Revista Mexicana de Biodiversidad 82: 679-687, 2011
http://dx.doi.org/10.22201/ib.20078706e.2011.2.463

The role of the matrix-edge dynamics of amphibian conservation in tropical montane fragmented landscapes

La dinámica del borde-matriz en bosques mesófilos de montaña fragmentados y su papel en la conservación de los anfibios

Georgina Santos-Barrera[1] and J. Nicolás Urbina-Cardona[1,2]*

[1]*Departamento de Biología Evolutiva, Facultad de Ciencias, Universidad Nacional Autônoma de México. 70-399, 04510 México D.F., México.*
[2] *Departamento de Ecología y Territorio. Facultad de Estudios Ambientales y Rurales, Universidad Javeriana. Transv. 4, núm. 42-00.*
**Correspondent: nurbina@yahoo.com*

Abstract . Edge effects play a key role in forest dynamics in which the context of the anthropogenic matrix has a great influence on fragment connectivity and function. The study of the interaction between edge and matrix effects in nature is essential to understand and promote the colonization of some functional groups in managed ecosystems. We studied the dynamics of 7 species of frogs and salamanders occurring in 8 ecotones of tropical montane cloud forest (TMCF) which interact with adjacent managed areas of coffee and corn plantations in Guerrero, southern Mexico. A survey effort of 196 man/hours along 72 transects detected 58 individuals of 7 amphibian species and 12 environmental and structural variables were measured. The diversity and abundance of amphibians in the forest mostly depended on the matrix context adjacent to the forest patches. The forest interior provided higher relative humidity, leaf litter cover, and canopy cover that determined the presence of some amphibian species. The use of shaded coffee plantations was preferred by the amphibians over the corn plots possibly due to the maintenance of native forest arboreal elements, low management rate and less intensity of disturbance in the coffee plantations than in the corn plots. Shaded coffee plantations reduce the edge effects in TMCF, improve the connectivity between TMCF fragments and increase habitat quality for the forest interior amphibian species. Future wildlife management research should take into account edge and matrix effects to understand species dynamics which move along anthropogenic-natural ecotones in managed ecosystems, thus prioritizing sites to buffer edge effects and increase habitat quality in remaining natural ecosystems.

Key words: amphibians, conservation, edge effects, environmental gradients, shaded coffee plantations, tropical montane cloud forest, vegetation structure.

Resumen. El efecto de borde es un evento clave en la dinámica de algunos bosques, la matriz que rodea a los fragmentos de bosque tiene una gran importancia en el funcionamiento y conectividad de estos fragmentos. El conocimiento de las interacciones entre el efecto de borde y la matriz es indispensable para entender el proceso de colonización de numerosos grupos de organismos en ecosistemas manejados o perturbados. Estudiamos la dinámica de 7 especies de ranas y salamandras que habitan en 8 ecotonos de bosque mesófilo de montaña que se encuentran adyacentes a zonas de cultivo de café y maíz en el estado de Guerrero, México. Tras un esfuerzo de captura de 196 horas/hombre a lo largo de 72 trayectos registramos 58 individuos de anfibios pertenecientes a 7 especies y se midieron 12 variables ambientales y estructurales. Se observó que la diversidad y la abundancia de los anfibios dependen del tipo de matriz adyacente al bosque. El interior del bosque proporciona a los anfibios mayor humedad relativa, mayor cobertura del dosel y de hojarasca. Estos resultados muestran que los anfibios prefieren los cafetales sobre los cultivos de maíz, posiblemente por la presencia de elementos de la vegetación original en los cafetales de sombra y a lo reducido de su manejo en comparación a los cultivos de maíz. Los cafetales reducen los efectos del borde en estos fragmentos de bosque mesófilo, mejoran la conectividad entre ellos e incrementan la calidad del ambiente para las especies que habitan en el interior del bosque. La investigación sobre el manejo de fauna silvestre debería tomar en cuenta este tipo de hallazgos para comprender la dinámica de las especies que se mueven a lo largo de ecotonos antropogénico-naturales.

Palabras clave: anfibios, conservación, efecto de borde, gradiente ambiental, cafetales de sombra, bosque mesófilo de montaña, estructura de la vegetación.

Recibido: 01 marzo 2010; aceptado: 22 septiembre 2010

Introduction

An irrefutable fact resulting from human development is the negative impact on natural environments. In this last decade, species has been fronting the collateral effects of the global biodiversity crisis due to the combination of several factors acting in synergy and causing enigmatic declines, perhaps more dramatic in amphibians than in any other vertebrate group worldwide (Stuart et al., 2004; IUCN, 2009). Changes in land use that directly cause habitat fragmentation and loss have been identified as the most critical factor affecting amphibian survival, although this has been poorly documented in the Neotropics (Cushman, 2006; Gardner et al., 2007; Urbina-Cardona, 2008).

