Geography Papers
2017, 63
DOI: http://dx.doi.org/10.6018/geografia/2017/259991 ISSN: 1989-4627

COMPLEXITY AND HETEROGENEITY ANALYSIS OF THE MÉXICOS'S LANDSCAPES

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1. INTRODUCTION

Geoecology or its synonym landscape ecology, is the result of integration of the (typically more functional) ecological approach and (typically more structural) landscape approach a holistic perspective (HASSE, 1986), which MOSS (2001) called the geoecological approach of landscape ecology. In this regard, the analysis of geo - ecological heterogeneity has proven to be an effective tool for understanding the spatial distribution of biodiversity, as well as for understanding the dynamics of spatial processes and ecological fragmentation of territories (LAVRINENKO, 2012 PRIEGO-SANTANDER *et al*., 2013).

In Mexico, different studies of the heterogeneity and complexity of geographic landscapes have been undertaken during the last decade, but these analyses cover partial territories and have almost always been done as part of other research. However, the mapping of landscape heterogeneity is essential in two directions of investigation: a) identify dominant, subdominant, rare and unique morphological units of a given territory and b) asses the representativeness of geosystems in protected areas system (GANZEI and IVANOV, 2012). In other words, cartography of heterogeneity makes it possible to know the richest and most diverse units of a territory (probable areas of high biodiversity), to establish which are more frequent and their reverse (the rarest), as well as those that exist in unique specimens (likely areas of high endemism).

Taking into account the above, the objective of this research is to asses the spatial distribution of the heterogeneity and geoecological complexity of the country. The cartography of the heterogeneity and complexity of the landscapes of Mexico will make it possible to clarify the distribution of the richest, complex and most diverse geosystems of the country and, in the medium term, to deepen their representation within the protected areas system, as well as to clarify the role of heterogeneity in today's productive systems.

2. MATERIALS AND METHODS

2.1 AREA OF STUDY. SITUATION, EXTENT AND LIMITS

Mexico is in the subcontinent of North America and has an area of approximately 2 million $km^{2.}$ It borders to north with the United States of America; to the South with Guatemala and Belize; to the east with the Gulf of Mexico and the Caribbean Sea and to the west with the Pacific Ocean.

2.2 THEORETICAL-METHODOLOGICAL FOUNDATIONS

The present research is based on the postulates of Landscape Geography. The scientific meaning of the landscape emerged in geosciences and developed more widely, within the theoretical and methodological approach of Complex Physical Geography or Landscape Geography (SOCHAVA, 1963; SOLNTSEV, 1997; BASTIAN, 2000, 2001; SHAW and OLDFIELD, 2007; MATEO, 1984, 2015; MIKLÓS, 2012). Geographic landscapes, geocomplexes, geosystems or natural territorial complexes (NTC) are parts of the surface that are qualitatively different from the rest, possess natural or socio-natural boundaries and have a definite qualitative integrity. This can be defined, briefly, as complexes of different taxonomic rank, formed under the influence of natural processes

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and the modifying activity of human society, which are in constant interaction and develop historically (MATEO, 1984, 2015). The heterogeneity of the geographic landscape varies in the space depending on the proportion between polygons and typological units. It is common to see the use of the concept of landscape heterogeneity to refer to the heterogeneity of vegetation or land use (FORMAN, 1995; SCHIPPERS *et al*., 2015) and, where it is considered as such, the spatial variation in the attributes of aggregation and contrast. Aggregation is understood as the dispersion of patches of coverage types. Contrast is understood as the degree of difference between patches or between patches and matrix. In this paper, landscape heterogeneity is understood as the differentiation of the horizontal structure of the geocomplexes, conditioned by the different landscape classes and number of polygons, with respect to the upper unit (ROWE, 1995; GANZEI and IVANOV, 2012). On the other hand, the complexity of the landscape places more emphasis on the complication of the morphological structure, but independently of the higher unit, that is, it only considers the information inside the unit that is analyzed (SNACKEN and ANTROP, 1983).

2.3 EVALUATION AND MAPPING OF COMPLEXITY AND GEOECOLOGICAL HETEROGENEITY

The map of Mexico landscapes (PRIEGO-SANTANDER *et al.,* 2012), distinguishes five taxonomic units in scale 1: 500 000; namely, class, subclass, group, subgroup and species (PRIEGO-SANTANDER AND BOCCO-VERDINELLI, 2016). Based on this cartographic base, the number of polygons and typological classes were computed by subgroups and with this information, complexity and geoecological heterogeneity were calculated at the subgroup of landscapes. According to FORMAN (1995), usually 2 or 3 indicators are enough for an answer to a specific question about landscape metrics. In the present study four indicators were used, namely: chorological complexity (CC) and typological complexity (TC) (SNACKEN and ANTROP, 1983) to assess the complexity of landscapes; and the relative wealth of landscapes (ROMME, 1982) and maximum diversity of landscapes (TURNER, 1989) to assess the geoecological heterogeneity. With these results the basic statistics were obtained and correlation analyses were carried out with the purpose of determining the probable association between indicators, to facilitate the optimization of the cartography. Statistical processing was carried out in BioStat 5 (ANALYSTSOFT, 2015).

The classification of the values was done according to the methods of equal classes and natural breaks. The latter method of classification (natural breaks) finds inherent clusters in the data, identifying break points between classes using optimization algorithms. The purpose was to construct cartograms for both approaches and thus to know which offers greater spatial differentiation and proceed then to the evaluation of complexity and geoecological heterogeneity. In both cases, cartograms were elaborated in five classes. The scale of work was that of the base map of natural landscapes of Mexico, that is, 1: 500 000 and the final edition of the cartograms was made on a scale of approximately 1: 13 500 000. Due to the final scale of editing, discussion of the distribution of the variables of complexity and heterogeneity is based on the proposal of physical-geographical regionalization of Mexico, proposed by BOLLO-MANENT *et al.,* (2015). All information was integrated, processed and edited, with support in ArcGIS Desktop Geographic Information System (ESRI, 2012) applications.

