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LANDSCAPE METRICS AS AN ANALYTICAL TOOL FOR THE PROSPECTION OF MALARIA IN THE PARIA PENINSULA, SUCRE STATE, VENEZUELA

MÉTRICAS DEL PAISAJE COMO HERRAMIENTA ANALÍTICA PARA LA PROSPECCIÓN DE LA MALARIA EN LA PENÍNSULA DE PARIA, ESTADO SUCRE, VENEZUELA

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ABSTRACT

A hybrid classified Landsat 7TM+ image was used to perform a statistical analysis to separate regions with different landscape patterns. Additionally, metrics corresponding to dominance, and contagious and fractal dimensions were calculated and used as indicators to measure the spatial difference of malaria incidence, and furthermore to establish a characteristic spatial pattern of widespread malaria in the Paria Peninsula, Sucre state, Venezuela. Field evidence collected reinforced the hypothesis that recent changes produced on the landscape pattern favors survival rate of mosquitoes (*Anopheles aquasalis),* the malaria vector in this region. They resulted in an increased probability of effective encounters of an infected mosquito with a human host. Consequently, malaria prevalence increased in the region. Based on this evidence, epidemiological surveillance and control policies should consider these events and take measures to reduce immature population stages of the mosquito vector, thus contributing to maintain the epidemic effect of malaria transmission on human communities at a low level, and reducing the expression of the so called malaria local foci. Similarly, such practices reinforce the idea that a more effective epidemiologic control must result from incorporating the specific ecological features of each locality into the policies design, and hence control effectiveness may be increased in comparison with a generalized control based only on the reduction of adult mosquito populations in a critical malaria focus or by means of a wide indiscriminate use of insecticides.

RESUMEN

Se utilizó una clasificación híbrida sobre una imagen satelital Landsat 7TM+, para posteriormente realizar un análisis estadístico que separa regiones con diferentes patrones del paisaje, Adicionalmente, se calcularon las métricas de Dominancia, Contagiosidad y Dimensión Fractal que fueron utilizadas como indicadores para medir la diferencia espacial de la malaria y mas allá para establecer un patrón espacial característico, asociado a su dispersión en la Península de Paria, estado Sucre, Venezuela. Las evidencias colectadas en el campo refuerzan la hipótesis de que los cambios recientes, inducidos sobre el patrón del paisaje, favorecen la tasa de sobrevivencia del mosquito (*Anopheles aquasalis*) vector de la malaria en la región. Tales cambios han producido un aumento en la probabilidad de encuentros efectivos de mosquitos infectados con humanos hospederos. Consecuentemente, la prevalencia de la malaria tiende a aumentar en la región. Basados en estas evidencias, deberían tomarse en cuenta estos eventos para la vigilancia epidemiológica y la elaboración de políticas de control específicas, tomando medidas para reducir la sobrevivencia de las formas inmaduras del mosquito vector, contribuyendo así a mantener la enfermedad a niveles bajos no epidémicos, al controlar hasta un nivel muy bajo, el proceso de transmisión de la malaria a las comunidades de humanos y reduciendo así el efecto conocido como foco malárico. Similarmente, tales prácticas refuerzan la idea de que un control epidemiológico más efectivo deberá incorporar elementos derivados de las características ecológicas de cada localidad en el diseño de sus políticas, aumentándose de esa manera la efectividad, en comparación con los controles generalizados, basados solamente en la reducción temporal de las poblaciones de mosquitos adultos, en los focos críticos de malaria o por un uso amplio e indiscriminado de insecticidas.

Keywords: Landscape metrics, malaria, landscape ecology, epidemiological surveillance.
Palabras clave: Métricas del paisaje, malaria, ecología del paisaje, vigilancia epidemiológica.

INTRODUCTION

Landscape ecology has been widely defined as the ecology branch studying the effects of landscape patterns over the ecological processes (Turner, 1980). It develops new elementary theory and concepts that noteworthy contribute to a better understanding of ecosystem structure-function relationships under a holistic and systemic analytical perspective. Most of its developed methodologies intend to quantify the spatial pattern with ecological events which have taken place or have been originated as consequence of such a spatial pattern. The method uses information of spatial pattern as a simple explicative variable, which is referred as a landscape metric or a landscape condition index. Remote sensing techniques, on the other hand, became one of the most efficient tools for data acquisition with the aim of quantifying and characterizing spatial patterns. Specifically, techniques based on multi spectral digital satellites image analysis have been highly useful for this particular task on either natural or strongly man modified ecosystems. The present paper refers on metrics derived from a spatial analysis using an optic multi spectral satellite image, acquired by the Landsat 7 TM+ during February of the year 1999, in which spatial pattern analysis allowed to explain ecological processes associated to malaria disease. In this approach we are considering all compartments configuring the malaria cycle, as a sub subsystem, whose processes are nested in the whole ecosystem structure and functionally related to the spatial landscape pattern of this particular region. With results of posterior geo-statistical analysis conducted on the metric calculation and including dominance (O' Neill, 1988; Turner, 1989), contagious and fractal dimension (Frohn, 1998), metrics were used to explain how malaria persistence was favored in the Paria peninsula, in Sucre state, at the Northeastern Venezuela, considered as one of the five great malaria foci in the country. In this region, annual reports account for the major number of annual malaria cases, making it a rural endemic zone for this zoonosis. Consequently, health and life quality of human settlements are significantly declined by the incidence of this illness.