Habitat fragmentation and the anthropogenic matrix surrounding forest fragments are one of the greatest barriers to amphibian dispersion by causing habitat loss and habitat split (Becker et al., 2007). In semi natural landscapes, forest fragments experience environmental shifts and the interspecific interactions generate an edge effect in the interface between the forest and the surrounding matrix with amphibians responding in a "cascade way" (Harper et al., 2005; Urbina-Cardona et al., 2006). The challenge for new conservationists is to learn how to deal with these new countryside landscapes composed mainly of patches of original vegetation commonly adjacent to human impacted or managed areas and settlements (Daily, 2001; Brown et al., 2008). The tropical montane cloud forest (TMCF) is at present one of the most threatened ecosystems worldwide. In Mexico TMCF exists as an archipelago formed by small fragments that tolerate a great rate of overexploitation (Challenger, 1998; Luna Vega et al., 1999) and have been declared as a priority for conservation by the Mexican Government due to their great diversity (Rzedowski, 1996; Challenger, 1998; Arriaga et al., 2000). In the case of amphibians, a distinctive group of the TMCF in Mexico, almost 50% of the known species which inhabit this ecosystem are endemic or micro endemic (Ochoa-Ochoa and Flores Villela, 2006).

The state of Guerrero, México accounts for an important diversity of amphibians reaching 70 species, 48% of these are endemic to the state (Pérez-Ramos et al., 2000). A great number of these species are currently classified as endangered or data deficient by the IUCN (2009). We studied an amphibian community inhabiting the Sierra Madre de Sur de Guerrero (SMSG) in order to assess the role of the matrix context for the amphibian dynamics based on the premise that the surrounding area of a forest patch may have a differential impact on the amphibian communities.

Materials and methods

Study area. El Molote is a communal or cooperative land spanning of about 8 411 ha located in the Municipality of Atoyac de Alvarez, state of Guerrero, Mexico (Fig. 1). The area is part of the SMSG system situated on the southern slope of the mountain range and southward to the highest peak of the area, the Teotepec (3 500 m asl; 17°24'50''-17°27'30''N and 100°09'40''-100°12'20''W). The community of El Molote is a small settlement with no more than 450 residents. The area was originally covered with TMCF, pine and pine-oak forests. Settlement of the area dates from the end of the 60's decade and since then extensive areas of TMCF have been intensively deforested and converted into cultivation land where the remnants of the original forest are now immersed in a matrix of managed areas (Lozada et al., 2003). The main productive activities of the community are the cultivation of coffee and corn in conjunction with cultivation of ornamental flowering plants (e.g. *Anthurium sp*.).

In the coffee plantations, the farmers maintain trees from the original forest to use as natural shade for the coffee plants which is a common practice in Mexico (Moguel and Toledo, 1999). The corn plantations are a monoculture which undergo a rotation management that includes clearing the parcels, burning of the dried debris, planting of corn, harvesting and abandonment of the parcel, followed by the colonization by different shrubs and ferns as *Pteridium aquilinum.* This complete cycle is repeated twice yearly. In the adjacent forest remnants there are some characteristic elements of the TMCF such as the trees *Alfaroa costaricensis* (Lauraceae) which occurs on the foothills forming forests that are gradually replaced upward with oaks (*Quercus).*

Study design and variables measured. The study was conducted in a 700 ha of TMCF fragment in which we selected 8 ecotones comprising 3 habitats (anthropogenic plantation-forest edge-forest interior) located north of El Molote. Four ecotones were adjacent to a coffee plantation and another 4 adjacent to a corn plantation. The ecotones were previously selected using digital aerial photographs and then verified in the field. We chose the matrix-forest ecotones under the following 3 criteria: 1) forest edge that had not been extensively managed or disturbed during the last 15 years, 2) forest edge associated with a coffee or corn plantation, 3) each ecotone with at least stream within or close by to standardize the relationship of this variable for the amphibian species with aquatic reproduction. Each ecotone was divided into 3 habitat types: plantation (corn or shaded coffee), forest edge (delimited within the first 20 m of forest), and forest interior (beyond the first 50 m

