Méreles F, Nazario g, Villalba L, Gareca E, Echeverria C. Designing biological corridors for the Pilcomayo River region (Gran Chaco) of Argentina, Bolivia and Paraguay, Rev. Soc. cient. Parag. 2023; 28(2): 220-249
https://doi.org/10.32480/rscp.2023.28.2.220
Recibido: 02/06/2023. Aceptado: 20/09/2023.
Editor Responsable Nélida Soria

ARTÍCULO ORIGINAL
ORIGINAL ARTICLE

Designing biological corridors for the Pilcomayo River region (Gran Chaco) of Argentina, Bolivia and Paraguay

Diseño de corredores biológicos para la región del río Pilcomayo (Gran Chaco) de Argentina, Bolivia y Paraguay

FÁTIMA MERELES[1-2-3], GABRIELA NAZARO[4-5], LAURA VILLALBA[6-2], EDGAR GARECA[7] & CLARA ECHEVERRÍA[8]

[1-]Centro para el Desarrollo de la Investigación Científica (CEDIC), Asunción, Paraguay.
[2-] Consejo Nacional de Ciencia y Tecnología, CONACYT, Programa Nacional de Incentivo a Investigadores, Asunción, Paraguay.
[3-] Universidad Nacional de Asunción, Facultad de Ciencias Química, Herbario FCQ, San Lorenzo, Paraguay.
[4]- Fundación Pro Yungas, Sistema de Información Geográfica y Ambiental, Bolivia.
[5]-Instituto de Ecología Regional, Consejo Nacional de Investigaciones Científicas y Técnicas, CONICET, Tucumán, Argentina.
[6]-Fundación Moisés Bertoni, Programa Nacional de Incentivo a Investigadores, Consejo Nacional de Ciencia y Tecnología. Asunción, Paraguay
[7]-Fundación NATIVA, Bolivia, Tarija, Bolivia.
[8]-Red Paraguaya de Conservación en Tierras Privadas, Asunción, Paraguay.
Correspondence author: fmereleshaydar@gmail.com

ABSTRACT: The Pilcomayo River region of the Gran Chaco is shared between three countries: Argentina, Bolivia and Paraguay. Land use changes in this region have resulted in gaps within the plant formations, and biological corridors serve as a conservation tool to provide greater resilience to the remaining formations. The objective of this work is to analyze existing data for the design of biological corridors that safeguard the connectivity

Este es un artículo publicado en acceso abierto bajo una Licencia Creative Commons

between important sites for biodiversity within the Pilcomayo River area, without this resulting in a high cost for the fauna. To achieve this, work was carried out in the area shared between the three affected countries. As a basis for connectivity, 14 nucleus zones or HVCA were identified: five in Argentina, two in Bolivia, six in Paraguay, and one shared between Bolivia and Paraguay. A minimum network of connections between these areas was generated as well as a cost matrix from wich were identified the minimum costs among the HVCA. Results indicate that 77% of the nucleus zones are forests and 6% are anthropized areas. Fourteen biological corridors were designed to define a network that guarantees the connectivity between them. Of this network, 53% is in Argentina, 27% in Paraguay and 15% in Bolivia.
Key words: biological corridors, connectivity, fragmentation, Gran Chaco, least-cost corridors, Pilcomayo River.

RESUMEN: La región del río Pilcomayo del Gran Chaco, es compartida por tres países: Argentina, Bolivia y Paraguay. Los cambios en el uso del suelo en la región, afectaron creando brechas dentro de las formaciones vegetales y los corredores biológicos constituyen una herramienta de conservación para brindar mayor resiliencia a las formaciones restantes. El objetivo del trabajo es analizar los datos existentes para el diseño de corredores biológicos que salvaguarden la conectividad entre sitios importantes para la biodiversidad dentro del área del río Pilcomayo, sin que esto signifique un alto costo para la fauna mayor. Para ello se trabajó en el área compartida entre los tres países afectados. Como base para la conectividad se identificaron 14 zonas núcleo o HVCA: cinco en Argentina, dos en Bolivia, seis en Paraguay y una compartida entre Bolivia y Paraguay. Se generó una red mínima de conexiones entre estas áreas y una matriz de costos, a partir de la cual se identificaron costos mínimos entre los HVCA. Los resultados indican que el 77% de las zonas núcleo son bosques y el 6% son áreas antropizadas. Se diseñaron catorce corredores biológicos para generar una red que garantice una conectividad entre ellos. De esta red, 53% se encuentra en Argentina, 27% en Paraguay y 15% en Bolivia.

Palabras clave: conectividad, corredores biológicos, corredores con menor costo, fragmentación, Gran Chaco, río Pilcomayo.

1. INTRODUCTION

The South American Gran Chaco, which occupies part of Argentina, Bolivia and Paraguay, is an area undergoing full agro-livestock development in all three of these countries, and particularly in Paraguay (1), where less than ten years ago, its natural plant formations remained considerably undegraded. The fragmentation of ecosystems and the loss of ecological connectivity are caused by human activities (2, 3, 4, 5, 6) and less frequently due to major natural disasters. Within the last 30 years, the Gran Chaco has become a center for agricultural intensification and expansion. In Argentina, forests have been replaced with croplands, while in Paraguay changes in land use have been mainly for the implantation of cattle pastures. The Bolivian Chaco has been the least modified area [(1).]

The Gran Chaco is the second most extensively forested region in South America; these forests are combined with shrublands and a wide variety of environments such as dry and hydromorphic savannas, marshes, wetlands, hill ranges, rivers and salt flats [(7).] The advance of productive activities is degrading these natural environments, and there is an urgent need for the use of ecological tools to help reduce further fragmentation of these natural formations before they disintegrate completely. The fragmentation of natural areas affects the survival of certain species, and protected areas alone are generally not enough to ensure stable populations in the regions

[8]. The implementation of connecting areas such as ecological corridors constitute a key tool for providing resilience, and in some cases even reaching a homeostasis of the natural remnants. Thanks to the continuity of these corridors, a strategy to support the conservation of biodiversity would be achieved, allowing for the permanence and movement of various species.

Connectivity is the degree to which a landscape facilitates or hinders the movement of wildlife between favorable habitats [9], thus enabling or limiting significant ecological processes, such that the preservation of connectivities minimizes the effects of the fragmentation of the habitat [10]. One way to contribute towards reducing the loss of ecological connectivities consists of designing ecological corridors as zones that buffer the negative effects of fragmentation [6].

According to [11], an ecological corridor was originally conceived as a linear habitat that differs from the matrix and that connects two or more natural fragments. This concept, however, has since evolved in a more general and comprehensive manner by considering other aspects of the landscape, such as soil types, and which is used to connect forest fragments throughout the landscape [12, 13].

Some authors, such as [14], mention that ecological corridors are strips of vegetation incorporated into the landscape to influence ecological processes, provide goods and services, and serve as passages for wildlife (greenways, windbreaks and others); meanwhile others, such as Tres & Reis [15], mention that many of these models fill the corridors with tree species that in the long run limit the space available for natural regeneration.

