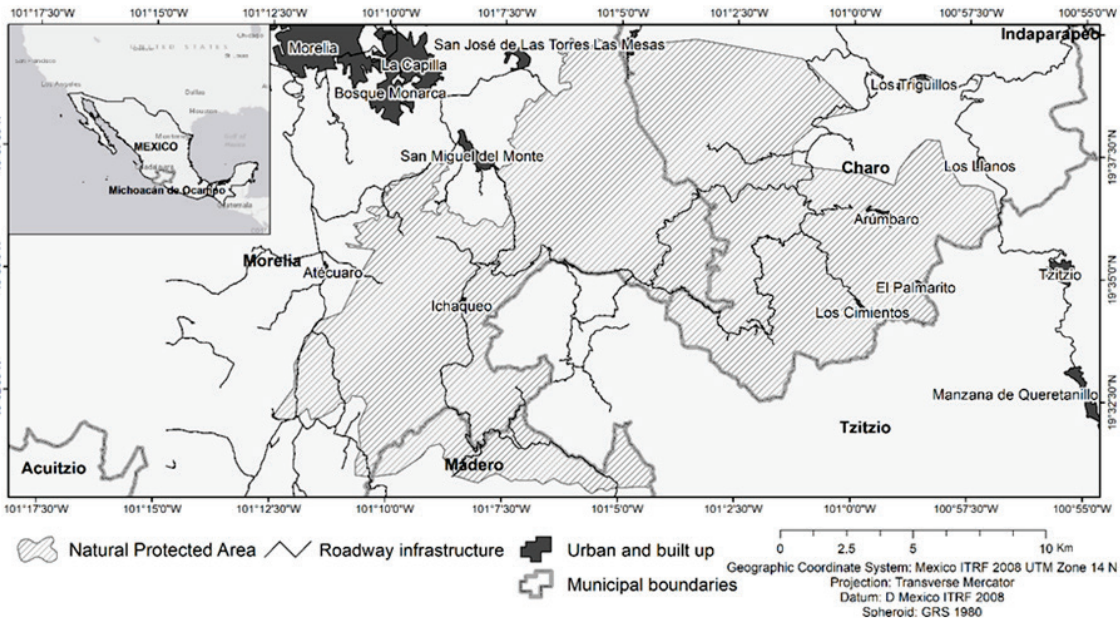

Figure 1. Geographic location of the Pico Azul-La Escalera Environmental Protection Zone.

It spans an area of 224 km² and is located in the transition zone between the mountains of the Neovolcanic Transverse Axis and the Sierra Madre del Sur, in the central-southern region of Mexico. The geographical coordinates of the area range between 19° 39' 48.52" - 19° 30' 31.33" N and 101°

12'24.77" - 100° 56' 48.57" W (Ramón and Bollo, 2023). Its altitude ranges from 1,171 to 2,640 meters above sea level.

The region has a temperate climate, with an annual temperature ranging between 12 and 18°C, and precipitation fluctuating between 200 and 1800 mm (García, 1988). The predominant soils are andosols (34.76%), luvisols (27.82%), and acrisols (26.40%) (INEGI, 2004). The main vegetation cover is forested, covering 85.5% of the studied area, with 86.7 km² considered primary vegetation, mainly in the north, northwest, and southwest. Of the total forested area, 40.9% (78.4 km²) shows a high degree of disturbance, and 30.9% exhibits a predominance of shrub species. Induced grasslands occupy 9.8% of the total area, areas allocated to rainfed agriculture cover 2.7%, and permanent crops cover the remaining 1.50% (Ramón and Bollo, 2023). Human settlements encompass only 0.5% of the total study area, with 27 established populations housing 2,789 inhabitants according to the official census (INEGI, 2020).

2.2. Territorial Analysis Unit: Anthropo-natural Landscapes

This research uses anthropo-natural landscape units within the PNA at a 1:50,000 scale as the basic analysis unit. These units were derived from overlaying the physical-geographical landscape map (Ramón and Bollo, 2023) and the land cover and land use map of 2021, generated from supervised classification of a Landsat-8 satellite image (Legend of the landscape units in Supplementary Material A).

2.3. Stages of Landscape Potential Assessment

The present study bases the assessment of landscape potential on Land Use Types (LUTs), which encompass the purposes and actions through which individuals engage with land and terrestrial ecosystems (Meyfroidt *et al.*, 2018). The selection and description of each LUTs, is a planning process that takes into account development objectives and the natural and socio-economic conditions of the territory. Palacio-Prieto and Sánchez-Salazar (2003) suggest considering criteria that guide government development objectives and policies, current land use, current markets, cultural acceptance of LUTs by local communities, and the availability of physical infrastructure, among others.

The process of identifying of landscapes potential was divided into three stages: a) identifying natural suitability regarding LUTs; b) evaluating the implementation of LUTs and the legal, environmental, socio-economic, and technical-financial compatibility of the study area; and c) determining the potential use of landscapes.

2.4. Natural Suitability of Landscape for Proposal Land Use Types

Based on the compatibility of permitted uses according to the category of the study area (Environmental Protection Zone), and the availability of information, the selection of LUTs was carried out following the methodological proposals of various authors (Bollo *et al*., 2010; Ramón *et al*., 2013; Pablo and Hernández, 2016). The selected LUTs are described below, and Table 1 shows the indicators and methods used for their identification:

- Conservation: This aspect focuses on identifying landscapes with high natural and conservation values that play a fundamental role in providing environmental services (Bollo *et al*., 2010; Chávez and González, 2015; Teixeira *et al*., 2018).
- Alternative Tourism: This includes non-conventional and non-massive tourism modalities, which aim to offer participants a more direct and active involvement with nature, local culture, and other special interest resources they visit (Báez and Acuña, 2003; Ramón *et al*., 2020; Bassan, 2022).

- Rehabilitation: This aspect aims to identify landscapes that require intentional intervention to initiate or accelerate the recovery of their natural conditions due to loss or deterioration in their environment. This is vital to ensure the environmental services that the PNA must provide according to its management category and declaration motive, based on the criteria of Keenleyside *et al.* (2014).
- Forestry: This aspect aims to promote the permanence of forests and maintain their environmental functions through the sustainable use of Non-Timber Forest Products such as resins, wild plants, medicinal plants, edible mushrooms, certain shrubs, and firewood (Anastacio-Martínez, 2016).
- Extensive Livestock Farming: This focuses on ensuring the sustainability of economic activity in the PNA for the resident population through the existence of induced pastures and certain soil properties (Bollo *et al*., 2010; Pablo and Hernández, 2016; Ramón *et al*., 2017).
- Rainfed Agriculture: This aims to ensure the sustainability of economic activity in the PNA for the resident population. The same indicators as for extensive livestock farming were established, except for those related to the presence of induced pastures and secondary forests dominated by herbaceous vegetation.

