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A BIOLOGICAL CORRIDOR FOR THE SIERRA MADRE ORIENTAL (SAN LUIS POTOSÍ, MEXICO): SOCIO-ECONOMIC VIABILITY FOR ENHANCING CONNECTIVITY

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ABSTRACT

Biological corridors have been developed as a conservation strategy to counteract biodiversity loss caused by habitat fragmentation. However, such areas are usually not under any protection category; therefore, their establishment has to consider biodiversity conservation and socio-economic aspects, which determine the viability of the corridor. The aim of this research was to integrate biophysical and socio-economic variables to find the best routes of connectivity for flora and fauna between relevant areas for biodiversity conservation. I conducted the research in the Sierra Madre Oriental, which has been proposed as a biological corridor and is under development but has not been established yet. I focused my work on the range located in the state of San Luis Potosí. Routes were obtained following several steps. First, I used MaxEnt to model the distribution of endemic species for Mexico and the Sierra Madre Oriental. With these models I determined areas with high levels of endemism; which were considered as priority sites for conservation. Second, suitability maps were created in the program IDRISI Selva with the integration of biophysical, social and economic parameters using a multi-criteria evaluation. Third, through a cost-distance analysis in ArcGIS, I obtained the best routes of connection between the priority sites and the protected areas using as the cost matrix the suitability maps. Finally, additional social and economic variables were measured in 9 ejidos through the application of questionnaires in the field. This information was used to determine the potential of these ejidos to be incorporated in different conservation strategies within the corridor. Four connection paths are proposed; these routes are located in the municipalities of El Naranjo, Ciudad Valles, Aquismón, Armadillo de los Infante, San Nicolás Tolentino, Ciudad Fernández, and Matlapa. In addition, from the sampled ejidos, *La Gavia* and *Gustavo Garmendia* showed the highest potentiality of participating in initiaties of conservation. The results of this research are useful to the definition of areas were conservation efforts and economic resources can be allocated.

RESUMEN

Los corredores biológicos han sido desarrollados como una estrategia de conservación para contrarrestar la pérdida de biodiversidad causada por la fragmentación del hábitat. Sin embargo, estas áreas no están consideradas bajo ninguna categoría de protección. Es por eso que su establecimiento debe considerar aspectos de conservación de la biodiversidad y socio-económicos, los mismos que determinarán la viabilidad del corredor. El objetivo de esta investigación fue integrar variables biofísicas y socio-económicas para definir rutas de conexión para flora y fauna entre áreas de importancia para la conservación. El estudio se llevó a cabo en la Sierra Madre Oriental (San Luis Potosi), cuya propuesta para constituir un corredor biológico está siendo desarrollada. Las rutas de conexión fueron obtenidas siguiendo varios pasos. Primero, se realizaron modelos de distribución de especies endémicas para México y la Sierra Madre Oriental usando el programa Maxent. Con las distribuciones obtenidas se obtuvieron áreas con niveles altos de endemismo, denominados sitios prioritarios para la conservación. Segundo, mediante la integración de variables biofísicas, sociales y económicas a través de un análisis multicriterio en IDRISI Selva, se crearon mapas de facilidad de movimiento. Tercero, con un análisis de costo-distancia en el programa ArcGIS, se obtuvieron rutas de conexión entre los sitios prioritarios para la conservación y las áreas naturales protegidas. Finalmente, se aplicaron cuestionarios en 9 ejidos para la obtención de información social y económica. Esta información fue usada para determinar el potencial de estos ejidos para ser incorporados en diferentes estrategias de conservación dentro del corredor. Como resultados principales, se proponen 4 rutas de conectividad localizadas en los municipios de El Naranjo, Ciudad Valles, Aquismón, Armadillo de los Infante, San Nicolás Tolentino, Ciudad Fernández, y Matlapa. Adicionalmente, de los ejidos muestreados en campo, La Gavia y Gustavo Garmendia mostraron potencial más alto para participar en iniciativas de conservación. Los resultados de esta investigación son importantes para la definición de áreas para enfocar esfuerzos de conservación y recursos económicos

1. INTRODUCTION

1. 1. THEORETICAL FRAMEWORK

Fragmentation: causes and consequences

An important consequence of deforestation is habitat fragmentation, which is defined as the transformation of a continuous habitat into patches (Fahrig, 2003). This process can be natural, although, when it is attributed to human causes, the consequences are reflected in some variables like velocity and pattern of change, scale and recuperation ability of the resulting patches (Hilty *et al*., 2006). For example, regarding to the velocity of change, cycles of 100000 years of glacial periods separated by interglacial periods of 20000 years caused fragmentation across large areas; nevertheless, during that period species were able to evolve separately and give rise to speciation (Hilty *et al*., 2006). Whereas, in Mexico, for example, fragmentation has been induced by the deforestation of the 50% of the vegetation cover in the last 20 years (Sahagún-Sánchez *et al*., 2011); this process, rather than speciation produces the declination of species' populations (Hilty *et al*., 2006).

In general, the main effects of fragmentation are: i) reduction in habitat amount (habitat loss), ii) increase of the number of habitat patches, iii) decrease in sizes of habitat patches, and iv) increase in isolation of patches. The effects of fragmentation per se on biodiversity are not well known because of the lack of empirical studies demonstrating this process separately from other parameters. Its impacts on biodiversity depend on the effects of fragmentation taken into account when measuring it (Fahrig, 2003).

Habitat loss, being the most obvious effect of fragmentation, has been largely studied and several negative consequences on biodiversity have been identified; such as: species richness, abundance, distribution, genetic diversity, population growth rate, reduction of trophic chain length, species interactions, breeding success, predation rate, among others (Fahrig, 2003).

Another consequence of fragmentation on biodiversity, measured through patch isolation, is genetic isolation. Due to geographical isolation the movement of populations between patches is restricted. Isolation of plant and animal populations, could potentially affect population viability and reduce their fitness (Hilty *et al*., 2006).

The necessity of counteracting these effects has lead to conservation measures to re-connect the landscape, such as biological corridors. Biological corridors are spatial structures composed by forests' remnants or other ecosystems; these allow the flux of species, matter, energy, and information between different habitats (Morera *et al.*, 2007).

The next section describes and defines important terms and features of biological corridors.

Theory about biological corridors

Biological corridors have been developed to counteract the effects of fragmentation (Lees and Peres, 2008). Corridors can be defined as a space, usually linear, that enhance the ability of organisms to move between habitat patches. Their main function is to promote connectivity, which is a measure of the extent to which plants and animals can move between habitat relicts (Hilty *et al*., 2006). Moreover, EUROPARC (2009) define connectivity as a property of the landscape that makes possible the flux of matter, energy and organisms between different ecosystems, habitats or communities.

Additionally, the following positive features can be related with corridors too: enhancing of immigration rates, maintenance of species richness and diversity, they can constitute habitat for some species, provide foraging, increase chances of escape from predators and disturbances, and avoid inbreeding depression in small populations (Chapa-Vargas, 1996).

Nevertheless, there is also controversy about their benefits, as some skeptics have questioned their function as landscape connectors (Beier and Noss, 1998); indeed, corridors can serve as connectors to some species but not to all the species depending on their vagility; they can even represent a barrier to some others (Hilty *et al*., 2006). Moreover, some authors suggest that they might promote spread of diseases, catastrophic disturbances (like wildfires), exotic or predator species into areas connected by corridors or lure animals into areas where they experience a high mortality, increase of negative edge effects, and provide non suitable habitat for area-sensitive species (Beier and Noss, 1998; Chapa-Vargas, 1996). However, there are no studies that had demonstrated these negative impacts and some of the effects like enhance predation can be diminished by increasing the width of the corridor (Beier and Noss, 1998; Chapa-Vargas, 1996).

There are different types and categories of corridors. On one hand, there are the facto corridors, which are unplanned corridors, human made or natural features of the landscape. These consist of locations where optimal habitat is left undisturbed, providing a different vegetation from the surrounding matrix. Some examples of the facto corridors are roadside corridors, fencerows, unmanaged ditches, creeks, shelterbelts, etc. On the other hand, there are planned corridors, which are designed for specific purposes. Some examples are greenways or greenbelts, riparian buffers, ecoducts, etc. (Hilty *et al*., 2006).

Furthermore, corridors can be grouped in three classes: permeable landscape, linear corridor and stepping-stones. A permeable landscape is composed by forests' patches of different stages of maturity; they permit the dispersion of certain species through forests remnants and other elements like fences or edges. A linear or continuous corridor permits the dispersion of animals and plants along them. Finally, stepping-stones are habitat patches immersed in a more or less impermeable matrix (EUROPARC, 2009).

Herein, the term matrix arises and it is important to define it due to its importance as a component of landscape structure and function. Matrix is the nature and spatial extent of communities surrounding focal habitat patches (Hilty *et al*., 2006). The features of the matrix will influence the degree of connectivity. In human-modified landscapes, the matrix usually consists of landscape features that caused fragmentation in the first place. Whereas, natural heterogeneous landscapes are composed by a mosaic of different vegetation patches. The designation of matrix depends on the target community of interest; for instance, the matrix considered when studying a frog is different from that for studying big mammals or birds (Hilty *et al*., 2006).

It has been suggested that biological corridors have been introduced as public policies too soon, without research proving their effectiveness (Chapa-Vargas and Monzalvo-Santos, 2012). Simberloff *et al*. (1992) are also very critical with the investment of economic resources in biological corridors; they argue that there are weak theoretical and empirical bases proving their effectiveness. In order for corridors to accomplish their function, good planning is essential. In particular, suitable areas must be selected to allow species movement; but a good planning and design have to take into account ecological, social and economic aspects (Williams, 1998).

In regard to the methodologies to establish corridors or measure connectivity between habitat/forest patches, a generalization can be done. They are based in physical and biological (habitat patches, quality of patches, species movement, matrix characteristics, etc.) features of the landscape. Some of these methodologies are the connected subgraph problem and minimum cost (Conrad *et al*., 2012), integral index of connectivity (Pascual-Hortal and Saura, 2006), cell immigration (Tischendorf and Fahrig, 2000a), circuit theory (McRae *et al*., 2008), cost-distance method, the conditional minimum transit cost and the multiple shortest paths (Pinto and Keitt, 2009), between others.

The method used in this study for calculating the best routes of connection was the least-cost distance (see methods). The cost-distance method (or least-cost distance) is widely used and is the basis for calculating paths in some GIS software as ArcGIS (Redlands, CA, 2011) and IDRISI (Eastman, 2012). The least cost distances consider spatial heterogeneity and movement resistance (friction) within the landscape (Foltete *et al*., 2008).

Nevertheless, most of the researches that have used these methodologies have not considered or included into their analyses social constraints; which is fundamental for the accomplishment of corridors' connectivity and conservation objectives.

1.2. BIODIVERSITY AND CONSERVATION IN MEXICO

Deforestation and biodiversity loss in México

Biodiversity is not uniformly distributed along the planet. In general, the tropical areas have the 75% of the world biodiversity; 7 of the 25 biologically richest eco-regions of the world are located in these areas (PNUMA, 2005). Nevertheless, there is a considerable loss of biodiversity due to human activities and, the accelerated loss rate of tropical and temperate forests is leading to the risk of the survival of species with restricted localities (PNUMA, 2005).

Mexico is a megadiverse country due to the high number of species, high level of endemism, richness of ecosystems, and wide genetic variability in some taxonomic groups (Espinosa Organista and Ocegueda Cruz, 2008). Unfortunately, the actual state of biodiversity is negatively impacted by human's activities. The state and the trends of change in biodiversity are related to social, economic, and political issues (Challenger and Dirzo, 2009).

Some of the drivers of biodiversity degradation are changes on vegetation cover and land use, overexploitation of organisms, introduction of invasive species, climate change and use of contaminant agents in industry and agriculture (Challenger and Dirzo, 2009).

However, the main driver is the land use change; by 2002, forests' coverage had changed and it was left around the 38% of the original cover. Mexico has, along with Brazil and Costa Rica, one of the highest rates of land use change in America (Sahagún-Sánchez *et al*., 2011). This land use change is often caused by deforestation; the rate of deforestation of Mexico was 0.51% per year between 1976 and 2000 and 1.3% between 1993 and 2000, where forests and scrubland were converted mainly to cropland and pastures (Mas *et al*., 2004).

In fact, 50% of the vegetation cover has been lost in the last 20 years (Sahagún-Sánchez *et al*., 2011). From 1990 to 2010 there was a diminution of forests of 5.5 millions hectares (FAO, 2010). In addition, most of the remnant vegetation is fragmented and in different states of conservation, with a high amount of secondary vegetation (Challenger and Dirzo, 2009).

Moreover, close to 80% of the remaining forest in Mexico are owned by ejidos[1] or indigenous communities (Bray and Perez, 2004 refered in Barnes, 2009) and this can represent some difficulties for its management and conservation, especially if the socio-economic factor is not included in the conservation plans. Most of the people in the ejido areas depend economically on the natural resources present in their territory (Thoms and Betters, 1998).

The portion of the Sierra Madre Oriental located in San Luis Potosí has lost more than 36200 ha of its natural cover from 1989 to 2005. The majority of the loss occurred in tropical moist forests (24013 ha) and in temperate and cloud forests (7600 ha). In contrast, rain-fed (25835 ha) and irrigated (2813 ha) agriculture, pastureland (6705 ha) and secondary vegetation (661 ha) have increased (Sahagún-Sánchez *et al*., 2011). These values represent an annual rate of deforestation of 2% for the Sierra Madre Oriental (Sahagún-Sánchez *et al*., 2013).

In general, some of the main causes of deforestation in Mexico are the increase of land used for agriculture and livestock, and the expansion of urban and industrial areas (CONAFOR, 2012). Furthermore, illegal logging, fires and the presence of plagues and diseases of trees threaten the forests. Other causes driving forests' degradation of the country are excessive grazing, inefficient forest management and the increase of the intensity of slash and burn agriculture. These

[1] An ejido is a type of land property that was created with the purpose of protecting people's collective properties. They are defined as parcels of land collectively owned and worked by the official tenants or ejidatarios (Assennatto and de León, 2006). Nevertheless, since the agrarian reform of 1992, the tenure regime can change from collective to private property and individual lots can be sold to other members or leased to outsiders (Barnes, 2009). The title of ejidatario can only be inherited; and, outsiders that buy a land in an ejido are called possessors. The decisions in an ejido are taken only by the ejidatarios; a possessor does not have the right to participate in the decision-making process (Ferney-Leonel, 2011).

causes are originated by the constant pressure of the population to satisfy their basic needs (CONAFOR, 2012).

Despite the negative anthropogenic impacts on ecosystems, there are also actions to counteract the biodiversity loss, such as reforestation programs, soil restoration, agroforestry programs, UMAS (Units for sustainable management), ecotourism, PES (Payment for ecosystem services), and establishment of protected areas (Challenger and Dirzo, 2009).The latter one has been a major strategy widely spread in most of the countries world-wide (Ceballos, 2007). Therefore, in the next section I will describe the different types of protected areas, both at the international level and specifically in Mexico, and how biological corridors fit into the categorization of these areas.

Protected Areas and Biological Corridors in Mexico

The International Union for Conservation of Nature (IUCN) defines a protected area as "a clearly define geographical space, recognized, dedicated and managed, through legal of other effective means, to achieve the long-term conservation of nature with associated ecosystem and cultural values" (IUCN, 1994). It has recognized seven categories of protected areas: (I) strict protection (Strict nature reserve/wilderness area), (II) ecosystem conservation and recreation (national park), (III) Conservation of natural features (natural monument), (IV) conservation through active management (habitat/species management area), (V) Landscape/seascape conservation and recreation (protected landscape/seascape), and (VI) sustainable use of natural ecosystems (managed resource protected area) (IUCN, 1994) (Table 1).

However, each country sets up national systems and the terminology can vary. In Mexico, protected areas are categorized in six categories as follows: biosphere reserves, national parks, natural monuments, protected areas of natural resources, protected areas of flora and fauna, and sanctuaries (CONANP, 2012a) (Table 1). Some of the categories of Mexico's system correspond to those established by the IUCN, although, some of the definitions of Mexico's categories are not clear enough to make a complete correspondence. The definition of each area, as well as the activities permitted in each one varies between the international and the national categorization (Table 1).

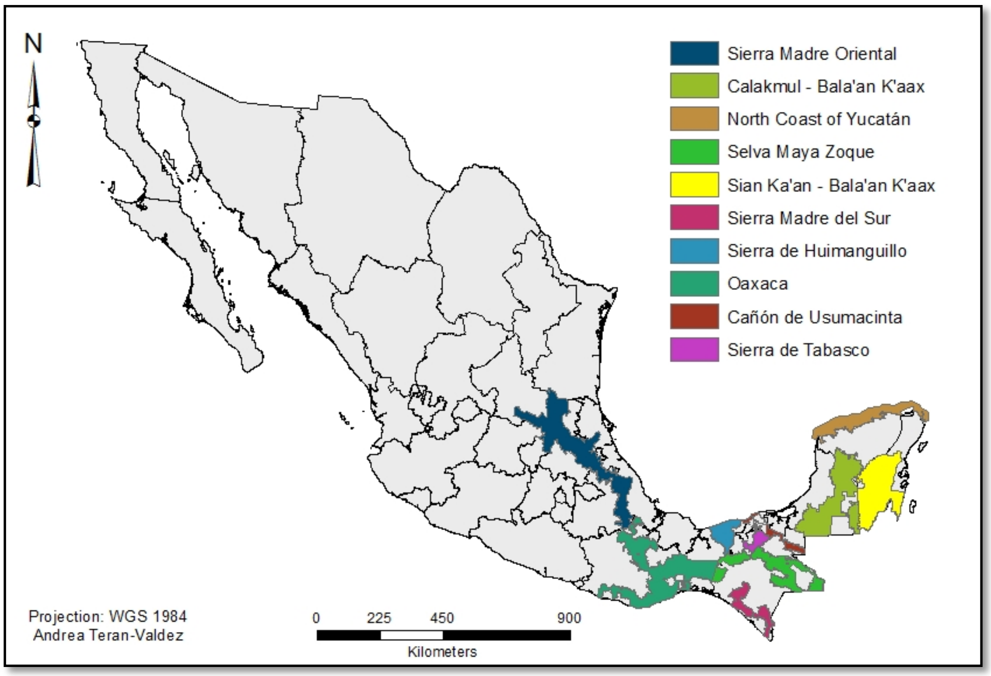
Until now, 12.9% of Mexico's territory is under protection at the federal level, with 174 protected areas (41 biosphere reserves, 67 national parks, five natural monuments, eight protected areas of natural resources, 37 protected areas of flora and fauna, and 18 sanctuaries) (CONANP, 2012a).

Biological corridors per se are not considered under any category of protection, neither by the IUCN nor the Mexican legislation. The assignation of a category of protection depends on whether or not they qualify under some of the categories mentioned above (IUCN, 1994). In spite of the lack of legal protection of some biological corridors, the integrity of the area can still be preserved through voluntary agreements and/or compensation; for example, tree plantations or managed natural forests can prevent the conversion of land. For instance, in Mexico, the biological corridor Chichinautzin is registered as an area of protection of flora and fauna and the Sian Ka'an-Calakmul corridor is not registered under any category of protection but is part of the Mesoamerican biological corridor initiative (CONANP, 2012b; SEMARNAT, 2007).

Regarding to biological corridors in Mexico, there is one recognized corridor (Chichinautzin) and other proposals to create new ones. There is a special interest on the southern part of the country, where some areas have been established like areas of interest for the development of biological corridors (Map 1). The next paragraph focuses on a general description of Mexico's existing and proposed corridors.

The biological corridor Chichinautzin, mentioned above, extends on part of Mexico D.F. and on the state of Morelos. It was created in 1988 but it was not until 2008 that Vega *et al.* generated the cartography of vegetation and land use of the corridor. The area's main threats and pressures are urban expansion, lack of management, exploitation of forestry resources, unsustainable tourism, and overexploitation of aquifers and the groundwater layer (CONANP, 2012b).

On the other hand, in 2006, there was a proposal for the creation of the protected area “Monumento Natural Río Bravo del Norte” which has its limits between Mexico and United States. In Mexico, this area adjoins with the protected areas “Cañón de Santa Elena” and “Maderas del Carmen” and has a length of 458.2 km. The proposal includes a riparian corridor along the Bravo river because several species use it as a migratory route (CONANP, 2006). Currently, just part of the area pertaining to the delta region of the river Bravo in Tamaulipas is included within the SINAP (CONANP, 2012b).



