

Peace in Colombia is a critical moment for Neotropical connectivity and conservation: Save the northern Andes–Amazon biodiversity bridge

Nicola Clerici¹  | Camilo Salazar¹  | Carolina Pardo-Díaz¹  | Chris D. Jiggins²  | James E. Richardson¹  | Mauricio Linares¹ 

¹Programa de Biología, Facultad de Ciencias Naturales y Matemáticas, Universidad del Rosario, Bogotá D.C., Colombia

²Department of Zoology, University of Cambridge, Cambridge, UK

Correspondence

Nicola Clerici, Programa de Biología, Facultad de Ciencias Naturales y Matemáticas, Universidad del Rosario, Cr. 24 No 63C-69, Bogotá D.C., Colombia.
Email: nicola.clerici@urosario.edu.co

Funding information

ERC grant SpeciationGenetics, Grant/Award Number: Grant 339873.

Abstract

Colombia is one of the most biodiverse countries in the world that has historically and is currently experiencing extensive deforestation and habitat fragmentation. Here we show how the most extensive region acting as a natural corridor between the Colombian Andes and Amazon biogeographical regions, the Picachos–Tinigua–Sierra de la Macarena–Chiribiquete megacorridor, is being eroded by large-scale agricultural expansion endangering the maintenance and connection of gene flow and biodiversity exchange. Several phylogenetic studies indicate that the complex dynamics between the Andean highlands and the Amazonian lowlands have strongly influenced the origin and maintenance of Neotropical biodiversity. We appeal for the attention of international conservation and governmental organizations to direct resources and promote projects focused on the preservation and sustainable management of this strategic Andes–Amazon bridge in both protected and unprotected areas. In the current postconflict era, Colombia has a unique opportunity to create a new social and economic paradigm based on long-term sustainably developed landscapes and more equitable sharing of wealth. We believe improved management and conservation efforts for the Picachos–Tinigua–Macarena–Chiribiquete megacorridor would demonstrate a collective will in helping to achieve this goal.

KEYWORDS

disconnection, ecological corridor, gene flow, Los Picachos, protected areas, Serranía del Chiribiquete, Sierra de la Macarena, Tinigua

1 | INTRODUCTION

Relative to land area, Colombia is the most biodiverse country in the world (Gonzalez-Salazar, Venturini, Pogonietz, Finkenrath, & Leal, 2017). It heads the list of countries with the greatest number of bird species, while boasting the second highest number of amphibians and freshwater fishes (Moreno, Andrade, & Ruíz-Contreras, 2017). A recent checklist indicated about 28,000 species of plants and lichens

(Bernal, Gradstein, & Celis, 2015) approximately 10% of the world's total, within a single medium-sized country. The biodiversity of Colombia hence represents a natural capital of immense importance to the planet.

Regrettably, Colombia has experienced extensive deforestation and habitat fragmentation in the past few decades, due primarily to agricultural expansion through cattle raising, development of linear infrastructure, and illegal cropping (Armenteras, Rodríguez, Retana, & Morales, 2011; Etter,

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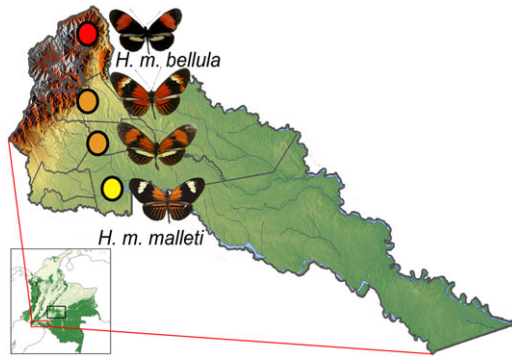


FIGURE 1 An example of gene flow across a corridor connecting the Andes and the Amazon in Putumayo, Colombia (red square in the inset map), close to the major corridor Picachos-Tinigua-Sierra de la Macarena-Chiribiquete (black rectangle). Main figure: the subspecies *H. m. bellula* (red circle) occurs in the Andes while the subspecies *H. m. malleti* (yellow circle) occurs in the Amazon. The two forms meet and hybridise, and genetic exchange is evident in hybrid individuals with mixed colour patterns (orange circles).