All indicators and variables were weighted on a scale of 1 to 5. The highest value was assigned to attributes that favored the LUT, while the lowest value was assigned when the attribute did not favor the evaluated LUT. The score of each indicator was summed up, and the result was reclassified into four suitability categories using the natural break method (Jenks, 1976): A1 (Suitable), A2 (Moderately Suitable), A3 (Marginally Suitable), and N (Not Suitable).

Table 1. Indicators used to identify the natural potential of the landscape according to the proposed land use type.

Indicator	Evaluation Method		Land Use Type	Reference
Degree of Naturalness	$Dn = \left(\frac{Sveg_{nat}}{A}\right) * 100$	Where: Dn = Degree of Naturalness $Sveg_{nat}$ = Primary vegetation area A = Landscape unit area	Conservation Alternative Tourism Rehabilitation Forestry	Bollo and Velazco (2018)
Landscape Degradation	$IAVC = \frac{\sum_{i=1}^{n} r_i * A_{ij}}{A_j}$	Where: $IAVC$ = Index of Vegetation Cover Anthropization r_i = Weighting value of land cover type *"i"* A_{ij} = Area of land use type in landscape unit A_j = Total area of landscape	Conservation Alternative Tourism Rehabilitation Forestry	Shishenko (1988)
Water recharge	$Water\ recharge = [0.27(S) + 0.23(ST) + 0.12(TR) + 0.25(PVC) + 0.13(LU)]$	Where: S = Slope ST = Soil Type TR = Type of rock PVC = Permanent vegetation cover LU = Land use	Conservation Rehabilitation Forestry	Matus *et al.* (2009)
Soil loss	$Soil\ loss = R * K * LS * S * P$	Where: R = Rainfall and runoff factor K = Soil erodibility factor LS = Topographic factor C = Cover and management factor P = Support practice factor	Conservation	Wischmeier and Smith (1978)
Slope Degree	Topographic maps (scale 1:50 000)		Alternative Tourism Rehabilitation Forestry	INEGI (2018)
Soil fertility	Soil maps (scale 1:50 000)		Rehabilitation Extensive Livestock Rainfed Agriculture	INEGI (1983)
Soil physical limitations	Soil maps (scale 1:50 000)		Rehabilitation Extensive Livestock Rainfed Agriculture	INEGI (1983)

Soil pH	Soil maps (scale 1:50 000)	Rehabilitation Extensive Livestock Rainfed Agriculture	INEGI (1983)
Soil depth	Soil maps (scale 1:50 000)	Rehabilitation Extensive Livestock Rainfed Agriculture	INEGI (1983)
Soil erodibility	Soil maps (scale 1:50 000)	Rehabilitation Extensive Livestock Rainfed Agriculture	INEGI (1983)
Carbon Sequestration	Carbon Storage and Sequestration model (InVEST)	Conservation	Natural Capital Project (2023)
Nutrient Delivery	Nutrient Delivery Ratio model (InVEST)	Conservation	Natural Capital Project (2023)
Primary Ecotourism activities	- Number of waterfalls per analysis unit - Number of rivers per analysis unit - Number of mountain peaks	Alternative Tourism	This study
Complementary Ecotourism activities	- Number of trails - Lodging capacity - Dining Options	Alternative Tourism	This study
Traditional economic activities or festivities	Surveys on Local Agricultural and Religious Festival Dates	Alternative Tourism	This study
Induced pastures	Area of induced pasture (Land cover and land use map 2021)	Extensive Livestock	This study
Secondary forest with herbaceous vegetation	Area of secondary forest with herbaceous vegetation (Land cover and land use map 2021)	Extensive Livestock	This study

2.5. Landscape Use Viability

The assessment of different viabilities is conducted through a comprehensive review of existing information. This includes analyzing the results of variables and indicators. These results facilitate an understanding of the temporal dynamics and interrelationships among sociodemographic factors, socioeconomic aspects, and the characteristics of the natural-physical environment.

Legal Compatibility: It assesses the presence of any potential legal restriction on the implementation of the LUT. This assessment is exclusive, meaning that if a landscape unit has certain natural suitability but is subject to legal regulations, it automatically renders such suitability as *Not Suitable*.

The criteria for assessing legal compatibility are based on the provisions set forth in the Decree declaring the study area, Pico Azul – La Escalera, as an Environmental Protection Zone (EPZ). Additionally, the assessment considers the local legal framework in Michoacán de Ocampo, given that it falls under state jurisdiction. Federal regulations on land use allocation are also taken into account. Table 2 summarizes all laws, regulations, and official standards considered in the analysis.

After analyzing the legal compatibility of each landscape unit, those units deemed 'Suitable' undergo a viability assessment process. Viability refers to the possibility of effectively and sustainably implementing the proposed LUTs. Three fundamental areas were defined for viability analysis: environmental, socioeconomic, and technical-financial. Landscape units that were deemed 'unsuitable' for socioeconomic use were classified according to their conservation or restoration characteristics.

Environmental Viability: This criterion was used to assess the ability of landscape units to support and maintain the proposed LUTs without compromising their long-term sustainability (Palacio-Prieto and Sánchez-Salazar, 2003). Given that it is a PNA, proposed LUTs that support management objectives (conservation and rehabilitation) received a positive evaluation and proceeded to further viability analyses. For landscape units with productive or natural resource use LUTs (Forestry, Extensive Livestock, and Agriculture), the criteria from Table 3 were used. Ecotourism, proposed and developed with low impact, had no recorded usage limitations. If any LUT showed no environmental viability, it was excluded from further evaluations.

Table 2. Federal and State laws, Federal and State regulations, analyzed to determine the legal compatibility of landscape units in the Pico Azul – La Escalera Environmental Protection Zone.