Map 1. Biological corridor of the Sierra Madre Oriental and potential corridors in Mexico. Source: Annex 1

Finally, there is a proposal of the corridor Sian Ka'an – Calakmul (Map 1) to connect two reserves in Campeche and Quintana Roo, which are considered areas with the highest biodiversity worldwide. The goal of this reserve is to preserve the integrity and conserve the Mayan jungle (Colchero *et al*., 2006). Nevertheless, this area has not been registered in the SINAP (CONANP, 2012b).

This corridor is part of the great Mesoamerican corridor, an initiative proposed in 1997 to define links between protected areas in Mesoamerica; the agreement was established between Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama and Mexico. In Mexico, the implementation of this initiative began in 2002 and was planned for seven years; the states within the project are Chiapas, Quintana Roo, Yucatan and Campeche. The expectations were that for the year 2009, Oaxaca, Veracruz and Tabasco would be added to the initiative (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Dirección de Comunicación Científica, 2009).

These efforts are the reflection of the importance that conservation is acquiring in Mexico, and the importance of biological corridors as a conservation strategy.

Table 1. Categories of Protected Areas by the IUCN and Mexico's legislation; comparison between both classifications (Congreso de la Unión, 1988; IUCN, 1994).

IUCN CATEGORY	DESCRIPTION	ACTIVITIES	MEXICO CATEGORY	DESCRIPTION	ACTIVITIES
Strict nature reserve	Protect biodiversity and geological/geomorphological features	Scientific research and monitoring	–	–	–
Wilderness area	Protect unmodified or slightly modified areas, retaining their natural character and influence, without significant human habitation	Protection and management to preserve their natural condition	**Biosphere reserve**	Areas unmodified by the human or that require its preservation and restoration. Presence of representative species of the national biodiversity	Inhabited by communities that were the place when the declaration of protecte area was made
National park	Natural or near natural areas set aside for its protection	Protection of large scale ecological processes and species characteristic of the area	**National parks**	Scenic, scientific, educational or historical value; presence of flora and fauna	Research, recreation, tourism and education
Natural monument or feature	Protection of an specific natural monument (landform, sea mount, submarine cavern, geological features)	Protection of natural monuments	**Natural monument**	Scenic, scientific, educational or historical value; presence of flora and fauna	Preservation, scientific research, recreation an education
Habitat/speci es management area	Protection of particular species of habitats	Interventions to address requirements of particular species or habitats. Public education and contact with nature	**Sanctuaries**	Flora and fauna richness and presence of species or habitats with restricted distribution	Research, recreation ar education; activities mu be compatible with the nature and characteristics of the ar

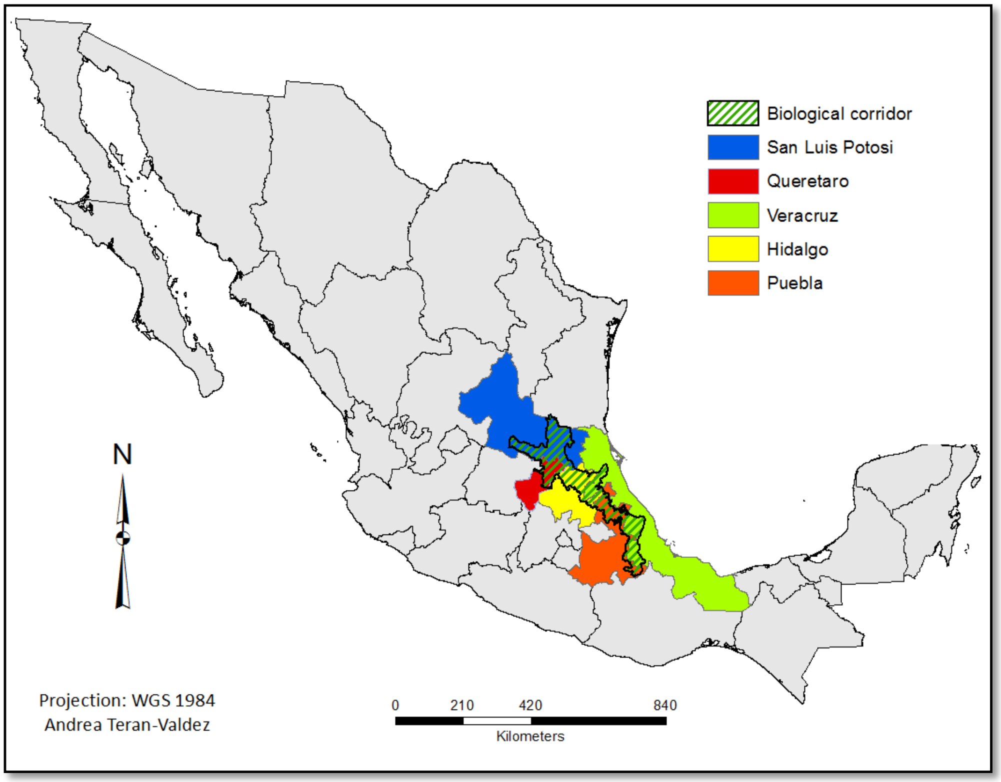
IUCN CATEGORY	DESCRIPTION	ACTIVITIES	MEXICO CATEGORY	DESCRIPTION	ACTIVITIES
Protected landscape/seascape	Areas with ecological, biological, cultural, and scenic value produced by the interaction of humans and nature	Safeguard the integrity of the interaction to protect and sustain the area	**Areas of protection of flora and fauna**	Habitats that sustain the existence, transformation and development of wild species of flora and fauna	Communities that inhal the place can exploit natural resources from the area
Protected area with sustainable use of natural resources	Conservation of ecosystem and habitats (cultural values and traditional natural resource management systems)	Sustainable natural resource management; low-level-non-industrial use of natural resources compatible with nature conservation	**Areas of protection of natural resources**	Preservation and protection of soil, watersheds, water, and natural resources located within forestal land	Preservation, protectio and sustainable exploitation of natural resources, research, recreation, tourism anc education

Sierra Madre Oriental Biological Corridor

The Ecological corridor of the Sierra Madre Oriental (CESMO by its acronym in Spanish) is an initiative of the CONANP (Comisión Nacional de Áreas Naturales Protegidas) and the GIZ (Deutsche Gesellschaft für Internationale Zuzammenarbeit); it has been in development since 2012. The CESMO has been thought as a strategy to promote the economic and social development in the territory, following criteria of conservation and sustainability of natural resources (GIZ, 2013).

The objective of the strategy is to connect (functionally and integrally) physical, biological, socio-economic and institutional aspects of different territories. The corridor will try to break the paradigm that conservation of natural resources is opposed to economic and social development (GIZ, 2013).

The states involved in this initiative are San Luis Potosí, Querétaro, Hidalgo, Puebla and Veracruz (Map 2). The activities that will be done in each territory are political (cooperation and integration), social (participation and inclusion), economic (promotion of sustainable productive systems) (GIZ, 2013).



Map 2. Biological Corridor of the Sierra Madre Oriental or so called CESMO (Corredor Ecológico de la Sierra Madre Oriental). Sources: Annex 1

1.3. STUDY AREA

SMO (Sierra Madre Oriental) description

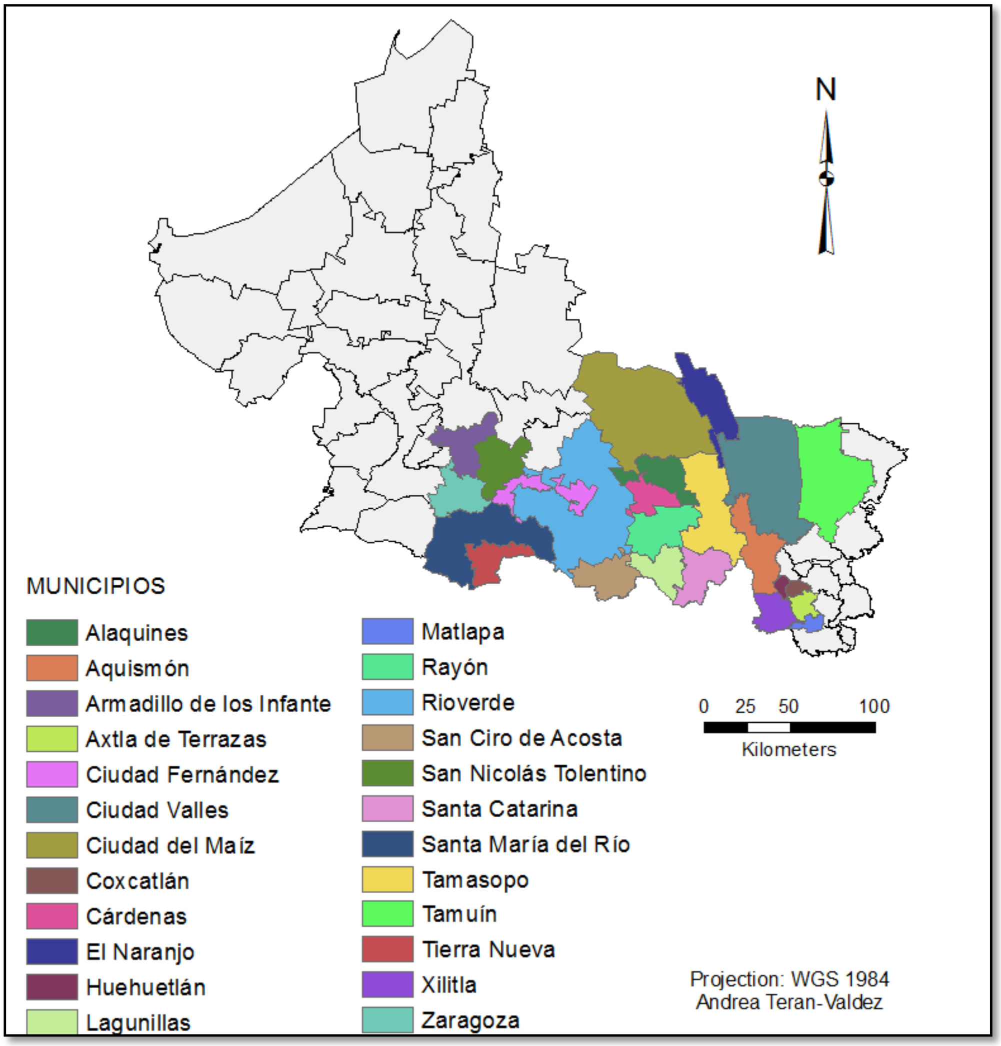
The Sierra Madre Oriental is a mountainous massif with 770,500 hectares (Chapa-Vargas and Monzalvo-Santos, 2012); it runs in a northeast-southeast orientation from the border of the United States of America to the middle of the Mexican Republic (Ruiz-Jiménez *et al*., 2004).

Its biological diversity indices are very high due to its topographical and weather complexity and its geographical position, including the transition zone between the tropical and temperate biogeographic regions (Chapa-Vargas and Monzalvo-Santos, 2012).

In the area, approximately 2500 vascular plant species, 532 birds, 207 amphibians and reptiles and 200 mammals are distributed (Sahagún-Sánchez *et al*., 2011). Additionally, the presence of the jaguar in the Sierra Madre Oriental is very important; therefore, it represents a priority area for the long term conservation of the jaguar (*Panthera onca*) (Villordo, 2009).

The following paragraphs describe the physical conditions of the Sierra Madre Oriental but with a focus on the portion of San Luis Potosí and the delimitation of the corridor made by the GIZ (CESMO). This area involves 24 municipalities of San Luis Potosí (Map 3).

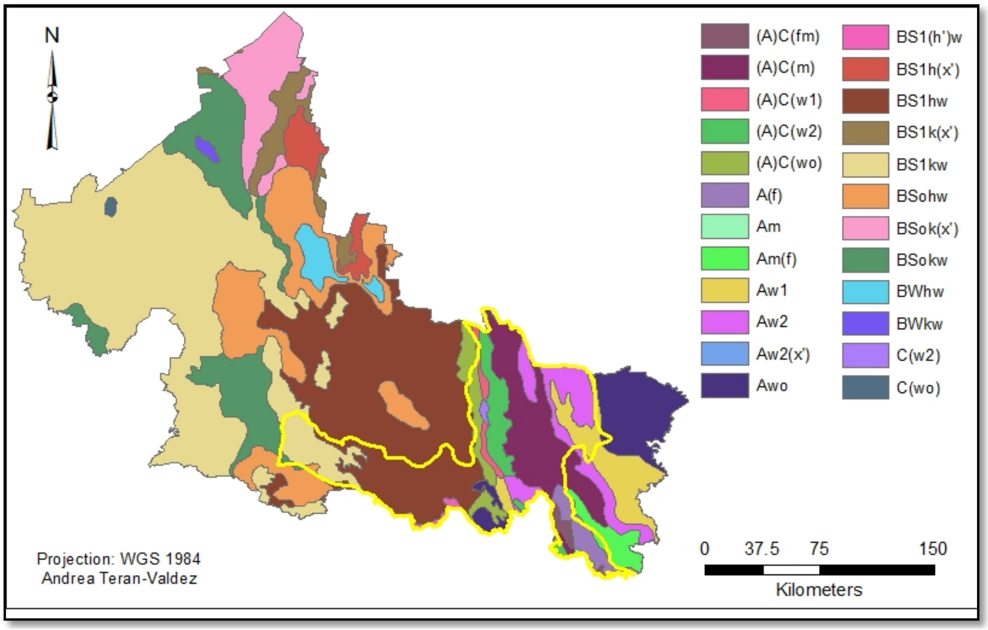
Regarding to the climate, the Sierra Madre Oriental has the 99% of the climates existing in Mexico; it is located across four climatic regions. The mean temperature oscillate from 12°C and 25.3°C. There have been registered four thermic zones: i) warm (22° and 26°C); ii) semi-warm (18° and 22°C); iii) temperate (12° and 18°C); and iv) semi-cold (5° and 12°C). Climate zones registered for the region are warm (Af, Am and Aw), temperate (Cf, Cm and Cw), and dry (BS and BW).



Map 3. Municipalities within the biological corridor of the Sierra Madre Oriental in San Luis Potosi

Map 4 shows the climate recorded for the state of San Luis Potosí, with a focus on the biological corridor of the Sierra Madre Oriental. Herein, 11 classes have been identified, pertaining to different climate zones, such as Af, Aw, BS, Cw, among others.

Regarding to annual precipitation, there are extreme values from less than 300 mm in the center and north, and more than 4000 mm in the south (Hernández-Cerda and Carrasco-Anaya, 2004).

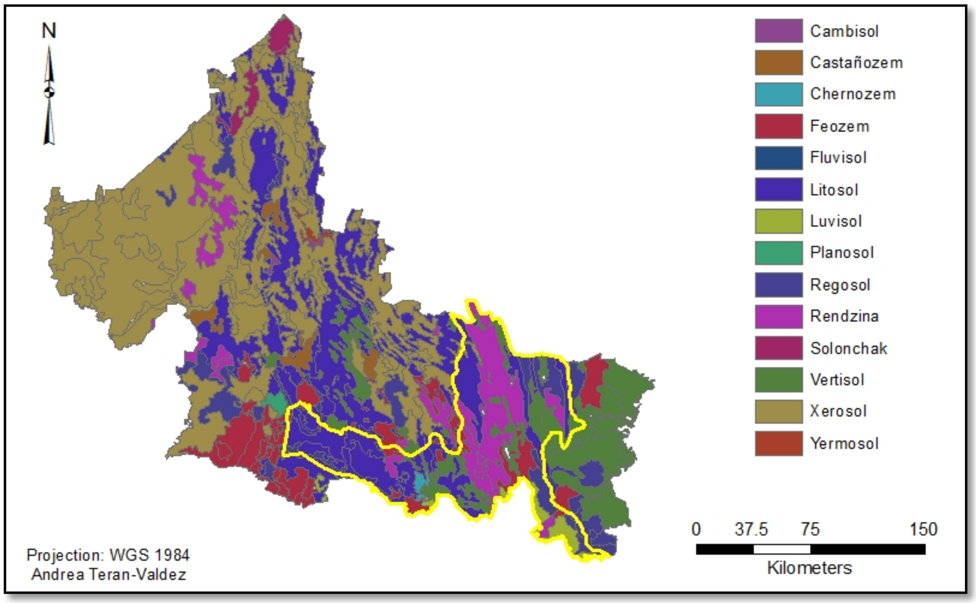


Map 4. Climate of San Luis Potosí; the yellow delimitation represents the Sierra Madre Oriental. Sources: Annex 1

Within the Sierra Madre Oriental, there are all the types of soil classified by the National Institute of Statistics and Geography (INEGI) (Cuevas Fernández, 2013). In the area pertaining to San Luis Potosí there is the predominance of three types of soils, rendzines, lithosols and vertisols, and the presence of yermosols and chernozem in a less extent (Map 5).

Moreover, the geographical position and the topographic features of the entire Sierra Madre Oriental permit the presence of all the types of vegetation registered by the INEGI (Cuevas Fernández, 2013). However, the best-represented ecosystems in the SMO are: crassicaulous scrubland, oak forest, deciduous forest, perennial forest, grassland, medium tropical moist forest, aquatic vegetation, thorn scrubland, agricultural land, and cultivated forests (Cuevas Fernández, 2013).

Focusing on the portion of the SMO located in San Luis Potosí, the main types of vegetation (following the classification made by Chapa-Vargas and Monzalvo-Santos, 2012) are oak forests, low and medium tropical moist forest, piedmont scrubland, and grassland and agriculture. The predominant ones are the oak and the low tropical moist forests (Map 6).



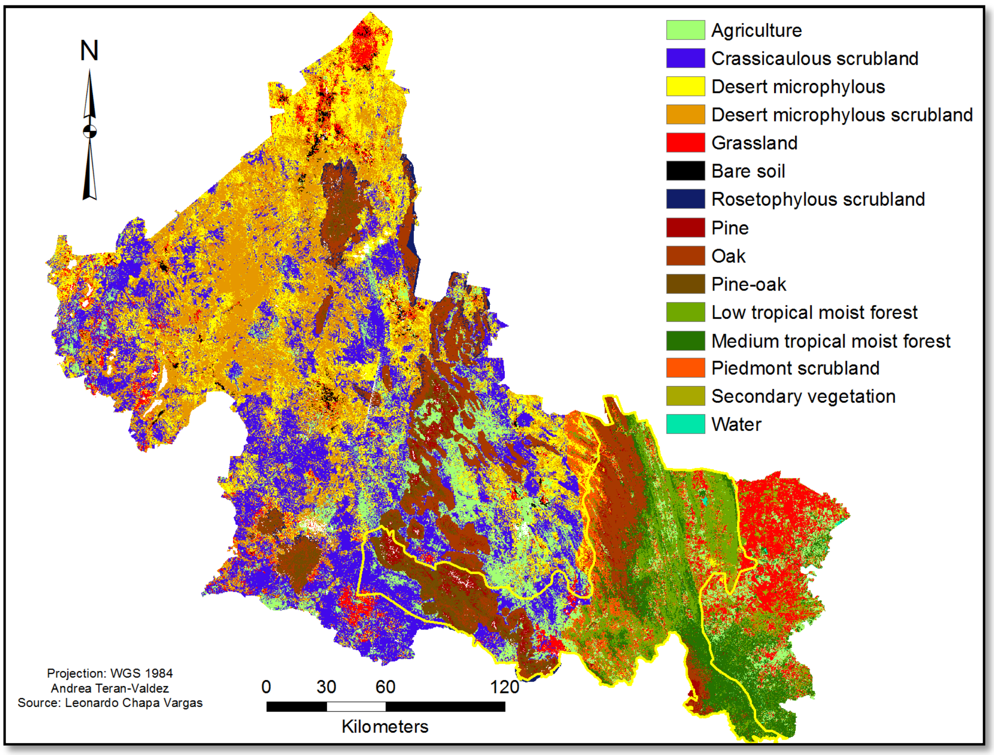
Map 5. Type of soils in San Luis Potosí, with a focus on the Sierra Madre Oriental (yellow delimitation). Source: Annex 1.

Cultural and human description of SMO

Most of the municipalities within the SMO are rural and have a total population of 15000 inhabitants and more; some municipalities have from 5000 to 15000 inhabitants and very few have 5000 inhabitants and less. Besides, the population density of most of the area is of 100 people per square kilometer or less (Cuevas Fernández, 2013). Some of the most populated municipalities are Ciudad Valles, Xilitla, Ciudad Fernández, Rioverde, Aquismón, and Santa María del Río (Map 3).

Furthermore, most of the municipalities have a low indigenous population, however, the States of San Luis Potosí, Veracruz, and Hidalgo have localities with 70% and more of indigenous population (CDI, 2006; Cuevas Fernández, 2013).

