




MINI REVIEW

Mind the Gaps: Shortfalls in Studies of the Intraspecific Genetic Diversity of Plants Across the Gran Chaco

María Laura González¹ | Gonzalo A. Camps²  | Alicia N. Sérsic¹  | Andrea Cosacov^{1,3} | M. Cristina Acosta^{1,3} | Dana L. Aguilar^{1,3} | Noelia E. A. Almirón^{4,5} | Ana Laura Chiapero⁶ | Diego López Lauenstein^{7,8} | Marisel Scaldaferrro^{1,3} | Maria Sosa-Pivatto¹ | Gisela Via do Pico⁴ | Ercilia M. S. Moreno^{4,9} | Carmen Vega^{7,8} | Viviana Solis Neffa^{4,9} | Matias C. Baranzelli^{1,3} 

¹Laboratorio de Ecología Evolutiva y Biología Floral, Instituto Multidisciplinario de Biología Vegetal (CONICET-Universidad Nacional de Córdoba), Córdoba, Argentina | ²Instituto de Investigación Biológica del Paraguay, Asunción, Paraguay | ³Facultad de Cs. Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Córdoba, Argentina | ⁴Laboratorio de Citogenética y Evolución Vegetal, Instituto de Botánica del Nordeste (CONICET-Universidad Nacional del Nordeste), Corrientes, Argentina | ⁵Administración de Parques Nacionales, Buenos Aires, Argentina | ⁶Laboratorio de Interacciones Ecológicas y Conservación, Instituto Multidisciplinario de Biología Vegetal (CONICET-Universidad Nacional de Córdoba), Córdoba, Argentina | ⁷Instituto Nacional de Tecnología Agropecuaria (INTA), Instituto de Fisiología y Recursos Genéticos Vegetales, Córdoba, Argentina | ⁸Unidad de Estudios Agropecuarios (INTA-CONICET), Córdoba, Argentina | ⁹Facultad de Ciencias Exactas y Naturales y Agrimensura, Universidad Nacional del Nordeste, Corrientes, Argentina

Correspondence: Matias C. Baranzelli (mbaranzelli@imbiv.unc.edu.ar)

Received: 26 June 2025 | **Revised:** 10 November 2025 | **Accepted:** 12 November 2025

Handling Editor: Joanna Freeland

Keywords: biodiversity data | conservation genetics | DNA barcoding | knowledge shortfalls | macrogenetics | South America | vascular plants

ABSTRACT

Intraspecific genetic diversity (IGD) is a fundamental component of biodiversity, essential for understanding the evolutionary histories and demographic processes of species, and is key to effective conservation planning. However, ecologically important regions such as the Gran Chaco, South America's second-largest forested biome, remain largely underexplored. Encompassing diverse vegetation across climatic and altitudinal gradients, it harbours more than 3400 vascular plant species, 11% of which are endemic. Despite its ecological importance, genetic research in the region is limited and often biased. We reviewed IGD studies on vascular plants in the Gran Chaco from 1985 to 2024, identifying 85 studies covering 74 species. Coverage remains alarmingly low, with only 2.14% of species and 9.95% of the phylogenetic diversity represented. Research is skewed towards perennial (91%) and tree (46%) species, with limited representation of annuals and herbaceous taxa. Most studies relied on nuclear DNA (66%), fewer used chloroplast DNA (27%) and only 7% combined both genomes. Geographically, 33% of the Gran Chaco has no IGD data, and a further 22% includes data from a single species. Genetic sampling is concentrated in more accessible areas with higher road density and proximity to research institutions, particularly at higher altitudes. We found that in the Argentine Chaco ecoregions, 4.4 species have been genetically studied for every 100 species recorded, while in the Bolivia and Paraguay Chaco ecoregions, this proportion drops to 1.1 species for every 100 in each country. Future research on IGD in the Gran Chaco should broaden its taxonomic scope, diversify genomic tools and expand geographic coverage. Addressing these gaps will provide critical insights into the biogeographic history of the Gran Chaco and strengthen conservation strategies in this threatened and understudied biome.

María Laura González and Gonzalo A. Camps are co-first authors.