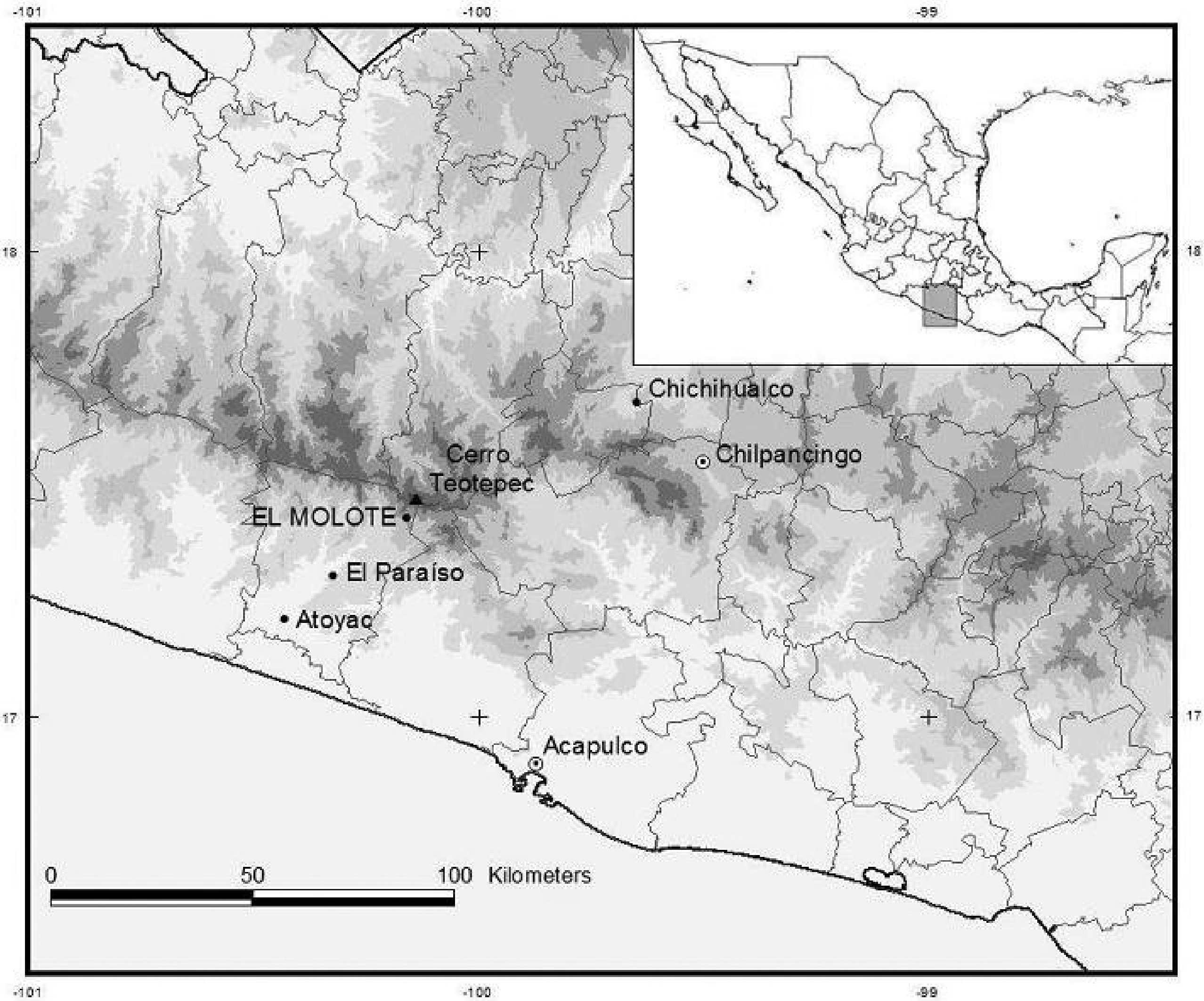

Figure 1. Location of the amphibian study site at the TMCF patches in El Molote town, Guerrero, México.

of forest from the edge to 150 m; *sensu* Williams-Linera et al., 1998; Urbina-Cardona et al., 2006). At each of these habitats we placed 3 permanent transects of 50 m in length chosen randomly and separated by predefined distances from the forest edge (Fig. 2). The study included 9 transects in each of the 8 ecotones for a total of 72 permanent transects.

Data were collected during 4 seasons covering 2 periods in the dry season (May 2007 and February 2008) and 2 periods during the rainy season (September 2007 and August 2008). For standardization purposes each transect was surveyed by 2 persons at night, searching during 20 minutes for amphibians from all possible microhabitats within 1 m along each side of the transect and up to 2 m in height for a total effort of 192 man/hours. For each organism 6 microhabitat variables were measured following Urbina-Cardona et al. (2006): temperature, relative humidity, leaf litter depth, height from forest floor, herbaceous cover and leaf litter cover. The temperature and humidity were obtained with a remote sensor Thermo hygrometer. Leaf litter depth and height from forest floor was directly measured by using a scaled ruler. The herbaceous and leaf litter coverage were estimated with a plastic 4 X 4 nylon divided quadrant. Other 6 variables depicting the site were measured at each transect: distance to the edge, altitude, distance to the town, distance to streams, canopy cover