Application Level	Oficial Law / Regulation	Reference
Study Area	- Decree establishing the Environmental Protection Zone	POGMICH, 2011
State (Michoacán de Ocampo)	- Climate Change Law and its regulations - Sustainable Forestry Development Law and its regulations - Sustainable Integral Rural Development Law and its regulations - Livestock Law - Water and Watershed Management Law and its regulations - Land Conservation and Restoration Law - Environmental Conservation and Sustainability Law - Regulation of the Environmental Law and Protection of Natural Heritage	POGMICH, 2014, 2018 POGMICH, 2004a, 2007a POGMICH, 2006a, 2006b POGMICH, 2007b POGMICH, 2004b, 2008 POGMICH, 2007c POGMICH, 2021 POGMICH, 2004c
Federal (Mexico)	- Regulation for the exploitation of Fungi - Regulation for the exploitation of Wild Soil - Regulation for the exploitation of Forest Roots and Rhizomes - Regulation for the exploitation of Moss, Hay, and Clubmoss - Regulation for the Rehabilitation and Conservation of Grazing Forest Lands - Regulation for the exploitation of Pine Resin - Regulation for Content of Forest Management Programs	SEMARNAT, 1996a SEMARNAT, 1996b SEMARNAT, 1996c SEMARNAP, 1996 SEMARNAT, 2001 SEMARNAT, 2005 SEMARNAT, 2006

Table 3. Environmental valuation criteria for productive land use types.

Land Use Viability	Criterion	Description
Environmental	Long-term degrading potential	The ability of a use or activity to cause environmental degradation over time.
	Carrying capacity for land use	Maximum amount of a specific type of use that a territory can sustainably support.
	Natural and anthropogenic threat limitations	Constrains due to the presence of phenomena occurring from natural processes (such as floods, seismic activity, landslides) and those caused by human actions (soil and water contamination, deforestation, etc.).
	Degradation process constrains.	Limitations due to the deterioration of the natural environment caused by the excessive exploitation of natural resources.
	Anthropogenic pressures	Factors or actions resulting from human activity that affect land use and management (agriculture, deforestation, hunting, logging, construction, livestock farming, and development of housing, service infrastructure, and transportation).
Socioeconomic	Inertia from traditional land uses	Deep-rooted and persistent trends in how a territory has been historically utilized.
	Job creation	Job creation for local community residents.
	Population needs	Requirements, necessities of a community or group of people living in a particular area. These needs can include various aspects such as access to healthcare, employment opportunities, infrastructure, and other resources necessary for sustaining and improving quality of life.
	Availability of labor force	Number of skilled labor for the land use type selected.
	Accessibility	Concerns the ease of reaching and utilizing a specific area, relying on transportation routes like roads, pathways, and transportation to connect various parts within the territory.
Technical-financial	Availability of technical and technological resources	Access to the knowledge, tools, and technologies necessary for the intended land use.
	Financial resource availability	Existence and accessibility of required financial resources.
	Availability of required infrastructure	Existence and accessibility of necessary facilities and services for the development of the corresponding land use.

Source: Modified and adapted from Aguiló-Alonso *et al.,* 2009, and Palacio-Prieto *et al.,* 2004.

Socioeconomic viability: Used to assess whether the landscape unit can generate long-term economic and social benefits while maintaining environmental sustainability (Ramírez *et al*., 2016). Evaluation criteria were derived from fieldwork data.

Technical and financial viability: assesses the ability to effectively implement the LUT from a technical standpoint, as well as the capacity to finance and sustain the LUT over time. It relies on the availability of government funding programs or support provided by Non-Governmental Organizations (NGOs). Existing technological means for the proposed LUT should be sustainable and cost-effective for conservation, protection, and production in these areas.

With the information obtained according to the criteria in Table 3, the information is used to assess the viability of each landscape unit for each LUT within a suitability range, as per the values in Table 4.

These results are reflected in a data matrix that includes landscape units, natural suitability values, and environmental, socioeconomic, and technical-financial viability assessments.

Table 4. Measurement scale for viability categories.

Viability category	Value
Non-viable	0
Viable with conditions	50
Viable	100

Source: Developed from Palacio-Prieto and Sánchez-Salazar (2003)

2.5.1. Assessment of Landscape Use Potential

Following the previous procedure, the quantitative assessment of the suitability of each landscape polygon for each LUT is continued. In this process, the categories obtained in Natural Suitability (Suitable, moderate, marginal, and not suitable) are converted into a numerical value with a common maximum of 100, as shown in Table 5.

With the values obtained for each landscape polygon and the results of the evaluation of each viability, the Land Use Suitability Index (LUSI) is calculated for different LUTs using Eq. (1) (Palacio-Prieto and Sánchez-Salazar, 2003)

$$LUSI = \frac{LNP+SEV+EV+TFV}{4} \quad (1)$$

Where LNP: Landscape natural potential; SEV: Socioeconomic viability, EV: Environmental viability, TFV: Technical-financial viability.

The index value will range from 0 to 100. Categories were established as Suitable (75.1-100), Moderately Suitable (50.1 – 75), Marginally Suitable (25.1 – 50), and Not Suitable (0-25) for each specific LUT.

Table 5. Equivalent value scale with a maximum of 100 according to natural suitability.

Category	Value
Suitable (S1)	100
Moderately Suitable (S2)	67
Marginally Suitable (S3)	33
Not Suitable (N)	0

Source: Palacio-Prieto and Sánchez-Salazar (2003)

The results obtained generate a matrix that identifies primary and secondary potential uses for each landscape polygon in relation to the evaluated LUTs. To determine the primary or potential primary uses, the LUTs with category S1 are selected from each landscape unit. If there is none, those in category

S2 are considered. The same procedure is applied to determine secondary potentials, where if category S1 is chosen as the primary potential, category S2 is considered as the secondary potential.

Both potentials were assessed with the aim of providing a wide range of options to decision-makers in territorial planning. The primary potential aligns with the highest natural aptitude and environmental, socio-economic, and technical-financial viabilities of the polygon in relation to the analyzed LUTs. The secondary potential refers to possible uses to maintain or develop but requires specific conditions and periodic monitoring to prevent degradation of the area's natural conditions. This matrix forms the basis for the development of maps of primary and secondary use potentials of the territory.

3. Results and Discussion

3.1. Anthropo-natural Landscapes

The land cover and land use map derived from the Landsat-8 satellite imagery classification for 2021 identified five categories of land cover or use and three subclasses within the Forest category (Table 6).

The resulting map was overlaid with regions from the physical-geographical landscape map (Ramón and Bollo, 2023), revealing 24 different types of anthropogenic landscapes within the PNA, totaling 136 polygons (See Fig. 2 and complete legend in Supplementary Material A).

Table 6. Land cover and land use types for the year 2021.