MATERIALS Y METHODS

Study area. Paria peninsula is located between coordinates 10°27'00'', 10°42'31''N and 61°32'00'', 63°11'00''W. It configures an extended land belt horizontally oriented, from the west end of the continent to the east, with the peninsula at the open Caribbean Sea just in front of Trinidad Island. In the middle of the land belt has a mountain system, as a backbone, originating an abrupt slope at the north facing the Caribbean Sea, and a extended south slope with an a smooth altitudinal gradient. Southern slope contains diverse types of wetland landscapes that form the Gulf of Paria coast. Wetland landscapes form another gradient, varying in salinity form the east edge as a marine environment toward the west as a zone of marshes forming the delta of Rio San Juan. Between both peninsula edges, at the Southern slope, several different strings and small rivers, most of them intermittent, mix their water with the salty one of the gulf, and at the west extreme they mix at the delta creating marshy shores. Figure1 shows the Sucre state at the north-eastern extreme of the Bolivarian Republic of Venezuela, and the Landsat Image below the state Silhouette, showing the Paria Peninsula as part of Sucre state.

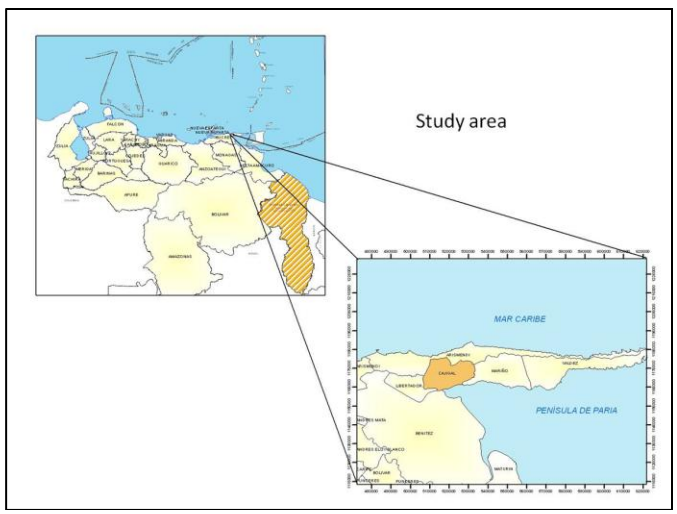

Figure 1. Image-map of the study area that shows the Paria Peninsula at Sucre state, located at North-eastern of the Bolivarian Republic of Venezuela.

Digital Image Processing and metric calculations. A basic methodology starts by selecting sets of layer that better discriminate landscape pattern differences over the registered image adjusted to Datum DWS84 and projected on UTM coordinate system, using (Zone) 20 for the Landsat 7, TM+ 153 of February 1999. Under major separability criteria (Lillesand and Kiefer, 1979), layer combination 4-5-3 was used to perform a hybrid classification satellite image map. Considering training areas visited during the year 2005, assuming that a low rate of change between image uptake took place; so the land field training allowed a good class separation based image interpretation as well as vegetation classes and land use recognition, both used as the fundament in the landscape separation criteria and classes discrimination. Figure 2 presents the image on the chosen combination, overlapped with the municipalities boundary vector layer, to latter relate both, landscape spatial pattern and malaria incidence on the Paria Peninsula settlements.

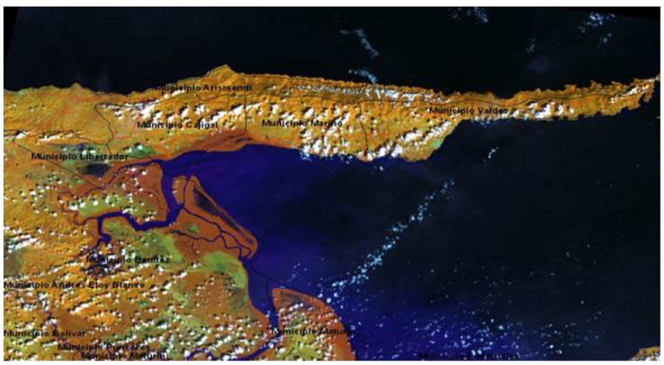

Figure 2. Image Landsat 7 TM+ 753 Image of 1999, 7,5,2 band combination, overlapped with municipalities delimitation vector cover for the study area.

