Biophysical landscapes of the Ejido Tzurumútaro, Michoacán, Mexico

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The Ejido of Tzurumútaro (ETZ) is located within the Lake Pátzcuaro basin which has great historical relevance in the state of Michoacán. The Purépecha Empire, one of the most important pre-Hispanic and current cultures in Mexico, was established and developed in this place. Through time, relationships between the natural environment and human beings have shaped a geographical scenario in this basin, whereby each of the elements shaping the current landscape (geological, biological, ecological, cultural, historical and architectural) have interacted with the potential of modifying the system as a whole (Centro-GEO, 2013). The ETZ internal community organization is based on cooperation and community feeling, which aims to exploit and make full use of its natural and human resources, through the personal work of its partners (ejidatarios) for their own benefit (Registro Agrario Nacional [RAN], 2016). The ETZ is recognized as an agrarian ejido and was one of the promoters of the post-revolutionary agrarian reform in the region.

Spatial analysis is a prerequisite for ecosystem conservation and an essential contribution to studies of land management, mainly in response to degradation of natural resources in many parts of the world (Chávez & González, 2015). Spatial decision-making for landscape conservation requires understanding the spatial distribution of landscapes and their components, including the bio-, geo-, and cultural-diversity (Zaragoza, Peters, Bollo, & Hernández, 2013). The landscape concept had its origin in geosciences and has been developed more widely by the theoretical and methodological approach of complex physical geography (Antrop, 2000; Bastian, 2002; Bastian & Steinhardt, 2002; Kolejka & Lipsky, 2014; Mazzoni, 2014; Solon, 2005; Troll, 2003; Vallés, Galiana, & Bru, 2013; Zonneveld, 1995). The theoretical bases of the landscape concept established by the naturalists of the nineteenth century, were developed by the European schools of Geography into a consideration of the landscape as a systemic composition of five main attributes: structure, function, dynamics, evolution and information (Buzai, 2004; Oropeza & Díaz, 2007). It can be defined as a spatial system formed by biophysical and geographic elements and influenced by anthropomorphic forces (Mateo, 2002).

The landscape Geoecology approach constitutes an interdisciplinary integration between geography, biology, anthropology, and architectural issues; It acquires a transdisciplinary character in the context of the so-called environmental and territorial sciences, focuses on the study of spatial-functional relationships, which allow to address the complex relationships that arise in the geographical space between human activities (the subject) and the environment (the object) (Bastian, 2002; Mateo, 2011; Serrano, 2014; Wu, 2013; Zonneveld, 1989).
The natural spatial units on which landscape analysis is based are characterized by their relative homogeneity of natural conditions (e.g. lithology, relief features, climate, hydrology, soil types) and the specific nature of their structure and functioning. Such studies are essential in environmental and regional planning (Farina, 2006; Foo, McCarthy, & Bebbington, 2018; Marsh, 2010; Mateo, 2007; Van Der Ploeg, Baartman, & Robinson, 2018). The characterization of the landscape units is a tool for describing the landscape of any part of the earth’s surface (Campos & Priego-Santander, 2011), which can be applied at regional and local scales, in land evaluation processes (Smyth & Dumanski, 1993), in the formulation of strategies for habitat conservation (Velázquez & Bocco, 2001), as well as being the first step in understanding the structure of landscapes (Van Eetvelde & Antrop, 2009).

Spatial units inform the Geocology perspective and constitute a complex system of taxonomic units linked to the cartographic representation scale, which ranges from the regional level (<1: 250,000 scale), to the local scale (>1: 250,000 scale). The local level (which is the case of the present study) has three main taxonomic levels: i.- the Physical-geographic locality, that is formed in its interior by ii.- Land areas, which contain iii.- the Sub-land areas. The representation of these taxa in a map shows the differentiation of the landscapes in a given space (horizontal structure of the landscapes) and allows to identify the heterogeneity of them (Mateo, 2002, 2007).