McAlpine, Wilson, Phinn, & Possingham, 2006). Colombian official sources reported about 2.4 million hectares deforested in the 1967–2012 period (IGAC, 2015), with a recent trend that is accelerating. In 2016, 178,597 hectares of forest were lost, a massive increase of 44% with respect to 2015 (Minambiente 2017; SIAC 2017). Among the more severely affected biogeographical regions is the Amazon, with the Caquetá and Meta departments being two of the most extensively deforested hotspots (IDEAM 2017a). Among the most significant adverse results of this extensive deforestation is the erosion of the connection between the Andean Cordillera and the Amazon, leaving few regions within the country that maintain and connect large-scale genetic flow and biodiversity exchange.

1.1 | The importance of highland–lowland connectivity for Neotropical biodiversity

Natural connections between the Andes and the Amazon are important to allow the regional migration and diversification of species. Phylogenetic evidence shows that the complex dynamics between the Andean highlands and the Amazonian lowlands have influenced the origin and maintenance of Neotropical biodiversity. Species dispersal between these regions has occurred since the Miocene (Hoorn et al., 2010), when multiple taxa that originated in the South American lowlands colonized highland areas in the Andes, and vice versa. Hummingbirds, for example, originated in the lowlands 22.4 million years ago (Mya) and then invaded high elevation Andean habitats, where they intensively diversified over the last 10 million years (McGuire et al., 2014). Also, in *Godyridina* butterflies (17 million years old), two major colonisation events from the lowlands to the Northern Andes occurred, resulting in the evolution of the genera *Hypomenitis*

(~10 Mya) and *Godyris* (4–5 Mya) (Chazot et al., 2016). In the opposite direction, “clearwing” butterflies of the genera *Ithomia* and *Napeogenes* originated and diversified at mid-elevations in the Andes during the Middle Miocene and then colonised the lowlands (~7 Mya), where *Napeogenes* diversified (Elias et al., 2009). Similarly, the Andean rodent genus *Calomys* invaded the lowlands about 9 Mya, where it underwent substantial radiation (Haag et al., 2007).

Such Andean–Amazonian species dispersals did not stop with the final uplift of the Northern Andes ~5–2 Mya. Instead, during the past 5 million years, there have been species dispersal events from one region into the other, with some populations maintaining gene flow. Recent studies in birds suggest that dispersals across the Andes after the uplift was completed have played a major role in avian speciation in the Neotropics. For instance, lowlands *Dendrocincla* woodcreepers colonized the Andes twice (2 and 0.9 Mya), resulting in the endemic trans-Andean species *Dendrocincla anabatina* and *Dendrocincla fuliginosa ridgwayi* (Weir & Price, 2011). Similarly, the lowland forest flycatcher *Mionectes oleaginosa* has experienced at least two post-Andean uplift dispersal events 1.0 and 0.2 Mya, from the Amazon into montane habitats in the Andes and established populations that have maintained gene flow (Miller et al., 2008). After uplift dispersal across the Andes has been suggested in plants, for example in *Theobroma* (Malvaceae; Richardson, Whitlock, Meerow, & Madriñán, 2015).

Examples of recent Andean–Amazonian dispersals include olingos and bats. Short-tailed fruit bats of the species *Carollia perspicillata*, which likely arose in the Atlantic coastal forest of Brazil, have recently crossed the Andes to enter and expand into Central America, and populations of this species currently occurring in cloud forests on both sides of the Andes have low differentiation (>2%), which is consistent with active or recent gene flow among them (Hoffmann & Baker, 2003). On the other hand, the olingo *Bassaricyon alleni*, which is endemic to the Amazon, arrived into this region in the Pleistocene (~1–2 Mya) in a likely dispersal event of its ancestor across the Northern Andes (Helgen et al., 2013).

In the emblematic *Heliconius* butterflies, the establishment of red wing mimicry between *Heliconius erato* and *Heliconius melpomene* throughout their distribution involved dispersal from the Andes into the Amazon and vice versa. Genealogies of the transcription factor *optix*, responsible for red wing variation in these two species, revealed that Andean red-band phenotypes were ancestral in *H. erato* and then spread in an eastward manner, thus originating the derived Amazonian orange-ray phenotype. In contrast, migration of the red phenotypes in *H. melpomene* likely followed a westward pattern from the Amazon into the Andes (Hines et al., 2011) and, once there, these red adaptive alleles introgressed into the ancestor of the submontane forest species *H. timareta*,

triggering its diversification and leapfrog distribution along the Eastern Andes.