The South American Chaco in the Pilcomayo River area: an overview

The South American Gran Chaco region covers around one million square kilometers, [16] and presents similar climate and soil characteristics throughout, as well as plant communities and species, which have been mentioned by various authors [17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 32, 33, 34, among others]. From a hydrographic point of view, the area includes the rivers Timane, Bermejo and Pilcomayo [25], whose source, sub-basin and delta are the main focus of this work and represent one of the most important ecological corridors in the Chaco region, together with the Paraguay and Bermejo rivers and all their tributaries.

The Shared Management Area (SMA) encompasses the trinational Pilcomayo River area, in the heart of the South American Gran Chaco, and finds itself surrounded by the agro-livestock expansion experienced in the region. The Pilcomayo River originates in Bolivia and flows within a canyon formed by the *Cordillera del Aguaragüe* (*Aguaragüe* hill range), and further south, between Yvybobo [21°32’S - 62°59’W] and Villa Montes [21°15’59”S - 63°27’3”W], it enters a plateau dragging about 50 tons/year of sediments, with a highly variable flow volume, often suffering from the siltation or plugging of its own channel [35]. From the hydro-ecological point of view, these changes are highly important since they form secondary meanders, various kinds of shallow water and lagoons, swales and others, limited by ridges [36], which help to alleviate the conditions of aquatic-palustrine dependent animals and plants, and resulting in excellent natural ecological corridors.

The need to establish connectivity between key sites for biodiversity was highlighted during the Second Ecoregional Assessment (Tarija, 2018), where it was agreed to focus on this as a main task. One of the reasons is the rich and specific diversity of the region where the SMA is located, considering the numerous changes in the use of forested areas and other types of formations to other productive systems such as agro-livestock farming, especially in Paraguay. It is hoped that this will help to reverse the loss of natural cover, the fragmentation of habitat, the lack of land use planning, the use of inappropriate agricultural practices, and the loss of water resources, among others [12], while supporting the sustainable development of the region.

Two different situations arise within the shared management area: a) the Paraguayan Chaco scenario, where major changes in land use can be observed, and b) the Argentine and Bolivian Chaco scenario, where these major changes have not flourish. It is intended that the area must not lose its characteristic of being a great corridor along the Pilcomayo River and that the connectivity proposal could thus be incorporated within the development of land use planning.

The objective of this work is to determine, through the analysis of existing data, the best design of ecological corridors that guarantees the connectivity of key biodiversity sites, without resulting in a high cost for fauna, while also ensuring the sustainable development of the Pilcomayo region.

2. MATERIALS AND METHOD

Climatic and biophysical characteristics of the study area

The SMA is located entirely within the sub-basin of the Pilcomayo River, which occupies part of the Argentine provinces of Formosa, Salta and Jujuy, the Paraguayan departments of Boquerón and Presidente Hayes, and the Bolivian department of Tarija. The dynamic river acts as the main axis on which a rectangular study area of 16,253,067 hectares has been delimited (Fig. 1).

The design was extended beyond the limits of the SMA to link connectivity with the entire South American Gran Chaco, through corridors designed for each of the countries affected [(37).]

Figure 1: Study area for corridor design that includes The Shared Management Area, SMA.

The climate in the SMA ranges from semi-arid, for the most part, to sub-humid towards the Paraguay-Pilcomayo Mesopotamia in Paraguay; a variable rainfall regime with a steep gradient range between 1200-1300 mm per year in the Presidente Hayes Department (Paraguay) and the Formosa Province (Argentina), to 500 mm per year over the semi-arid Chaco in the rest of the area [(38, 39)].

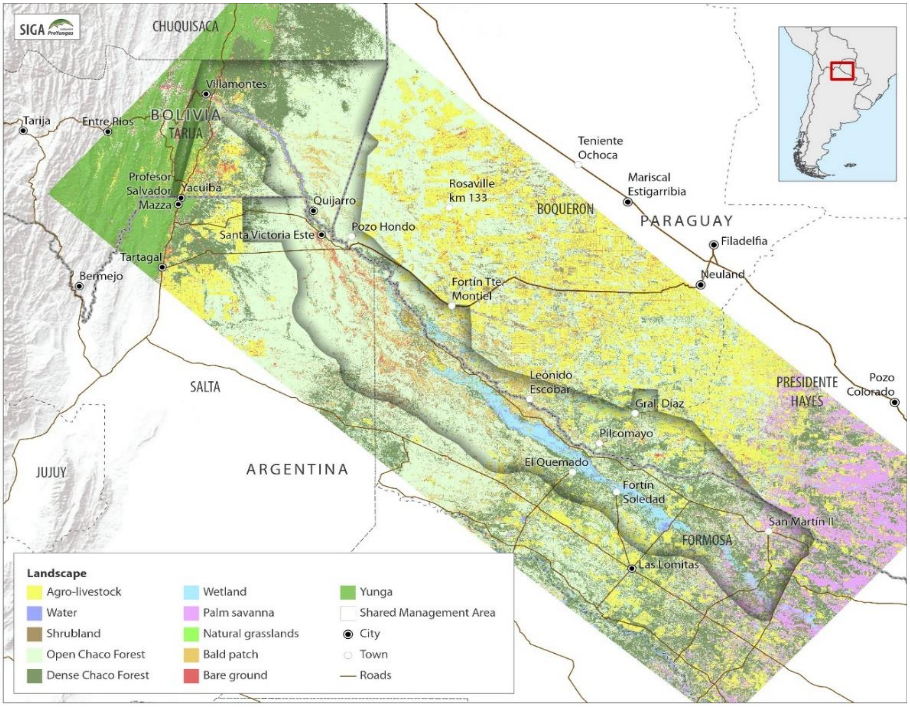

Figure 1: Study area for corridor design that include The Shared Management Area, SMA.

Figura 1: Área de estudio para el diseño de corredores que incluyen el Área de Gestión Compartida, AGC.

Soils also vary throughout the region. At the higher altitudes, found around the Aguaragüe hill range, Bolivia, they present a dominance of partially consolidated coarse-grained sands. Down in the plains, a dominance of clays and silts and enclaves of hydric sands carried by the river can be observed [39]. Biotic elements, however, are quite similar and they share types of plant formations and common species. In Argentina, the area included in this study occupies the ecoregions known as Dry Chaco and

Humid Chaco, in the provinces of Salta and Formosa. In Paraguay, the ecoregions are also named the same and include the departments of Boquerón and Presidente Hayes.

The xerophytic and sub-humid plant formations and their components are very similar, with extensive hydromorphic savannas with *Copernicia alba;* sub-humid forests with *Schinopsis cornuta*, *S. quebracho-colorado*, *Sarcomphalus mistol*, *Geoffroea decorticans*, *Gonopterodendron sarmientoi*, *Salta triflora*, *Stetsonia coryne*, *Bulnesia foliosa*, among others; typical azonal formations of the site such as the so-called *peladares* (bald patches) with *G. sarmientoi* and *S. coryne*, that developed on paleochannels recently formed and silted-up by the Pilcomayo River; gallery forests and flooded forests with *Neltuma alba*, *Vallesia glabra*, *Solanum argentinum*, among others. Other highly important systems include the wetlands with marshes and small, shallow lagoons, with aquatic-palustrine vegetation. In Bolivia, the landscape is different because the Pilcomayo River has two stages: the first where it flows swiftly within an enclosed channel down the Aguaragüe hill range, where the Yungas develop, and the second stage where the river opens and widens onto the Chaco plain, depositing much of its alluvial sediment. Both landscape types are visible from the city of Villa Montes [21°15’59” S - 63°27’3” W]. All these plant formations and associations found within the SMA have been widely studied by several authors, such as (23, 38, 26, 27, 30, 32, 40, 41, 42, 43, 44, 45, 34), among others.