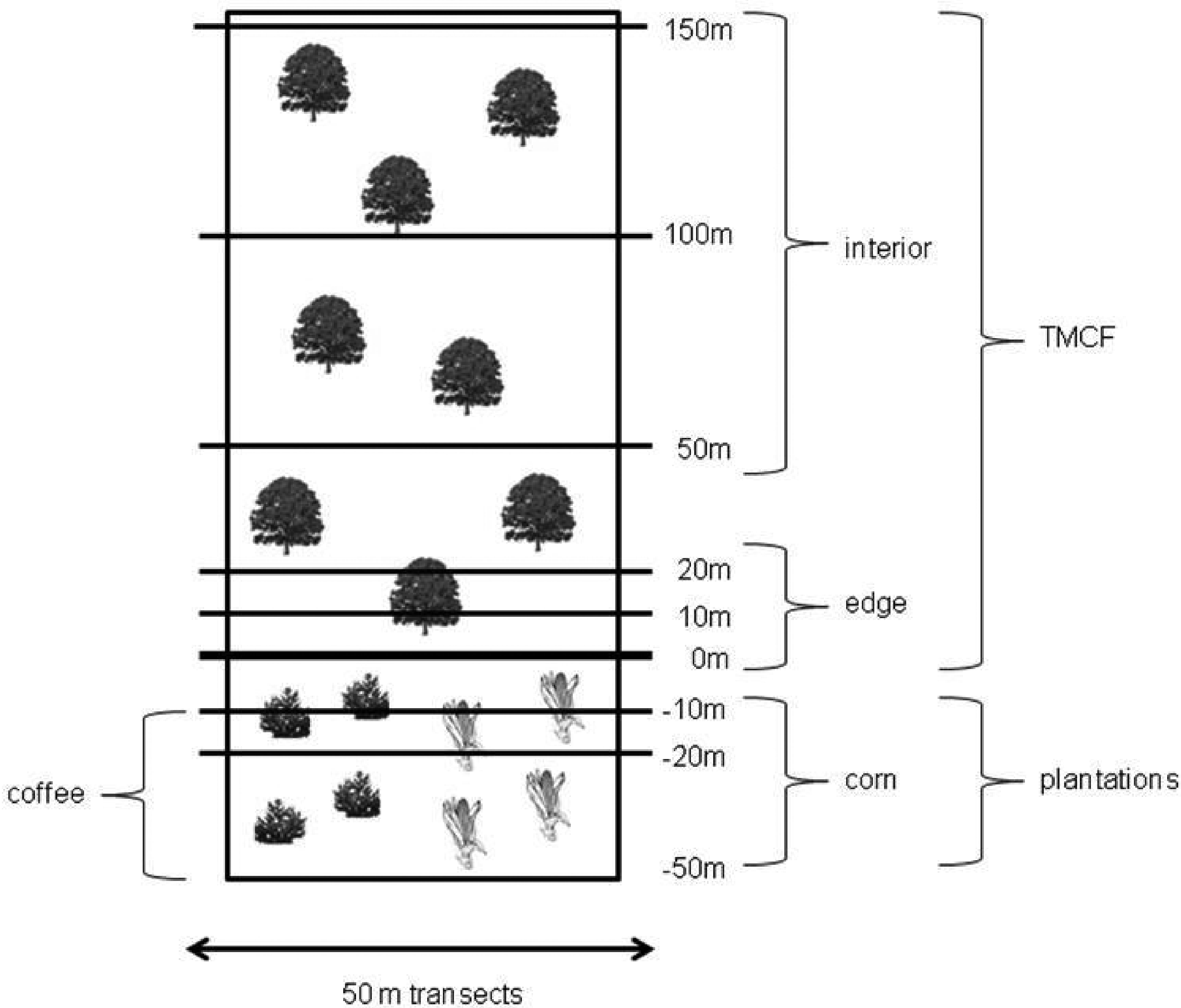

Figure 2. Study design to survey amphibian ensembles in the ecotones matrix (coffee or corn)-forest edge- forest interior in the TMCF in El Molote, Guerrero, Mexico.

and slope. All distances were calculated with the use of a GPS from the transects to the nearest forest edge, stream and town; altitude was directly measured with an altimeter; slope with a clinometer; and the canopy cover was estimated with a spherical densitometer by measuring 4 times (facing north, east, south and west), the number of filled quadrants with canopy vegetation reflected in a convex mirror. The following formula was used to calculate open spaces in the canopy: the total count is multiplied by 1.04 to obtain percent of overhead area not occupied by canopy.

Data analyses. To compare species richness among study habitats with an equal sampling effort, we made a prediction of species richness using 3 non-parametric estimators Bootstrap, Chao1 and Chao2 in the EstimateS 8 program (Colwell, 2005). The function of expected richness (Sobs) is the accumulation function of species along transects (n = 72) per habitat (Colwell, 2005). To determine the diversity between habitats (Beta diversity) we used the complementarity index that represent the distinctness of species composition between habitats ranging from 0 when amphibian composition for 2 habitats are identical, and 1 when the species composition are totally different (Colwell and Coddington, 1994). Pearson correlation coefficients were used to determine correlations among microhabitat variables and to identify non-correlated variables. All analyses were performed using the software Statistica (StatSoft, 2001).