There are indices that reflect the social situation of an area, like the marginalization and the human development indices (HDI). The first one, a measure that shows the lack affecting the population, varies from low to very high along the SMO, with the medium to high values as predominant (CONAPO, 2010; Cuevas Fernández, 2013). The HDI, an index that combines data of longevity, education, and life quality, ranges from medium-low to medium-high, being the second one the predominant in the area (CONAPO, 2001).



Map 6. Land Use Land Cover for San Luis Potosí. Source: Annex 1

Protected areas within the SMO (Sierra Madre Oriental) in San Luis Potosí

The state of San Luis Potosí has 1.6% of its territory protected at the federal level and 6.6% at the state level, however, not all of the biodiversity is represented within these areas (Chapa-Vargas and Monzalvo-Santos, 2012).

Regarding only to the area pertaining to the SMO there are 8 protected areas (Map 7, Table 1): the biosphere reserve *Sierra del Abra Tanchipa*, the state reserve

Sierra del Este y Sierra de Enmedio, the natural monuments *Sótano de las Golondrinas* and *La Hoya de las Huahuas*, the natural sacred site *Las Cuevas del Viento y la Fertilidad*, the state park *Media Luna*, the national park *El Potosí*, and the flora and fauna protection area *Sierra de Alvarez*. In addition, there are two Ramsar sites: *Arroyos y Manantiales de Tanchanchín* and the *Ciénega de Tamasopo/Cabezas*. Finally, there are two areas of importance for bird areas (IBAs), *San Nicolás de los Montes* and *Sierra del Abra Tanchipa* (CIPAMEX-CONABIO, 1999; CONANP, 2012c).

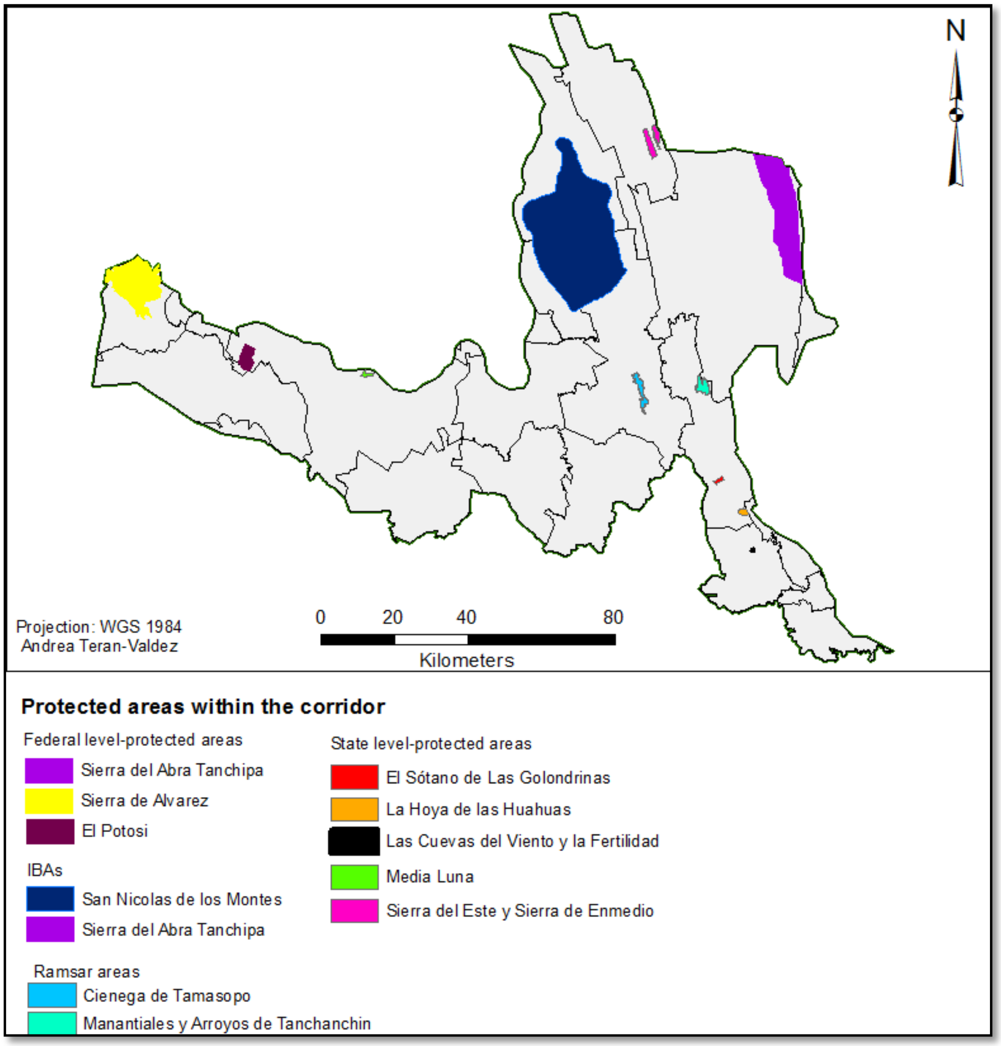
The *Sierra Abra de Tanchipa* (municipality of Ciudad Valles), the largest protected area within the SMO, and the *Sierra del Este* y *Sierra de Enmedio* (El Naranjo) are protecting mostly low tropical moist forest. The *Sierra de Álvarez* (Zaragoza) and *El Potosí* (Rioverde) protect oak and pine-oak forests.

The geological formations *Sótano de las Golondrinas* (Aquismón), *La Hoya de las Huahuas* (Aquismón), and *Las Cuevas del Viento y la Fertilidad* (Huehuetlán) are caves that are protected due to its importance as special attributes of the landscape and for the protection of birds.

Ramsar and IBAs are global initiatives that are not under any legal category of protection. IBAs are identified, monitored and protected by national and local organizations and individuals. Ramsar sites are wetlands of international importance, designated under the Ramsar Convention (Iran, 1971). Although they are not legally protected, these are powerful tools to protect birds and wetlands worldwide (BirdLife International, 2013; Natural England, 2013).

The IBA *San Nicolás de los Montes* is a large area that covers part of the municipalities of Tamasopo, Alaquines and Ciudad del Maíz. The area has mainly three types of vegetation, oak, and low and medium tropical moist forests.

The Ramsar areas *Arroyos y Manantiales de Tanchanchín* (Aquismón) and *Ciénega (Cabezas) de Tamasopo* (Tamasopo) are located in the Huasteca region. They are important sources of water and harbor important endemic species; nevertheless, they are strongly impacted by the change of land use to agricultural activities (CODESUHCC, 2013; Torres, 2007).



Map 7. Protected areas within the biological corridor of the Sierra Madre Oriental, San Luis Potosí, Mexico, including Ramsar and IBAs. Sources: Annex 1.

1.4. JUSTIFICATION OF THE STUDY

Conservation initiatives that do not take into consideration the human factor (socio-economic component) have low probabilities of been successful in the long-term.

Biological corridors, as an important conservation strategy, must incorporate this component in its development. Nevertheless, so far, the methodologies used for the creation of corridors do not include the socio-economic factor as a variable.

Therefore, the importance of this research lies in the incorporation of biological, physical, social and economic components in a methodology to establish routes of connectivity along an area that not only have problems of biodiversity loss, but also problems related to poverty.

2. OBJECTIVES

Main objective:

Determine connectivity routes between important areas for conservation of biodiversity in the biological corridor of the Sierra Madre Oriental in San Luis Potosí, taking into account biophysical, social and economic data.

Particular objectives:

1. Develop distribution models for endemic species of amphibians, reptiles, birds, and mammals for the Sierra Madre Oriental in San Luis Potosí and determine areas of priority for the conservation of the modeled species.

2. Obtain suitability maps for connectivity through multi criteria evaluation that incorporates biophysical, social and economic data.

3. Establish routes of connectivity between priority areas for conservation and protected areas using as a matrix the suitability maps.

4. Obtain socio-economic data in some ejidos located in the study area and analyze their potentiality to be part of conservation initiatives carried out within the biological corridor.

3. METHODS

For a better understanding of the methods followed during the study, a general overview of the objectives, methodology and results was done (Figure 1). The details of the diagram are described in the following section.

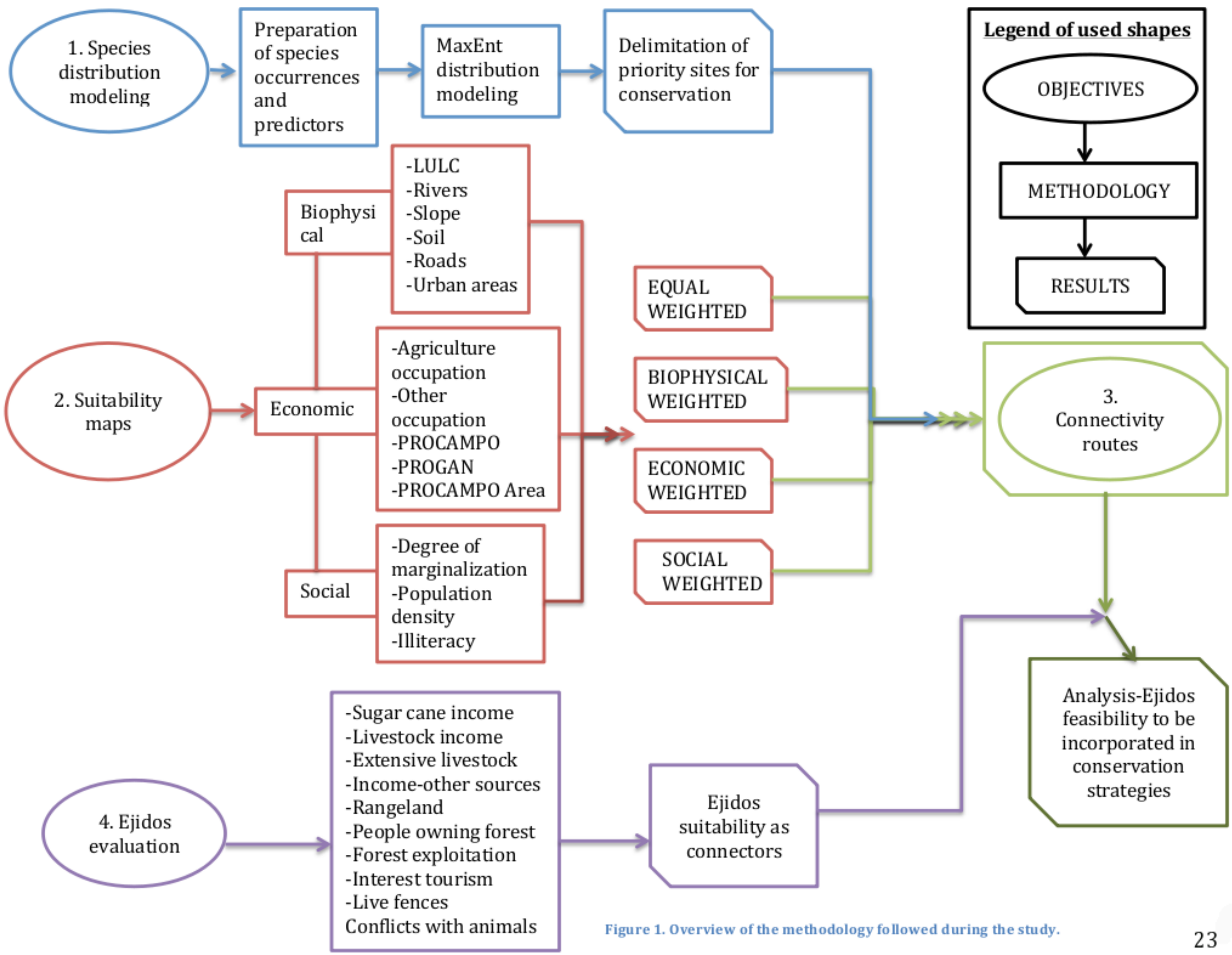


Figure 1. Overview of the methodology followed during the study.

3.1. SPECIES DISTRIBUTION MODELING (Table 2: Objective 1)

Prioritizations of conservation areas are based, in a general overview, on spatial vulnerability and/or irreplaceability. The most common measure of irreplaceability is endemism because if a region with a high level of endemism is lost, then more biodiversity is lost as well (Brooks *et al*., 2006). Hence, in this work the distribution modeling of birds, mammals, amphibian and reptiles was made only for endemic species for Mexico and for the Sierra Madre Oriental (Table 2).

Table 2. Fauna species used for the distribution modeling. Abbreviations- IUCN: Vulnerable (VU), Critically endangered (CR), Endangered (EN), Data deficient (DD), Least concern (LC), Near threatened (NT). NOM-059: Endangered (P), Threatened (A), Probably extinct in the wild (E), Special Protection (Pr), Not included into the list (–).

	Species	Red List Category-IUCN	Nom-059-SEMARNAT-2001 Mexico	# Occurrences
Amphibian	*Eleutherodactylus verrucipes*	VU	Pr	6
	Lithobates johni	EN	P	5
	Chiropterotriton arboreus	CR	Pr	–
	Chiropterotriton magnipes	CR	Pr	5
	Chiropterotriton multidentatus	EN	Pr	7
Reptiles	*Xenosaurus newmanorum*	EN	Pr	7
	Storeria hidalgoensis	VU	–	5
	Geophis latifrontalis	DD	Pr	5
	Rhadinaea gaigeae	DD	–	4
Mammals	*Sciurus oculatus*	LC	Pr	19
	Chaetodipus lineatus	DD	–	4
	Microtus quasiater	NT	Pr	4
	Peromyscus furvus	DD	–	13

	Species	Red List Category-IUCN	Nom-059-SEMARNAT-2001 Mexico	# Occurrences
	Peromyscus levipes	LC	–	13
	Peromyscus melanophrys	LC	–	48
	Panthera onca	NT	P	84
Birds	*Amazona oratrix*	EN	P	13
	Glaucidium sanchezi	LC	P	4
	Micrathene whitneyi	LC	E	8
	Caprimulgus salvini	LC	–	12
	Cynanthus latirostris	LC	Pr	14
	Amazilia yucatanensis	LC	–	39
	Lampornis clemenciae	LC	–	10
	Calothorax lucifer	LC	–	9
	Archilochus alexandri	LC	–	6
	Empidonax wrightii	LC	–	5
	Empidonax oberholseri	LC	–	14
	Empidonax occidentalis	LC	–	4
	Tyrannus vociferans	LC	–	115
	Aphelocoma ultramarina	LC	–	18
	Toxostoma longirostre	LC	–	5
	Melanotis caerulescens	LC	Pr	7
	Basileuterus rufifrons	LC	–	6
	Arremonops rufivirgatus	LC	–	66
	Spizella pallida	LC	–	6
	Rhodothraupis celaeno	LC	–	19
	Pheucticus melanocephalus	LC	–	8
	Passerina versicolor	LC	–	19

Icterus graduacauda	LC	–	11
Icterus parisorum	LC	–	32

Data of occurrence of fauna species (amphibians, reptiles, birds, and mammals) in San Luis Potosí were obtained from records from the CONABIO, personal records from Dr. Leonardo Chapa (IPICYT) and Dr. Sahagún-Sánchez (University of Guadalajara), and the web-databases World Biodiversity Information Network (REMIB, 2008), VertNet (VertNet, 2006), Vertebrate Zoology of the American Museum of Natural History for Herpetofauna (AMNH, 2013), and Global Biodiversity Information Facility (GBIF, 2013).

The classification of endemic species was adopted from the publication "Biodiversidad de la Sierra Madre Oriental" (Luna *et al*., 2004) for all the groups with the exception of birds, for which the classification of Sahagún-Sánchez *et al*. (2013) was taken. Regarding endemism, one exception was made with *Panthera onca* (jaguar); it was also considered in this work due to its critical conservation status and because biological corridors has been suggested as a conservation strategy for the species (Rodríguez-Soto *et al*., 2011).

Generic names for amphibians are according to the taxonomy proposed by Frost (2013); for the other groups they are according to the taxonomy stated in Red List of Threatened Species (IUCN, 2012).

For the distribution models only those species with 4 or more occurrences were taken in consideration. At the end, there was enough information available for 40 species (four amphibian, four reptiles, 26 birds and six mammals) (Table 2).

The modeling was carried out with MaxEnt (Phillips *et al*., 2006) using as predictors the 19 bioclim layers of World Clim at the finest resolution possible, pixel size of 1 km (Hijmans *et al*., 2005). The models were run using the default properties and the occurrences were separated in training data (75%) and validation data (25%) (Sahagún-Sánchez *et al*., 2013).

The resultant distribution maps were reclassified in ArcGIS (Redlands, CA, 2011) taking as areas with presence of the species (assigning a value of 1) only those with a P > 0.5. Then, using the tool 'raster calculator', the individual distribution maps were summed up pixel by pixel to determine the distribution of endemic species of all the groups throughout San Luis Potosí.

The next step was determining clusters of concentration of endemic species within the corridor by grouping in polygons all those values of endemism greater than 0.7 (Map). These areas were considered as "priority areas for conservation" (PSCs), which were used subsequently for the elaboration of the connectivity maps (next section).

A comparison was made between these obtained sites and other priority areas previously determined by other authors (CONABIO, 2004; CONABIO et al., 2007; GIZ, 2013). An overlay of these layers was done and the shared area was calculated in ArcGIS.

3.2. SUITABILITY MAPS (Table 2: Objective 2)

Preparation of variables

At the municipal level, biophysical, social, and economic shapefiles and tables were obtained from the Portal of Geoinformation (Table 2; CONABIO, 2013). The shapefiles of the Corridor of the Sierra Madre Oriental (CESMO) were provided by the GIZ, and the map of land use for San Luis Potosí was provided by Dr. Leonardo Chapa (Annex 1)

All the maps were converted to a raster format in the program ArcGIS (Redlands, CA, 2011). In order to avoid errors when overlapping the layers at the IDRISI analysis (see below), all the raster files were standardized with the following attributes: a) cell size: 30 m; b) datum: WGS 1984; c) spatial reference: WGS 1984 UTM Zone 14N; d) number of columns and rows: 18618, 14101, respectively.

Another step to prepare the maps was its reclassification (Table 3). The data analysis requires that all the maps have numerical values; therefore, for the maps of land use, soil type, roads, and degree of marginalization a reclassification was done to obtain numerical data.

The land use layer was reclassified in 3 categories from 0 to 2, being 0 non-suitable for the corridor objectives and 2 the most suitable. The assignation of suitability or non-suitability to the different types of land use and land cover lies in the following criterion. The planning of this specific corridor considers different species of flora and fauna and does not focus on only one specific group or species; consequently, there could not be a differentiation between the different ecosystems in terms of how they facilitate the species movement. For that reason, the reclassification only considered the type of land use. Then, agriculture, pastureland, water, and bare soil had a value of 0, as they represent a resistance to species movement; secondary vegetation a value of 1; and the other types of vegetation a value of 2 (representing the most suitable cover for species movement) (Table 3).

Soil reclassification was done according to the suitability of each type of soil for agricultural production (Améndola *et al*., 2006). Fertile soils used for agriculture were not considered suitable for the corridor purposes of conserving areas to enhance connectivity. A considerable part of the rural population is dedicated to agriculture and depends economically on it. Hence, fertile soils cannot be considered for other purposes rather than agriculture. A range from 0 to 3 was assigned, being 0 the most suitable and exploited soils for agriculture (Table 3).

Finally, roads were reclassified as a constraint for movement in two categories, main paved roads as a complete restriction and roads of secondary order, not paved, as a medium constraint (Table 3). The difference between these two categories lies on the road traffic, being the paved ones the most used. Roadsides are conduits for few species, but in general, they represent a frontier for animals' movement. Death of animals on roads is an important mortality source. In addition, animals can avoid roads due to traffic noise (Forman and Alexander, 1998).

Furthermore, it was established a buffer area of 500 m for rivers and roads, as suggested by Ferretti and Pomarico (2013) and a buffer area of 1000 m for urban areas. I did not find a previously established buffer area for urban areas; therefore, it was established the double distance of that assigned to roads because of its larger area of influence.

The occupation of the population was clustered in two groups; one contained the proportion of the population working with agriculture, and the other the proportion of population dedicated to other activities such as industry, services, and trade. The proportion dedicated to agriculture was considered a constraint for the corridor.

Regarding to government subsidies, during the fieldwork, PROCAMPO[2] and PROGAN[3] stood out as the most important government subsidies for the rural population. Therefore, only the data of these two government subsidies was used.

For both subsidies, I obtained the number of beneficiaries for each municipality and calculated the proportion of the population receiving that payment. In addition, the total area in the municipality pertaining to the program PROCAMPO could also be used; whereas it was not possible to do the same to PROGAN because that information is not available. The presence of these subsidies was considered a constraint to the corridor because they can promote the cut of forest and growth of pastures (Turner II *et al*., 2001).