Contemporary species movement and gene flow across forest corridors connecting the Andes and the Amazon remain poorly studied. This is especially true in Colombia, where there is a lack of studies testing dispersal events and their implications for genetic connectivity and diversification. Nonetheless, extant hybrid zones in *Heliconius* provide evidence of active gene flow between these regions. In the southern Colombian department of Putumayo, crossing the Andes and the Amazon, it is frequent to find individuals with hybrid wing patterns resulting from hybridisation between the Andean species *H. melpomene bellula* and *H. erato dignus* with their respective Amazonian conspecifics, namely *H. melpomene malleti* and *H. erato lativitta* (Figure 1; Vargas & Salazar, 2007; ML, CJ, CS, and CPD, personal observation).

2 | THE PICACHOS–TINIGUA–SIERRA DE LA MACARENA–CHIRIBIQUETE CORRIDOR

The most extensive Colombian region that acts as a natural corridor is represented by three contiguous National Natural Parks (NNP): Cordillera de los Picachos, Tinigua, and the Sierra de la Macarena. This group of national parks, established respectively in 1977, 1989, and 1971, aims to protect a unique highly biodiverse and endemic rich region globally, and covers one of the last key connections between Andean ecosystems and the humid lowland regions of Colombia. Following the biogeographic regionalization of the Neotropical region proposed by Morrone (2014), these parks represent an ecological connection between the mountainous Páramo province in the South American Transition Zone and the Imerí province in the Boreal Brazilian dominion (Figure 2). These three protected areas constitute a landscape continuum beginning in the Eastern Andean Cordillera with páramo and tropical montane forests ecosystems, continuing south-east through an ecological gradient that reaches lowland wet forest and through unprotected areas that finally connect to the large NNP Serranía del Chiribiquete, the heart of the Colombian Amazon (4, in Figure 2). The whole of this region is the Picachos–Tinigua–Sierra de la Macarena–Chiribiquete megacorridor.

Regrettably, illegal armed and nonarmed groups have been exploiting new land for coca cropping and cattle expansion by hiring *colonos*, farmers often displaced by violence that represent the initial perpetrators of deforestation. In combination with a widespread lack of state governance, this resulted in rapid forest conversion within and around these parks. In the case of coca, it is also worth noting the unpredictable nature of its cultivation, with much temporal

and spatial variation of coca-driven deforestation in the region (Rincón Ruiz, Pascual, & Romero, 2013).

Using the Hansen et al.'s (2013) Global Forest Change dataset ver.1.3, we calculated 634 km² of forest loss (about 4.9% of the overall protected surface) detected in the years 2000–2015 inside the three NNPs, and 1,152 km² of loss in a 10-km buffer zone around them in the same period. This demonstrates massive human mediated habitat conversion and ineffective park management in this protected region. From 1990, the Colombian Forest and Carbon Monitoring system (IDEAM 2017b) also provides historic forest–no forest data for the country. Forest loss estimations using this dataset for the study area are uncertain due to the presence of cloud-coverage in the mountainous region. Despite this, the data provide a unique 26-year picture of the dynamics of forest loss and landscape fragmentation in the region. The IDEAM forest–no forest temporal series shows increasing isolation of the park's complex due to the rapid increase in deforestation from both the western (Caquetá Department) and the eastern (Meta and Guaviare) sides (see Supporting Information). The natural continuation of the protected corridor to the south of the NNP Sierra de la Macarena in the Amazon biogeographical region, once a homogeneous and pristine forest landscape, has been severely eroded, and reduced to forest patches dispersed through a matrix of large cattle ranches, rapidly appearing in State-owned vacant lands (Figure 3). Large-scale landowners feed the conversion process by acquiring cheap cleared land from the colonos with the prospect of claiming land possession from the State. Additionally, such dynamics occur in a region characterized by extensive native savannas, natural gaps in forest cover that can enhance the effect of deforestation for forest dependent species. By observing historical and recent trends, in a business as usual scenario, these dynamics will inevitably lead to a regional disconnection of the forest continuum between the Colombian biogeographical Andes and the Amazon, separating source and receiver regions of this extensive and critical corridor of genetic and biodiversity exchange.

A further additional threat is also rapidly materializing in the region. A large segment of road connecting the town of San José del Guaviare with San Vicente del Caguán (Figure 3) is planned by the Colombian Government. The total 381 km of the *Marginal Jungle Road* would provide the country connectivity to Ecuador and Venezuela, but at the cost of facilitating access to further uncontrolled colonization, which would eventually boost natural habitat conversion and reduce corridors connectivity.