The Chacoan fauna throughout the area is also very similar and very rich, with a great diversity of mammals, birds and reptiles, which have also been widely studied by several authors (46, 47, 48, 49, 50, 51, among others.

Stages of the study

Identification of High Conservation Value Areas (HCVAs): or areas with healthy environmental conditions, which can host viable populations of the species of interest for which the corridors have been designed. These included protected areas with official national or international protection status, wetlands, forest areas with certification for sustainable use, protected productive landscapes, among others. Fourteen reserve areas were included, representing a total area of 1,010,814 hectares; two of these are in Bolivia, five in Argentina and six in Paraguay, representing 12%, 65% and 23% for each country, respectively. One additional area is shared between Bolivia and Paraguay by two bordering private nature reserves: El Corbalán and Cañada El Carmen (Table 1, Fig. 2).

Table 1. High Conservation Value Areas of the three countries to be connected.

Of the nucleus zones or reserve areas included to establish connectivities (Fig. 2), 77% of the surface area corresponds to forests (xerophytic forest and yungas), while another 6% corresponds to anthropized areas (agro-livestock and urban). Seven of the conservation areas are located within the SMA between the three countries (74%), while the remaining are external and were included to link the connectivity strategy of the shared area at a regional scale.

Table 1. High Conservation Value Areas (HCVA) of the three countries to be connected.

Tabla 1. Áreas de Alto Valor de Conservación (AAVC) de los tres países a conectar.

Code	Name	Label	Category	Jurisdiction	Country	Surface area (has)
1	Aguaragüe	Aguaragüe	National Park and Integrated Management Natural Area	National	Bolivia	119,014
2	La Ceiba	La Ceiba			Bolivia	912
3	Reserva Natural Cañada El Carmen y El Corbalán	Carmen-Corbalán	Nature Reserve	Private	Paraguay-Bolivia	10,084
4	Reserva Natural Arcadia	Arcadia	Nature Reserve	Private	Paraguay	5,073
5	Pilcomayo Salta	Pilcomayo Salta	Category OTBN	Provincial	Argentina	40,611
6	Reserva Natural Palmar Quemado	Palmar Quemado	Nature Reserve	Private	Paraguay	10,357
7	Reserva Natural TSM	TSM	Nature Reserve	Private	Paraguay	1,237
8	Reserva Natural Toro Mocho	Toro Mocho	Nature Reserve	Private	Paraguay	18,940
9	Tinfunqué	Tinfunqué	Managed Resources Reserve	National	Paraguay	187,334
10	Toldo Cué	Toldo Cué	Protected Area	Private	Paraguay	1,049
11	Reserva de Caza Agua Dulce	Agua Dulce	Hunting Reserve	Provincial	Argentina	8,674
12	Bañado la Estrella	La Estrella	Public Nature Reserve	Provincial	Argentina	408,355
13	Riacho Teuquito	Teuquito	Biosphere Reserve		Argentina	163,046
14	El Impenetrable	El Impenetrable	National Park	National	Argentina	36,127

Figure 2. High Conservation Value Areas of the three countries to be connected in The Shared Management area, SMA (refer to Table 1 for the identification codes of the HCVAs).

Interconnection network: once the areas to be connected were identified, a minimum network of connections was designed to secure communication between them, to identify *a priori* which are the minimum fundamental connections that guarantee the interconnection of the entire system. This analysis was carried out using the minimum spanning tree calculation. This algorithm defines the optimal network of least-cost links between regions [(53)]. In this case, proximity is not defined in terms of Euclidean distance, but rather as a distance weighted by a friction value assigned to a cost matrix.

Cost surface: we worked with a cost surface that quantitatively estimates how certain ecological-environmental parameters, as well as others of anthropic origin (roads, towns, reservoirs), affect the movement of fauna species (54). Lower values in the cost matrix indicate ease of movement, while higher values indicate movement restrictions or even a barrier (Table 2). Four environmental variables that influence the movement of large land mammals were considered. These variables were subsequently transformed into resistance values, based on consultation with experts and a literature review (55, 56, 57). The variables were land cover, outpost/community distances, distances to roads and distances to rivers. The matrices and surface costs are detailed in Tables 1 and 2, as well as in Figure 3.

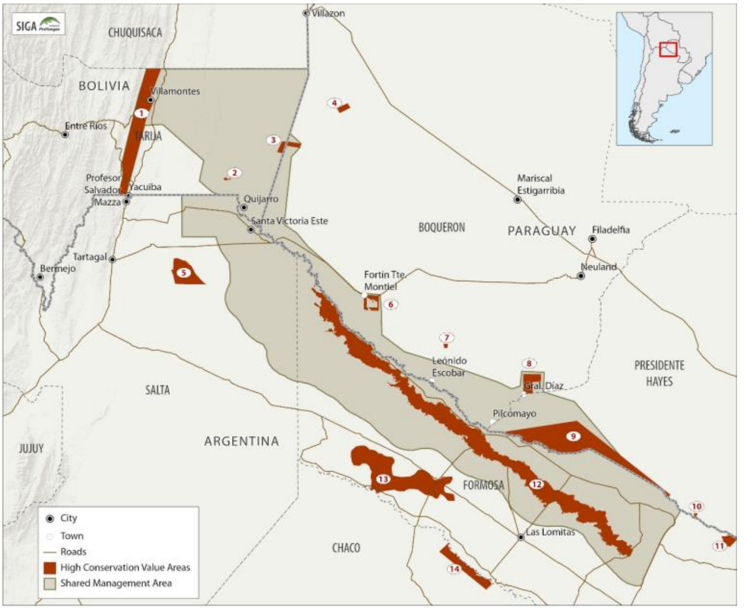

Figure 2. High Conservation Value Areas of the three countries to be connected in The Shared Management area, SMA (refer to Table for the identification codes of the HCVAs).

Figura 2. Áreas de Alto Valor de Conservación de los tres países que se conectará en el área de Gestión Compartida, AGC (consulte la Tabla 1 para los códigos de identificación de los HCVAs).

Table 2. Costs assigned to the criteria of roads, rivers and outposts/communities, used in the definition of the cost surface. Ranges of distances assigned and the costs of each.

For natural landscapes, the movement costs were applied to each type of cover and combined in a single layer from a linear sum, thus obtaining the cost surface of the landscape (Table 3, Figure 2).

Table 2. Costs assigned to the criteria of roads, rivers and outposts/communities, used in the definition of the cost surface. Ranges of distances assigned and the costs of each.

Tabla 2. Costos asignados a los criterios de carreteras, ríos y puestos avanzados/comunidades, utilizados en la definición de la superficie de costos. Rangos de distancias asignadas y los costos de cada uno.

Roads		**Rivers**		**Outposts/Communities**	
Class (m)	Cost	Class (m)	Cost	Class (m)	Cost
0-60	1	0-5000	1	<1000	8
60-500	2	5000-20000	2	1000-3000	4
500-1500	5	>20000	3	>3000	1
>1500	9				

Table 3. Costs assigned to the various environments (types of land cover), for the definition of the cost surface.