Category	Area (ha)
Forest	19,151
-Primary forests	8,681
- Shrubland secondary forests	2,644
- Herbaceous secondary forests	7,826
Induced pastures	2,192
Rainfed agriculture	613
Peremanent crops	336
Urban and built up	108
Total	22,401

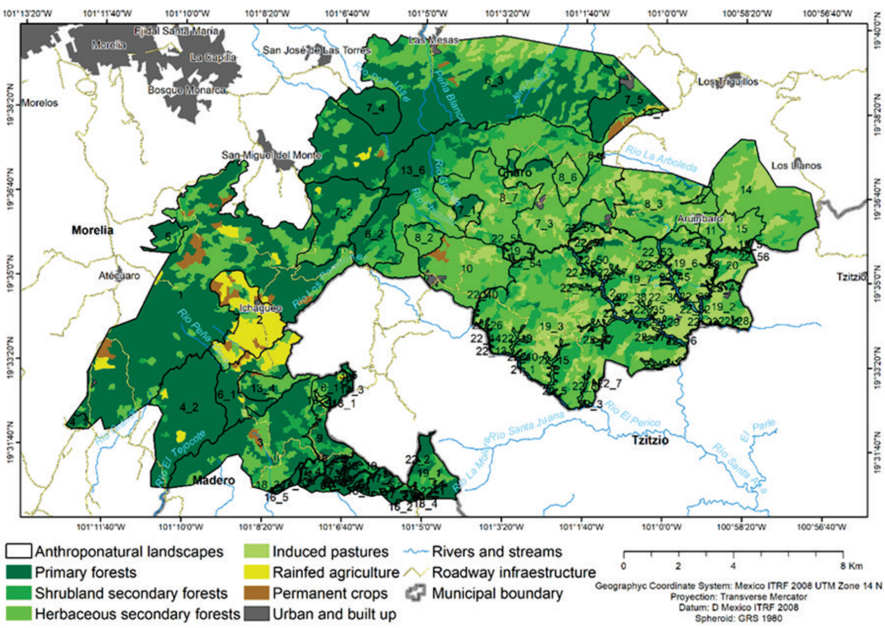

Figure 2. Anthropo-natural Landscape Units for the year 2021.

3.2. Landscape Suitability and Viability for Proposed Land Use Types

The spatial evaluation of landscape suitability for the proposed LUTs is depicted in Fig. 3. *Conservation, Alternative Tourism, and Restoration LUTs* demonstrated legal compatibility across all landscape units, as they prioritize environmental conservation, protect natural resources, and entail low environmental impact. However, the legal analysis revealed limited compatibility for the Non-timber Forest Products Harvesting in landscapes with slopes exceeding 45 degrees and riparian vegetation protection zones. *Extensive Livestock Farming* and *Rainfed Agriculture* faced legal restrictions in forested areas and riparian zones due to soil erosion prevention and restoration regulations.

Viability assessment for *Conservation* considered opportunities provided by payment for ecosystem services (PES) and Sustainable Forest Development programs, which support market creation for forest landowners (CONAFOR, 2022; Wunder *et al.,* 2007). The landscape units with higher conservation potential (Fig. 3A) consist of 51 polygons, representing 56.9% of the territory (see Table 7). These landscapes are mainly located in the north, northwest, and southwest, associated with less degraded forest cover, which enhances the viability for implementing the PES scheme. Categories S2 and S3, covering 24.3% of the area (43 polygons), are linked to forested landscapes with moderate degradation levels, with lower chances for PES scheme application. The remaining 18.8% of the PNA (42 polygons) comprises landscapes with the highest degradation levels, primarily used for agricultural and livestock activities, with minimal forest cover.

For *Alternative Tourism*, the PES scheme presented financing opportunities, particularly where ecotourism is considered an effective environmental service (Ruiz-González *et al.,* 2022). This incentive could represent, for some communities with traditions of mezcal production (a type of tequila) or religious practices, an influx of visitors, making the socio-economic and technical-financial viability of this LUT feasible. Landscape units with the highest tourism potential (Fig. 3B) encompass nine polygons, representing 51.8% of the PNA (Table 7). They extend to the north and northwest, coinciding with regions of high conservation potential (Fig. 3A) and having higher feasibilities for implementing PES scheme. In the central and western regions (Fig. 3B), some landscapes, despite low forest cover, show high suitability values due to cultural traditions and the presence of primary ecotourism activities, lodging facilities, and restaurants. The S2 category, representing only 4.0% of the landscape area, is associated with the presence of some service infrastructure and good accessibility. The remaining 44.2% of the PNA (Table 7) comprises landscapes located in the south and west (Fig. 3B). These areas exhibit low significance for tourism activity (S3 and N), primarily due to accessibility challenges, absence of primary activities, or degradation resulting from agricultural and livestock activities.

The results regarding the socioeconomic viability for the *Rehabilitation* LUT indicate job creation and opportunities, stemming from the accessibility to the areas targeted for rehabilitation. The technical and financial viability was confirmed as positive. This was attributed to the availability of knowledge, technical and technological resources, and financial support from existing programs on forest and sustainable productive development by the central government (Cravioto, 2019). The S1 category for Rehabilitation (Fig. 3C) covers 95 landscape polygons, representing 70.0% of the territory (Table 7), mainly extending to the north, south, east, and a group of polygons to the southwest (Fig. 3C). These coincide with polygons exhibiting some level of forest cover degradation, high water recharge capacity, topography, and soils unsuitable for other uses. Landscape classified with S2 comprise 37 polygons, accounting for 8.7% of the total area. These landscapes are mainly located in the southwest, featuring preserved forest cover. However, they encounter challenges in socioeconomic viability due to low population density and limited accessibility. The S3 category is absent, and the remaining 21.3% of the territory consists of polygons in the northwest (Fig. 3C) with high conservation levels.

The use of non-timber *Forest* resources (NTFR) demonstrated excellent socioeconomic viability due to the employment opportunities and economic prospects it provides for the land use. The technical and financial viability is also very high, as it generally does not rely on substantial resources to be implemented. The S1 category of the NTFR LUT covers 17 landscape polygons (Fig. 3D), representing

57.5% of the territory (Table 7), primarily extending to the north, northwest, and south. It coincides with polygons characterized by higher forest cover, better accessibility, and lower slope ranges. The polygons categorized as S2 (six polygons), representing 1.1%, encompass some isolated polygons in the northwest, center, and southeast (Fig. 3D), with moderate values of forest cover and degradation, as well as limited accessibility. The remaining categories S3 and N, accounting for 41.4%, consist of polygons with very little or no forest cover or with legal restrictions on exploitation.