Figure 3 describes the North and South Slopes of Paria peninsula originated by the Venezuelan coastal mountain system and the saline gradient from the open ocean edge of the Gulf of Paria to the marshes and swamp of the river delta.

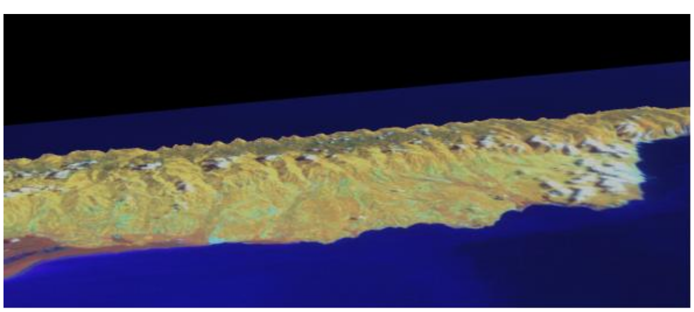

Figure 3. A 3D terrain model of the Paria Peninsula combined with the satellite image to describe North and South slopes and East to West saline gradient.

RESULTS

Results presented here were obtained with a systematic application of class or region criteria to evaluate the three chosen landscape metrics. Those indicators are based on the image pixel features. They are really a form of quantitatively expressing landscape pattern attributes. In the case of the dominance index it was calculated though the formula described by O'Neill (1988) and improved by Forman (1998). This formula reflects the importance of more conserved areas with respect to the dominance of their natural vegetation type, assuming that the vegetation changes due to the influence of either North or South slopes gradients or East-West salinity gradients of the inside gulf coast producing coastal landscape diversity. This dominance of a general landscape pattern is disrupted by the two factors associated to important ecological processes. One is the change in the surface topography due to the drainage in micro basin dynamics, on each slope; such dynamics produces a major differentiation on landscapes of the south slope, because springs have longer paths and act on more heterogeneous wetlands landscapes types. The second factor is the change of the landscape pattern produced by human activity. It generates a landscape pattern fragmentation, which is more evident at the middle southern slope areas, corresponding to foothills and small valleys of river basin of this slope.

This result is a landscape mosaic with small patches of different types of land uses, which sometimes the same use but in different intensities. This is evidenced with the values obtained for metrics of Contagious and Fractal Dimension (Frohn, 1998). So a new landscape pattern emerges in the middle areas, as a product of man activities and land use changes, mainly for rural human settlements (urban processes), rudimentary agriculture practices and a mix of agriculture and cattle management to manage small farm units. However, there are relicts of areas that were extensive cocoa cultures that may be recovered to some extent in the lower and well irrigated lands, at flat lands not influenced by wetlands dynamics and representing an intermediate zone in the landscape pattern of the south slope.

In the general view of the image analysis appears a zone with patches of different vegetation composition, where introduced plant species emerge, when the human intervention moves to the high lands. This process is accompanied with significant deforestation.

Clearing of woody zones is also evident at the north and south slopes, and is also accompanied with manmade artificial shallow water bodies to maintain small reservoirs for cattle and domestic animals as well as for human consumption.