Table 3. Costs assigned to the various environments (types of land cover), for the definition of the cost surface.

Tabla 3. Costes asignados a los distintos ambientes (tipos de cobertura del suelo), para la definición de la superficie de coste.

Environments	Cost
Open Chaco Forest	1
Dense Chaco Forest	1
Yunga	8
Palm savanna	2
Shrubland	3
Natural grasslands	3
Bald patch	4
Wetland	2
Water	3
Bare ground	6
Agro-livestock	8
Urban	10

The land cover was updated to 2019 and was built upon a supervised Sentinel scene classification (Fig. 3). The outposts/communities variable represents the presence and influence of small human groups on the natural environment, including cattle ranches and farms in Paraguay, as well as the indigenous communities of the three countries (Tables 2 and 3, Fig. 4). We worked with a resolution of 10 m. The cost values were standardized to 1 (minimum cost for the movement of species) and 10 (maximum cost).

Figure 3. Costs assigned to the criteria used in the definition cost surface for the design of biological corridors within The Shared Management Area.

Definition of Biological Corridors: once the nuclei and patches to be connected and the cost matrix to be used were defined (Fig. 4), the optimal routes were determined through the cost surfaces, using the Cost Distance function of the ArcGIS Spatial Analyst. This function calculates the accumulated costs from the conservation nuclei, considering distance and direction. These assembled grids were used as inputs to the ArcGis Spatial Analyst Corridor function, which determines the least-cost corridors between pairs of nuclei.

Figure 3. Costs assigned to the criteria used in the definition cost surface for the design of biological corridors within The Shared Management Area.

Figura 3. Costes asignados a los criterios utilizados en la definición de la superficie de costes para el diseño de corredores biológicos dentro del Área de Gestión Compartida.

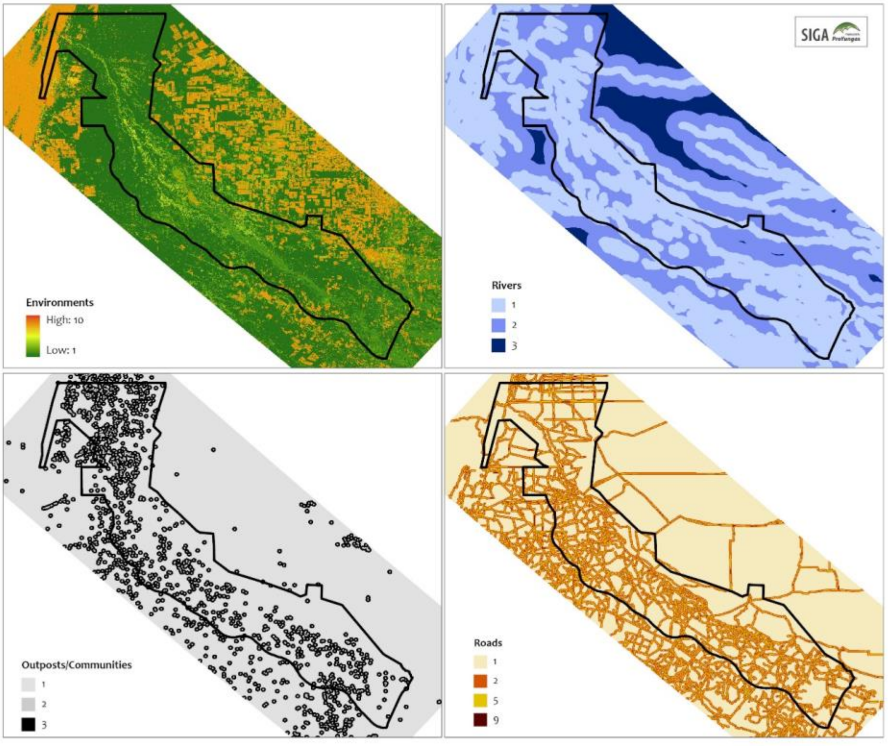

Figure 4. Cost surface based on land cover type, distance to outposts/communities, waterways and roads, used for the design of biological corridors within The Shared Management Area, SMA.

The Bolivian portion of the Pilcomayo River was defined as a fluvial corridor, by delimiting a kilometer-wide buffer zone around the river and its banks, which makes up its lamination zone once the enclosed channel opens near the city of Villa Montes (Bolivia). The widths of the established corridors were variable.

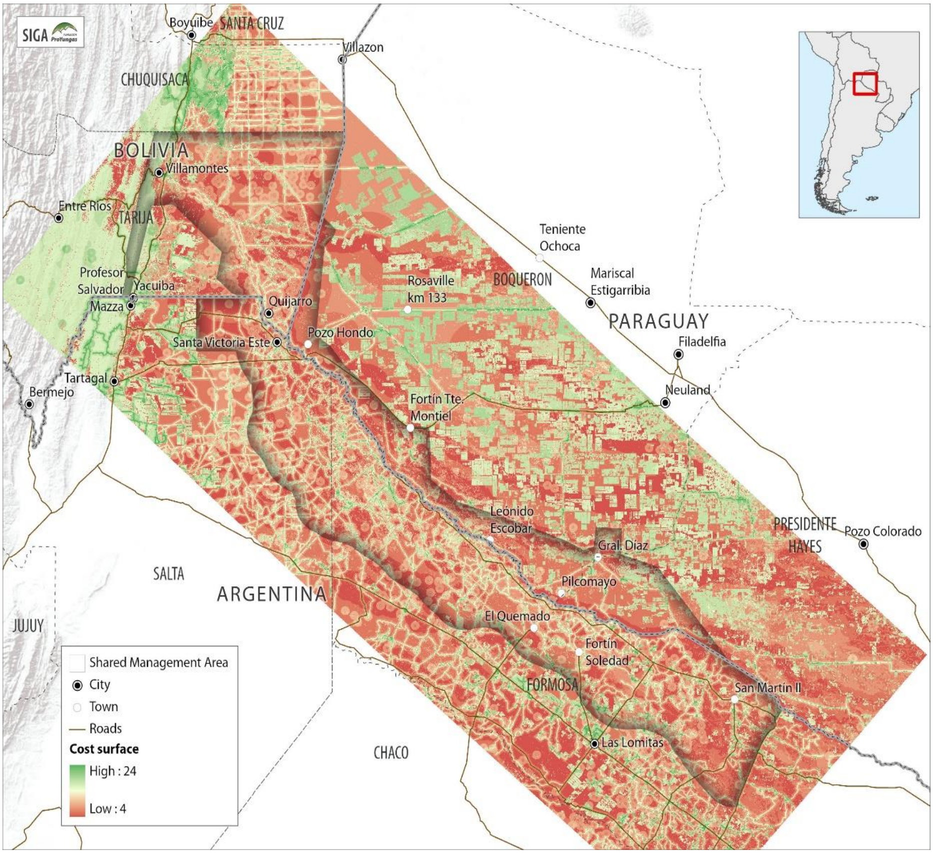

Figure 4. Cost surface based on land cover type, distance to outposts/communities, waterways and roads, used for the design of biological corridors within The Shared Management Area, SMA.