Results

Species diversity and composition among habitats. A total of 58 individuals of 7 amphibian species were captured after 192 man/hours of survey effort. For the entire area, the expected richness according to the predictions was 87.5% (Table 1). The forest edge and interior were expected to have more additional species (1 and 4, respectively), if the survey effort increases. Based on the non-parametric richness estimators the survey represented all the expected amphibian species in coffee and corn plantations (Table 1). This just slightly differs from our observations of the amphibian diversity in the area.

The ensemble of species in the TMCF of El Molote was dominated by the Mexican robber frog (*Craugastor mexicanus*) and the pygmy free-fingered frog (*Craugastor pygmaeus*) with 39.6 and 38% of the total captures, respectively. Along the corn plantation-forest edge-forest interior, 4 individuals were recorded on the forest edge belonging to 2 dominant species (Table 1). Eighty-six percent of all amphibian richness was captured at forest edge and interior habitats and 28.5% at coffee and corn plantations (Table 1). The highest percentage of amphibian individuals were captured at the forest edge (43%) and in the forest interior (31%), meanwhile only 22 and 4% were captured in the coffee and corn plantations, respectively. At the forest edge and in forest interior habitats, 32-33% of the individuals were adults, 32-33% were juveniles and 33-36% were froglets. At the coffee plantations, 18% of the individuals were adults, 72% were juveniles and 9% were froglets (Table 1).

All habitats showed a low mean complementarity of 49% being (a) the coffee and corn plantations, and (b) the forest edge and forest interior (when limiting with shaded coffee plantations) showed the lowest complementarity index, which could indicate that they have a similar species composition (Table 2). The surrounding coffee matrix was equally dominated by *C. mexicanus* and *C. pygmaeus.* With regard to the seasonality analysis, during the wet season the observed richness was higher (86%), as well as, the abundance of individuals (64%) than in dry season, excepting perhaps for 1 season for *C. pygmaeus* (Table 3).

Correlation among environmental variables. Some of the environmental variables were strongly correlated (Table 4). A high direct positive correlation between distance to streams and slope was found. Relative humidity was negatively correlated with temperature and distance to river, and positively correlated with canopy cover (Table 4). The matrix–edge–interior distance gradient was positively related to relative humidity, leaf litter cover, and canopy cover; and negatively related with slope and distance to streams (Table 4). Altitude did not correlate significantly with the matrix–edge–interior distance gradient (Table 4), demonstrating that the effect of this variable was adequately controlled by the sampling design in this study.

Discussion

The data obtained from our study seem to indicate that species diversity and abundance of amphibians in El Molote are low. Recently, in another study of herpetofaunal diversity of the TMCF at El Molote and surroundings, similar results were found (Blancas Hernández, pers. comm. 2009). According to that data and the predictions used in the study, the estimated species richness is not considerably different from our results (see Tables 1 and 2). Outside of the surveyed transects we found the Pine toad (*Incilius occidentalis*), although close to the study sites, but closer to the human settlement suggests a tolerance by this species to disturbed areas. In general, the study area supports a natural low abundance and as well as a low diversity of amphibian species when compared to other TMCF adjacent to coffee plantations, such as the ones located at the Atlantic versant of Mexico (see Pineda and Halffter, 2004; Pineda et al., 2005; Gonzalez-Romero and Murrieta-Galindo, 2008). In this study 2 leaf litter species (*C. mexicanus* and *C. pygmaeus*) were the most abundant in the area, but the population structure and viability of the other 2 salamanders and 3 frogs studied here should be carefully treated due to their high degree of rarity, endemism and vulnerability to habitat fragmentation. Urbina-Cardona and Loyola (2008) determined that *C. mexicanus* and *C. pygmaeus* require additional protection since the present distribution of these species includes only the periphery of the Federal Protected Areas (PA), even with the support of the Social Initiatives in Conservation (SIC) the area is not large enough to guarantee their survivorship (Ochoa-Ochoa, et al., 2009). The SIC's are fragments of land, private or communal dedicated to protect biodiversity. *Plectrohyla pentheter* is protected in 6.4% of its remnant distribution in PA's and 18.7% by SIC's, while *Ptychohyla leonhardschultzei* is protected 5.3% by PA's and by 17.7% by SIC's. Pineda and Halffter, (2004) observed that the capacity of anthropogenic habitats to support frog fauna varied notably between the shaded coffee plantations and

Table 1. Abundance, age structure, species diversity, and observed and estimated species richness for habitats at the entire landscape studied in the TMCF of El Molote, Guerrero, Mexico

		Cofee-TMCF ecotone			*Corn-TMCF ecotone*
	Landscape	*Coffee*	*Forest edge*	*Forest interior*	*Forest edge*
Abundance	58	11	25	18	4
Adult/Juvenile/Froglets	16/23/19	2/8/1	8/8/9	6/6/6	0/1/3
Sobs	7	2	6	6	2
Chao1	8	2	7	9	2
Chao2	8	2	7	10	2
Bootstrap	8	2	7	7	2