DISCUSSION

When landscape patterns were analyzed using the selected metrics and were associated to malaria prevalence in the study area for the time corresponding to the satellite image, a spatial relation between the diseases appearance with the low wetlands and human settlements was observed. There is also a spatial concordance between the fragmented landscape patterns, due to anthropic activities, with malaria cases. Previous studies conducted by Delgado *et al*. (2005) showed that some types of land uses favored the incidence of malaria, such uses include rudimentary agriculture in small areas with the culture of the so called “ocumo chino”, a tubercle, used as bread substitute in the daily diet of inhabitants of this zone. It is usually cultivated in flooded woodlands that are partially cleared to take the advantage of barely flooded wet soils, under the shadow of big trees. However those are wet land areas, considered optimum for mosquito vector of malaria. When the landscape pattern was analyzed with the metrics and associated to malaria disease prevalence values, there was a direct relationship of major number of cases with the pattern favoring mosquito population development. Among those places, the most evident were human settlements nearest to the wetlands, but, additionally, there is a concordance between fragmented landscape pattern, due to an anthropic action, and malaria disease incidence. Previous studies (Keating *et al*., 2003; Klinkerberg *et al*., 2004; Delgado 2005; Ramos *et al*., 2006: Delgado and Ramos 2006) show that land uses like agriculture and cattle management, in small units with low technical development, favor malaria disease prevalence at most. The image classification done in this study (Fig. 4) allowed discrimination of different habitat types, for mosquito populations in the Paria Peninsula, but field sampling of wet lands indicates that *An. aquasalis*, the main malaria vector in the region, is present in most water bodies types, such as small and shallow environments, and the delta swamps, as well as in the salty pond near the coastal marine mangrove marshes and in the above mentioned coconut trees plains. All this suggests a high plasticity to colonize most kind of wet environments in the zone. A particular observation in the field let to assure that altitude is a limiting factor for anopheles to colonize high lands, but when manmade water bodies appeared in the landscape of higher lands, mosquitoes larvae were found in such water bodies and may be the reason why some malaria cases were eventually reported in mountainous human villages. In general, the municipalities most affected by malaria disease are the wetlands and man fragmented landscapes (Fig. 5). At the less populated, northern slope, malaria was related to man alterations of landscape natural pattern, mainly produced by the artificial introduction of water bodies for different reasons. More homogenous habitats belonging to wetland types are concentrated at the southern slope coastal zone, and the spatial distribution of malaria disease cases define this land tract as the local optimum for development of *An. aquasalis* populations, the vector responsible for widespread malaria disease in the region, and prevalence of malaria cases in human settlements.

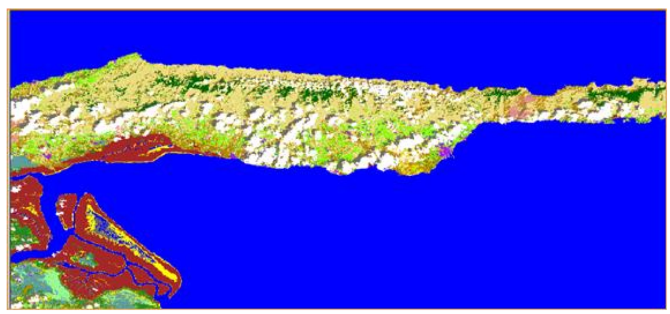

Figure 4. Map-Image resulted out of the hybrid classification and use of landscape metric performed on the Landsat 7+ TM image.

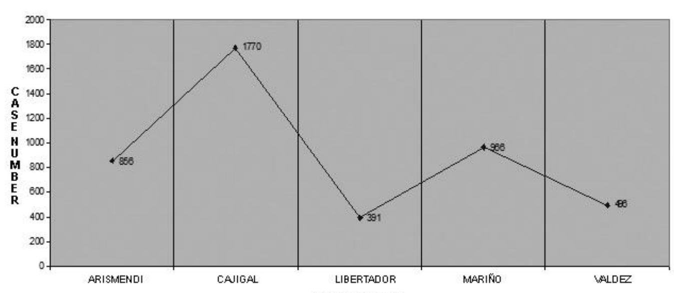

Figura 5. Malaria disease cumulative incidence by municipalities in Paria Peninsula, during year 1999 (Source: Malariology Bulletin. Ministry of Sanitation and Public Health, Venezuela).

Most ecosystem interactions dealing with the malaria disease cycle are associated to wetlands environments and they are favored by the kind of man made natural landscape fractioning pattern. This suggests that such process increases spatial connectivity among the elements that configure the malaria disease cycle, but also is worth considering the high plasticity of the mosquito *An. aquasalis*, allowing it to reproduce using diverse types of water bodies, with a variety of temperatures, altitudes, salinities and oxygen conditions, and being able to exploit shallow lagoons or small ponds made by man, often accidentally, and which promote the fractioning of the natural landscape pattern.

CONCLUSIONS

Malaria prevalence in the Paria Peninsula is strongly related to the landscape pattern configuration. When the landscape pattern was analyzed using metrics, an association with malaria disease prevalence values was obtained. Corresponding to the same year of the satellite image used, it was clear a spatial relation to wetlands sites nearest to human settlements, but also a tendency to form a continuous land track for malaria disease prevalence, due to the man made fractioning of the original landscape patterns. Values of metrics like fractal dimension and contagiousness, related to landscape fractioning process, strongly suggest that there is a factor favoring the stability of malaria disease in the zone, and there is evidence of a nested set of ecosystem interactions or a subsystem within the total ecosystem, that are reflected in the malaria disease prevalence. These result, as well as those from previous studies by Delgado and Ramos (2006), showed evidences that landscape use related to small parcel management for agriculture and cattle rising, at low level of technical development, have a significant incidence in raising the number of cases of malaria disease. Evaluation of the landscape configuration through metrics reinforced this result, as well as the interpretation of the relation of landscape pattern and malaria disease prevalence in rural environments in Venezuela.

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