The degree of marginalization was reclassified to 5 categories (very high, high, medium, low and very low; Table 3). I included the higher levels of marginalization as suitable areas because of the aims of the proposed biological corridor by the CONABIO and the GIZ (CESMO). The purposes of this corridor are

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[2] PROCAMPO–"Programa de Apoyos Directos al Campo" (Direct rural support program) is a field subsidy created in 1993 as a compensatory measure for Mexican producers after entering the "Free trade agreement of North America". Farmers that applied for the subsidy receive a payment for each cultivated hectare. PROCAMPO reaches more rural population than any other federal program (SAGARPA, 2013).

[3] PROGAN–"Programa de Producción Pecuaria Sustentable y Ordenamiento Ganadero y Apícola". This program is a modification of the original program "Programa de Estímulos a la Productividad Ganadera" (Program of incentives for livestock productivity). This subsidy promotes the production of bovines, sheeps, and goats, as well as the apiarian production (SAGARPA, 2013).

related to conservation of nature and enhancing connectivity, as well as the promotion of economic and social development within the area (GIZ, 2013).

Table 3. Reclassification (Rc) of variables; assigned values to each category

Vegetation	Rc	Soil type	Rc	Degree of marginalization	Rc	Roads	Rc
Agriculture	0	Lithosol	2	Very high	5	Main	2
Crassicaulous scrubland	2	Xerosol	2	High	4		
Desert microphylous	2	Solonchak	3	Medium	3	Secondary	1
Thorn scrubland	2	Rendzina	2	Low	2		
Desert microphylous	2	Regosoil	2	Very low	1		
Grassland	0	Feozem	0				
Bare soil	0	Fluvisol	2				
Rosethophylous scrubland	2	Vertisol	0				
Pine	2	Castañozem	1				
Oak	2	Cambisol	0				
Pine-oak forest	2	Luvisol	0				
Medium tropical moist forest	2	Yermosol	1				
Low tropical moist forest	2	Planosol	3				
Piedmont scrubland	2	Chernozem	1				
Secondary vegetation	1						
Water	0						

All the variables, biophysical, economic and social, as well as the ejidos' measures were standardized to a common continuous range from 0 to 1 with a linear function using the fuzzy tool in IDRISI Selva (Eastman, 2012). The standardization was monotonically increasing or decreasing depending on the variable. If the high value of the variable represented a favorable condition for the corridor, then the increasing function was used (for example, slope); on the other hand, if the high value represented a constraint, the decreasing function was applied (for example, roads).

The weight for each variable was assigned using a pairwise comparison in IDRISI Selva (Eastman, 2012). This method provides a continuous range of 9 possibilities to compare two variables, depending on the level of importance of one variable over another. Therefore, the scale ranges from extremely less important to extremely more important (1/9 to 9, respectively).

This weight assignation is usually determined by a group of experts; nevertheless, this was not the case and, in order to avoid subjectivity I only used 3 out of the 9 values from the range: moderate less important (1/3), equal (1), and moderate more important (3). This criterion was used for all the variables.

Variables were compared in pairs within their own group; for instance, a physical variable was only compared against other physical variables. Table 4 shows the individual final weight obtained for each variable with the pairwise comparison. The interaction between the components was reflected in the created maps, as described in the following paragraph.

Table 4. Resultant weights obtained with a pair-wise comparison. For the description of ejidos' variables see Annex 3

Component	Variable	Individual weight
Physical	Land use	0.2880
	Rivers	0.2880
	Slope	0.0849
	Soil type	0.0580
	Urban areas	0.1405
	Roads	0.1405
Economic	Agriculture occupation	0.3333
	Other occupation	0.3333
	PROCAMPO	0.1111
	PROGAN	0.1111
	PROCAMPO area	0.1111

Component	Variable	Individual weight
Social	Population density	0.5842
	Degree of marginalization	0.2808
	Illiteracy	0.135
Ejidos	Income-sugar cane	0.1577
	Income-livestock	0.1389
	Agricultural area	0.1260
	Extensive livestock	0.1175
	Income-other sources	0.0937
	People owning forest	0.0875
	Rangeland	0.0805
	Forest exploitation	0.0663
	Interest tourism	0.0573
	Live fences	0.0373
	Conflicts with animals	0.0373

Development of maps

Four suitability maps for the corridor were generated in IDRISI using a Multicriteria Evaluation (MCE) with the Weight Linear Combination method (WLC). This method allows the interaction between the qualities of the different variables; for instance, a very poor quality of a variable can be compensated with a very favorable qualities of other variables (Eastman, 2012).

These four maps varied on the assigned weights to each of the three components (physical, economic and social). Hence, the first map had more weight assigned to the physical component, the second to the economic, the third to the social, and the fourth assigned equal weight to each component (Table 5).

To obtain the weight of the variables in each case, the individual weights of the variables (Table 4) were multiplied by the weight assigned to the component.

Table 5. Variation of weights assigned to each component.

	Prioritization	Physical	Economic	Social
1	Physical	0.5	0.25	0.25
2	Economic	0.25	0.5	0.25
3	Social	0.25	0.25	0.5
4	Equal	0.33	0.33	0.33

3.3. CONNECTIVITY MAPS (Table 2: Objective 3)

Once the matrix was developed (suitability maps), connections between PSC and protected areas were evaluated. A broad overview was done overlaying the protected areas and the PSC with the suitability maps. Some areas of major connectivity were identified.

In addition, paths between the protected areas were obtained. The tool of "cost distance" in ArcGIS (Redlands, CA, 2011) calculates the least accumulative cost distance over a cost surface (matrix defining the cost of moving through the cells; ESRI, 1995). The cost surface used to obtain the maps was the equal weighted suitability map; low values of suitability represented a major cost for movement.

The cost distance was calculated for each of the protected areas and the PSCs. The obtained maps were overlaid and the path was traced manually following the least cost distances between areas. Within the areas of least cost, the paths were traced considering the presence of roads, urban areas, rivers and type of vegetation. Roads, urban areas, agriculture land and grasslands were avoided as far as possible. Whilst, when rivers were present, paths were traced following the natural feature.

3.4. EJIDOS' EVALUATION (Table 2: Objective 4)

Data gathering through fieldwork

The criteria to choose the ejidos for the sampling which: i) are located in areas with vegetation to conserve, ii) have not received PES (with the exception of San Nicolás de los Montes), iii) are large in size (large ejidos), and iv) belong to different municipalities.

In each site I applied questionnaires (Annex 2) mostly to ejidatarios. The reason to interview them is because they are the persons that own the land and with the power of decision over the activities of common interest carried out within the ejido. When there was the opportunity, I applied some questionnaires to possessors too but the priority was always to interview the ejidatarios. People interviewed were the ones that were available at the moment

In total, questionnaires were applied to 91 people pertaining to nine ejidos (Map 8). The percentage of ejidatarios interviewed in each ejido varied considerably: El Jabalí (3%; municipality Rioverde), Gustavo Garmendia (38%; Ciudad Valles), La Gavia (6%; Tamasopo), Ojo de Agua (9%; Ciudad Fernández), San Nicolás de los Montes (6%; Tamasopo), Santa María Tampalatín (15 interviewed, no information about number of ejidatarios; Tamasopo), Tampemoche (24%; Aquismón), Pinihuan (12%; Lagunillas). The ejido Nuevo Centro Ganadero Papagayos (Ciudad del Maiz) was an especial case because the ejidatarios decided in an assembly, and by accordance of the majority, that one person would give the information for the complete ejido (Figure 2).

Figure 2. Assembly of ejidatarios at the ejido *Nuevo Centro Ganadero Papagayos*

Information gathered through the questionnaires include: agricultural and livestock practices, agricultural alternative and sustainable practices, main sources of income, conflicts with animals due to damage of cattle or crops, interest in tourism, and exploitation of the forest. All the information gathered through the interviews is synthetized in Annex 3.

In order to incorporate this information into the analysis, I converted the values of each variable to percentages. The standardized variables (Table 4, Annex 3) were combined in a multi criteria analysis using the program IDRISI. I applied the same process described above for the development of the suitability maps.

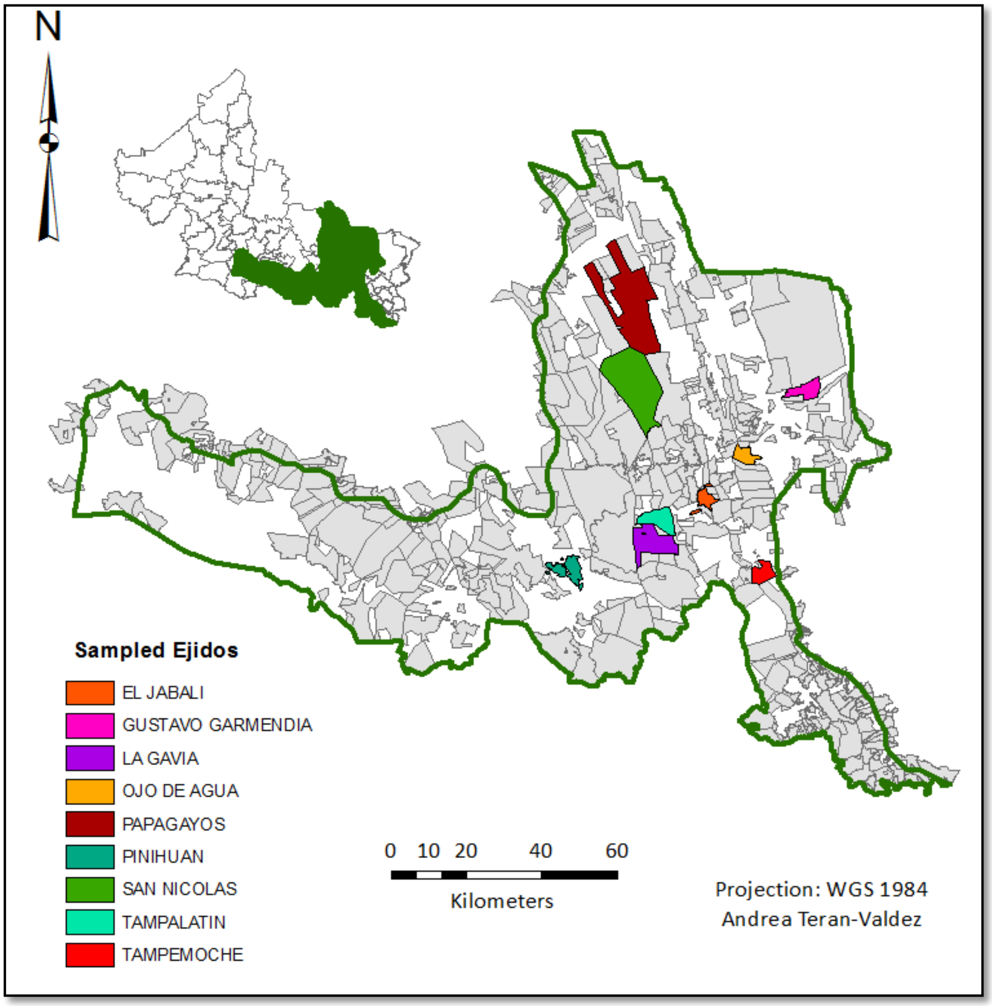
The resultant ejidos' maps presented values within a category from 0 to 1, being 0 the less appropriate for the application of conservation strategies and 1 the most suitable. I overlaid these ejidos to the connectivity maps and analyzed the extent in which they fitted into the connectivity routes and how could low values be a constraint within these routes.

The focus of this analysis was to get a general view of how ejidos can act as connectors within the matrix. Therefore, I did not use all the suitability maps but just took into account the equal weighted map. I chose this specific one because it presents the lowest differences with the other maps.

Payment for ecosystem services (PES) was also incorporated into the analysis. PES has been introduced in Mexico as an important incentive mechanism for forest conservation (REDD, 2012). Areas of high priority, associated with water supply, overexploited aquifers or high biodiversity can apply to receive a compensatory payment for avoiding deforestation.

Consequently, the ejidos within the program of PES show an interest of conserving their natural resources and could be considered as facilitators for enhancing connectivity.

Therefore, I overlaid the ejidos receiving PES with the equal weighted suitability map to evaluate how the presence of this ejidos can enhance connectivity. The criterion of using just one map of suitability applies here in the same way as in the previous section (suitability of ejidos).



Map 8. Ejidos of the Sierra Madre Oriental, San Luis Potosí. Sampled ejidos during fieldwork are highlighted. Source: Annex 1

4. RESULTS

4.1. SPECIES' DISTRIBUTION MODELING

In general, in the state of San Luis Potosí, the higher concentration of endemic species occurs throughout the Sierra Madre Oriental.

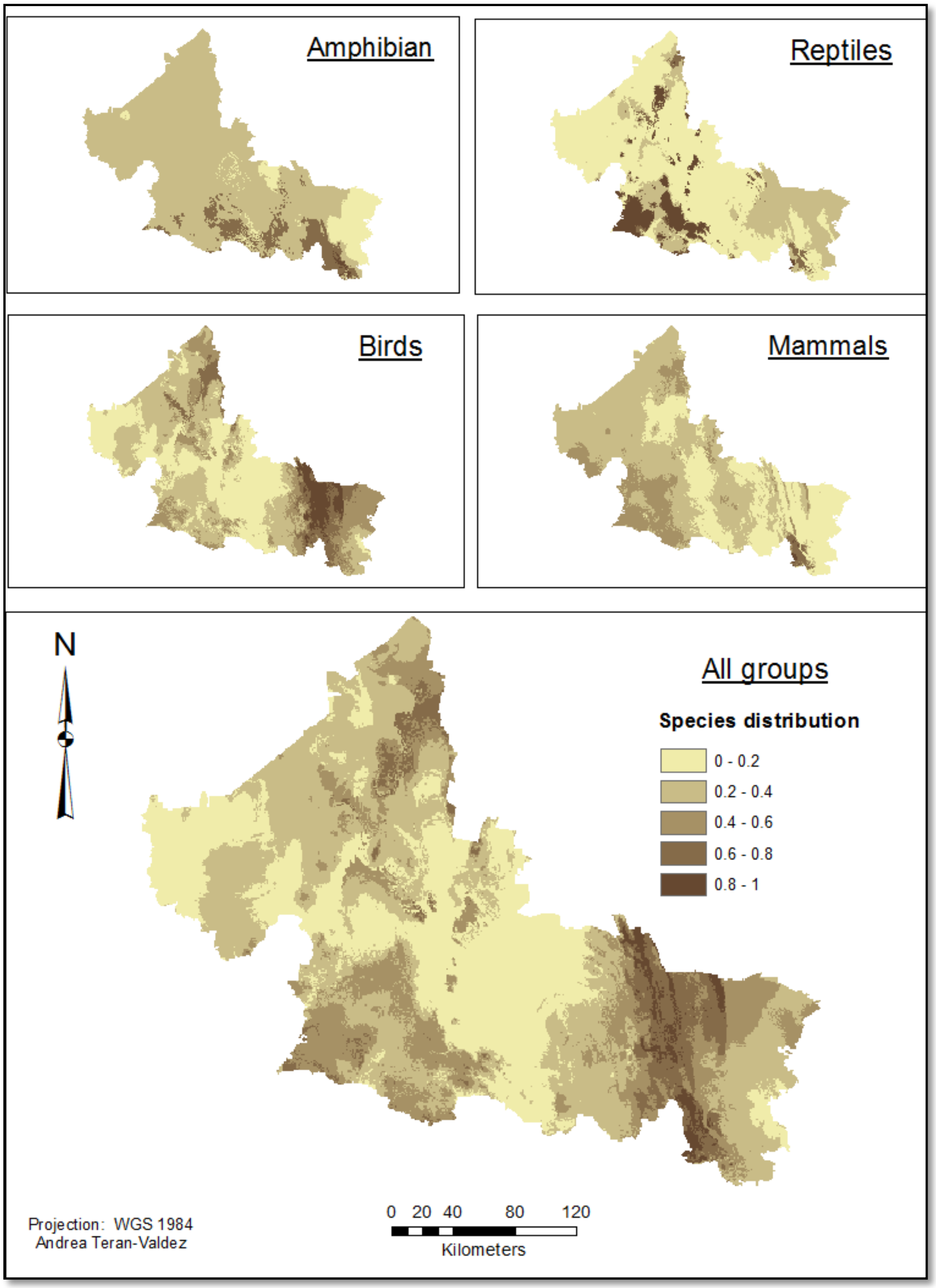
Map 9 shows the overall distribution of endemic species for Mexico and the Sierra Madre Oriental, as well as the distribution obtained for each taxonomical group of animals. Values of species richness showed in the map were standardized to a scale from 0 to 1, being 0 the absence of species and 1 the highest value of species richness.

Birds are the group that contributed the most to the species richness of the area of the Sierra Madre Oriental, followed by amphibians and finally reptiles and mammals.

Reptiles have a low presence in the Sierra Madre Oriental. They are more abundant in the southwest part of the state of San Luis Potosí, an area corresponding to the bio-geographical area "Altiplano Potosino" (Plateau of San Luis Potosí; CONABIO, 1997); which is a region with crassicaulous scrubland as the prevailing type of vegetation.

The distribution of mammals showed high values of presence only in a part of the municipality of Xilitla, at the southern part of the Sierra Madre Oriental. A medium to low presence was identified in the entire western region, an area corresponding also to the "Altiplano Potosino". The predominant vegetation in the area is desert microphylous scrubland.

Amphibian showed a more or less uniform distribution of low values through all the state. Nevertheless, there is a greater presence of species in the southern part of the corridor, corresponding to the "Huasteca Potosina"; where the prevailing type of vegetation are low and medium tropical moist forests.



Map 9. Distribution of endemic species in the state on San Luis Potosí. Richness of endemic species is standardized in a scale from 0 to 1, being 0 the absence of species and 1 the highest richness value. Sources: Annex 1.

Finally, birds are abundant throughout the Sierra Madre Oriental with another area of abundance in the northwestern part of the state (Plateau of San Luis Potosí). This area shows as prevailing types of vegetation, desert microphylous and desert microphylous scrubland.

Establishment of priority sites for conservation

In the area of the Sierra Madre Oriental, the clustering of high values of endemism gave as a result four large areas of richness of endemic species (Map 10). From now on, I will refer to them as PSC "priority areas for conservation". Three of these areas are located on the mid zone of the Sierra Madre Oriental; which overlap mainly with four types of vegetation, low and medium tropical moist, oak and pine forests.

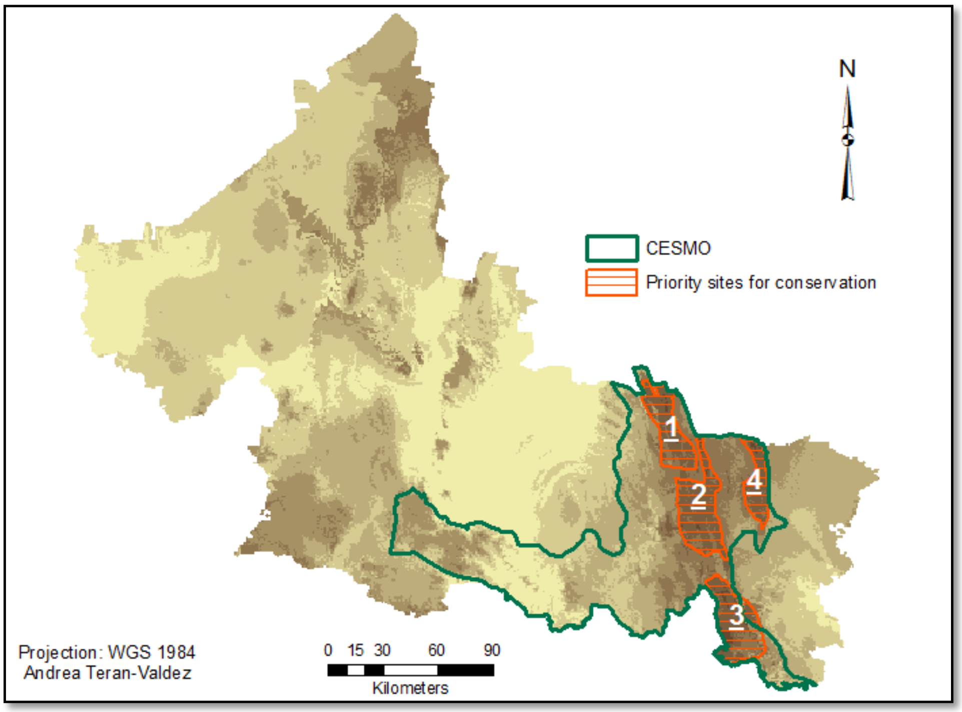
PSC 1 is located in the northern part of the Sierra Madre Oriental. Most of the area pertains to the municipality El Naranjo, where the prevailing types of vegetation are oak, low and medium forests. This site is located between the protected area *Sierra del Este y Sierra de Enmedio* and the IBA *San Nicolás de los Montes*.