Figura 4. Superficie de costos basada en el tipo de cobertura terrestre, distancia a puestos avanzados / comunidades, vías fluviales y carreteras, utilizada para el diseño de corredores biológicos dentro del Área de Gestión Compartida, AGC.

3. RESULTS/RESULTADOS

Fourteen biological corridors were defined, totaling an approximate area of 615,926 hectares and working as a network between the reserve areas that ensures connectivity between them (Figs. 5 and 6, Table 4). Of the area occupied by biological corridors 53% corresponds to Argentina, 19% to Bolivia and 27% to Paraguay. The Pilcomayo River Corridor is the largest, while the La Estrella-Tinfunqué corridor has the smallest surface area (Table 4).

Table 4. Details of the biological corridors and their connections, within The Shared Management Area, SMA.

Table 4. Details of the biological corridors and their connections, within The Shared Management Area, SMA.

Tabla 4. Detalles de los corredores biológicos y sus conexiones, dentro del Área de Gestión Compartida, AGC.

Code	Corridor	Surface Area (has)	% of Area
1	Carmen Corbalán-Arcadia	53,688	8.72
2	Ceiba-Carmen Corbalán	48,815	7.93
3	Pilcomayo	98,352	15.97
4	Ceiba-Pilcomayo Salta	92,842	15.07
5	Aguaragüe-Pilcomayo Salta	64,522	10.48
6	Pilcomayo Salta-La Estrella	70,961	11.52
7	La Estrella-Palmar Quemado	20,700	3.36
8	La Estrella-TSM	23,098	3.75
9	Tinfunqué-Toro Mocho	32,071	5.21
10	La Estrella-Tinfunqué	11,982	1.95

11	La Estrella-Teuquito	20,814	3.38
12	Teuquito-El Impenetrable	46,864	7.61
13	Tinfunqué-Toldo Cué	15,762	2.56
14	Toldo Cué-Agua Dulce	15,455	2.51

Figure 5. Biological Corridors within The Shared Management Area, SMA (refer to Table 4 for the identification codes of the BCs).

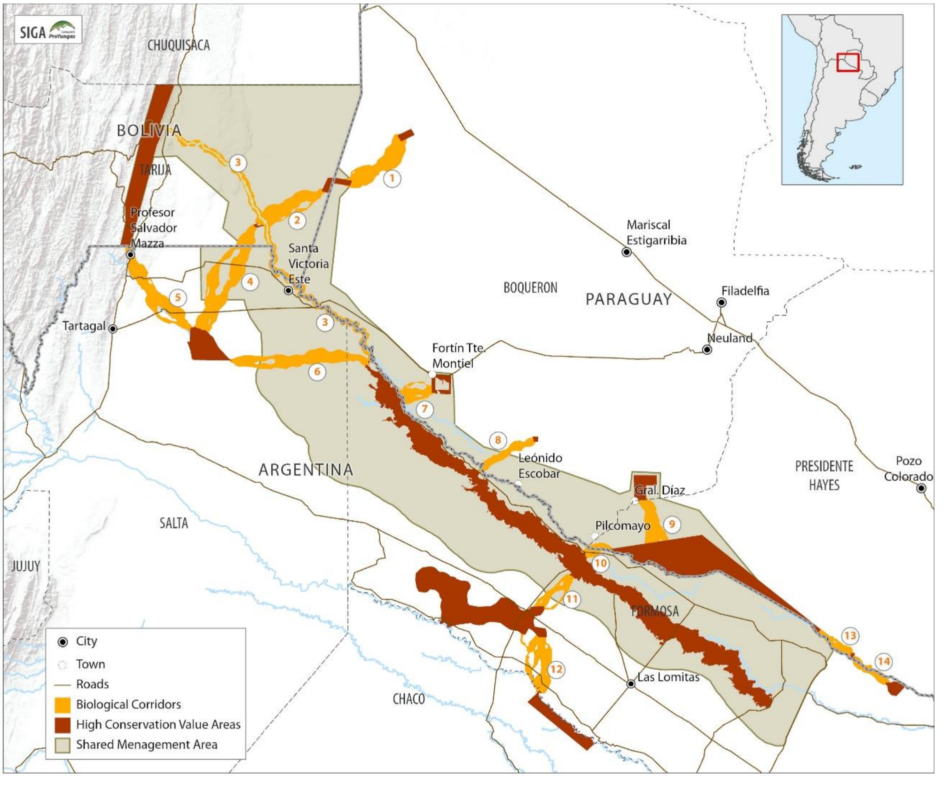

Figure 5. Biological Corridors within The Shared Management Area, SMA (refer to Table 4 for the identification codes of the BCs).

Figura 5. Corredores Biológicos dentro del Área de Gestión Compartida, SMA (consulte el cuadro 4 para los códigos de identificación de los CBs).

Figure 6. Types of environments found within the biological corridors in The Shared Management Area, SMA (refer to Table 4 for the identification codes of the BCs).

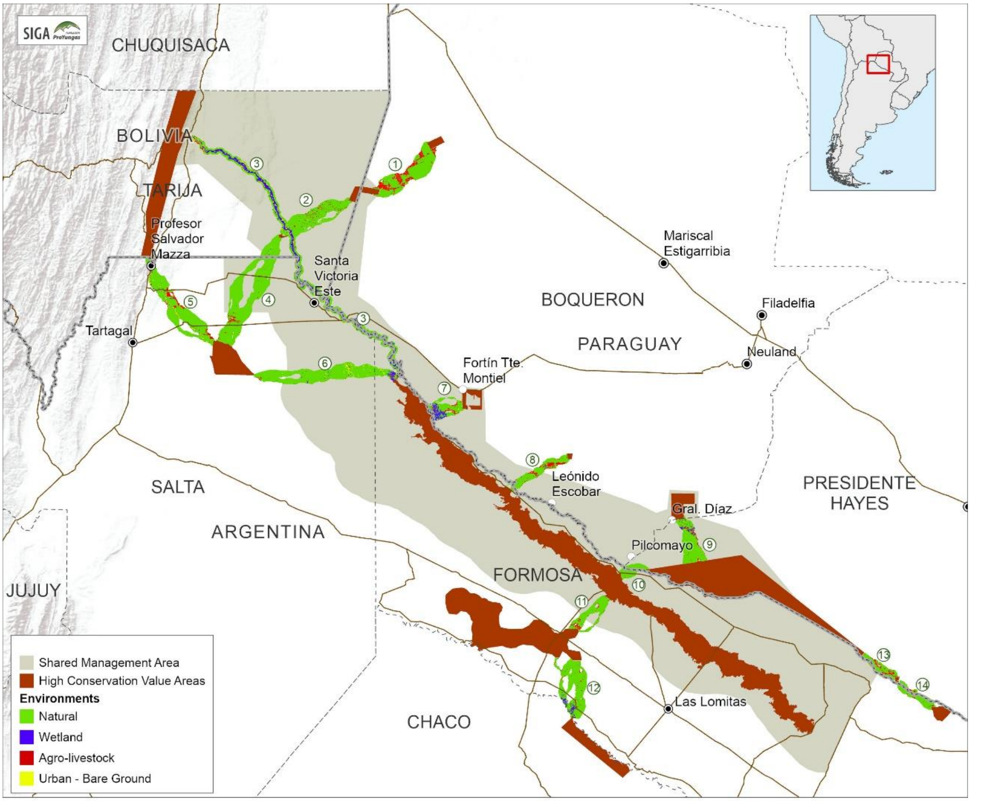

Figure 6. Types of environments found within the biological corridors in The Shared Management Area, SMA (refer to Table 4 for the identification codes of the BCs).

