Fragmentation of the temperate and tropical forests in Mexico: implications for their conservation and sustainable management

R. Moreno-Sanchez
Department of Geography and Environmental Sciences, University of Colorado Denver, USA

Abstract

Recently a comprehensive, consistent evaluation of the fragmentation of the forests at the national level in Mexico has been carried out. This paper discusses the implications of the results of this study for the conservation and sustainable management of the forests in the country. It is concluded that the information on the level of fragmentation of the remaining forests can assist in: changing the way forest conservation and restoration projects are conceived; in deciding how areas are prioritized to carry out these projects; and in identifying the forest types and locations that due to their level of fragmentation are unable to support specific forest ecosystems functions or that could be more sensitive to degradation processes. Also, the fragmentation information is an important parameter that can be incorporated into forest management plans to develop more effective management plans that target the specific ecological conditions created by the level of fragmentation in the remaining forest masses.

Keywords: Mexico, forests, fragmentation, conservation, management.

1 Introduction

Anthropogenic and natural processes have significantly changed the extent, composition, structure, and spatial pattern of the forests in Mexico [1–3]. These changes have affected the capacity of these ecosystems to sustain flora and fauna species, and the production of goods and services at different temporal and spatial scales (e.g. [3–10]).

The commonly reported remaining area and deforestation rates are important parameters to estimate the sustainability of forest ecosystems. However, equally

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important are the conditions of the remaining forests with regard to their ownership, composition, structure, and spatial pattern. This last factor is estimated through different measures of fragmentation. Forest fragmentation is a critical parameter that influences the capacity of the forests to sustain vital ecosystem components and functions [11].

In Mexico there have been some studies of the fragmentation of the forests. These studies have used different methodologies to evaluate the forest fragmentation and have been limited to specific types of forests [3], or to the effects of fragmentation on specific flora or fauna species at the local and regional levels [4–10]. Recently a nation-wide evaluation of the fragmentation of the temperate and tropical forests in Mexico has been carried out [12]. This paper builds up on the results of this study and discusses the implications of these results for the conservation and sustainable management of the temperate and tropical forests in Mexico.

2 Brief background on forest fragmentation

The issue of forest fragmentation has been extensively studied. There are numerous studies on its effects on the functioning of ecosystems and conservation of diverse flora and fauna at different temporal and spatial scales (e.g. [3, 13, 14]). Due to the diversity of the findings in these studies there is still ambiguity on what "fragmentation" is and what its effects are.

Several factors contribute to make the concept of habitat fragmentation ambiguous and context depend [15–18]: 1) Habitat fragmentation consist of both reduction in the total area of the original habitat and change in the spatial pattern of what remains; 2) there is no clear standard for assessing human-caused fragmentation; all natural environments are fragmented to some degree, and they are subject to continuous change due to natural process; 3) different organisms and ecological systems respond to the degree of fragmentation of a particular environment in different, even contradictory ways; 4) numerous temporal and spatial scales must be considered, the relevant scales for different species, geographic regions, and types of environments are likely to be different; and 5) there is a lack of consistency in study design and methodologies used to analyze habitat fragmentation making comparisons, integration of information and results, and replication of studies difficult.

Although it is not easy to draw broad general conclusions regarding forest fragmentation, there is general agreement among scientists and forest managers on the need to quantify the level of fragmentation of the forests and to integrate these estimations into conservation and management plans, and simulations that will assist us in better understanding the interactions among human activities, forest features, and ecological processes [15].

3 Estimation of the fragmentation of the forests in Mexico

Moreno-Sanchez [12] presents an estimation of the fragmentation of the temperate and tropical forests in Mexico. This study used the fragmentation

model proposed by Riitters et al. [19]. This model belongs to a group of moving-window fragmentation indices. The moving window defines a neighbourhood that is analyzed to estimate the fragmentation value of the centre cell in the window. The details of the fragmentation model are presented in [12] and [19]. Five fragmentation categories are generated by the model, in increasing level of fragmentation they are: interior, perforated, edge, transitional, and patch.