PSC 2 covers part of three municipalities, Tamasopo, Ciudad Valles and Aquismón. The main type of vegetation is low tropical moist forest with some areas of grassland and agricultural land. Within this site there is located the Ramsar *Ciénega de Tamasopo*.

PSC 3 corresponds to the municipalities of Xilitla and Aquismón; the main types of vegetation are medium tropical moist, oak and pine forests. It contains the natural monuments *Sótano de las Golondrinas* and *Hoya de las Huahuas* and the natural sacred site *Cuevas del Viento y la Fertilidad* (Map 6).

PSC 4 is located on most eastern part of the corridor, in the municipality of Ciudad Valles. A major part of the site corresponds to the protected area "Sierra Abra de Tanchipa" where low tropical moist forests are predominant.

Finally, as shown in Map 10, the western branch of the corridor, where the protected area *Sierra de Álvarez* is located, presented medium values of endemism. These values were not high enough to compose a cluster of richness of endemic species. Hence, there is a gap in this area in relation to the established priority sites for conservation. Herein, the main types of vegetation are oak, pine and oak-pine forests. As a consequence, oak-pine forests are not included into any of the obtained PSCs.

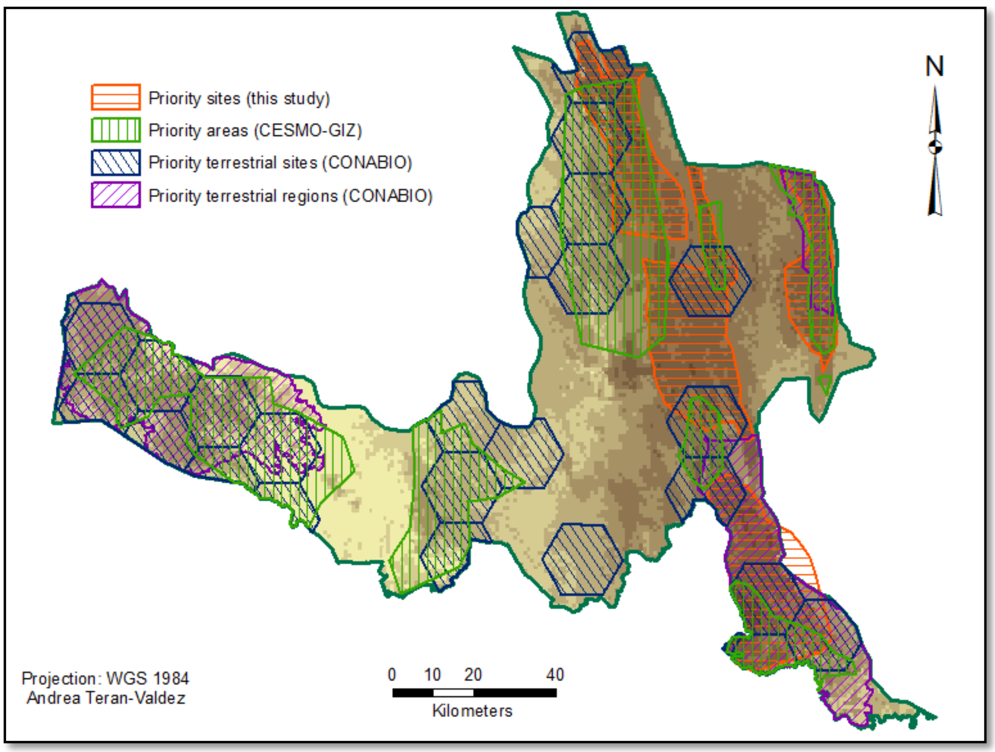


Map 10. Priority sites for conservation (PSC) within the Sierra Madre Oriental, San Luis Potosí. Polygons were defined by the clustering of high values of species richness in some areas. Modeling distribution of amphibian, reptiles, birds and mammals were considered for their definition of the areas. Sources: Annex 1

In addition, a comparison was made between these obtained areas and other three previously defined sites for conservation by other authors. Two of the sites were defined by the CONABIO and named as "priority terrestrial regions for the conservation of biodiversity" (CONABIO *et al.*, 2007) and "priority terrestrial regions" (CONABIO, 2004). The other sites used for the comparison were defined in a workshop organized by the GIZ for the planning of the CESMO.

Map 11 shows the overlay of these four important sites for the conservation of biodiversity.

The overlay of the PSC with the areas obtained by the GIZ resulted in a coincidence of 1134.815 km^2 (42% of the total area of the PSC). The comparison with the priority terrestrial sites determined by (CONABIO, 2004; CONABIO *et al.*, 2007; GIZ, 2013) showed an overlapping of 1007.422 km^2 (37% of PSC area). Finally, there is a coincidence of 914.11 km^2 (34% of the total area) with the terrestrial priority regions (CONABIO, 2004).



Map 11. Overlay of priority areas for conservation in the Sierra Madre Oriental (San Luis Potosí) obtained by different authors and contrasted with the ones obtained in this study (PSC). Sources: Annex 1.

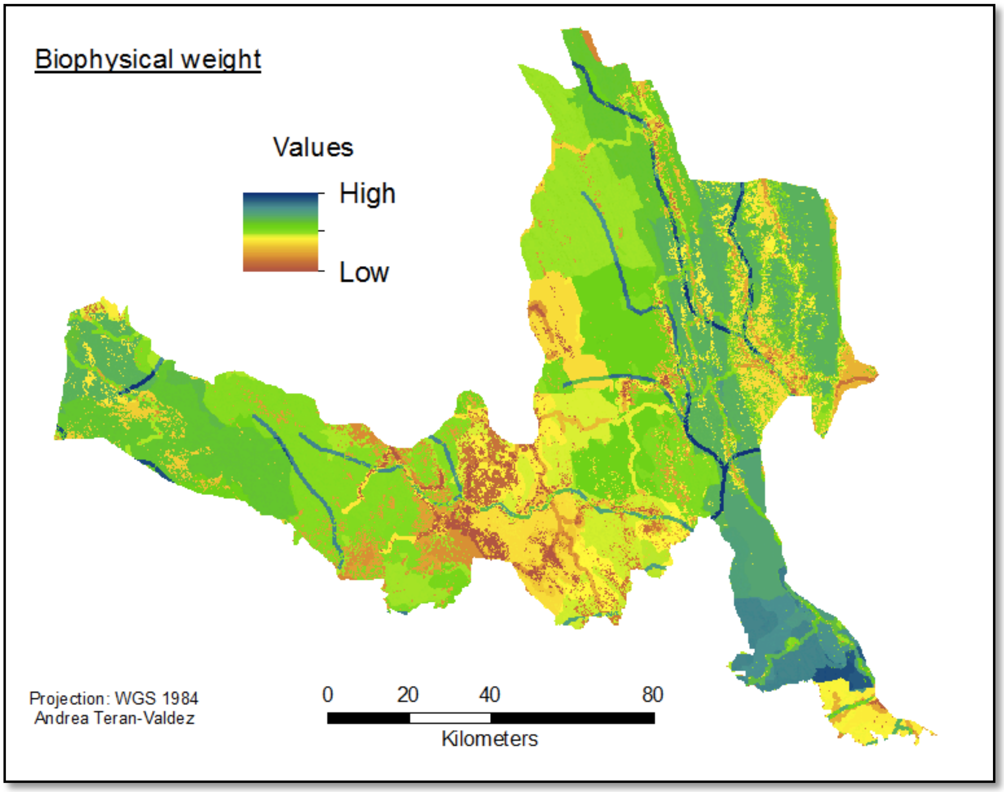
4.2. SUITABILITY MAPS

Spatial differences between maps were obtained through the calculation of different cells. Therefore, Table 6 shows the percentage of different cells between the compared maps. Maps generated with the assignation of equal weights presented less than the 50% of differences with the others; but the physical, economic, and social maps' differences were slightly higher than the 50%. Due to these differences, I worked with all the maps separately.

Table 6. Percentage of different cells between suitability maps.

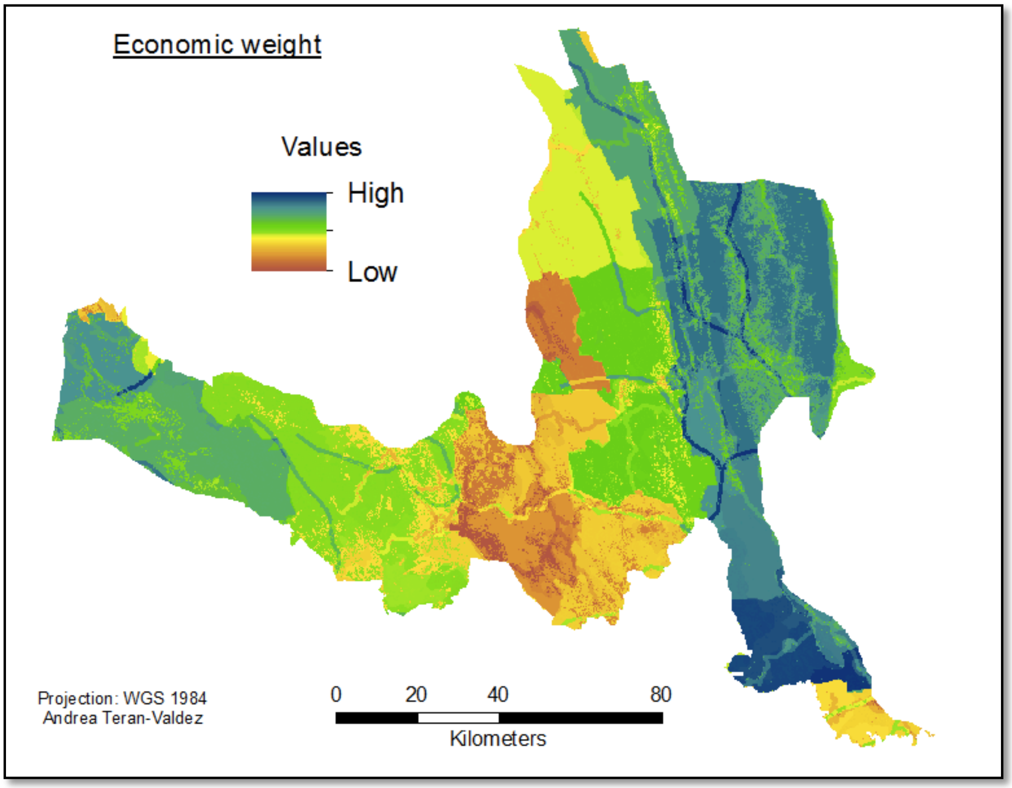
	Equal weight	Physical weight	Economic weight	Social weight
Equal weight	–			
Physical weight	33.30%	–		
Economic weight	41.70%	55.70%	–	
Social weight	32.80%	55.80%	54.60%	–

Despite the dissimilarities, all the maps share one area of high values of suitability in the middle portion of the SMO running on a north-south direction, with an aggregation of high values on the most southern area (part of the "Huasteca potosina"). They also share an area of low values in the southern part between the main body of the corridor and the western branch that separates from it.



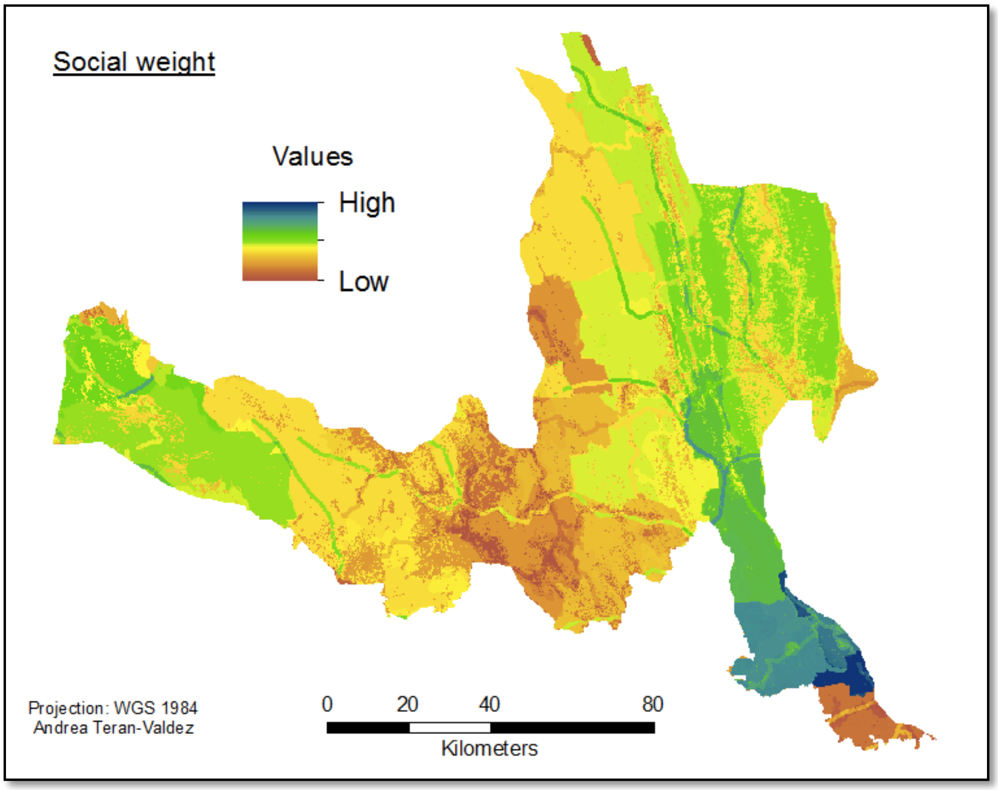
Map 12. Suitability map with greater weight assigned to the biophysical component

The biophysical weighted map presents the highest values o of suitability in the most southern part of the corridor and along rivers (Map 12). In fact, it is clearly noticeable the network of rivers that could serve as connections along all the Sierra Madre Oriental. The lowest values of suitability are separating the western branch of the corridor; these low values reflect the agriculture as the type of land use dominating the area.



Map 13. Suitability map with greater weight assigned to the economic component

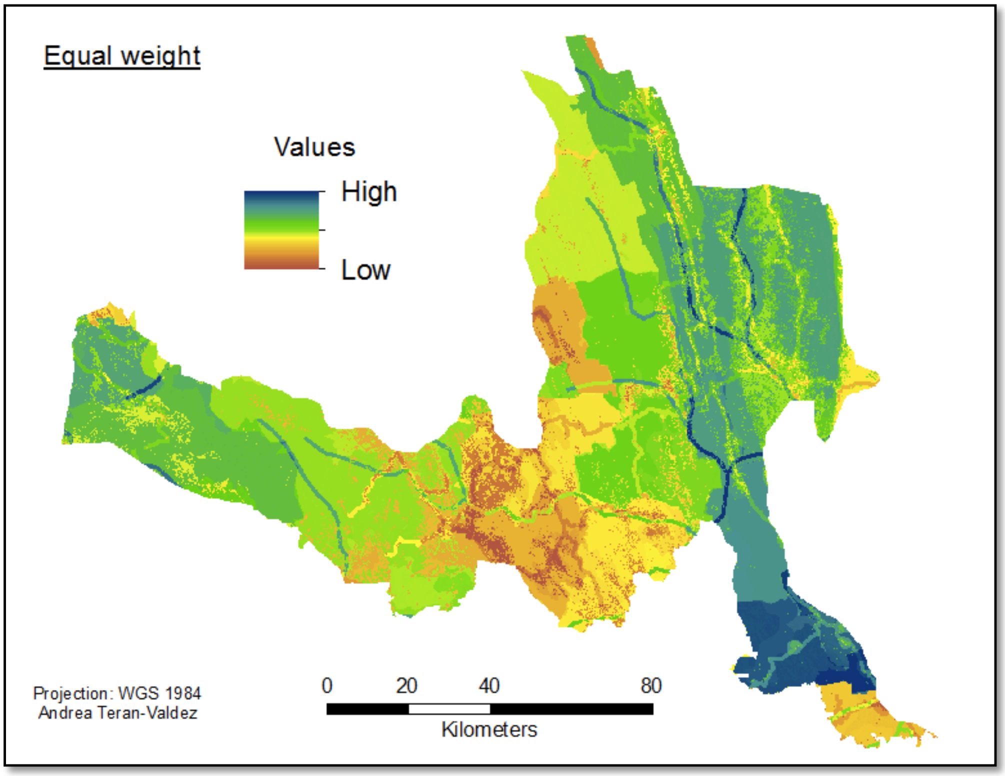
The economic weighted map shows the greatest high values of suitability and the largest areas of matrix with high suitability (Map 13). According to this map, the entire eastern part of the corridor has a matrix that could allow connectivity. It presents also a large barrier for connectivity along the municipalities of Lagunillas, Rayón and Santa Catarina (Map 3).



Map 14. Suitability map with greater weight assigned to the social component

On the contrary, the social weighted map shows more values of non-suitable areas on almost all the eastern part of the corridor (Map 14). The high values are present on the southern part at the municipality of Xilitla; medium-high values are present on the municipality of Aquismón and the rest of the corridor shows form medium to low values of suitability.

Map 15 shows the result of assigning equal weights to each of the three components. It follows a similar pattern from the biophysical and economic weighted maps. However, it has higher values of suitability than the biophysical and lower values than the economic. The best suitability is located on the southern part, on Xilitla and the lowest values on the municipalities of Lagunillas and el Rayón. The network of rivers as connectors is well delimitated in this map, as in the biophysical map (Maps 12 and 15).



Map 15. Suitability map with equal weight assigned to each of the components.

4.3. CONNECTIVITY MAPS

General overview of connectivity in the SMO

To find the best routes of connection between protected areas and PSC, one first approach was the overlaying of PSC and protected areas with each one of the four suitability maps (Maps 16-19). The result reflected two evident facts that show, in a broad view, the connectivity situation within the SMO between the areas of interest for conservation.

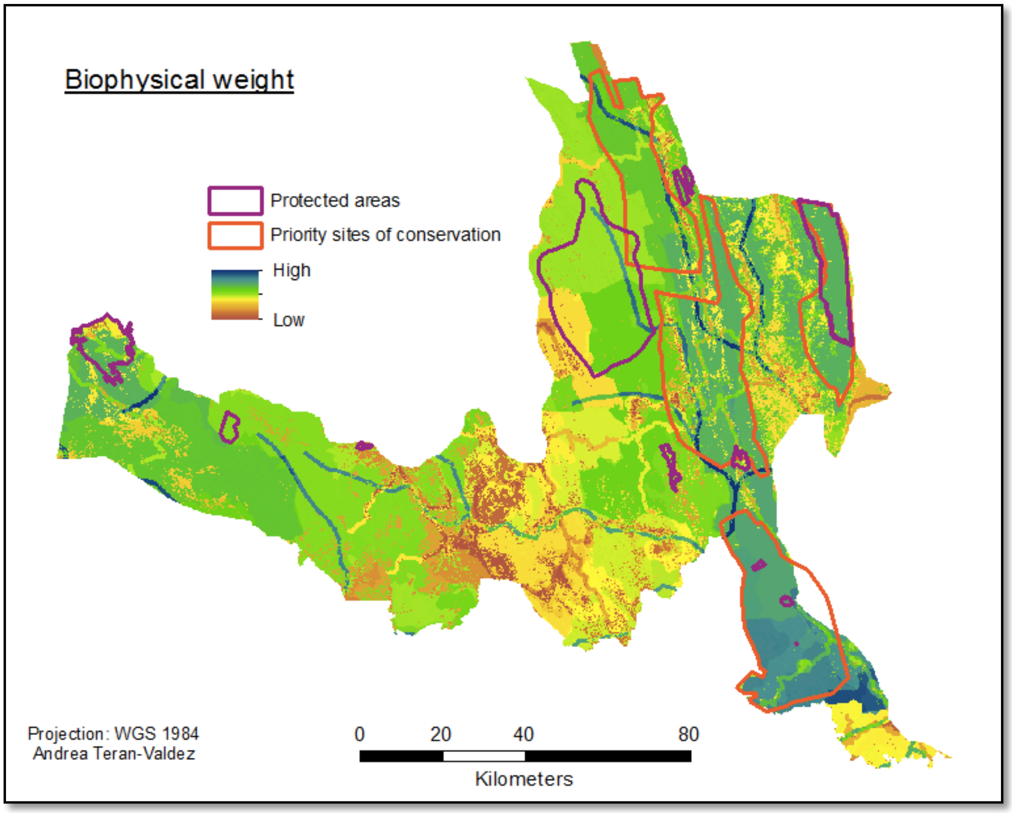
First, the PSC coincide with areas with high values of suitability, as well as most of the protected areas; there are some exceptions as, the IBA *San Nicolás de los Montes*, the national park *El Potos*í, the *Ciénega de Tamasopo* and the state park *Media Luna* (Map 7) which are not located on low values but in medium values. This fact applies to all the maps with the exception of the social weighted map, which only present high values for the priority site number 3, located in the southern part of the "Huasteca potosina".