The objective of this study is to characterize the structure of the physical-geographical landscapes of the ETZ, Michoacán on a scale of 1: 25,000 Main Map. This area was selected because the Ejido has a historical significance in the region of Lake Pátzcuaro, since it is one of the first Ejidos founded in the Mexican West. According to the criteria applied for the definition of the landscape unit, three hierarchical levels were distinguished: Landscapes or localities, Land areas and Sub-land areas. With the characterization of the physical-geographical landscapes, the ETZ will be a tool for the formulation of strategies to optimize the use, management and development more appropriate in time and space of each of the landscape units (Mateo, 2002).

2. Study area

The ETZ (19° 29’ to 19° 35’N; 101° 30’ to 101° 36’W) has a surface area of 26 km² and is made up of five different disconnected areas. From a geological point of view, it consists of Cenozoic volcanic rocks, as well as Quaternary lacustrine sediments. In terms of hydrography, the ETZ lies in the hydrologic region number 12 (Lerma-Santiago, HR 12), and in the Western portion of the closed basin of Lake Pátzcuaro at four km NE of the town of Pátzcuaro. It is part of a poorly permeable area drained by intermittent streams, where the annual precipitation ranges from 1000 to 1200 mm, and the average annual temperature is 16°C (INEGI, 1985). The Tzurumútaro irrigation unit, is located in this area and is administered by the Irrigation District No. 20, Morelia (IMTA, 2002).

3. Methods

3.1. Landscape characterization

For the purposes of this work, the physical-geographic typology of the landscape was considered, such as the hierarchical classification and mapping of biophysical landscapes. This includes the understanding of the composition, structure, relationships, differentiation and development of the landscape units (Priego-Santander, Bocco, Mendoza, & Garrido, 2010). To make the landscape differentiation of the territory, three classification levels were used: locality, land areas and sub-land areas. Each one of these categories correspond to a structural-functional level and to a defined distribution of the geo-ecological complex according to the given level (Mateo, 2002, 2007).

Landscape units with the major hierarchical rank are defined by the more stable terrestrial components (geology, type of relief and climate), while landscapes with lower ranges are formed based on more dynamic geographical features, such as soils, vegetation and land use (Priego-Santander et al., 2010). Therefore, according to the structure and complexity, distinctions can be made between the three typological levels of the landscape: landscape or locality, land area and sub-land area (small units). The map legend follows the hierarchical structure of the units; it provides explicit information on which inferior units contribute to the immediate superior landscape unit (Table 1).

The biophysical landscape map was obtained through the morphogenetic discontinuities of the relief, based on the variation of landscape vertical structure; this entailed the analysis of regular change of shape, genesis and morphometry of the relief, and the association of soils with plant communities and land use (Priego-Santander, Morales-Iglesias, & Guadarrama, 2004; Ramírez-Sánchez, Priego-Santander, & Bollo, 2012; Priego-Santander, Campos, Bocco, & Ramírez-Sánchez, 2013) (Table 2). In this way, a landscape unit means a unit of geographically defined or limited basic attributes (Bastian, 2002; Bastian, Kronert, & Lipský, 2006).

The field work consisted on the verification of the landscape map previously obtained. The information on vegetation and land use was taken from the work of Cumaná (2014). The classification of soils corresponds to the FAO-UNESCO scheme. 60 survey stations were selected and checked in order to do map rectification; for this purpose, collection of data on the lithological composition, type and genesis of the relief, type of vegetation and morphological properties of the soils, was done. Subsequently, the
Table 1. Diagnostic indices used to delineate landscape units (Modified from Campos & Priego-Santander, 2011).