This model was applied to The Land Use and Vegetation cover vector dataset scale 1:250,000 (known as INEGI Series III) first edition from 2005 produced by the National Institute of Statistics, Geography, and Informatics (INEGI), Mexico. This data set was created using Landsat ETM satellite images from the years 2000 and 2002, and ground truthing work during 2002, 2003, and 2004. This dataset was converted to a raster of 100x100 meters cell size to apply the fragmentation model.

The fragmentation model was run at three different analysis window sizes: 3x3, 5x5 and 9x9 cells. Each of these window sizes was selected to represent different degrees of penetration of anthropogenic or natural processes into the forest patches. In the 3x3 cells analysis window the centre cell has a neighbourhood of 100 meters in radius. The 5x5 and 9x9 cells window sizes have neighbourhoods of 200 and 400 meters in radius respectively. The different analysis window sizes classify the areas into the fragmentation categories differently. Figure 1 presents an example of the results obtained for a sample area.

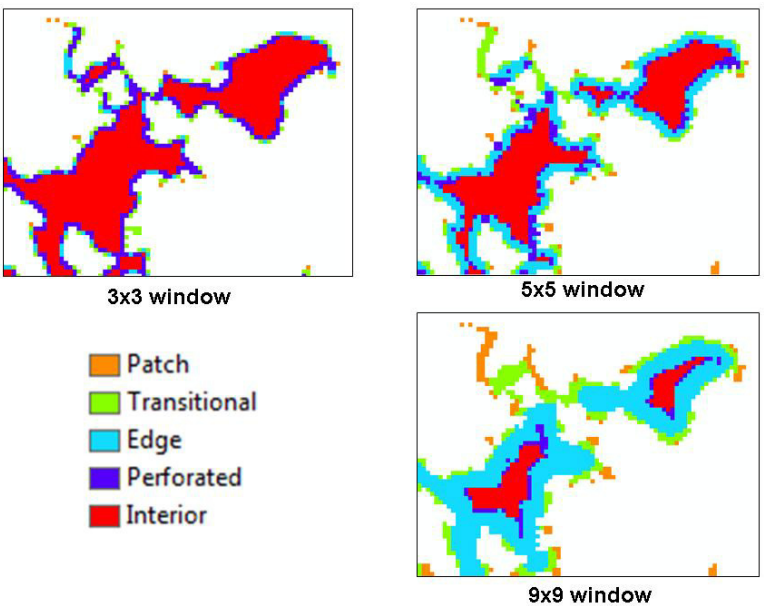

Figure 1: Example of how the size and distribution of the fragmentation categories created by the fragmentation model change when using the 3x3, 5x5, and 9x9 cells windows.

The results of the fragmentation model shown in table 1 indicate that the *Broadleaf forests* followed by the *Tropical dry deciduous forests* have the most complex spatial patterns of all the forest types studied. These two forest types have the lowest percentages of the total areas classified as "interior", and the highest percentages of their total areas classified in the "patch" and "transitional" categories that correspond to highly fragmented areas (see figure 1). In contrast the *Tropical sub-evergreen rain forests* have the largest percent of their total area classified as "interior" and the smallest areas classified as "patch" or "transitional" of all the forest types studied at every analysis window size. This indicates that at the national level, the *Tropical sub-evergreen rain forests* tend to be arranged in more compact with less edge clusters than any other forest type.

The *Tropical evergreen rain forests* have the smallest total extent of all the forest types studied. These forests also have the largest percent change increases in the areas that become classified "patch" or "transitional" as the analysis window increases. These results indicate that these forests have the largest proportion of their total area arranged in isolated patches with complex edges, small patches, or narrow peninsulas of all the forest types studied.

4 Implications for the conservation and sustainable management of the forests in Mexico

The forests in Mexico have been subjected in recent decades to severe deforestation and degradation processes [1–3, 20, 21]. The total remaining area and deforestation rates are important parameters to estimate the sustainability of these ecosystems. However, equally important for this estimation are the conditions of the remaining forests in regard to their ownership, composition, structure, and level of fragmentation.

The fragmentation analysis results can be used to support different forest conservation strategies, for example: Identify regions for protection and preservation based on their persistence as "interior" areas as the fragmentation analysis window increases; identify areas where restoration efforts could be concentrated to expand the extent of "interior" areas by filling the "perforated" areas; support a strategy of reducing vulnerability by focusing on places that are near critical fragmentation thresholds ("transitional"); or create a strategy of restoration that concentrates on areas that are already fragmented ("patch").