3 | CONCLUDING REMARKS

The postconflict era in Colombia will undoubtedly bring immense positive impacts, but it is important that these are

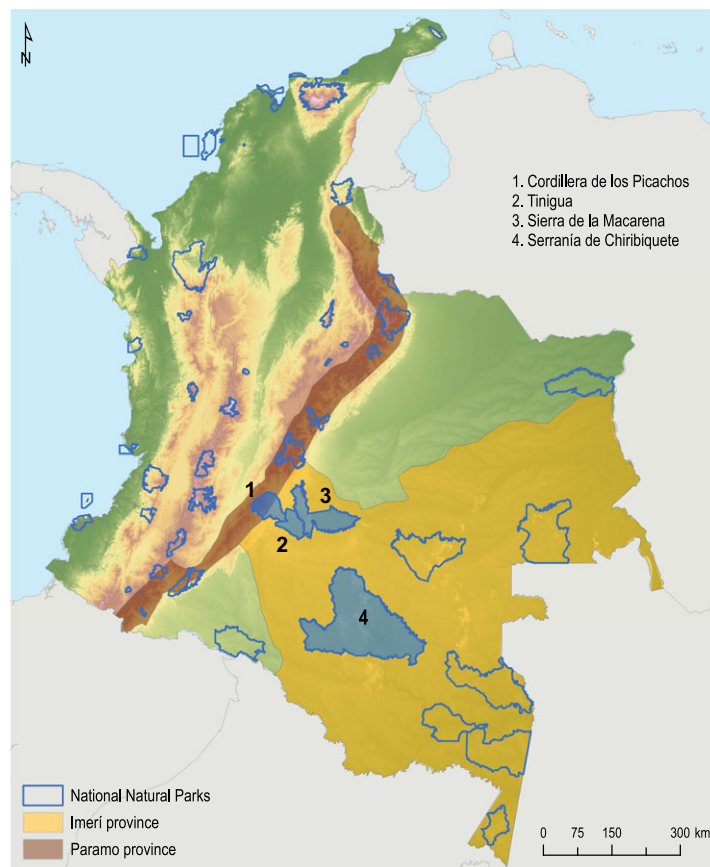


FIGURE 2 Extent of the biogeographical provinces of Imeri and Paramo in Colombia (after Morrone 2014) and Colombian NNPs (IUCN UNEP-WCMC 2017).

felt by all sectors of society and in an environmentally sustainable manner. Colombia is now experiencing the consequences of the power vacuum left by the FARC over large parts of its territory (Clerici et al., 2016). Armed groups including FARC dissidents, paramilitaries, and other organized crime groups are now using this unique opportunity to expand illegal activities into new uncontrolled areas. These include protected areas, whose State control and management in some Colombian regions is still extremely difficult. Additionally, in unprotected land the widespread inefficiency of government territorial control makes the action of colonos in pristine vacant lands an extensive phenomenon, supported economically by large landowners.

The disruption of primary tropical forests is a major threat to global biodiversity (Gibson et al., 2011). In systematic conservation planning, regional connectivity is a major factor to take into account within multiscale socioecological systems (Cumming et al., 2015; Hodgson, Thomas, Wintle, & Moilanen, 2009) in order to maintain genetic exchange, species dispersal, support metapopulations resilience, and ecosystem services provision. The Picachos–Tinigua–Macarena–Chiribiquete megacorridor and its role in connecting two megadiverse biogeographical regions has not received the

attention it deserves. The recent proposed expansion of the NPP Serranía de Chiribiquete by the government, if implemented, will help maintain the interconnectivity in the region and within this protected areas system. However, the remaining unprotected land in the corridor is experiencing rapid habitat conversion and fragmentation that needs to be prevented. To this end we appeal for the attention of international conservation organizations and governmental organs to funnel both research and development funds and resources to promote and nourish projects focused on the preservation and sustainable management of this strategic Andes–Amazon bridge in its protected and unprotected land. Farmers, colonos, and local communities should be active participants in this process, by encouraging them to change their activities and work in a manner that is better aligned with the objectives of Natural Parks and sustainable unprotected land management, toward a protection *de facto* versus current protection *de jure*. This much-needed effort would help the country achieve its 2020 zero-deforestation targets, and be aligned with Aichi Target 11, and the recent governmental interest in the Andes–Amazon–Atlantic transnational corridor. In the postconflict era Colombia has a unique opportunity to create a new social and economic paradigm based on sustainable