The second fact is that there is a clear pattern of connection and non-connection between certain areas, which will be described individually for each of the maps.

The connectivity between PSC 1, 2 and 3 is high due to high values of suitability between them. In addition, the *Sierra Abra de Tanchipa* has areas of connection with high values with the PSC 2. Again, this fact does not apply to the social map, where there is a disconnection between these two areas, leaving the *Sierra Abra de Tanchipa* isolated from the other areas (this can also be seen in the physical weighted map but in a less extent).

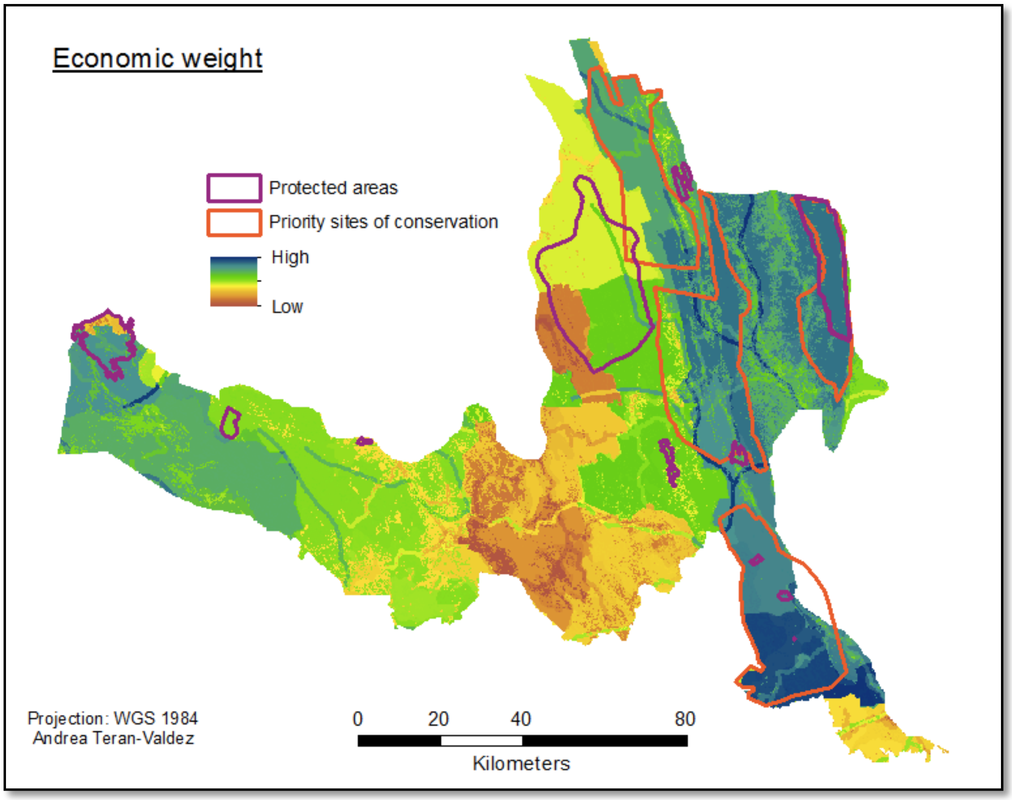
Finally, for all the maps, the protected areas *Sierra de Álvarez, El Potosí* and the *Media Luna* are isolated from the other sites. Although, *Sierra de Álvarez* and *El Potosí* are connected to each other with medium-high values of suitability. The IBA *San Nicolás de los Montes* is also somehow disconnected but in a less extent than the *Sierra de Álvarez* (Maps 16-19).

The biophysical weighted map (Map 16) connects the PSCs 1, 2, and 3 with medium-high values. Furthermore, the rivers *Gallinas* and *Santa María* connect PSCs 1 and 2. PSC 4 is not connected to the other sites due to the presence of urban areas in between.



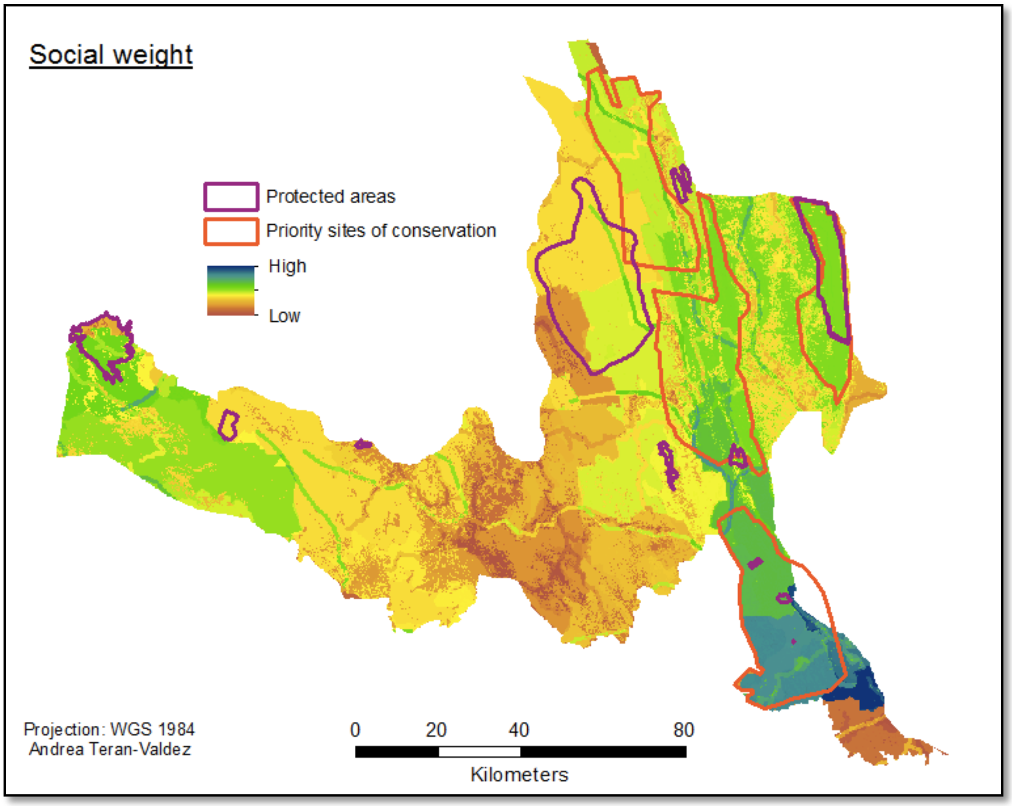
Map 16. Biophysical weighted map with overlay of PSCs and protected areas.

The protected area *Sierra de Álvarez, El Potosí* and *La Media Luna* are isolated from the other protected areas and the PSCs by a matrix of low values of suitability. Nevertheless, the river *Rioverde* highlights over the low suitability matrix and could act as a connector.



Map 17. Economic weighted map with overlay of PSCs and protected areas.

The economic weighted map (Map 17) shows a high suitability matrix that could allow the connectivity between the four PSCs. However, herein the IBA *San Nicolás* is not well connected with the PSCs but the river *El Salto* could act as a connector. This map shows a complete disruption of the connection of the protected areas located at the western branch of the corridor with the PSCs and other protected areas in the mid zone of the Sierra Madre Oriental.

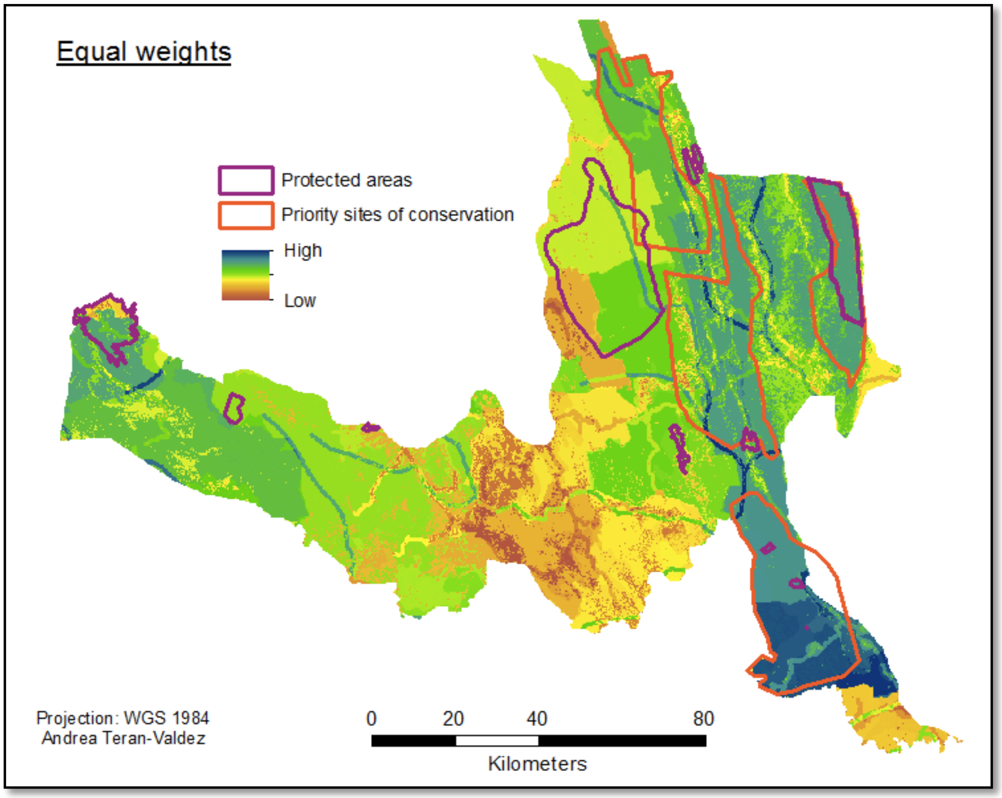


Map 18. Social weighted map with overlay of PSCs and protected areas.

The social weighted map (Map 18) shows a matrix that does not allow connection between the areas of interest for conservation. The only connection possible is between PSCs 2 and 3. The low values of this map leave the protected areas and the PSCs isolated within the matrix.

Finally, the equal weighted map (Map 19) follows a similar pattern of connectivity of that obtained with the biophysical map. Although, this one allows a greater connection between the PSC 4 with the other PSCs. Another difference with the mentioned map is that the western branch of the corridor is more isolated; the river *Rioverde,* that could act as connector for the protected areas located within this branch, has lower values of suitability.

In general, Maps 16, 17 and 19 show a fringe of connection of the low and medium tropical moist forests; whilst, forests of oak, pine and pine-oak are less connected or not connected between each other.



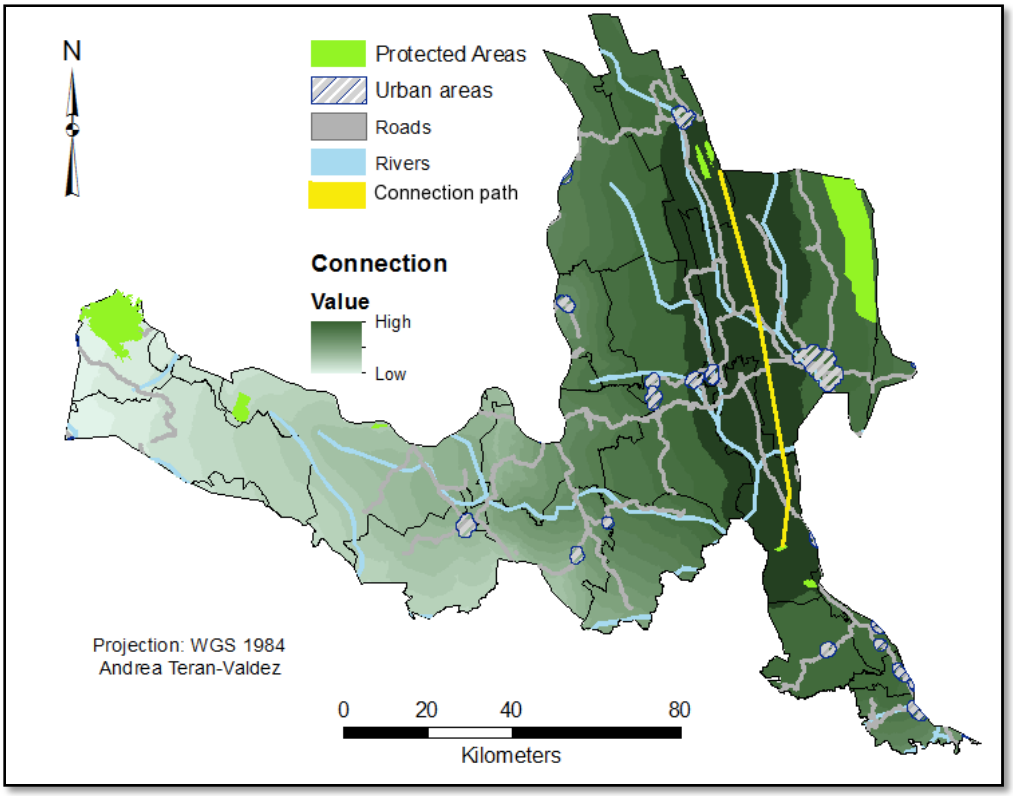
Map 19. Equal weighted map with overlay of PSCs and protected areas.

4.4. CONNECTIVITY ROUTES

Connectivity paths were traced to connect protected areas and PSCs. Therefore, North-South and East-West paths were traced within the corridor.

Map 20 shows a connection between the *Sierra de Enmedio y del Este* and the *Sótano de las Golondrinas*. The path was not traced to *La Hoya de las Huahuas* (south from the *Sótano de las Golondrinas*; map 7) because of its closeness to the *Sótano de las Golondrinas* and the high values of connection between these two areas.

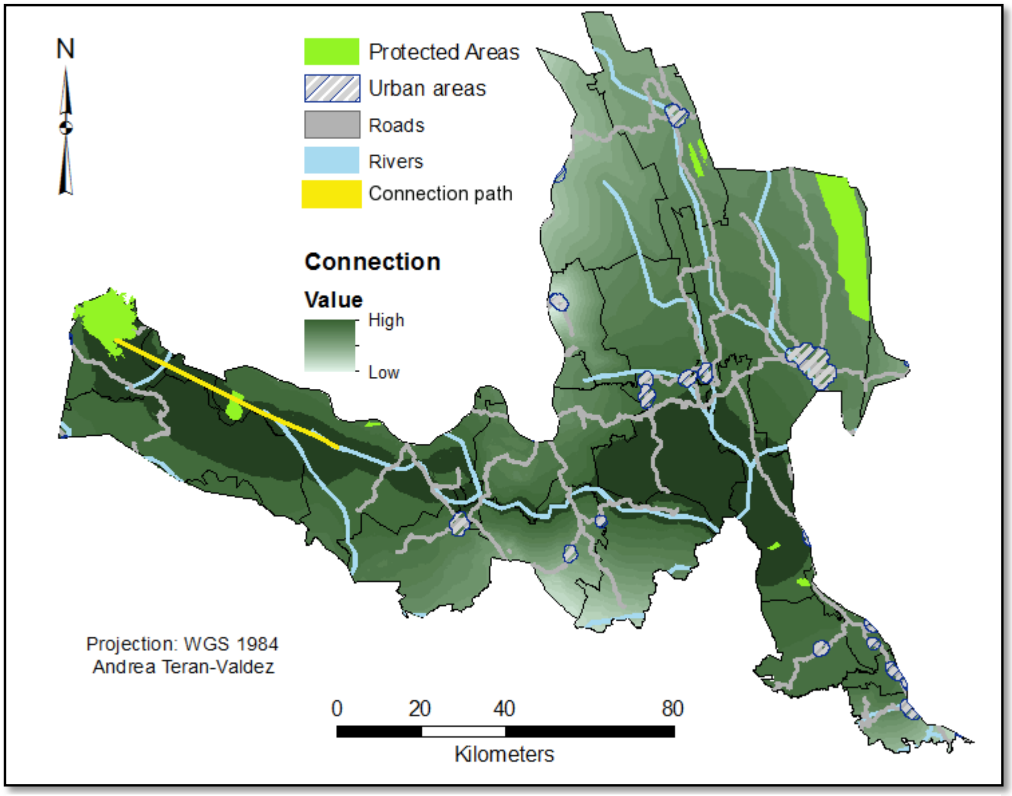
The traced path North-South crosses the municipalities of El Naranjo, Ciudad Valles and Aquismón. The path is located mostly on low tropical moist forest and in a minor extent on medium tropical moist forest. Some of the constraints of this route are that it has to go across grassland and agriculture areas; in addition, it has to go through three roads (one main paved road and two secondary, non-paved roads).



Map 20. North-South connection path between protected areas.

Map 21 shows the path East-West between *Sierra de Álvarez* and the *Sótano de las Golondrinas* and *Hoya de las Huahuas*.

The route crosses the protected area *El Potosí* and then the path follows the course of the river *Rioverde*. The movement cost in the municipalities of Lagunillas and Rayón is very high due to extended areas of agriculture. Herein, the best possibility of connection is afore mentioned river.

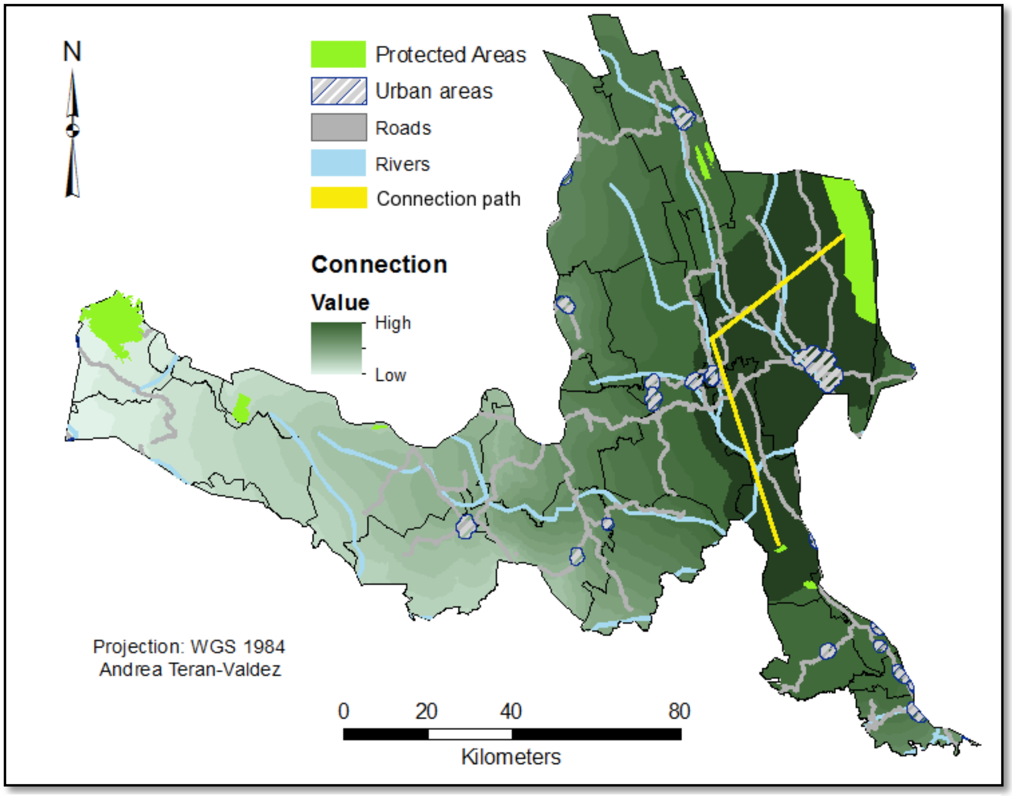


Map 21. West-East connection between the protected areas of Sierra de Álvarez and Sótano de las Golondrinas and Hoya de las Huahuas.

The best route of connection between the protected area *Abra de Tanchipa* and the southern part of the corridor is shown in Map 22. This path connects also the PSC 3 and 4.

The cost distance analysis gave a large area of low cost distance values. Nevertheless, the traced path, located in the municipalities of Ciudad Valles and Aquismón, has to go across areas of agriculture and grassland and several roads (three main paved and two secondary non-paved).