Figura 6. Tipos de ambientes que se encuentran dentro de los corredores biológicos en el Área de Gestión Compartida, AGC (consulte la Tabla 4 para los códigos de identificación de los CBs).

1. DISCUSSION AND CONCLUSIONS/CONCLUSIONES Y DISCUSIONES

Maintaining connectivity between important biodiversity HVCAs is what is sought with the design and subsequent implementation of biological corridors on the ground, and even more so in the case of the Chaco region, a last representative stronghold of dry and sub-humid forests that still harbors a considerable number of emblematic species of wild flora and fauna (37). Although the surfaces covered by the biological corridors are very important, the connectivity that may exist between these corridors is no less important. The more intertwined and connected they are, the more opportunities for wildlife -especially mammals- to survive.

Connectivity corridors are a tool that helps to build a territorial ordering, connecting small nucleus zones while leaving areas set aside for production, in addition to protecting areas that are not usually included within the normal system of legally declared protected natural areas, bearing in mind that these are in private areas, which can also offer other benefits such as environmental services.

Nevertheless, biological corridors are still a controversial issue. When prioritizing important biodiversity nuclei, in many cases sites with wildlife concentrations are selected, such as permanent or temporary water sites (lagoons, waterholes, streams, others) that have a low cost for fauna, which is normal in xerophytic environments; however, at the same time, these sites frequently become prone to the hunting of birds and mammals, which in turn represents a high cost for them.

The current situation must prioritize the conservation of threatened and endangered fauna, such as big cats, and include within the connectivity the protected productive landscapes such as crops, private reserves and windbreaks. These are used by all kinds of fauna to travel back and forth, and this has been confirmed with camera trap imagery.

Although the connectivities are designed mainly for the passage of fauna, it is very important to take into consideration the vegetation and other natural systems that are also key to the conservation of biodiversity. Although this would seem most logical, the current problem -for which methods that include anthropic costs are employed- is that changes in land use have preceded the territorial ordering plans implemented in areas such as the Chaco, which are in full development.

Given that SMA is extensive and encompasses several ecoregions in all three countries, it was necessary to incorporate the most typical plant formations from each of them, so that they remain as core areas and connect the most outstanding ecosystems that occur along the Pilcomayo River and within its surroundings, such as: the hydromorphic savannas of *Copernicia alba*; the dry forests with *Schinopsis cornuta*, *S. quebracho-colorado*, *Aspidosperma quebracho-blanco*, and *Gonopterodendron sarmientoi*; the sub-humid forests with *Schinopsis balansae*; the yungas with *Myroxylon peruiferum*, *Juglans autralis*, and *Cascaronia astragalina*;

Amburana cearensis and *Pseudobombax* in the Aguaragüe hill ranges; and the riparian areas with *Neltuma alba* and *Vallesia glabra* among the most noteworthy, as well as the large areas of wetlands with permanent and temporary water with aquatic-palustrian vegetation, which harbor a rich and characteristic flora and fauna of the Chaco, typical of the Pilcomayo River area (detailed in Table 5). Despite their fragmentation, they continue to maintain important components (58), of the Chaco and Pilcomayo fauna. Corridors also elude the negative effects of fragmentation and improve the prospects for biodiversity in both natural and urban environments (59, 60, 61, 6).

Table 5. Types of Biological Corridor cover, surface areas and percentages, within The Shared Management Area, SMA.

Table 5. Types of Biological Corridor cover, surface areas and percentages, within The Shared Management Area, SMA.

Tabla 5. Tipos de cobertura del Corredor Biológico, superficies y porcentajes, dentro del Área de Gestión Compartida, AGC

Environment	Environment Detail	Surface Area (has)	Surface Area (%)
Natural	Open Chaco Forest	322,053	52.29
Natural	Dense Chaco Forest	148,240	24.07
Natural	Yunga	5,464	0.89
Natural	Palm Savanna	7,939	1.29
Natural	Shrubland	14,304	2.32
Natural	Natural Grassland	456	0.07
Natural	Bald Patch	25,852	4.20
Wetland	Wetland	19,223	3.12
Wetland	Water	22,613	3.67

Urban-Bare Ground	Bare Ground	13,569	2.20
Productive	Agro-livestock	34,901	5.67
Urban-Bare Ground	Urban	1,313	0.21

The design of the corridors is quite simple on paper, though this is not always so simple on the ground. One or more variables, that can be either physical, legal, biological or even social and economic, must all be considered. Consequently, the socioeconomic aspect was included in the design (62), considering the populations found in the area and their activities (Tables 2 and 3, Fig. 2). Indeed, in this region, the resident populations are mostly native to the area and depend on the shifting of the water, without paying much attention to the political boundaries. Therefore, it would be of greater benefit for them that the natural ecosystems be maintained, with a greater resilience resulting from the corridors, and that they be supported in their economic activities, such as the production of honey, artisan crafts and products derived from the native flora (such as basket weaving), the fruits and roots used for food, as well as the protein sourced from wild fauna.

The connectivity corridors should provide continuity within the territories of each of the countries, or they would fail to fulfill their connecting role, especially those that link important nuclei (37). The nuclei in turn should also be evaluated periodically; not just the connectivities. It is for this reason that the type of management implemented will be of utmost importance to ensure the positive results of the connections on the ground. In many cases, it will be necessary to take advantage of the already existing natural patches of vegetation to facilitate the effective implementation of the corridors. (63) mentions, the greater the connectivities, the greater the fauna's expectations for its survival.

ACKNOWLEDGEMENTS/AGRADECIMIENTOS

To the European Union, for financing the Project which promotes studies and actions that contribute to the development, management and conservation of the South American Gran Chaco region. To Alejandro Brown, Yan Speranza, Ivan Arnold, Yaiza Reid Rata, Marcela Zamora, and Andrés Morillo, from the Trinational Chaco Initiative, whose support was key to the success of this work.

CONTRIBUCIÓN DE LOS AUTORES

Los autores han contribuido significativamente en la elaboración del presente manuscrito.

CONFLICTO DE INTERÉS

Los autores declaramos no tener conflicto de intereses.

FUENTES DE FINANCIACIÓN: Ninguna

REFERENCES

1. Baumann, M., I. Gasparri, M. Piquer-Rodríguez, G. Gavier Pizarro, P. Grifiths, P. Hostert, and T. Kuemmerle. 2017. Carbon emissions for agricultural expansión and intensification in Chaco. Global Change Biology 23: 1902-1926. https:// doi.org/10.1111/gcb.13521
2. Rodríguez-Soto, C., O. Monroy-Vilchis and M. M. Zarco-Gonzalez. 2013. Corridors for jaguar (*Panthera onca*), in Mexico: Conservation Strategies. Journal for Nature Conservation 21(6): 438-443.
3. De León Mata, G. D., A. P. Alvarez and J. H. M. Guerrero. 2014. Aplicación de sensores remotos en el análisis de la fragmentación del paisaje en Cuchillas de la Zarca, Mexico. Investigaciones Geográficas 84: 42-53.