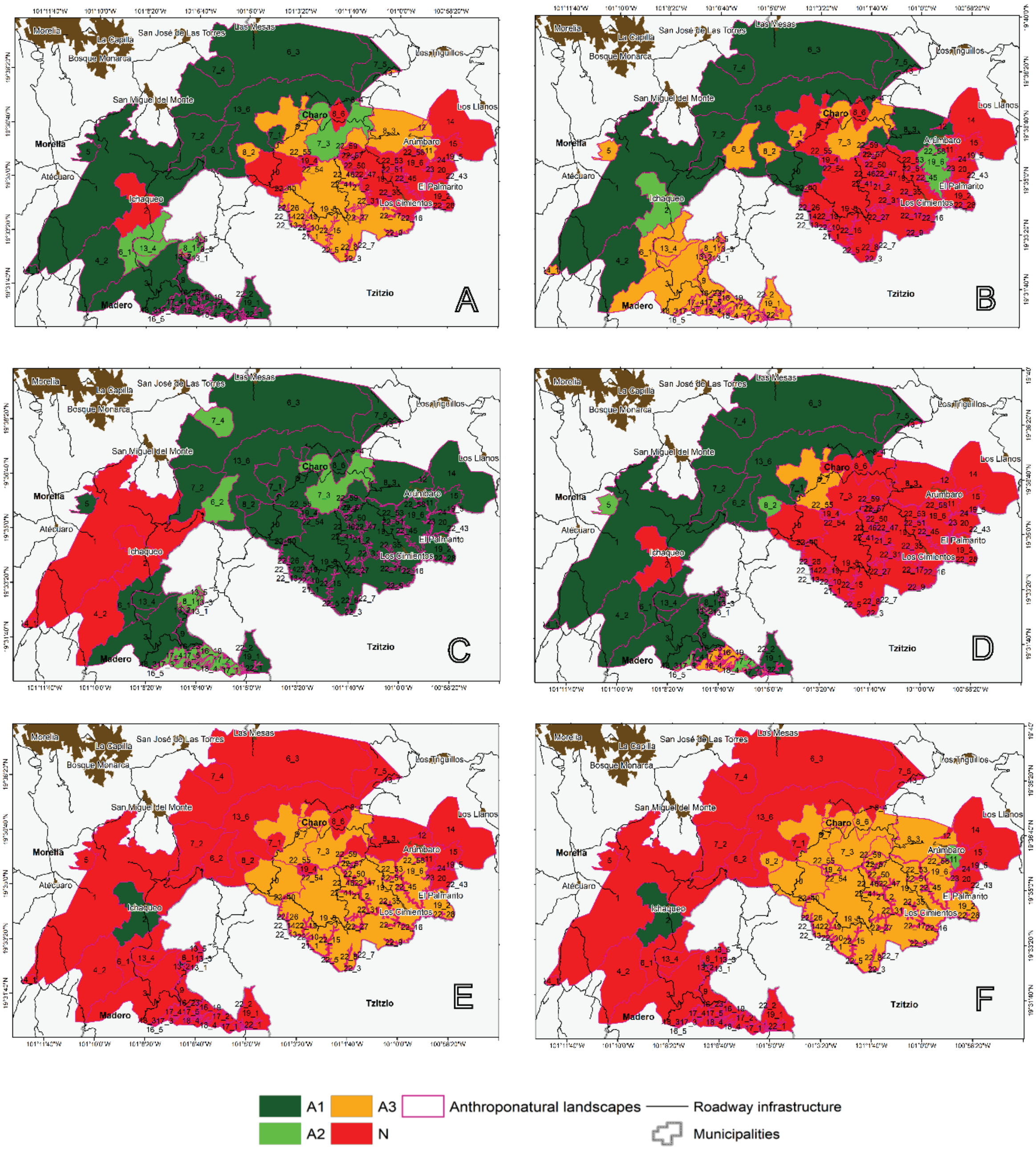

Figure 3. Spatial distribution of landscape potential on Land Use Types in PNA Pico Azul-La Escalera Environmental Protection Zone. Land Use Types: A) Conservation; B) Alternative Tourism; C) Rehabilitation; D) Forestry; E) Extensive Livestock Farming; F) Rained Agriculture.

Table 7. Surface area of potential suitability for each proposed land use type.

Land Use Type / Suitability	Conservation	Alternative Tourism	Rehabilitation	Forestry	Extensive livestock farming	Rainfed Agriculture
Suitable (S1)	12,743.0 ha 56.9% 51 LP	11,610.8 ha 51.8% 9 LP	15,675.5 ha 70.0% 95 LP	12,886.5 ha 57.5% 17 LP	549.1 ha 2.5% 2 LP	550.7 ha 2.4% 4 LP
Moderately Suitable (S2)	1,451.2 ha 6.5% 15 LP	898.3 ha 4.0% 2 LP	1,958.0 ha 8.7% 37 LP	238.8 ha 1.1% 6 LP	729.5 ha 3.2% 1 LP	82.0 ha 0.4% 1 LP
Marginally suitable (S3)	4,001 ha 17.8% 28 LP	4,126.7 ha 18.4% 68 LP	-	881.2 ha 3.9% 26 LP	657.8 ha 2.9% 1 LP	940.9 ha 4.2% 2 LP
No Suitable (N)	4,205.3 ha 18.8% 42 LP	5,764.7 ha 25.8% 57 LP	4,767.1 ha 21.3% 4 LP	8,394.0 ha 37.5% 87 LP	20,464.2 ha 91.4% 132 LP	20,827.0 93.0% 129 LP

LP: Landscape polygons

The socioeconomic viability for *Extensive Livestock Farming* largely depends on the accessibility of the areas to be occupied. The technical and financial viability is positive due to the availability of knowledge and technical resources, which generally require low economic inputs. The land area categorized as S1 for livestock farming represents 2.5% of the total area. However, this suitability is limited due to its topographical characteristics, soils, and environmental viability. The two landscape units with this suitability are located in the central-western part (Fig. 3E), coinciding with polygons of lower slope, induced grasslands, and better accessibility. The moderate category (S2) represents 3.2% of the PNA, located in the central-eastern part, with some areas of high slopes, which is what gives it this category. The remaining 133 polygons of landscape units, covering practically the entire territory (94.3% of the total area); belong to categories S3 and N. These units have high slopes, primarily in the northern and northwestern sectors (Fig. 3E), with abundant primary or secondary forest vegetation dominated by shrubs.

The socioeconomic and technical-financial viability for *Rainfed Agriculture,* similar to extensive livestock farming, proved positive owing to job creation and opportunities, along with low-cost input requirements. However, its success hinges largely on accessibility to suitable areas for this use. Category S1 represents 2.4% of the territory (Table 7) and mainly located in the north and northwest (Fig. 3F). This area coincides with land already dedicated to rainfed agriculture and induced pastures, better accessibility, and low slope ranges. The polygons under category S2 (one polygon) represent 0.4% and is located to the east, exhibiting the same characteristics as category S1, but with more restrictive slope ranges for the development of this activity. The Remaining 129 landscape polygons, representing 97.2% fall under categories S3 and N, covering virtually the entire PNA (Fig. 3F). These units have slopes unsuitable for this LUT or abundant primary or secondary forest vegetation.