| Main diagnostic indices: complexity of the horizontal structure of the geo-system | Morphological unit | Complementary diagnostic indices: natural factors (relief, lithology conditions, hydrology, and climate) |
|----------------------------------|--------------------|--------------------------------------------------------------------------------------------------|
| A landscape structure of many levels, consisting of individual land areas and sub-land areas. | Landscape or locality | Units with a certain complex of meso-forms of relief (positive and negative) on the boundaries of a region; they present a similar moisture regime, specific type of lithology, and a complex or associations of soil types and biocenosis. |
| A second-level landscape structure, formed by sub-land areas and facies | Land area | Units usually with meso-landforms in the relief (or association of similar morphological conjunctures), characterized by the association of moisture regimes, soil-forming rocks, soil types and biocenosis. |
| Landscape structure of one level, composed of groups of facies that are highly related | Sub-land area | Units characterized by the location of a single meso-landform of the relief. They are similar with respect to entry of heat and sunlight (exposure). Units with the same correlation in deposits or lithology and soil-forming layers, the same type of moisture regime and soil mantle. Units with the same type of soil and biocenosis. |

Table 2. Steps in the mapping of biophysical landscape units of the ejido of Tzurumútaro. (Modified from Ramírez-Sánchez et al., 2012).

| Step | Method | Product |
|------|--------|---------|
| I    | Using the contour map, we identified the different ‘ranks’ of terrain vertical dissection. | Morphometric map |
| II   | The resulting map was transformed from raster to vector format, and then overlain on the lithologic map to obtain the superior lithologic units. | This output was generalized by eliminating the minimum mapping area (MMA 4 × 4 mm) to obtain a morpho-lithologic map. |
| III  | We overlaid the climatic information with morpho-lithologic map. | The MMA was eliminated to obtain a morpholitho-climatic map. |
| IV   | The digital elevation model was used to define slope ranks; the resulting database was converted into vector format and overlain with, the previous to identify watersheds, mountain peaks and valleys. | Morpho-litho-climatic map, at this stage we have the preliminary landscape level map. |
| V    | We overlaid land use/cover and soil type information to discriminate among the inferior Landscape units. | Cartographic hypothesis |
| VI   | Finally, the field verification of the cartographic hypothesis is carried out | Final cartography of localities, land areas and sub-land areas. |

Table 3. Cartographic references used in generating the map of biophysical landscapes.

| Input | Source | Scale |
|-------|--------|-------|
| Contour lines map | INEGI (2015) | 1:50,000 |
| Vertical dissection map | Own elaboration from the contour lines map | 1:25,000 |
| Geology map | INEGI (1978) adjusted to the study area | 1:50,000 |
| Climate map | INEGI (1979a) adjusted to the study area | 1:50,000 |
| Slope map | Own elaboration from the contour lines map | 1:25,000 |
| Vegetation and land use map | Cumana (2014) | 1:25,000 |
| Soil map | INEGI (1979b) adjusted to the study area | 1:50,000 |

complementation and rectification of the boundaries of the landscape units by using data collected and previous map information was carried out. At this step the deductive method was applied, that is, the analysis from the particular to the general was carried out, from the inferior units to the superior ones. Some cartographic references were found at a scale of 1: 50,000, but these were taken as a basis to generate the cartography corresponding to the scale of work and cartographic edition, which was a final scale of 1: 25,000 (Table 3).

For this study, vertical dissection (VD) was taken as a morphometric parameter that represents the amplitude of the relief (relative height) per unit area and is expressed in m/km². It serves mainly to define some types of relief (mountains, hills, flattened plains, undulating plains and subhorizontal plains), and offers information about the relief energy (Priego-Santander et al., 2010). For the case of the DEM, a pixel size of 20 m was used, which according to the scale that was used seems to be adequate. The slope map is the basic input to delimit the land areas and sub-land areas. Finally, the minimum mapable area that was managed was 4 × 4 mm, which at a scale of 1:25,000 is 10,000 m².

4. Description of landscape units

Differentiating factors have a significant weight in the fundamental composition of the system and can be partially transformed by anthropogenic activity. Spatial differentiation is expressed in the existence of hierarchical units of different rank. The main factor in geo-ecological differentiation within the territory is morphogenesis of the relief, which determines the subdivision of the study area into undulated plains, plains with gentle slope, and hills.