4. García Marmolejo, G., L. Chapa Vargas, M. Weber, and E. Huber-Sannwald. 2015. Landscape Composition Influences Abundance Patterns and Habitat Use of Three Ungulate Species in Fragmented Secundary Deciduous Tropical Forest, Mexico. Global Ecology and Conservation 3: 744-755.
5. Burkart, S., F. Gugerli, J. Senn, R. Kuhen and J. Bollinger 2016. Evaluating the Functionality of Expert-Assessed Wildlife Corridors with Genetic Data from Roe Deer. Bassic and Applied Ecology 17(1): 52-60.
6. Cartaya, S., S. Zurita and R. Mantuano-Eduarte. 2016. Propuesta de corredores ecológicos y áreas de amortiguamiento como medidas para restaurar la conectividad del hábitat de la especie Cuniculus paca en Ecuador. Ambiente y Desarrollo 20 (39): 69-82.
7. Morello, J. & J. Adámoli. 1974. La vegetación de la República Argentina. Las grandes unidades de vegetación y ambiente del Chaco argentino I: objetivos y metodología. Instituto Nacional de Tecnología Agropecuaria, INTA, serie Fitogeográfica 10: 1-125.
8. Lovejoy, T.E., R. O. Bierregaard, A. B. Rylands, J. R. Malcom, C. E. Quintela, L. H. Harper, K. S. Brown, A. H. Powell, G. V. N. Powell, H. O. R. Schubart and M. B. Hays. 1986. Edge and other effects of isolation on Amazon Forest fragments. IN: M. E. Soulé (ed.), The Science of Scarcity and Diversity. Conservation Biology. Sinauer Associates Inc. Sunderland, MA, 257-285.
9. Noss, R. 1991. Landscape Connectivity: different functions at different scales. IN: Hundson, W. (ed.), Landscapes, Linkages and Biodiversity. USA. Defender of Wildlife. 196 p.
10. Johnstone, C. P., A. Lill and R. D. Reina. 2014. Habitat Loss, Fragmentation and Degradation Effects on Small Mammals: Analysis with Conditional Inferences. Tree Statistical Modelling. Biological Conservation 176: 80-98.
11. Primack, R., R. Roíz, P. Feinsinger, R. Dirzo and F. Massardo. 2001. Fundamentos de Conservación Biológica. Fondo de Cultura Económica. México, D. F. 796 pp.
12. Bennet, A. 1998. Enlazando el paisaje: el papel de los corredores biológicos y la conectividad en la conservación de la vida silvestre. Unión Internacional para la Conservación de la Naturaleza, UICN. Gland, Suiza. 276 pp.
13. Miller, K., E. Chang, and N. Johnson. 2001. En Busca de un Enfoque Común para el Corredor Biológico Mesoamericano. EE.UU. Word Resources Institute. 49 p.
14. Bentrup, G. 2008. Zonas de amortiguamiento para conservación: lineamientos para diseño de zonas de amortiguamiento, corredores y vías verdes. Informe Técnico General. Asheville N. C., s/pag.

15. Tres, D. R., and A. Reis. 2007. La nucleación como propuesta para la restauración de la conectividad del paisaje. IN: Memorias del II Simposio Internacional de Restauración Ecológica. Santa Clara, Cuba.
16. The Nature Conservancy (TNC), Fundación Vida Silvestre Argentina (FVSA), Fundación para el Desarrollo Sostenible del Chaco (DesDelChaco, Paraguay) y Wordlwildlife Conservation Society Bolivia. 2005. Evaluación Ecorregional del Gran Chaco Americano. 82 pp.
17. Fiebrig, K. and T. Rojas. 1933. Ensayo fitogeográfico del Chaco boreal. Revista Jard. Bot. Mus. Hist. Nat. Paraguay 3: 3-87.
18. Frenguelli, J. 1941. Rasgos principales de la fitogeografía argentina. Revista Mus. La Plata secc. Bot. 3(13): 65-131.
19. Cárdenas, M. 1945. La Vegetación de Bolivia. 16: 312-313. *in*: Verdoorn, F. (eds.) Plants and Plant Science in Latin America. Waltham, Massachusets, U.S.A.
20. Hauman, L. 1947. El Parque Chaqueño. 69-90. *in:* Hauman, L., A. Burkart, L. Parodi, and A. L. Cabrera (eds.). La vegetación de la Argentina: geografía de la República Argentina. Ed. Coni, Buenos Aires.
21. Cabrera, A. L. 1953. Esquema fitogeográfico de la República Argentina. Revista Mus. La Plata, secc. Bot. 8(33): 87-168.
22. Cabrera, A. L., A. Willink. 1973. Biografía de América Latina. Organización de Estados Americanos (O.E.A.), ser. Biología 13: 72-174.
23. Morello, J. and J. Adámoli. 1967. Vegetación y ambiente del nordeste del Chaco argentino. Instituto Nacional de Tecnología Agropecuaria, INTA, Vol. 3. 75 pp.
24. Morello, J. 1970. Ecología del Chaco. Bol. Soc. Argentina Bot. 11: 161-174.
25. Adámoli, J. 1976. Aprovechamiento Múltiple de la cuenca del río Pilcomayo. Informe Intermedio Cuenca del Río de la Plata 2: 159-192.
26. Sanjurjo, M. 1977. Proyecto Biológico Forestal I: Estudio de algunos aspectos forestales. Organización de Estados Americanos (O.E.A.) e Instituto de Ciencias Básicas, Universidad Nacional de Asunción. 69 pp.
27. Hueck, K. 1978. Los bosques de Sudamérica: ecología, composición e importancia económica. Sociedad Alemana de Cooperación Técnica (GTZ). Eschborn 1: 255-294.
28. Lewis, J. P. and E. F. Pires 1981. La vegetación de la Argentina: reseña sobre la vegetación del Chaco Santafesino. Instituto Nacional de Tecnología Agropecuaria (I.N.T.A.), ser. Fitogeográfica 18: 20-41.
29. Sarmiento, G. 1983. The Savannas of Tropical America. IN: Goodall, D., Ecosystems of the Worlds. Elsevier Scientific Publishing Com. 13: 271-272.