Table 2. Species complementarity values between habitats along the ecotones in the TMCF of El Molote, Guerrero, Mexico**.** Bold values correspond to the number of unique species in each habitat. Up to boldface numbers are the complementarity values, 0= species composition are identical between 2 habitats, 1= species composition completely different between 2 habitats

	Cofee-TMCF ecotone			*Corn-TMCF ecotone*
Habitat	*Coffee*	*Forest edge*	*Forest interior*	*Forest edge*
Coffee	**0**	2	2	2
Coffee-Forest edge	0.66	**1**	5	2
Forest Interior	0.66	0.28	**1**	2
Corn-Forest edge	0	0.66	0.66	**0**

Table 3. Species richness and abundance in wet and dry seasons across 2 ecotones limited by coffee and corn matrices respectively, in the TMCF of El Molote, Guerrero, Mexico

	Cofee-TMCF ecotone						*Corn-TMCF ecotone*					
	Coffee		*Edge*		*Interior*		*Corn*		*Edge*		*Interior*	
	WET	*DRY*	*WET*	*DRY*	*WET*	*DRY*	*WET*	*DRY*	*WET*	*DRY*	*WET*	*DRY*
Pseudoeurycea sp1.	0	0	1	0	0	0	0	0	0	0	0	0
Pseudoeurycea sp2.	0	0	2	0	1	0	0	0	0	0	0	0
Craugastor pygmaeus	0	5	2	11	1	2	0	0	1	0	0	0
Craugastor uno	0	0	1	1	1	0	0	0	0	0	0	0
Craugastor mexicanus	5	1	6	0	8	0	0	0	3	0	0	0
Plectrohyla pentheter	0	0	1	0	4	0	0	0	0	0	0	0
Ptychohyla leonhardschultzei	0	0	0	0	0	1	0	0	0	0	0	0
Total abundance	5	6	13	12	15	3	0	0	4	0	0	0
Species Richness	1	2	6	2	5	2	0	0	2	0	0	0

Table 4. Pearson correlation coefficients among 12 environmental variables measured in the TMCF of El Molote,Guerrero, Mexico. Bold values correspond to the significant correlations. *p Values* [a] *<0.05,* [b]*<0.01,* [c] *<0.001*

Variable	*Dist. edge*	*Temp*	*Relat. Humid.*	*Leaf litter depth*	*H from floor*	*Grass cover*	*Leaf litter cover*	*Altitude*	*Dist. to town*	*Dist. to stream*	*Canopy cover*
Distance to edge	1										
Temperature	-0.18	1									
Relative humidity	**0.36**[b]	**-0.35**[b]	1								
Leaf litter depth	0.18	0.23	-0.01	1							
h from floor	0.22	0.1	0.003	0.1	1						
Grass cover	0.06	0.12	0.09	-0.05	-0.11	1					
Leaf litter cover	**0.31**[b]	-0.1	0.1	**0.4**[b]	0.006	0.01	1				
Altitude	-0.09	-0.07	-0.03	0.2	-0.2	-0.14	0.16	1			
Distance to town	-0.1	0.13	0.05	**-0.3**[a]	-0.06	0.08	-0.2	**-0.35**[b]	1		
Distance to streams	**-0.7**[c]	0.15	**-0.56**[c]	-0.15	-0.06	-0.11	-0.1	0.25	-0.13	1	
Canopy cover	**0.34**[b]	**-0.27**[a]	**0.26**[a]	-0.01	0.1	-0.2	0.06	**-0.28**[a]	0.25	**-0.48**[c]	1
Slope	**-0.56**[c]	0.002	-0.21	-0.1	-0.15	-0.13	-0.07	0.22	0.12	**0.51**[c]	**-0.31**[a]

pastures. Anthropogenic habitat disturbances generate changes in the composition, diversity and abundance patterns of frogs, although those variables might change between seasons-habitat gradients (Caceres-Andrade and Urbina-Cardona, 2009). In this study we conclud that the interior of TMCF, when limited by coffee plantations supports a higher amphibian diversity than the remaining habitats. Furthermore, it can be noted that the forest edge is a preferred habitat for the amphibians, as has been found in other fragmented tropical landscapes. The amphibians can move along the ecotone for reproduction or just movement (Gascon et al., 1999).

Although capture rates were low, it can be noted that the composition and abundance is clearly different between coffee and corn plantations, the results of this study show a clear trend to define the context of coffee plantations as an important habitat to attenuate the edge effects for amphibian species in the TMCF by increasing the quality of the forest interior. On the contrary, the corn plantations negatively affect amphibian's habitat quality in the remaining forest due to higher disturbance intensity and frequency and different vegetation structure, this can be confirmed from the absence of individuals along the ecotone.