3.3. Landscape Use Potential

The results obtained from the evaluation of the landscape use potential for each landscape unit with respect to the evaluated LUTs (*Conservation, Alternative Tourism, Rehabilitation, Forestry, Extensive Livestock Farming,* and *Rainfed Agriculture*) form the basis for determining the primary and secondary potential of the territory. Figure 4 shows the spatial distribution of primary and secondary use potential by polygon for the year 2021.

Due to its designation as a Protected Natural Area, conservation, ecotourism, and rehabilitation were prioritized as primary potentials (solid colored Fig. 4). As secondary potentials (hatched and cross-hatched lines Fig. 4), emphasis was placed on the utilization of territorial resources, particularly for forestry purposes. Additionally, primary suitability was prioritized for socioeconomic uses in landscape units with higher resident populations and better environmental, socioeconomic, and technical-financial conditions for implementation. In these units, secondary uses were determined as those that could be carried out without destroying or degrading natural values.

The Figure 4 and Table 8 show that landscapes with primary conservation potential are the most abundant, collectively representing 59.3% of the territory's landscape area. They are distributed across the north, northwest, west, southwest, and south. In terms of categories, landscapes with exclusive primary conservation potential cover 13.6% of the PNA and are characterized by the highest conservation levels and minimal or no resident population. They are mainly found in the southwest and south, with isolated units in the center and northwest. Within this category, 1.2% exclusively have primary conservation potential, while 98.8% have secondary potential for rehabilitation due to some degree of deterioration in primary forest cover (3,008.7 ha). Additionally, 85.3%, regardless of their secondary potential for restoration, can be exploited under regulatory guidelines for obtaining non-timber forest products.

In the Conservation-Tourism category, which represents 45.7% of the total, landscapes exhibit a higher level of forest degradation compared to those in the previous category. They also feature better accessibility and scattered settlements within them, while still retaining values attractive to alternative tourism. These landscapes are distributed in the north, northwest, and west regions. Within this category, all units have rehabilitation as a secondary potential, and 52.4% have the possibility of exploiting non-timber forest resources according to regulations governing their use.

Suitable for forest cover rehabilitation encompasses 38.3% of the area, primarily located in the eastern and central regions, historically more exploited for timber extraction and agricultural production despite suboptimal conditions for these activities.

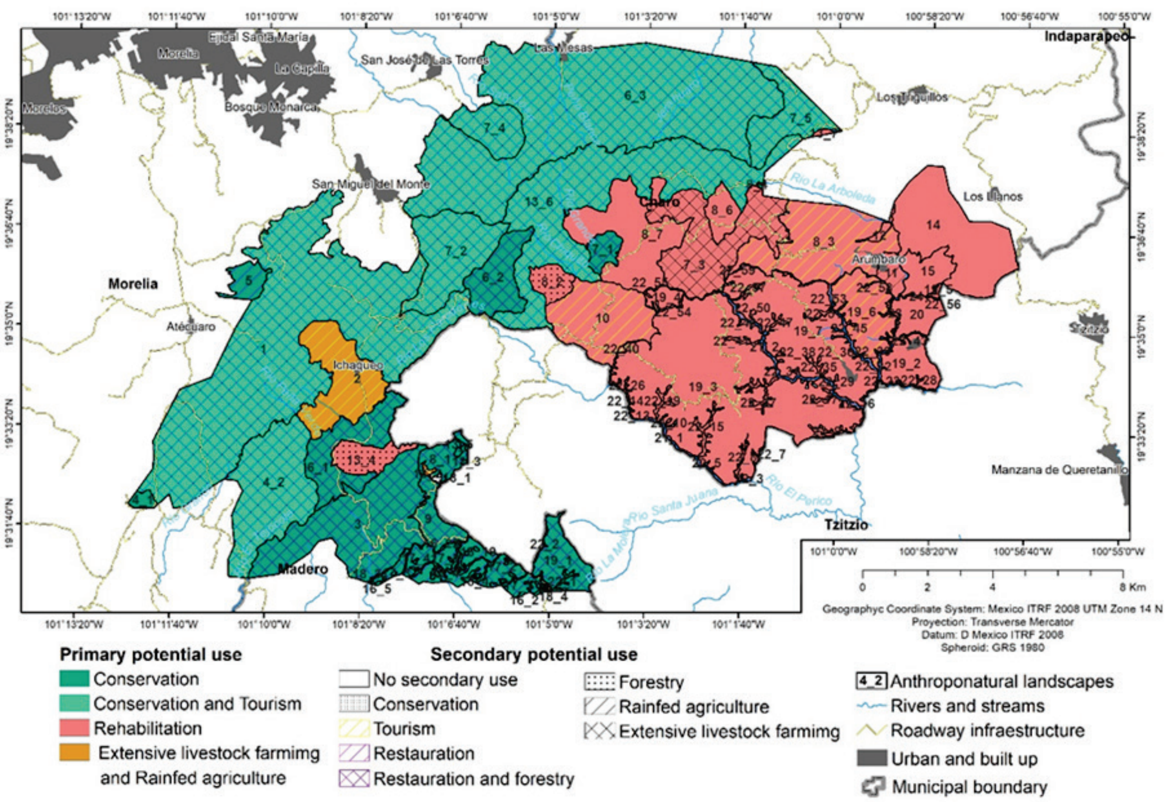

Figure 4. Primary and secondary landscape potential use.

Table 8. Landscape Use Potential.

Primary Use	Area (ha)	Landscape units	Secondary Use	Area (ha)	Landscape units
Conservation	3,043.6	44	No secondary use	34.9	1
			Rehabilitation	413.1	31
			Rehabilitation-Forestry	2,595.6	12
Subtotal	**3,043.6**	**44**	**Subtotal**	**3,043.6**	**45**
Conservation – Alternative Tourism	10,230.3	7	Rehabilitation- Forestry	4,864.0	2
			Forestry	5,366.2	5
Subtotal	**10,230.5**	**7**	**Subtotal**	**10,230.5**	**7**
Rehabilitation	8,576.0	81	No secondary use	5,720.3	61
			Conservation	21.4	12
			Alternative Tourism	1,737.3	4
			Forestry	285.5	2
			Extensive Livestock Farming	729.5	1
			Rainfed agriculture	82.1	1
Subtotal	**8,576.0**	**81**	**Subtotal**	**8,576.0**	**81**
Rainfed Agriculture – Extensive Livestock Farming	550.7	4	Alternative Tourism	541.5	1
			Rehabilitation-Forestry	7.5	1
			Rehabilitation	1.6	2
Subtotal	**550.7**	**4**	**Subtotal**	**550.7**	**4**
Total	**22,400.6**	**136**	**Total**	**22,400.6**	**136**

Within this category, 66.7% of landscape units are solely designated for rehabilitation (5,720 ha), while 0.3% still maintain some forest cover suitable for conservation (21.4 ha) as secondary use. Additionally, 20.3% possess values for alternative tourism (1,737.3 ha) linked to local cultural traditions or existing infrastructure (such as restaurants and lodges). Furthermore, 3.3% of the area (285.5 ha) is suitable for non-timber forest product harvesting in residual forests, in compliance with current regulations, while 9.5% can accommodate extensive livestock farming (729.5 ha) and rainfed agriculture (82.1 ha) in appropriate areas as secondary landscape potential uses.