In total, five superior units or landscapes, nine land areas, and 30 sub-land areas were defined. The final landscape map has an explanatory legend regarding the composition and structure of geo-complexes. Each landscape is assigned a Roman numeral (I), and its constituent land areas are assigned that numeral with Arabic numeral (I.1); finally, sub-land areas are assigned successive natural numbers (1, 2, 3…). Because land use/cover information was applied to differentiate among the smallest homogeneous units (land areas and sub-land areas), the same landscape unit may have two or more land uses (Campos &..
A total of eight landscape units at the village level were defined, but only five of them are within the limits of the ETZ, and then the detailed description thereof is made:

**Landscape IV:** Volcanic hills, from slightly to strongly dissected (41 < VD < 100 m/km²), formed by basalt, basic volcanic basalt-breccia, and basic volcanic breccia, in a typical temperate climate. This unit has 91 polygons and an area of approximately 5.9 km². It consists of two land areas and 11 sub-land areas. There are four types of soil (Andosol, Luvisol, Ranker, and Phaeozem); vegetation cover is mainly pine-oak, oak-pine, and eucalyptus forests; and other covers such as pastures and areas of rainfed crops are also present.

**Landscape V:** Volcanic plains with gentle slope, slightly to strongly dissected (16 < VD < 40 m/km²), formed by basalt, basic volcanic basalt-breccia, and basic volcanic breccia, in a typical temperate climate. This unit has 113 polygons with an area of just over 6 km². It lies in the southern part of the area and consists of two land areas and seven sub-land areas. There are three types of soil (Luvisol, Andosol and Acrisol); vegetation cover is mainly pine-oak, oak-pine, and eucalyptus forests, and other covers such as induced grasslands and rainfed crops are also present.

**Landscape VI:** Fluvial plains with gentle slope, slightly to strongly dissected (16 < VD < 40 m/km²), formed by alluvial deposits in a typical temperate climate. It has 21 polygons with an area of 0.85 km² and lies in the central portion of the ejido. It consists of two land areas and five sub-land areas. There are four types of soil (Luvisol, Andosol, Acrisol, and Gleysol) and 2 main types of forest (oak-pine and eucalyptus), besides having induced pasture lands and irrigated crops.

**Landscape VII:** Volcanic undulated plains, slightly to strongly dissected (2.6 < VD < 15 m/km²), formed by basalt in a typical temperate climate. This unit has 24 polygons in an area of 1.29 km² and extends from the center to the S of the ejido. It consists of one land area and three sub-land areas. There are several soil types such as Luvisol, Andosol, and Vertisol and the main vegetation is eucalyptus forest; other land uses such as induced pasture lands and rainfed and irrigated crops are also present.

**Landscape VIII:** Undulated fluvial plains slightly to strongly dissected (2.6 < VD < 15 m/km²), formed by alluvial deposits in a typical temperate climate. This unit is the largest within the ejido with 25 polygons and an area of 8.1 km². It consists of two land areas and four sub-land areas. There are four soil types (Luvisol, Ranker, Vertisol, and Gleysol) and eucalyptus forest and tule bulrush are the main types of ‘natural’ vegetation; other land uses such as induced pasture lands and rainfed crops are also present.

5. Conclusions

The landscape approach used in this study allowed us to classify the structure and physical-geographical composition of the ETZ. There are five localities or landscapes, nine land areas, and 30 sub-land areas. Within these units, the main differentiation variable is the morphology of the relief, which favors the subdivision of the territory into undulated plains (41% of the total study area), plains with a gentle slope (32%), and hills (26%). On the other hand, it has that Landscape V is the largest with 6 km² and seven subland-areas, and Landscape III is the smallest with 0.85 km² and five subland-areas.

The methodology used in this article allowed us to characterize the configuration and biophysical structure of the landscapes in the ETZ. Although the methodology is complex, the resulting cartography gives us the composition of the landscape units, in addition to obtaining a strong geographical knowledge of the study area. The resulting cartography can assist in environmental and territorial planning, as well as in designing scenarios for incorporating sustainability into local development processes.

Software

The spatial processing was performed and edited using the geographic information system ArcGIS 10.2, and the working environment and edition of the final map was made at a scale of 1:25,000.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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