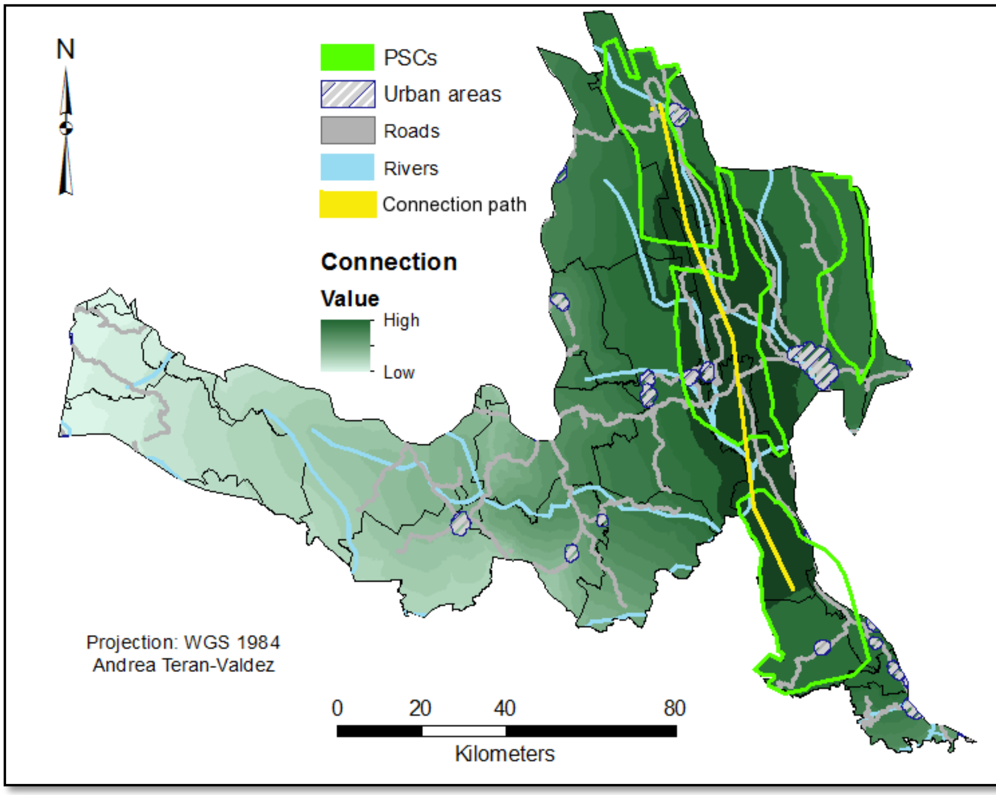
Furthermore, the urban area of Ciudad Valles, as well as the agricultural land surrounding it, disrupts the shortest path possible.



Map 22. Connectivity path between the protected area *Sierra de Abra Tanchipa* and *Sótano de las Golondrinas*

Finally, the connection between the PCSs 1 to 3 runs parallel to the North-South path and is also located on low tropical moist forest (Map 23). It can be an alternative route for the North-South path because it can also connect the protected areas of *Sierra de Enmedio y del Este* with the *Sótano de las Golondrinas.*

The path crosses the municipalities of El Naranjo, Ciudad Valles and Aquismón. Besides, it has to cross through two main paved roads and one secondary non-paved road.



Map 23. Connectivity path between the PSCs 1, 2 and 3.

4.5. EJIDOS EVALUATION

In a scale from 0 to 1, the values of potentiality (potentiality referred as the extent in which an ejido could be part of conservation strategies) for the ejidos varied from 0.4 to 0 (Map 24). The ejidos *La Gavia* and *Gustavo Garmendia* presented the highest values, whereas, *NCG Papagayos, Tampemoche*, *El Jabalí* and *Tampalatín* presented the lowest values of potentiality. Out of nine ejidos taken into account in the analysis, six are completely or partially located in PSCs. In addition, the ejidos *NCG Papagayos* and *San Nicolás de los Montes* are located partially within the IBA *San Nicolás* (Maps 8 and 24).

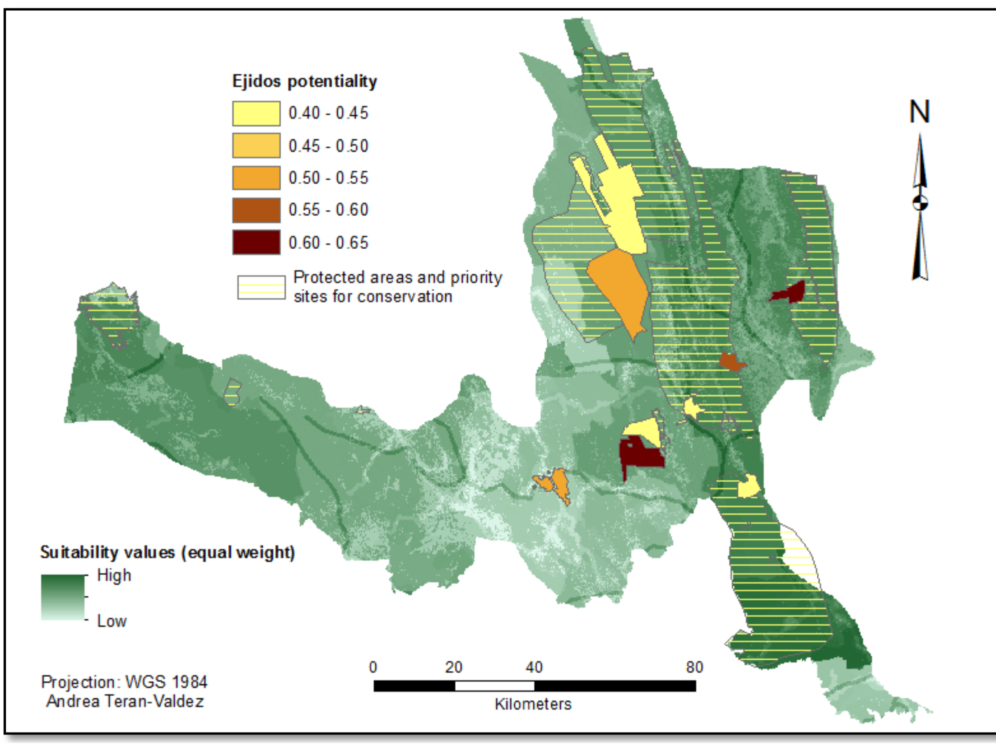
The values of potentiality of the ejidos do not completely match with the suitability maps; there is certain contradiction. For instance, the ejido *Pinihuan* that has medium potentiality values is located in a low suitability area; whilst, the ejidos

Tampemoche, and *El Jabalí*, with low potentiality values, are located in high suitability areas.

La Gavia and *Santa María Tampalatín*, which are located together in a medium suitability area, have opposite values. The first one present a high potentiality for conservation, whereas, the second one has low values.

Ojo de Agua and *Gustavo Garmendia* match with the values obtained in the suitability maps. Both have high potentiality and are located in high values of suitability.

NCG Papagayos occupies a large extension of the northern part of the corridor and is situated on medium values of suitability; nevertheless, it has low values of potentiality. These low values are due, mainly, to the domination of livestock practices as the economic source of income of the people inhabiting the ejido (Annex 3).



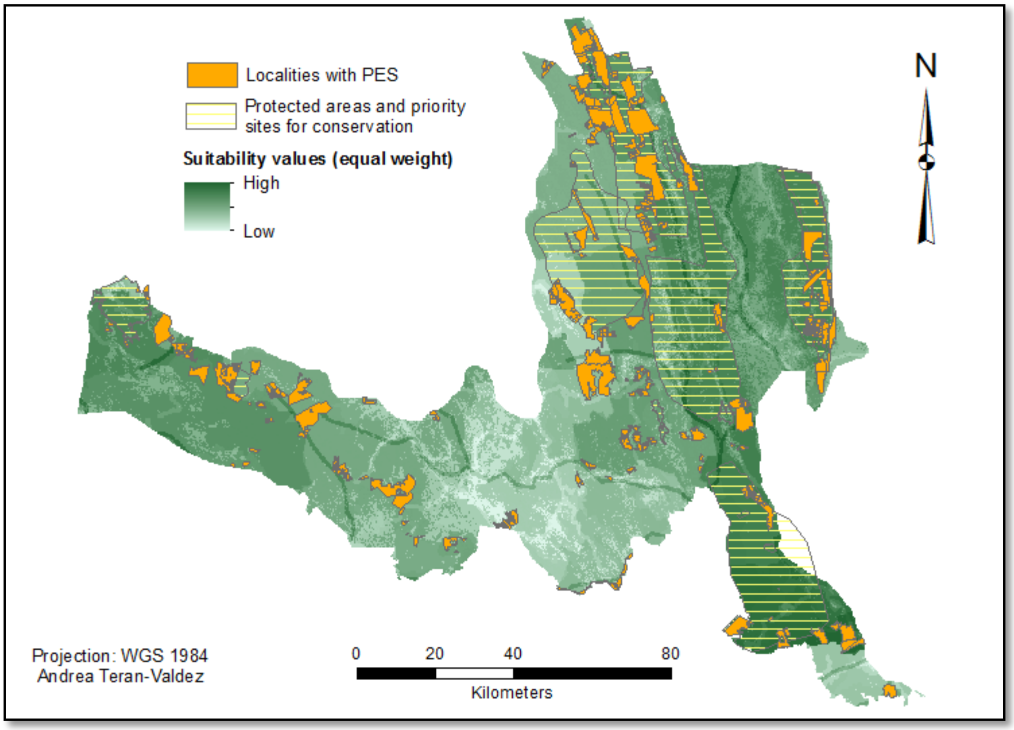
Map 24. Potentiality of ejidos for participating in conservation strategies. Sources: Annex 1

Finally, *San Nicolás de los Montes* has a medium potential for conservation and is located in medium-high values of suitability. This was the only sampled ejido that received, in the present moment, PES. Nevertheless, there was not perceived an important difference in the behavior of people towards nature or its conservation, in relation with other visited ejidos. For instance, people inhabiting the ejido have serious problems with the jaguar because it predates calves. The livestock is an important source of income for some ejidatarios and, for that reason, the jaguar is many times hunted by them.

Furthermore, some of the sampled ejidos intersect with the connectivity paths described in the previous section; *Ojo de Agua, Tampemoche, El Jabalí, Pinihuan, La Gavia,* and *Tampalatín* (the last two do not directly intersect with the path but are located close to it). From these ejidos, only *La Gavia* and *Ojo de Agua* show high values of potentiality; *Pinihuan* has medium values, and the others show low values (Map 24).

Regarding to the PES program, the overlay of ejidos receiving PES with the equal weighted suitability map showed that most of these are located within the PSCs. However, there are some ejidos outside these areas and in the western branch of the corridor, where the suitability maps showed low values (Map 25).

Finally, regarding to the location of this ejidos within the study area, there are three major clusters (Map 25). There is one aggregation of ejidos receiving this subsidy on the northern part of the corridor, corresponding to an area of forests of oak, and medium and low tropical moist forests. The other cluster is located in the area belonging to the *Sierra del Abra Tanchipa*, which corresponds to low and medium tropical moist forests. The final aggregation is located on the western branch, where pine and pine-oak forests prevail (Chapa-Vargas and Monzalvo-Santos, 2012).



Map 25. Ejidos that have received or receive Payment for Ecosystem services. The matrix map corresponds to the equal weight suitability map selected for the analysis at the ejido level. Sources: Annex 1

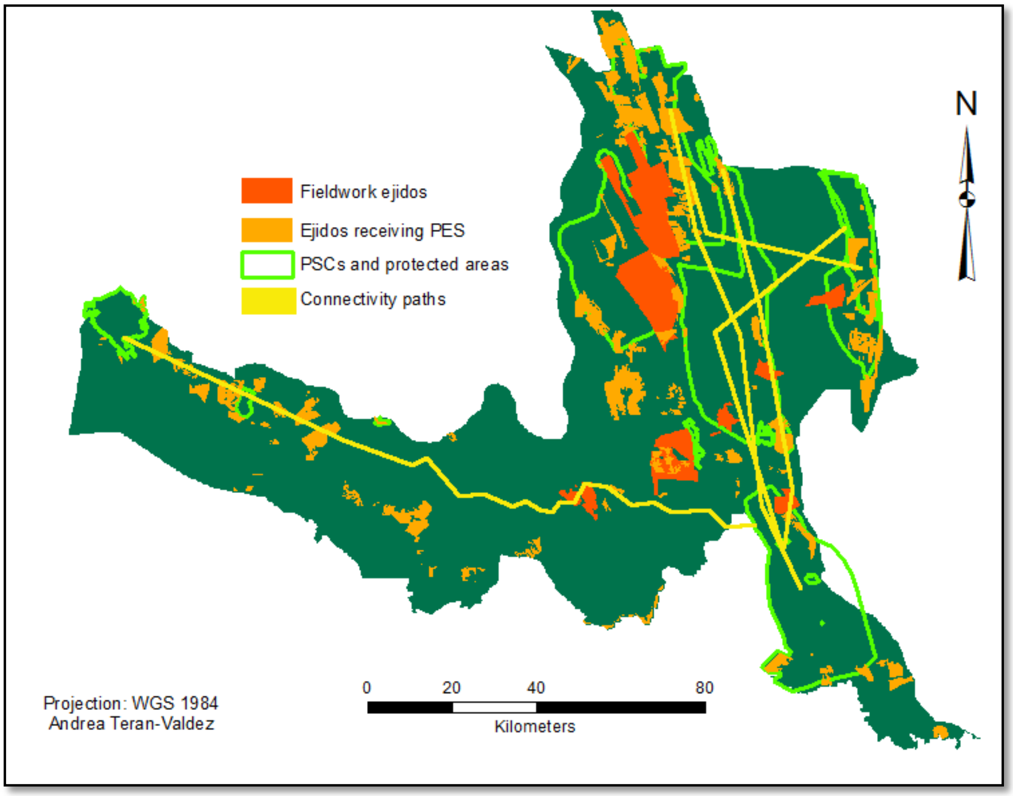
Finally, the overlay of connectivity paths with ejidos shows the intersection of certain ejidos with the traced routes (Map 26).

On the North-South path, there are located the sampled ejidos *Tampemoche* and *Ojo de Agua*; the first one shows low potentiality of participating in conservation initiative, whereas the second one shows a higher potentiality. On the other hand, there are some ejidos already receiving PES that are located on the route, such as: *Chuchupe* (Ciudad Valles), *La Pila* (Ciudad Valles), *Estación Micos* (Ciudad Valles), *Charcos de Oriente* (El Naranjo).

The path West-East from *Sierra de Álvarez* and *Sótano de las Golondrinas* intersects with the sampled ejido *Pinihuan*, which presents a medium value of potentiality. The ejidos *La Gavia* and *Santa María Tampalatín* do not intersect directly but are located near the path.

The path connecting *Sierra del Abra Tanchipa* with *Sótano de las Golondrinas* intersect with the ejido *El Jabalí* with low values of potentiality.

The path connecting the PSCs 1, 2 and 3 intersects in the northern part (municipality El Naranjo) with the ejidos *Minas Viejas, Los Álamos,* and *La Soledad,* which receive PES.



Map 26. Connectivity routes overlaid with sampled ejidos and ejidos receiving PES

5. DISCUSSION

5.1. DATA GATHERING AND SPECIES' DISTRIBUTION MODELING

Distribution modeling using presence records for species has been used widely for conservation assessments purposes (Anderson and Martínez-Meyer, 2004). However, there are some limitations that have to be considered when working with such approaches; for example, occurrences of species may be biased to certain better-sampled areas (Anderson and Martínez-Meyer, 2004; Phillips *et al*., 2006). Some localities may be more sampled due to easy accessibility (Phillips *et al*., 2006) or just because they are more interesting to researchers. In addition, the sample effort varies also between researchers. In general terms, sampling effort decreases with increasing difficulty of sampling; thus collection in remote areas is low (Raedig and Kreft, 2011).

Differences of sampling between areas and the bias to certain localities could be identified; for example, there are more records of species for localities, which are easier to access as Xilitla, El Naranjo, and *Sierra del Abra Tanchipa* (Ciudad Valles). Probably this is one of the reasons for these areas to exhibit higher level of species richness, as seen in the Map 9.

In addition, there can be also some errors with species misidentification or lack of sufficient geographic detail (Phillips *et al*., 2006). The latter I observed in this research when searching for information to carry out the modeling. Web-databases many times show several records for species, but just a limited number of records have the necessary geographic description. Unfortunately, solving the problem of misidentification of species is not possible in most of the cases due to logistic constraints; visiting the collections of different museums is very difficult if not impossible. Furthermore, misidentification could be a common error in web-databases that are not checked by experts.

There is also a difference between the sampling of groups of species; for instance, birds are widely sampled, maybe for the relatively "easy" sample techniques, in contrast with reptiles, amphibians or mammals for which few records are available.

This issue is reflected on the obtained distributions in the study; I obtained detailed records for 26 birds species, whereas, a total of 14 for the other groups (amphibians, reptiles and mammals). From 49 endemic species of amphibians and reptiles (28 restricted to the Sierra Madre Oriental) (Canseco-Márquez *et al*., 2004), there was information available for only eight species for which the distribution models were done. For 20 endemic species of mammals (León-Paniagua *et al*., 2004), there was only sufficient information for 6 species. Finally, from 41 endemic birds (Sahagún-Sánchez *et al*., 2013), sufficient information for 26 species was available; this is due to the existence of more birds species and hence more records in general.

This limitation on species records' availability can represent a serious problem and have important implications on conservation assessments, especially when working with endemic species that present restricted distributions. Species with few records or no records at all are not taken into account in the analysis; nevertheless, these species with the smallest ranges can be of greatest conservation concern (Graham and Hijmans, 2006 in Raedig and Kreft, 2011).

Another limitation arised when working with data sources that included museums records collected over some decades. This impeded the use of land use land cover as a variable for the distribution modeling because of differences at the temporal scale. Anderson and Martínez-Meyer (2004) state that there should be a temporal correspondence between occurrences' localities and environmental variables due to change of the vegetal cover over the years.

However, data obtained from experts in the biological field in Mexico provide confidence to the modeled distributions.

In this research, the obtained distributions contributed to the generation of areas with high presence of endemic species and consequently of high relevance for conservation. Nonetheless, many endemic species were excluded from the analysis because of lack of data; hence, there could be areas of importance that are left aside in this study.

The comparison between the PSC ("priority sites for conservation") with other areas that have been previously determined as priority sites by other authors (CONABIO, 2004; CONABIO et al., 2007; GIZ, 2013) shows some areas of junction. This shows that, regardless of the methodology used to establish areas for conservation, there are certain places that gather all the criteria used to consider an area as a priority for conserving it. Consequently, there should be a special focus on these areas.

5.2. SUITABILITY MAPS

The establishment of priority areas is important and it can be complemented with a next step to look for connections between them to avoid the isolation of endemic species (referring specifically to this study case). A mid-step before defining connectivity routes is the definition of the matrix; which will determine the resistance for species movement and hence, the degree of connectivity (Hilty *et al*., 2006).

Corridors have been designed taking into account mostly bio-physical variables; for instance, the design of a corridor in "Canada's Carolinian Zone" establishes as main goals the conservation and recuperation of natural areas (Jalava *et al*., 2000), as well as the design of the corridor Sian Ka'an-Calakmul in Mexico that considers changes on vegetation and distribution of the jaguar as umbrella species (Colchero *et al*., 2006).

Nevertheless, with time, the purposes of biological corridors have changed to constitute not only a tool for nature conservation, but also to improve socio-economic conditions of the people inhabiting within corridor (GIZ, 2013; Programa Nacional de Corredores Biológicos de Costa Rica, 2010).

Nevertheless, how to incorporate the socio-economic variables remains unclear and there are no standard methods to do so. Therefore, the approach developed in this study incorporates different methods and is new in some aspects (Figure 1). For example, the way of combining the three components (biophysical, social and economic) by the subdivision of the weight used in a multi-criteria evaluation (Table 5).

Using these maps obtained with the multi criteria evaluation as a matrix for movement, instead of just the vegetation cover or attributes of the landscape is also a new approach.

This could be a standard methodology to apply in the design of corridors when the problems which occurred in this study are solved in future research; for example, the assignment of the weights to the variables in the multi criteria analysis can be done by a group of experts and not only by one person. The weight given to each component is flexible depending on the purposes of the corridor and the major needs of the area where it will be established.

Besides, other variables could be added to the analysis. Economic data has being used previously by Conrad *et al*. (2012). The authors consider the cost of parcels to optimize the use of the resources given budget constraints and maximize environmental benefits. Nevertheless, adding the cost of the parcels to this case is too difficult because of the type of tenancy of the territory (ejidos) that can sometimes even include communal property.

Regarding to the weight assigned to each variable (Table 4), some of them were based on observations done in the field. For instance, the low weight assigned to slope and soil type was based on the fact that people, when the available land is limited, does not consider these two physical attributes as constraints. It is very common to find crops in steep slopes as well as sugar cane or corn plantations in rocky soils (Figure 3).