The majority of species recorded in this study were captured during the wet season, the activity of amphibians decreased during the dry season which extends for no more than 3 months and its effects were stronger along corn-forest edge-forest interior gradients. Some species, like the endangered endemic species, P. pentheter, and the 2 salamanders (Pseudoeurycea sp1. and sp.2) were only recorded at the edge and forest interior during the wet season and exclusively when the forest were associated with shaded coffee plantations. Considering that the forest interior provides higher relative humidity, leaf litter cover, and canopy cover and that the presence of some amphibian species is determined by those variables, it is expected that edge effects over amphibians in the TMCF could be amplified during drought-related climatic extremes as demonstrated by this study along corn-forest edge-forest interior gradients. In other additional surveys it was observed that during the dry season many amphibian individuals congregate at the permanent streams located at the edges of the forest.

The TMCF of El Molote is immersed in one of the priority regions for conservation in Mexico (Arriaga et al., 2000; Urbina-Cardona and Flores-Villela, 2010). In this last decade, the authorities and population from El Molote decided to assign part of the land for forest protection thus creating a non Federal declared protection area, but a common land where non exploitation of resources is supposedly permitted, then acting as a SIC. Recently, it was demonstrated that these types of areas may play an important role in the protection of endemic amphibian species including several species not integrated in the Natural Protected Area System of Mexico (Ochoa-Ochoa et al., 2009). In addition, several coffee and other abandoned cultivation areas in the region are in the process of reforestation due to an ambitious program of the Mexican Government called PROARBOL which is dedicated to restore extensive areas previously devoted to coffee or flowering plant cultivation that had insignificant production therefore substituting these non productive activities with trees.

Based on the results of several studies, we propose to improve the use of shaded coffee plantations more so than other land use (e.g. pastures, corn plantations) in order to increase ecological connectivity, which may also allow the colonization of other biological groups and therefore the persistence of biodiversity in fragmented montane landscapes. The design of this present study can be replicated in other similar habitats to study the dynamics of the amphibian and even reptile communities occurring in disturbed habitats and this type of management may promote the preservation biological diversity. In the scope of this new scenario of human dominated landscapes any effort to preserve the biodiversity should be welcomed, especially in countries where limited economic resources are addressed for conservation projects. In these fragmented landscapes, amphibian conservation efforts should be focused at a local scale (e.g. reproduction sites) and regional scale (e.g. the establishment of additional conservation areas) to prevent the extinction-driven process. For the case of the SMSG region where habitat fragmentation is increasing, the conservation of the TMCF should focus on the management of the internal dynamics and in the case of small fragments this management should be centered on the external influences from the surrounding matrix.

Acknowledgments

This project was fully supported by the Conservation Leadership Program (CLP-United Kingdom). We also thank the people of El Molote and surroundings areas, especially Gelasio Valladares for the permission to conduct this research in the forest El Molote. Thanks to Leticia Barragán, María Cecilia Londoño, Emilio Saturno, Mariel Familiar, and Luis Felipe Hernández for her invaluable guidance and assistance in the field. To Cristian Blancas and Luis Canseco for species identification and field collaboration.

Literature cited

Arriaga, L., J. M Espinoza, C. Aguilar, E. Martínez, L. Gómez and E. Loa (eds.). 2000. Regiones terrestres prioritarias de México. Comisión Nacional para el Conocimiento y uso de la Biodiversidad, México. Mexico, D. F. 609 p.

Becker, C. G., C. R. Fonseca, C. F. B. Haddad, R. F. Batista and P. I. Prado. 2007. Habitat split and the global declines of amphibians. Science 318:1775-1777.

Brown, G. W., A. F. Bennett and J. M. Potts. 2008. Regional faunal decline – reptile occurrence in fragmented rural landscapes of south-eastern Australia. Wildlife Research 35:8-18.

Caceres-Andreade, S. and J. N. Urbina-Cardona. 2009. Anuran ensembles inhabiting productive systems and forests at the Piedemonte Llanero, Meta department, Colombia. Caldasia 31:175-194.

Challenger, A. (ed.). 1998. Utilización y conservación de los ecosistemas terrestres de México: pasado, presente y futuro. CONABIO-UNAM, Instituto de Biología-Agrupación Sierra Madre. Mexico D. F., Mexico. 847 p.

Colwell, R. and J. Coddington. 1994. Estimating Terrestrial Biodiversity through extrapolation. Philosophical Transaction: Biological Science 344:101-108.

Colwell, R. K. 2005. EstimateS: Statistical estimation of species richness and shared species from samples. Version 8.0.0. User's Guide and application published at: http://purl.oclc.org/estimates

Cushman, S. A. 2006. Effects of habitat loss and fragmentation on amphibians: A review and prospectus. Biological conservation 128:231-240.

Daily, G. C. 2001. Ecological forecast. Nature 411:245.

Gardner, T. A., J. Barlow and C. A. Peres. 2007. Paradox, presumption and pitfalls in conservation biology: The importance of habitat change for amphibians and reptiles. Biological Conservation 138:166-179.