The information on the level of fragmentation of the forests can also help to change how conservation and restoration efforts are conceived and approached in Mexico. For example, large reforestation efforts have been carried out in Mexico with very limited success [22]. These efforts have concentrated in areas where current socio-cultural, economic, institutional-legislative, or environmental conditions are not likely to allow the long-term support of forests in the near future. Instead, or parallel to these reforestation efforts, resources could be channelled to areas where investments can potentially return greater benefits in terms of conservation and expansion of the forest areas (particularly "interior"

Table 1: Area in hectares in each fragmentation category and the percentage of the vegetation type group total area they represent. The area and percentage values are displayed for each of the analysis window sizes (3x3, 5x5 and 9x9).

	Fragmentation Categories (area in hectares)											
Forest type	**Patch (ha)**	**%**	**Transitional (ha)**	**%**	**Edge (ha)**	**%**	**Perforated (ha)**	**%**	**Interior (ha)**	**%**	**Total area (ha)**	**% of national territory**
Coniferous forest											16,780,993	8.59
3x3 Window	8,693	0.05	363,295	2.16	411,292	2.45	1,158,384	6.90	14,839,329	88.43		
5x5 Window	44,762	0.27	526,363	3.14	2,462,789	14.68	621,233	3.70	13,125,846	78.22		
9x9 Window	229,088	1.37	1,081,253	6.44	4,491,546	26.77	429,433	2.56	10,549,673	62.87		
Broadleaf forest											17,373,441	8.90
3x3 Window	12,564	0.07	544,136	3.13	609,483	3.51	1,681,641	9.68	14,525,617	83.61		
5x5 Window	69,675	0.40	798,350	4.60	3,565,870	20.52	876,502	5.05	12,063,044	69.43		
9x9 Window	367,239	2.11	1,673,234	9.63	6,181,553	35.58	541,583	3.12	8,609,832	49.56		
Tropical dry decidious forest											21,097,487	10.80
3x3 Window	13,882	0.07	500,434	2.37	597,903	2.83	1,578,665	7.48	18,406,603	87.25		
5x5 Window	62,406	0.30	719,735	3.41	3,439,617	16.30	866,994	4.11	16,008,735	75.88		
9x9 Window	296,144	1.40	1,505,080	7.13	6,308,112	29.90	603,108	2.86	12,385,043	58.70		
Tropical sub-evergreen rain forest											7,001,725	3.58
3x3 Window	2,891	0.04	88,733	1.27	115,158	1.64	282,146	4.03	6,512,797	93.02		
5x5 Window	12,776	0.18	127,170	1.82	627,602	8.96	156,795	2.24	6,077,382	86.80		
9x9 Window	53,618	0.77	266,584	3.81	1,175,013	16.78	114,291	1.63	5,392,219	77.01		
Tropical evergreen rain forest											3,488,303	1.79
3x3 Window	1,482	0.04	77,701	2.23	87,054	2.50	232,912	6.68	3,089,154	88.56		
5x5 Window	8,381	0.24	113,961	3.27	507,060	14.54	121,033	3.47	2,737,868	78.49		
9x9 Window	47,807	1.37	242,324	6.95	894,201	25.63	77,316	2.22	2,226,655	63.83		

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areas). This would be the case of the "perforated", "edge", and "transitional" areas identified in the study by Moreno-Sanchez [12]. In these areas forests still remain and investments can help to slow down or reversed degradation processes and contribute to protect and expand "interior" forest areas.

The information on the spatial pattern of the remaining forests will allow a better estimation of the capacity of these ecosystems to maintain critical ecosystem functions, support specific flora, fauna, and supply marketable and non-marketable goods and services. This revised capacity will be a better foundation to develop more effective management plans that target the specific ecological conditions created by the level of fragmentation in the remaining forest masses.

Future research efforts to complement the fragmentation results here presented include: Estimation of the accessibility to forest areas and their proximity to anthropogenic land uses and activities; and evaluation of the evolution of the fragmentation of the forests by comparing forest cover conditions from different dates. We are currently collecting the information necessary to carry out these projects.

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