30. Ramella, L. and R. Spichiger. 1989. Interpretación preliminar del medio físico y de la vegetación del Chaco Boreal. Contribución al estudio de la flora y la vegetación del Chaco. I. Candollea 44 (2): 639-680.
31. Spichiger, R. and L. Ramella. 1989. The Forest of the Paraguayan Chaco. Tropical Forest. Acad. Press. 259-270.
32. Spichiger, R., R. Palese, L. Ramella and M. F. Mereles. 1991. Proposición de leyenda para la cartografía de las formaciones vegetales del Chaco paraguayo. Contribución al estudio de la flora y vegetación del Chaco. III. Candollea 46(2): 541-564.
33. Iriondo, M. 1995. El Cuaternario del Chaco. IN: Argollo, J. & P. Mourguiart (eds.), Climas Cuaternarios en América del Sur. ORSTOM, La Paz.
34. Mereles, M. F. 2005. Una aproximación al conocimiento de las formaciones vegetales del Chaco boreal, Paraguay. Rojasiana 6(2): 5-48.
35. Alvarez, M. C. 2016. El río Pilcomayo. Informe Técnico: Area: Clima y Recursos Naturales. Investigación para el Desarrollo, Asunción. Presentación Oral. Inédito.
36. Cordini, R. 1947. Los ríos Pilcomayo en la región del Patiño. Anales de la Dirección de Minas y Geología. Buenos Aires 1: 1-83.
37. Mereles, M. F., G. Céspedes, J. L. Cartes, R. Goerzen, L. Rodríguez, J. De Egea-Elsam, A. Yanosky, L. Villalba, A. Weiler & P. Cacciali 2019. Biological Corridors as a Connectivity Tool in the Region of the Great American Chaco: Identification of the Biodiversity Hotspots in the Ecorregions of the Paraguayan Chaco. Research in Ecology (02-01): 27-36.
38. Morello, J. & J. Adamoli. 1974. Las grandes unidades de vegetación y ambientes del Chaco argentino. Segunda Parte: Vegetación y Ambiente de la provincia del Chaco. Instituto Nacional de Tecnología Agropecuaria, INTA, serie Fitogeográfica 13. 130 Pp.
39. Proyecto Sistema Ambiental del Chaco. 1992-1995. Informe Técnico: suelos y vegetación. Dirección de Ordenamiento Ambiental, Ministerio de Agricultura y Ganadería (DOA-MAG), Paraguay e Instituto Federal de Geociencias y Recursos Naturales, Hannover, Alemania.
40. Prado, D. and P. Gibbs. 1993. Patterns of species distributions in the dry seasonal forest in South America. Ann. Missouri Bot. Gard. 80(4): 902-927.
41. Navarro, G. 1997. Contribución a la clasificación ecológica y florística de los bosques de Bolivia. Revista Boliviana de Ecología 2: 3-37.
42. Killeen, T. J., A. Jardim, F. Mamani, and P. Saravia. 1998. Diversity, compotition and structure of a tropical semideciduous forest in the Chiquitanía región of Santa Cruz, Bolivia. Journal of Tropical Ecology 14: 803-827.

43. Fuentes, A. & G. Navarro. 2000. Estudio fitosociológico de la vegetación de una zona de contacto Chaco-Cerrado en Santa Cruz (Bolivia). Lazaroa 21: 73-109.
44. Navarro, G. & M. Maldonado. 2002. Geografía Ecológica de Bolivia: Vegetación y Ambientes Acuáticos. Centro de Ecología Simon I. Patiño – Departamento de Difusión. Cochabamba. 719 pp.
45. Barberis, I., W. Batista, E. Pire, J. P. Lewis, & J. León. 2002. Woody population distribution and environmental heterogeneity in a Chaco Forest, Argentina. Journal of Vegetation Science 13: 607-6014.
46. Bucher, E. 1980. Ecología de la fauna chaqueña. Una revisión. Ecosur 7: 111-159.
47. Lavilla, E. O., E. Richard, and G. Scrocchi (eds.). 2000. Categorización de los anfibios y reptiles de la República Argentina. Asociación Herpetológica Argentina, Tucumán. 97 pp.
48. Yanosky, A., J. R. Dixon, & C. Mercolli. 1996. Ecology of the snake community at El Bagual Ecological Reserve, northeastern Argentina. Herpetololical Natural History 4: 97-110.
49. Waller, T., P. A. Micucci, & E. Richard. 2000. Categorización de los yacarés de Argentina. 45-50. *in:* Lavilla, E., E. Richard, and G. Scrochi (eds.). Categorización de los Anfibios y Reptiles de la Argentina. Asociación Herpetológica Argentina, Tucumán.
50. Giraudo, A. R. 2001. Diversidad de serpientes de la selva Paranaense y del Chaco Húmedo: Taxonomía, biogeografía y conservación. Ed. LOLA, Buenos Aires. 285 pp.
51. Villalba, L., B. Ortíz & N. Gengler 2018. Principales mamíferos del Chaco central. 66p. *in*: Fleytas, M. C., A. Brusquetti and S. Isaak (eds.). Estudio de ocupación de la fauna silvestre en hábitats modificados del Chaco central, Departamento Boquerón. Wordlwidlife Conservation Society (WCS), Alianza para el Desarrollo Sostenible (FCAA) y Cooperación Técnica de los Estados Unidos de América (USAID).
52. Villalba, L., B. Ortíz & N. Gengler 2018. Principales mamíferos del Chaco central. 66p. *in*: Fleytas, M. C., A. Brusquetti and S. Isaak (eds.). Estudio de ocupación de la fauna silvestre en hábitats modificados del Chaco central, Departamento Boquerón. Wordlwidlife Conservation Society (WCS), Alianza para el Desarrollo Sostenible (FCAA) y Cooperación Técnica de los Estados Unidos de América (USAID).
53. Adriaensen, F., J. P. Chardon, G. De Blust, E. Swinnen, S. Villalba, H. Gulnick, & E. Matthysen 2003. The aplication of Least-Cost modelling as a functional landscape model. Landscape and Urban Planning 64: 233-247.

54. Zeller, K. A., K. Mc Gharigal & A. R. Whiteley. 2012. Estimating landscape resistance to movement: a review. Landscape Ecology 27: 277-297.
55. Torres, N., N. I. Gasparri, P. G. Blendinger & H. R. Grau. 2014. Land-use and land-cover effects on regional biodiversity distribution in a subtropical dry forest: a hierarchica integrative multi taxa study. Reg Environ Change.
56. Brown, A. D., S. Pacheco & L. Cristóbal. 2012. Bitácora Los Caminos del Chaco. Obras viales y Paisajes de Conservación en la región Chaqueña. Ediciones del Subtrópico. 147 pp.
57. Rabinowitz, A. & K. A. Zeller. 2010. A range-wide model of landscape connectivity and conservation of the jaguar, *Panthera onca*. Biological Conservation 143: 939-945.
58. De Osma Vargas-Machuca, A., P. Ramírez-Barajas, M F. Roldán Tutivén, L. Ortíz Gómez, & Y. Soledispa Bravo. 2014. Patrones de actividad de tres especies de mamíferos cinegéticos en remanentes de bosques. Hippocampus 4: 3-7:
59. Vergnes, A., I. Le Viol, & P. Clergeau. 2012. Green Corridors in Urban Landscapes Affect the Arthropods Communities of Domestic Gardens. Biological Conservation 145(1): 175-178.
60. Guneroglu, N., C. Acar, M. Dihkan, F. Karsli, & A. Guneroglu. 2013. Green Corridors and Fragmentation in Souht Eastern Black See Coastal Landscape. Ocean and Coastal Management 83: 67-74.
61. Loro, M., E. Ortega, R. M. Arce, & D. Geneletti. Ecologycal Connectivity Analysis to Reduce the Barrer Effect of Roads. An Innovative Graph-teory Approach to Define Wildlife Corridors with Multiple Paths and without Bottlenecks. Landscape and Urban Planning 139: 149-162.
62. Sistema Nacional de Áreas de Conservación (SINAC). 2008. Guía práctica para el diseño, oficialización y consolidación de los Corredores Biológicos en Cosra Rica. San José de Costa Rica. 54 p.
63. Alonso-F., A. M., Finegan, B., Günter, S. & X. Palomeque. 2017. Caldasia 39(1): 140-156.