Gascon, C., T. E. Lovejoy, R. O. Bierregaard, J. R. Malcolm, P. C. Stouffer, H. Vasconcelos, W. F. Laurance, B. Zimmerman, M. Tocher and S. Borges. 1999. Matrix habitat and species persistence in tropical forest remnants. Biological Conservation 91:223-229.

González-Romero, A. and E. Murrieta. 2007. Anfibios y Reptiles. *In* Agroecosistemas cafetaleros de Veracruz: biodiversidad, manejo y conservación, R. H. Manson, V. Hernández-Ortíz, S. Gallina and K. Mehltreter (eds.). Instituto de Ecología, A.C. - Instituto Nacional de Ecología-SEMARNAT: Mexico, D. F. p. 135-147.

Harper, K. A., S. E. Macdonald, P. J. Burton, J. Chen, K. D. Brosofske, S. C. Saunsders, E. S. Euskirchen, D. Roberts, M. S. Jaiteh and P.A. Essen. 2005. Edge influence on forest structure and composition in fragmented landscapes. Conservation Biology 19:768-782.

International Union for Conservation of Nature - IUCN. 2009. IUCN Red List of Threatened Species. Version 2009.1 <http://www.iucnredlist.org>; last access: 29.V.2009.

Lozada, L., M. E. León, J. Rojas and R. de Santiago. 2003. El Bosque mesófilo de montaña en El Molote, Estudios Florísticos en Guerrero, No. 13. Facultad de Ciencias, Universidad Nacional Autónoma de México, México, D. F. 35 p.

Luna-Vega, I., O. Alcántara Ayala, D. Espinosa Organista and J. J. Morrone. 1999. Historical relationships of the Mexican cloud forest: a preliminary vicariance model applying parsimony analysis of endemicity to vascular plant taxa. Journal of Biogeography 26:1299-1305.

Moguel, P. and V. M. Toledo. 1999. Biodiversity conservation in traditional coffee systems of Mexico. Conservation Biology 13:11-21.

Ochoa-Ochoa, L. M. and O. Flores-Villela. 2006. Áreas de diversidad y endemismo de la herpetofauna mexicana. UNAM-CONABIO, México D.F. 211 p.

Ochoa-Ochoa, L., J. N. Urbina-Cardona, O. Flores-Villela, L-B. Vázquez and J. Bezaury-Creel. 2009. The role of land protection through governmental protected areas and social action in biodiversity conservation: the case of Mexican amphibians. PlosOne 4:6878. doi:10.1371/journal.pone.0006878.

Pérez-Ramos, E., L. Saldaña de la Riva and Z. Uribe-Peña. 2000. A checklist of the reptiles and amphibians of Guerrero, Mexico. Anales del Instituto de Biologia, Universidad Nacional Autónoma de México. Serie Zoología 71:21-40.

Perfecto, I., A. Mas, T. Diestch and J. Vandermeer. 2003. Conservation of biodiversity in coffee agroecosystems: a tri taxa comparison in southern Mexico. Biodiversity and Conservation 12:1239-1252.

Pineda, E. and G. Halffter. 2004. Species diversity and habitat fragmentation: frogs in a tropical montane landscape in Mexico. Biological Conservation 117:499-508.

Pineda, E., C. Moreno, F. Escobar, and G. Halffter. 2005. Frog, bat and dung beetle diversity in the cloud forest and coffee agrosystems of Veracruz, Mexico. Conservation Biology 19:400-410.

Rzedowski, J. 1996. Análisis preliminar de la flora vascular de los bosques mesófilos de montaña de México. Acta Botánica Mexicana 14:3-21.

Statsoft. 2001. *STATISTICA:* Data analysis software system, Version 6.0. StatSoft. Oklahoma.

Stuart, S., J. Chanson, N. A.Cox, B. E.Young, A. S. L.Rodrigues, D. L. Fishman and R. W. Waller, 2004. Status and trends of amphibian declines extinctions worldwide. Science 306:1783-1786.

Urbina-Cardona, J. N., M. Olivares- Pérez and V. H. Reynoso. 2006. Herpetofauna diversity and microenvironment correlates across the pasture-edge-interior gradient in tropical rainforest fragments in the region of Los Tuxtlas, Veracruz. Biological Conservation 132:61-75.

Urbina-Cardona, J. N. and R. D. Loyola. 2008. Applying niche-based models to predict endangered-hylid potential distributions: Are neotropical protected areas effective enough? Tropical Conservation Science 1:417-445.

Urbina-Cardona, J. N. 2008. Conservation of Neotropical herpetofauna: research trends and challenges. Tropical Conservation Science 1:359-375.

Urbina-Cardona, J. N. and O. Flores-Villela. 2010. Ecological-niche modeling and prioritization of conservation-area networks for Mexican herpetofauna. Conservation Biology 24:1031-1041.

Williams-Linera, G., V. Domínguez-Gastelu and M. E. Garcıa-Zurita. 1998. Microenvironment and floristics of different edges in a fragmented tropical rainforest. Conservation Biology 12:1091-1102.