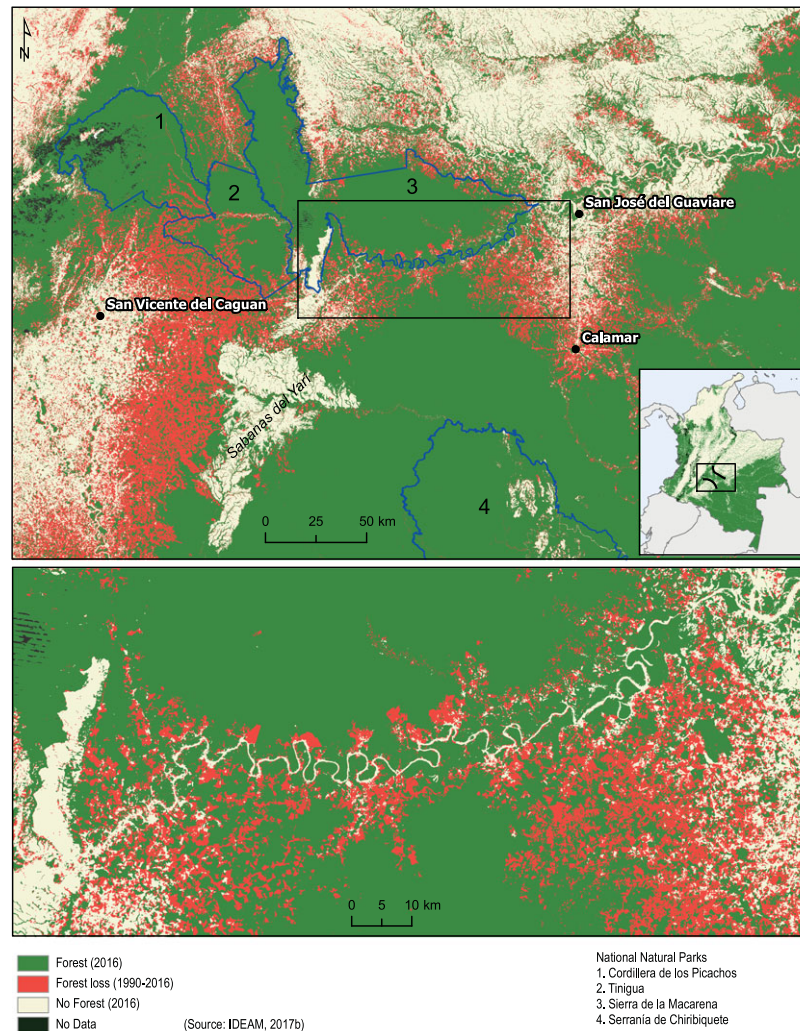


FIGURE 3 Upper figure: stable forest, stable no forest (natural and non natural), and forest loss in the study region (1990–2016). Lower figure: corridor erosion due to forest loss and landscape fragmentation (South of NNP Sierra de la Macarena). Source: (IDEAM 2017b). Inset map: location of the megacorridor within Colombia.

landscapes and more equitable sharing of wealth in the long term. We believe improved management and conservation efforts for the Picachos–Tinigua–Macarena–Chiribiquete megacorridor would demonstrate a collective will in helping to achieve this goal. On a general level, we stress the importance of acquiring improved scientific information on multispecies regional genetic flows, and of monitoring and ensuring its maintenance, especially in rapidly changing geopolitical landscapes. Finally, during the postconflict recovery period, effective control of protected and unprotected land by the state should be guaranteed not only by a reinforced physical presence but also by the rapid implementation of rural development programs where local involvement in conservation of biodiversity rich areas and management of the natural capital is a primary objective. We hope that Colombia can learn from other postconflict zones, such as in Guatemala, where a strategy of local community engagement in the management of forest resources

contributed in large regions to effective conservation, while providing significant income streams to resident stakeholders (e.g., Multiple-Use Zones of the Maya Biosphere Reserve; Radachowsky, Ramos, McNab, Baur, & Kazakov, 2012). We also hope that the experience Colombia gains will result in it contributing to improved chances of recovery in other regions that are currently experiencing conflict.

ORCID

Nicola Clerici <http://orcid.org/0000-0003-4547-7606>

Camilo Salazar <http://orcid.org/0000-0001-9217-6588>

Carolina Pardo-Díaz <http://orcid.org/0000-0002-7259-1183>

Chris D. Jiggins <http://orcid.org/0000-0002-7809-062X>

James E. Richardson <http://orcid.org/0000-0001-9014-4865>

Mauricio Linares <http://orcid.org/0000-0002-1021-0226>

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Clerici N, Salazar C, Pardo-Díaz C, Jiggins CD, Richardson JE, Linares M. Peace in Colombia is a critical moment for Neotropical connectivity and conservation: Save the northern Andes–Amazon biodiversity bridge. *Conservation Letters*. 2018;e12594. <https://doi.org/10.1111/conl.12594>