Regarding productive activities, 2.5% have common primary potential for both rainfed agriculture and extensive livestock farming (550.1 ha). These areas are located in the flattest zones of the territory, featuring better soil for such activities and significant human settlements traditionally linked to these land uses. Within this category, 98.3% possess secondary potential for alternative tourism (541.5 ha), attributed to factors such as accessibility, existing infrastructure, and proximity to key attractions within the PNA. The remaining 1.7% of landscape units could potentially shift to rehabilitation if agricultural activity were abandoned and 1.4% could serve as secondary potential for non-timber forest resource utilization within their forest remnants.

The use of landscape units to assess the potential of a PNA for various LUTs has not been previously addressed. There are references to the use of landscape units to assess the natural potential of the territory (aptitude) in the works of Bollo *et al*. (2010) and Ramírez-Sánchez *et al.* (2016), applied to state-level studies in Mexico. However, the analyses proposed here of viability and landscape potential to address possible types of use are not addressed in those studies. These aptitude assessments are characteristic of works that address environmental land management and follow the execution proposal of Palacio-Prieto and Sánchez-Salazar (2003) during their execution phases, as seen in the work conducted by Ramón *et al*. (2011).

Ramón *et al*. (2013) made a methodological proposal for the use of landscape units, involving the evaluation of use aptitude and the various feasibilities discussed here to assess landscape potential in ANPs, without documentation of its use or references to its application being found. The evaluation conducted here could be considered an initial validation of the methodology proposed by the aforementioned authors, which builds upon the proposal of Palacio-Prieto and Sánchez-Salazar (2003), with adjustments made within the context of Mexico and the category of the Pico Azul-La Escalera PNA for its application.

Studies on landscape potentials in various regions of the world have been extensively conducted to evaluate the tourism potential of landscapes (Cetin, 2015; Mikulec and Antoušková, 2011; Martínez-Rodríguez *et al*., 2021; Torres *et al*., 2015; Huerta and Sánchez, 2011). Therefore, the evaluation conducted in this study in the context of a PNA can be considered the first assessment from this perspective, with results that support its implementation.

4. Conclusions

The assessment conducted constitutes a comprehensive methodological proposal for assessing land use potential that can contribute to the zoning of protected natural areas. Including social, legal, and natural factors in this assessment provides administrators of these spaces with solid arguments to support and diversify proposed land uses according to existing physical-geographic and socioeconomic conditions. The use of anthropo-natural landscapes as the fundamental unit of analysis for evaluating territorial potential offers the opportunity to zone potential landscape uses into categories for various purposes. These units represent a synthesis of the physical-geographic and socioeconomic components and processes that characterize the homogeneity of the protected natural area's surface.

Based on the designed indicator evaluation procedure, it was found that the Pico Azul - La Escalera Environmental Protection Zone has a primary potential for conservation activities on 59% of its territory. This percentage comprises preserved forests maintaining the environmental services and natural processes specified in the creation decree.

On the other hand, the incompatibility of uses assessed through environmental, legal, socio-economic, and technical-financial indicators determined that 38% of the Pico Azul - La Escalera Environmental Protection Zone has a primary potential for rehabilitation. This Land Use Type, aligned with the objectives of the protected area, could emerge as a pivotal revenue stream for local communities.

Tourism is often regarded as a low-impact alternative activity within NPA, offering socio-economic benefits to local communities. Typically, these tourist activities prioritize showcasing the natural attractions of the region. However, this study demonstrates that by considering comprehensive planning criteria and appropriate land use, tourism can emerge as a secondary and marginal potential only linked to the presence of infrastructure and cultural-religious themes.

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Supplementary Material A

Legend of the anthropo-natural landscape map of the year 2021 (from Ramón and Bollo, 2023)

A. Physiographic Province Neovolcanic Transmexican Axis, Mil Cumbres subprovince

I. Volcano-tectonic mountains, denudative-erosive, conical in shape with horseshoe-shaped collapse structures (calderas), (1,800-2,641 masl) in a subhumid temperate climate, ranging from slightly to heavily dissected (200<Vd<500), with slopes ranging from slightly to heavily inclined (0-30º), composed of andesite-volcanic breccia, basalts, acidic extrusive igneous rocks, limolites, and conglomerates, with Andosol, Acrisol, and Luvisol soils, and mixed coniferous and broadleaf forests, broadleaf forests, and cloud forests coverages.

1. Volcanic cone and domes, with slopes ranging from flat to very steep (0-30º), composed of andesite-volcanic breccia, with humic Andosol and chromic Luvisol soils, and primary pine-oak forests, primary pine forests, and secondary forests predominantly of pine-oak herbaceous species.

2. Foothills with slopes ranging from flat to steep (0-20º), composed of andesite-volcanic breccia with humic Andosol soil, and coverages of rainfed agriculture, permanent crops, secondary pine-oak forests with herbaceous predominance.

3. Foothills with slopes ranging from flat to steep (0-45º), composed of acidic extrusive igneous rocks with humic Andosol and orthic Acrisol soils, and coverages of primary pine-oak forests, secondary pine-oak forests with herbaceous predominance, primary pine forests, and secondary pine-oak forests with shrub predominance.

4. (4_1 - 4_2) Foothills with slopes ranging from flat to steep (0-30º), composed of basalts, with humic Andosol soil, and coverages of primary pine-oak forests and secondary pine forests.

5. Volcano-erosive depression, with steep slopes (10-30º), composed of andesite-volcanic breccia, with chromic Luvisol, humic Andosol, and orthic Acrisol soils, and coverages of primary pine-oak forests and secondary pine-oak forests.