3. RESULTS AND DISCUSSION

3.1 CORRELATION BETWEEN INDICATORS OF HETEROGENEITY

In the case of Mexico at the regional level, a significant correlation was found between indicators of complexity (typological and chorological), as well as between richness and diversity of landscapes. This allowed the development of matrix systems to optimize mapping. In both, spatial differentiation was more useful by the natural breaks method, which respects the points of discontinuity inherent in the data and, therefore, the natural peculiarities of the territory. With the geographical coincidence of units with equitability between the number of polygons and the area, as well as between the number of polygons and typological classes (minimum values of the TC and CC variables) being possible and certain, the geographical coexistence of units with maximum values of complexity is very unlikely, since this would involve geosystems with many polygons in very little area (very high chorological complexity), coinciding with geosystems that have many polygons in very few typological classes (very high typological complexity), which is contradictory and at least on this scale, remains purely hypothetical for Mexico. However, the inverse extreme cases (maximum value of one variable and minimum of the other) if they occur, suggest the possibility of two subcategories with the same degree of complexity.

3.2 COMPLEXITY OF THE LANDSCAPES OF MEXICO

In Mexico, landscapes of remarkable and high complexity (type B) predominate. Landscapes of remarkable complexity are characterized by the occurrence of average values of chorological complexity and low to very low typological complexity or vs., that is, relative proportionality between the number of landscape classes and the number of polygons in relatively large areas. Below are the landscapes of remarkable and high complexity (type B), the landscapes of basic complexity, and finally the geosystems of very high and high complexity (type A), in that order.

The landscapes of high complexity (type B) are characterized by the occurrence of high to very high chorological complexity and low to very low typological complexity, that is, units with many polygons in little surface and in unison, and a certain balance between the number of geographical entities and the number of typological classes to which they belong.The landscapes of basic complexity extend over more than 21% of the territory of Mexico and have as a peculiarity the occurrence of geosystems with relatively few polygons in large extensions of surfaces or small proportions of the number of polygons and the typological classes to which they belong. The landscapes of very high complexity and of high complexity type A are those of more restricted and atomized distribution, appearing as small patches inside the previous classes. The former are characterized by occurring in units with numerous polygons in a relatively small area or with few typological classes. The latter are presented in geocomplexes with few polygons in large geographic extensions or many polygons in a few typological classes. Between them they cover a little more than 15% of the Mexican territory, mainly, in atomized form to the interior and periphery of the previous categories.

3.3 HETEROGENEITY OF THE LANDSCAPES OF MEXICO

As in the case of geoecological complexity, three categories of heterogeneity cover more than 80% of Mexican territory and two have a more restricted distribution. In Mexico, there are predominantly heterogeneous landscapes, which cover almost 33% of the national territory and are formed by 5-11 typological classes. Next are the landscapes of remarkable heterogeneity, which are characterized by having 2-4 typological classes and are distributed in more than 26% of the Mexican territory. Thirdly, the very heterogeneous landscapes, whose peculiarity is that they possess the maximum richness in the composition with 18-23 lower typological units and they extend in more than 25% of the area of the territory. Finally, the categories of heterogeneous landscapes and landscapes of basic heterogeneity appear, which between them cover a little more than 13% of the total of the country. The first occurs in almost all the national territory in fragmented form and is characterized by the presence of units formed by 12-17 geosystems. In the case of landscapes of basic heterogeneity, these are geocomplexes formed by a single typological class, that is, they literally have no diversity at this scale.

3.4 SOME CONSIDERATIONS ON THE COMPLEXITY AND HETEROGENEITY OF THE LANDSCAPES OF MEXICO

The complexity and heterogeneity of Mexican landscapes must be interpreted carefully. The degrees of classification refer to the value of the indicators CC, TC, R and $H_{max.}$; but the concepts of "simplicity" and "homogeneity" should in no way be understood as "poverty" or "simplicity". The constant alternation between geocomplexes with so diverse a degree of complexity and heterogeneity, confers to the territory of Mexico a high ecological connotation. The results obtained on the complexity and heterogeneity of the landscapes of Mexico can support current biogeographic research, helping to explain the spatial distribution of biodiversity at the national level and from the applied point of view, the design of the system of protected areas, as well as the definition of priorities in public policies for the protection and conservation of nature. However, in all cases it should be noted that this is a regional scale study, i.e., its basic purposes are indicative and should not be used for local decision-making.

4. CONCLUSIONS

At the regional scale, Mexico is characterized by a significant and negative correlation of the typological and chorological complexity of its landscapes, while geoecological richness and diversity have a very high and positive correlation.The regional scale of analysis, with an indicative character, has made it possible to clarify two significant facts: 1) even the most simple and homogeneous geocomplexes of Mexico encompass a unique richness of inferior units at subclass level of landscapes, which suggests prudence in the treatment of the grades of classification and at the same time, reveals that any unit can be important for the conservation of natural values; and 2) the need to undertake these investigations at a more detailed scale that allows definition of the local regularities of the distribution of geoecological complexity and heterogeneity, since the regional scale is mainly indicative.These results can support inferences about the current biogeography of the territory of Mexico and the design of public policies for the conservation of nature at the national level, given the regional nature of the scale of analysis.

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