Figure 3. Parcel on rocky soil "cleaned" for cultivation. Ejido *San Nicolás de los Montes*

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Furthermore, forests on the “Sierra” as they refer to areas with steep slope are frequently used as pasture for cattle.

On the other hand, rivers were assigned a higher weight because they can represent natural connectors of the landscape and its importance for some species assembles (Hilty *et al*., 2006; Lees and Peres, 2008); furthermore, local people give a high value to the water resource and have realized that conserving the vegetation surrounding the water bodies prevent the drying of the water source (for example, in the ejidos *El Jabalí,*and *Gustavo Garmendia*; Figure 4).

Figure 4. River *Gallinas* at the ejido *El Jabalí*. Vegetation is preserved along the river, whilst it is surrounded by sugar cane plantations

Finally, the resultant maps of suitability in this work differed in the quantity of cells considered as suitable or not suitable for the corridor; however, the major variation presented the economic and the social weighted maps.

The economic map presented greater areas of high values of suitability. This could be because of the variables considered for the analysis. The major weight was assigned to the occupation of the population, establishing the occupation to agriculture as a constraint and other types of occupation as a favorable condition. This decision was taken because conversion of forest to agricultural land is a major driver of land use change (Sahagún-Sánchez *et al*., 2011). Therefore, if people's livelihood is based on agriculture, the impediment of such activities will be harmful for the population and will hardly happen.

The social weighted map resulted in greater areas of low suitability. This could be reflecting the conflict between human activities and nature conservation. Areas of importance for conservation, such as PSCs or protected areas, are usually located in rural areas; where the people have not completely satisfied their fundamental necessities and depend on the exploitation of natural resources. The consideration of this fact is extremely important when the planning of conservation measures is carried out.

Nonetheless, working at the municipal level may not be the best scale because of the heterogeneity of socio-economic conditions in one municipality; especially, between urban and rural areas. Hence, some characteristics of rural localities can be masked by the characteristics of larger urban areas, as occupancy of the population.

For instance, in most of the municipalities, the available map with information of economic activities determined that most of the people's occupancy was other than agriculture (CONABIO, 2010). This fact could represent a sampling bias because of the focus in urban areas; where, in deed, people are no longer dedicated to agriculture. Nonetheless, in rural areas, which were visited during the fieldwork, most of the people depend on this activity as a source of income and for their own food supply.

5.3. CONNECTIVITY MAPS

Finally, with the incorporation of the priority sites for conservation and the generated suitability maps, some suggestions for best routes that enhance connectivity can be made.

Connecting the landscape has represented a matter of discussion since the 1970s, when the effects of patchiness of the landscape started to be examined (Tischendorf and Fahrig, 2000a). Nevertheless, there is a difference between structural and functional connectivity; structural refers to the contiguity of the landscape; whereas, functional refers to the actual movement of species through a matrix (Tischendorf and Fahrig, 2000a). The contiguity of the landscape, in a human-modified landscape can be difficult to achieve. Therefore, a functional connectivity could be more feasible. Although, there is discussion about the extent of real movement of species through corridors (Simberloff *et al*., 1992)

Consequently, connectivity is not easy to achieve and the attributes of the matrix can promote or impede the connection (Chardon *et al*., 2003; Goodwin and Fahrig, 2002). Measures of connectivity are usually species-specific because it takes into account the ability of an organism to disperse and move along a matrix (Chardon *et al*., 2003; Hilty *et al*., 2006; Tischendorf and Fahrig, 2000b). Nevertheless, designing a corridor for one or few species is hardly achievable, with exception of corridors designed for umbrella species like the grizzly bear or the jaguar (Colchero *et al*., 2006; Conrad *et al*., 2012), where important economic resources are allocated.

Frequently, the human “attribute” of the landscape is considered but not included when measuring the movement along a matrix. The human factor has been evaluated mostly as a constraint for movement; nevertheless, biological corridors can be planned as an area of coexistence between nature and human activities in a sustainable environment. Hence, corridors will not only enhance nature conservation and species’ movement, but also will constitute a social initiative to improve the livelihood of people inhabiting the corridor area.

During the study, a gap appeared regarding to the conservation of pine-oak forests. These are mainly located in the protected areas *Sierra de Alvarez* and *El Potosí*, which showed to be relatively isolated when considering the suitability maps as a matrix of connectivity. Conservation strategies should consider most of the ecosystems present in the corridor area. For that, a special focus must be done on the areas of low suitability leading to the isolation of this type of vegetation. Rivers, for instance, can be used as *de facto* corridors. As demonstrated in this study, in areas of low connectivity, natural features of the landscape, such as the *Rioverde* in the southwestern part of the corridor, may be the best alternative of connection.

The mid zone area of the Sierra Madre Oriental showed a high potential of connectivity and two of the proposed routes of connectivity lie there. This area is important for the conservation of low and medium tropical moist forests and of cloud forests. The last one is considered as a threatened ecosystem in Mexico mainly for two reasons. First, it has a restricted geographical distribution; second, human activities have lead to its deforestation. Furthermore, none of the areas sheltering this ecosystem is protected officially by the law (Leija et al., 2011). Therefore, the enhancement of connectivity along this area should be promoted.

5.4. LOCAL (EJIDOS) PARTICIPATION

Logistic issues, like the difficult access to some areas, limited the obtaining of socio-economic data in ejidos. In addition, the number of questionnaires applied varied in each of the ejidos, having some ejidos with a sample size of 3% of the ejidatarios, and others with 30%. The reason for short sample sizes in some ejidos is that meeting with the ejidatarios is difficult because they work in the field most of the day.

Nonetheless, the information gathered during fieldwork is valuable because people's perception about conservation was captured, as well as information about the use that they give to natural resources. Knowing people's use of resources and the consequent conflicts that this use brings to nature conservation, it is possible to look for conservation strategies. These strategies should involve nature conservation and socio-economic development of the involved localities.

Furthermore, it has been stated that sampling social variables can be more flexible than biological or physical variables; and the sampling size depends on the research question (Marshall, 1996). In regard to people's perception towards conservation and relation with nature, the sample size was appropriate; nevertheless, some information (such as "extension of crops", "type of agriculture" and "livestock") could have been more representative with a larger sample in some of the ejidos.

In general, people are aware of the negative impacts of deforestation on the water cycle. Furthermore, there is a common concern among adult people about the future of the children without natural resources. However, the use that they give to the forest is for wood obtainment. And, it was repeated several times during the interviews that they could not use the forest because they did not have money to "clean" it; that means that the forest is seen often as land to cultivate different crops.

An important part of the corridor planning process is the development of specific actions and conservation strategies. For that, areas to invest the available resources must be identified. To accomplish this step, the active participation of the people inhabiting the corridor is essential; therefore knowing the perception of the people towards conservation and related issues is important as a first step of including them in the planning process.

The incorporation of the ejidos' information to the connectivity maps had some limitations. On one hand, the difficulty of interviewing the ejidatarios; and, on the other hand, filtering the information is difficult because sometimes people avoided to answer certain questions or did not answer with the truth, specially the ones regarding to the conflicts with animals and the use given to the forest. People were afraid of sanctions applied by the government if they were caught hunting or cutting down the forest. Therefore, this information was added to the analysis but it might be incomplete and hence, it has to be treated with those considerations.

Regarding to the sources of income, special attention was given to sugar cane practices; therefore, the highest weight was assigned to this variable. The monocultures of sugar cane represent a serious constraint for species movement because of the completely lack of forest cover in sugar cane crops and also because the characteristics of the process of cultivation; the plant has to be burned before being cut (Figure 5).

Consequently, all the possible movement is inhibited for species that could otherwise tolerate that kind of disturb (vegetation cover removal). Moreover, people working for the sugar cane industry have access to health insurance and the retiree's pension when they are 60 years old (fieldwork data). In consequence, it is an activity that hardly will be changed by the people to participate in alternative economic practices.

Regarding to the weight assigned to livestock and agricultural area, it is high too because for many families this is the only source of income; in addition they receive a subsidy from the government when they practice these activities (PROCAMPO and PROGAN). Some of the variables were summed to the analysis but were assigned a low weight due to the uncertainty of the gathered information (conflicts with animals, forest exploitation, live fences and interest in tourism).

Figure 5. Sugar cane crops in *San Nicolás de los Montes*, municipality of Tamasopo

Working at the level of ejido can be a feasible option when routes are already established within the corridor. Evaluation of the potentiality of people from ejidos to participate in conservation strategies can help to allocate economic resources in areas that are committed in the long term.

Furthermore, ejidos own proximately 80% of the remaining forests of Mexico and most of the people inhabiting the ejidos base their economy on the exploitation of natural resources (Bray and Peres in Barnes, 2009; Thoms and Betters, 1998). Consequently, working at the ejido level is the most feasible alternative to success with nature conservation strategies.

Ejidos receiving PES were also incorporated to the analysis, as they represent the intention of conserving natural resources and can serve as areas of enhanced mobility of species. PES are considered as one of the most notable incentive mechanism for forest conservation. PES were established in Mexico in 2003 as a compensatory measure to prevent deforestation in priority areas for conservation (REDD, 2012). However, this subsidy has to be evaluated to find out whether the purpose of the subsidy is being reached.

The idea of the PES is to gradually change people's agricultural or livestock practices to more sustainable alternatives in the period of the subsidy support (5 years). Nevertheless, beneficiaries perceive it as another governmental subsidy as PROCAMPO or PROGAN. Therefore, there is a lack of information in terms of the purposes of the PES, and a lack of monitoring the success of the subsidies.

In conclusion, with the analysis at the ejido level, there were some ejidos that are more suitable and open to work with conservation efforts. The location of ejidos with a high potentiality of working with conservation in areas of low suitability (Map 20) can enhance the low connectivity between certain protected or priority areas.

6. CONCLUSIONS AND RECOMMENDATIONS

Species distribution modeling contributes to generate essential input to identify priority areas for conservation. It is needed more sampling effort in areas with poor accessibility. These sites could be areas of importance due to the presence of species with short ranges.

There are different criteria to establish priority sites for conservation; their selection depends on the purpose of the research. Moreover, connectivity studies should include the work of other authors; different results can be combined to have a more complete assessment as a basis for developing conservation strategies.

In order to develop effective conservation measures, social data collection is recommended; particularly in areas with high levels of poverty and marginalization.

Methodologies to establish corridors are complicated due to the great number of variables that have to be taken into consideration. Standard methodologies for the design of corridors have to be adapted to the local environment where different sets of variables influence the area conditions.

The work at a fine level (ejidos level) is very important to effectively allocate resources in specific areas with potentiality to conserve in the long term.

The way PES are being applied to the communities should be evaluated to avoid this subsidy to be one more subsidy for the field that do not promote any change in the livelihood of the people.

Biological corridors are a strategy that could change the paradigm that social development is opposed to nature conservation. Their establishment could show that it is possible to live in a sustainable way without compromising our future. But biological corridors are long-term measures, and to prove the effectiveness, it is necessary to establish a mechanism of constant monitoring. Selecting and monitoring indicator species for flora and fauna could be a strategy to prove corridors objectives in the long term.

7. OUTLOOK

Regarding to the records of presence of species, there is a gap in the sampling of certain groups and certain areas. As an objective of a biological corridor, there should be a sampling effort in areas where collections have not been carried out.

This will contribute to the general knowledge of existent biodiversity of the region and to measure the level of conservation of areas of interest.

The focus on endemic species could help to conserve important species due to their restricted geographical distribution.

The variables to include in the analysis should be chosen in a local way, considering the requirements of the people and their main economic activities. Working at the most fine level will give better results; a coarse scale could lead to a mask effect of larger or urban populations over small and rural populations.

Connectivity can be approached from different perspectives; the strict concept of connectivity will consider only species movement through a matrix taking into consideration biophysical attributes of the landscape. Nevertheless, as stated in this study, connectivity must consider the human component as part of the landscape and therefore, include it in the analysis. The social and economic components will determine, along with the biophysical component, the permeability and resistance of the matrix.

After the establishment of a corridor, species monitoring must be carried out to prove that the objectives of the corridor are being accomplished. Indicator species of flora and fauna should be selected to keep a constant monitoring and corroborate the extent on which a corridor enhance the movement of the species; especially on this large scale corridors that cover large extensions and cross several political divisions. Furthermore, the long-term monitoring should include the evaluation of possible negative effects of corridors such as dispersion of plagues or spread of fires, among others.

Addressing to the strict biological meaning of connectivity, the extent to which different species use an established corridor remains to be proved.

People's active participation in a conservation strategy will determine the success of the same. Ejidos with potential of participating in conservation could serve as stepping-stones within the matrix, and conservation efforts should be focused on these areas. I recommend an evaluation of the PES, as how they can contradict with other subsidies like PROCAMPO and PROGAN.

Some municipalities stood out for presenting high values of suitability for connectivity and shelter important areas for conservation. Conservation efforts and resources could be allocated to these areas (El Naranjo, Ciudad del Maiz, Tamasopo, Aquismón, Xilitla, Armadillo de los Infante, Zaragoza, San Nicolás Tolentino).

The connectivity routes are located mainly in the municipalities of Ciudad Valles, El Naranjo, Aquismón, Armadillo de los Infante, and San Nicolás Tolentino.

Other municipalities stood out for having low values of suitability (Lagunillas, Rayón, San Ciro de Acosta); therefore a different approach should be used for these areas, for instance, reforestation or social development programs. The work in these municipalities is extremely important because they are interrupting the connectivity potential of the matrix, leaving some areas in isolation.

At the ejido level, I suggest *Pinihuan* to be considered as a stepping stone. It has a relatively high potential for participating in nature conservation but is embedded in a low suitability matrix. *La Gavia* and *Gustavo Garmendia* could be acting as connectors on the landscape too.

Ejidos receiving PES have shown interest in conservation; therefore, other conservation activities could be proposed to these localities to fit into the corridor initiative. Especially to those intersecting with the proposed connectivity paths.

The presence of ejidos with low potential in areas of high suitability (*Tampemoche, Ojo de Agua* and *NCG Papagayos*) suggest that the socio-economic situation is a constraint for conservation and this could have negative impacts on biodiversity. I suggest the evaluation of other ejidos within the area to allocate resources efficiently, focusing on those intersecting with connectivity routes.

Finally, a socio-economic assessment should be applied to other states of Mexico that are part of the biological corridor of the SMO; in that way allocation of economic resources destined for conservation and social programs could be directed to appropriate areas.

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9. ANNEXES

Annex 1. Maps' sources used for the elaboration of maps.

LAYER	SCALE	YEAR	SOURCE
Soil	1:1000000	1995	INIFAP-CONABIO
Land use and vegetation	–	2011	Chapa-Vargas
Rivers	1:4000000	1990	Maderey and Torres
Digital Elevation Model	–	–	Dr. Humberto Reyes
Protected areas (state level)	–	2009	Bezaury-Creel, Torres, Ochoa, Castro-Campos, Moreno
Protected areas (federal level)	1:1000000	2010	CONANP
Important Bird Areas (IBA)	1:250000	1999	CIPAMEX and CONABIO
Ramsar	–	2010	CONANP
Priority terrestrial regions	1:1000000	2004	CONABIO
Priority terrestrial sites for conservation	1:1000000	2007	CONABIO, CONANP, TNC Mexico, Pronatura
Areas of interest for the creation of biological corridors	–	2012	DAT-CCRB, CONABIO
Payment for ecosystem services (PES)	–	2009-2012	CONAFOR
Urban localities	–	1997	SEDESOL
Roads	1:1000000	1985	Digital Chart of the World
Degree of marginalization	1:1	2006	CONABIO
PROCAMPO	–	2012	SAGARPA
PROGAN	–	2012	SAGARPA
Economic activity (municipalities)	1:250000	2010	CONABIO

Literacy (municipal level)	1:250000	2010	CONABIO
Demographic characteristics	1:250000	2010	CONABIO
Localities with indigenous population >75%	1:1	1995	CONABIO
Total indigenous population	1:250000	2004	CONABIO
CESMO		2013	GIZ
Priority areas (CESMO)		2013	GIZ

Annex 2. Questionnaire applied to ejidatarios during fieldwork

ENCUESTA SOCIO-ECONOMICA SIERRA MADRE ORIENTAL, SLP

Fecha: ____________ Lugar: ______________________

Sexo: M ☐ F ☐ Edad: _______ Ocupación:___________________ Años en la escuela:________

Agrícola y forestal

1. ¿Con cuanta superficie cuenta en total?_________________

   Forestal:__________Agricultura:___________Ganadería:___________Otro:_____________

2. Principales cultivos____

3. ¿Cuál es la principal fuente de ingreso económico del hogar?

Agricultura/ganadería ☐ Comercio ☐ Servicios ☐ Otras___________________________________

4. ¿Le da algún tipo de uso productivo al bosque? Si ☐ No ☐

   ¿Cuál?____

5. ¿Conoce las siguientes prácticas agrícolas alternativas?

   Silvopastoril ☐ Agroforestal ☐ Cercas vivas ☐ Otra________________________________

6. ¿Estaría dispuesto a incorporarlos en su sistema de producción? Si ☐ No ☐
   Motivo:

7. ¿Qué animales reconoce usted en sus alrededores?

8. ¿Alguno de estos animales ha tenido conflictos con actividades agrícolas que se realizan en la zona? Si ☐ No☐

   ¿Cuál/cuáles?____

Programas gubernamentales

1. ¿Sabe usted si hay algún programa del gobierno que incentive la conservación del bosque?

Si ☐ No☐ ¿Cuál?____

2. ¿Sabe si alguno de estos programas incluye pagos económicos? Si ☐ No☐

Monto:________________________

3. ¿Recibe algún subsidio de parte del gobierno? Si ☐ No☐

¿Cual/es? Tiempo y monto:

¿Se puede extender el subsidio? Si ☐ No ☐

¿Por cuanto tiempo?____

Turismo

4. ¿Le gustaría o estaría dispuesto a trabajar con turismo? Si ☐ No ☐

5. ¿Cómo podría usted apoyar al sector turístico?

6. ¿Qué opina sobre las áreas naturales protegidas?

Annex 3. Systematized information gathered during fieldwork. Values are percentages of the number of ejidatarios pertaining to each ejido. Description of variables: ejidatarios percentage of ejidatarios interviewed; sugar cane, people within the ejido cultivating sugar cane; agriculture, people dedicated to agriculture; agriculture area, surface of the land owned by interviewed ejidatarios dedicated to agriculture; livestock, ejidatarios owning livestock; extensive and rangeland, type of livestock practiced by ejidatarios; forest, ejidatarios owning forest; forest use, people having some kind of benefit from the forest; sugar cane, livestock and other income, main source of income of the ejidatarios live fences, ejidatarios that have live fences around their crops; conflict animal, people facing conflicts with animals due to damage of agriculture and/or cattle; interest tourism ejidatarios interested in getting involved with touristic practices in the area.

	EJIDATARIOS	SUGAR CANE	AGRICULTURE	AGRICULTURE AREA	LIVESTOCK	EXTENSIVE	RANGELAND	FOREST	FOREST USE	SUGAR CANE INCOME	LIVESTOCK INCOME	OTHER INCOME	LIVE FENCES	CONFLICT ANIMAL	INTEREST TOURISM
SAN NICOLAS	5.88	60.00	80.00	5.74	60.00	33.33	66.67	70.00	71.43	70.00	90.00	0.00	40.00	70.00	70.00
GUSTAVO GARMENDIA	38.33	52.17	82.61	34.39	21.74	40.00	60.00	43.48	10.00	8.70	0.00	60.87	17.39	34.78	39.13
NCG PAPAGAYOS		–	–	2.92	–	–	–	–	–	–	100.00	0.00	–	–	–
TAMPEMOCHE	24.44	9.09	90.91	25.00	72.73	62.50	0.00	0.00	–	0.00	45.45	27.27	36.36	18.18	0.00
TAMPALATIN		73.33	100.00	26.85	46.67	57.14	14.29	33.33	40.00	60.00	13.33	20.00	20.00	20.00	13.33
LA GAVIA	6.36	85.71	85.71	8.88	85.71	33.33	83.33	57.14	100.00	14.29	71.43	42.86	14.29	57.14	0.00
PINIHUAN	11.54	0.00	100.00	41.94	33.33	33.33	66.67	0.00	–	0.00	33.33	77.78	0.00	11.11	0.00
OJO DE AGUA	9.18	33.33	88.89	34.12	44.44	25.00	50.00	44.44	50.00	22.22		22.22	0.00	55.56	66.67
EL JABALI	3.10	57.14	85.71	25.66	14.29	100.00	0.00	28.57	50.00	57.14		28.57	42.86	14.29	28.57