II. Volcano-tectonic mountains, denudative-erosive, with horseshoe-shaped collapse structures (calderas), (1,965-2,608 masl) in a subhumid temperate climate, ranging from slightly to heavily dissected (200<Vd<500), with slopes ranging from slight to very steep (0-45º), composed of andesite-volcanic breccia, basalts, acidic extrusive igneous rocks, limolites, and conglomerates, with Acrisol, Andosol, Luvisol, and Ranker soils, and mixed coniferous and broadleaf forests, broadleaf forests, and cloud forests coverages.

6. (6_1 - 6_3) Volcanic cone, with slopes ranging from flat to very steep (0-45º), composed of andesite-volcanic breccia, with orthic Acrisol, humic Andosol, and Ranker soils, and coverages of primary pine-oak forests, secondary pine-oak forests, primary pine forests.

7. (7_1 - 7_5) Volcanic domes, with slopes ranging from flat to steep (0-45º), composed of andesite-volcanic breccia, with humic Andosol, orthic Acrisol, and chromic Luvisol soils, and coverages of primary pine-oak forests, secondary pine-oak forests, induced grasslands, primary pine forests.

8. (8_1 - 8_7) Foothills with slopes ranging from flat to steep (0-45º), composed of andesite-volcanic breccia, with chromic Luvisol and orthic Acrisol soils, and coverages of secondary pine-oak forests, induced grasslands, and primary pine-oak forests.

9. Foothills with slopes ranging from flat to steep (0-30º), composed of acidic extrusive igneous rocks, with orthic Acrisol soil, and coverages of primary pine-oak forests, secondary pine forests, and primary pine forests.

10. Foothills with slopes ranging from flat to steep (0-30º), composed of conglomerates, with chromic Luvisol and orthic Acrisol soils, and coverages of secondary pine-oak forests, induced grasslands, and permanent crops.

11. Foothills with slopes ranging from flat to steep (0-30º), composed of limolite-sandstone, with chromic Luvisol soil, and coverages of secondary pine-oak forests and induced grasslands.

12. Foothills with slopes ranging from flat to steep (0-30º), composed of rhyolitic tuffs, with chromic Luvisol soil, and coverages of secondary pine-oak forests.

13. (13_1 - 13_7) Volcano-erosive depression, with slopes ranging from flat to steep (0-45º), composed of andesite-volcanic breccia, with orthic Acrisol, humic Andosol, and chromic Luvisol soils, and coverages of secondary pine-oak forests and primary pine-oak forests.

III. Polygenetic volcano-tectonic mountains, denudative-erosive, in a subhumid temperate climate, ranging from slightly to heavily dissected (200<VD<500), (1,294-2,837 masl) with slopes ranging from slight to heavily inclined (1-30º), composed of andesite-volcanic breccia, basalts, acidic extrusive igneous rocks, limolites, and conglomerates, with Luvisol and Regosol soils, and mixed coniferous and broadleaf forests, broadleaf forests.

14. Foothills with slopes ranging from flat to steep (0-30º), composed of andesite-volcanic breccia, with chromic Luvisol and dystrophic Regosol soils, and coverages of secondary pine-oak forests with herbaceous predominance, induced grasslands, and secondary pine-oak forests with shrub predominance.

15. Foothills with slopes ranging from flat to steep (0-30º), composed of limolite-sandstone, with chromic Luvisol soil, and coverages of secondary pine-oak forests with herbaceous predominance and induced grasslands.

IV. Denudative volcano-tectonic mountains (1,327-2,302 masl) in a subhumid temperate climate, moderately dissected (200<Dv<300), with slopes ranging from slight to steep (0-30º), composed of acidic extrusive igneous rocks and andesite-volcanic breccia, with Acrisol and Andosol soils, and mixed coniferous and broadleaf forests, broadleaf forests.

16. (16_1 - 16_23) Summits with slopes ranging from flat to steep (0-30º), composed of acidic extrusive igneous rocks, with orthic Acrisol soil, and coverages of primary pine-oak forests and secondary pine-oak forests.

17. (17_1 - 17_5) Slopes, with slopes ranging from flat to steep (0-30º), composed of acidic extrusive igneous rocks, with orthic Acrisol soil, and coverages of primary pine forests, secondary pine forests, and secondary pine forests with herbaceous predominance.

18. (18_1 - 18_4) Fluvio-denudative, erosive, V-shaped valleys, with slopes ranging from slight to steep (5-30º) and intermittent river currents, composed of acidic extrusive igneous rocks, with orthic Acrisol soil, and coverages of primary pine forests and secondary pine forests.

B. Physiographic province Sierra Madre del Sur, subprovince Balsas Depression. V. Denudative volcano-erosive mountains (984-2,384 masl), in a subhumid temperate climate, moderately to heavily dissected (300<VD<500), with moderately to heavily inclined slopes (10-45º), composed of andesite-volcanic breccia and conglomerates, with Luvisol, Feozem, Regosol, and Acrisol soils, and mixed coniferous and broadleaf forests, deciduous lowland forests, and broadleaf forests.

19. (19_1 - 19_7) Denudative volcano-mountains with slopes ranging from flat to steep (0-30º), composed of andesite-volcanic breccia, with chromic Luvisol, haplic Feozem, and eutric Regosol soils, and coverages of secondary pine-oak forests, induced grasslands, and secondary deciduous lowland forests.

20. Denudative volcano-mountains with slopes ranging from strong to very steep (30-45º), composed of conglomerates, with chromic Luvisol soil, and coverages of induced grasslands and secondary pine-oak forests with shrub predominance.

21. (21_1 - 21_2) Fluvio-denudative-erosive valleys, V-shaped, with slopes ranging from slight to very steep (5-45º), and permanent river currents, composed of andesite-volcanic breccia, with chromic Luvisol, haplic Feozem, and eutric Regosol soils, and coverages of induced grasslands, secondary pine-oak forests, and secondary deciduous lowland forests.

22. (22_1 - 22_59) Fluvio-denudative valleys, erosive, V-shaped, with slopes ranging from slight to very steep (5-45º), and intermittent river currents, composed of andesite-volcanic breccia, with chromic Luvisol, haplic Feozem, and eutric Regosol soils, and coverages of secondary pine-oak forests, secondary deciduous lowland forests, and induced grasslands.

23. Fluvio-denudative valleys, erosive, V-shaped, with slopes ranging from slight to very steep (5-45º), and permanent river currents, composed of conglomerates, with chromic Luvisol soil, and coverages of secondary deciduous lowland forests, secondary pine-oak forests, and induced grasslands.

24. Fluvio-denudative valleys, erosive, V-shaped, with slopes ranging from slight to very steep (5-45º), and intermittent river currents, composed of conglomerates, with chromic Luvisol soil, and coverages of secondary pine-oak forests.