1 | Introduction

Intraspecific genetic diversity (IGD), defined as the genetic variation within and among populations, is a fundamental component of biodiversity that underpins the evolutionary processes shaping species' responses to environmental change (Miraldo et al. 2016). It provides a historical record of demographic fluctuations, population connectivity and selective pressures, revealing essential insights into how species persist, adapt and evolve through time (Sork 2016; Chung et al. 2023). By examining geographic patterns of IGD within and among species, we can reconstruct past population dynamics, infer biogeographic histories, and identify key evolutionary and ecological processes that govern species distributions (e.g., Sérsic et al. 2011; Turchetto-Zolet et al. 2013; Baranzelli et al. 2020, 2022). Despite its great significance, IGD remains strikingly underexplored across many ecosystems and taxonomic groups at a global scale (Miraldo et al. 2016; Fonseca et al. 2023; Kartzinel et al. 2025), which limits our ability to reconstruct the evolutionary histories of species and fully understand the biogeographic processes shaping current biodiversity patterns. The genetic knowledge gap is particularly evident in regions characterised by high ecological heterogeneity and rapid environmental change, where the distribution and drivers of genetic diversity remain poorly documented (Satler et al. 2021; Theodoridis et al. 2020; Rudbeck et al. 2022; Xiong et al. 2024; Kartzinel et al. 2025). Closing these gaps is essential not only for advancing evolutionary biology but also for informing effective biodiversity conservation strategies at regional and global scales (Des Roches et al. 2021). In this context, the Gran Chaco—a vast biome of remarkable ecological, social and cultural diversity facing growing threats—provides a compelling case study.

The Gran Chaco is the second-largest continuous forest in South America and the most extensive and threatened seasonally dry forest on the continent (Moglia and Giménez 1998; Kuemmerle et al. 2017). However, it remains poorly studied (Prado 1993; Naumann 2006; Schröder et al. 2021). This diverse mosaic of ecological regions encompasses forests, savannas and grasslands, varying from humid to arid conditions and ranging from lowlands to elevations nearly 3000 m above sea level (Cabrera 1951; Morello et al. 2012; Oyarzabal et al. 2018). It hosts around 3400 vascular plant species, 11% of which are endemic (Baumann et al. 2016), but many remain poorly documented or underexplored at the genetic level (Guillory et al. 2024; Kartzinel et al. 2025). A recent review on phylogeographic studies in the arid regions of South America indicates that studies in the Chaco are scarce and limited to a few taxonomic and ecological groups; this knowledge gap is even higher when considering plant species (Guillory et al. 2024). Therefore, assessing the scope and distribution of IGD knowledge deficits in the Gran Chaco vascular plants—including their magnitude, spatial coverage, methodological approaches and overlooked taxa and regions—should be prioritised to guide future research on biogeography and evolutionary biodiversity drivers.

Understanding IGD is crucial for conservation planning, as genetic variation underpins the adaptive potential of species facing habitat loss, climate change and other anthropogenic pressures (Andrello et al. 2022; Baranzelli et al. 2022; Chung et al. 2023; Pearman et al. 2024). The importance of maintaining the IGD

of wild species for the protection of global biodiversity was recognised by the Convention on Biological Diversity (CBD 2022), and therefore, monitoring the IGD of as many species as possible is essential (Hoban et al. 2020, 2023, 2024; Pearman et al. 2024). This is particularly important in regions such as the Gran Chaco, which faces increasing environmental pressures due to ongoing deforestation (Bouza et al. 2016; Verga and López Lauenstein 2020; de la Sancha et al. 2021), in addition to climate change (Almazroui et al. 2021), with the concomitant risk of population (or genetic diversity) and species losses.

In this review, we aim to answer the following questions: What is the magnitude of the knowledge shortfall regarding the study of IGD of vascular plants in the Gran Chaco? Are there biases in the study of the IGD in plants of the Gran Chaco? If so, what factors contribute to these biases? Addressing these questions will clarify the extent and nature of existing biases, helping to refine future research efforts and conservation strategies. This review builds on the foundations laid by Guillory et al. (2024) and Kartzinel et al. (2025), with a geographic focus on the Gran Chaco. By characterising existing IGD of vascular plants, we aim to identify underrepresented botanical families, life forms, molecular methods, geographical regions and ecological zones. In doing so, we seek to guide future research and lay the background work for a broader study of eco-evolutionary and biogeographical drivers of IGD in the native flora of the Gran Chaco.

2 | Current State of Knowledge

The study of IGD in native species across a region enhances our understanding of the evolutionary processes underlying biodiversity patterns and helps us predict how organisms can respond to environmental impacts, thereby improving conservation strategies (Leigh et al. 2021; Andrello et al. 2022). Despite the importance of ecosystem services provided by the Gran Chaco native plant communities and the increasing rate of habitat loss in recent years (Bouza et al. 2016; de la Sancha et al. 2021), the IGD of plant species in this region remains understudied (Turchetto-Zolet et al. 2013; Guillory et al. 2024; Kartzinel et al. 2025). After an extensive review of IGD research on native plants in the Gran Chaco (see Section S1), we identified 85 studies published between 1985 and 2024, covering 74 plant species (Table S1).

We categorised the studies into four groups according to the research question, the experimental design and the methodology used (Table S2). Our analysis revealed that 51% of the studies focus on population genetics, which has consistently been the primary area of research over time (Figure 1A). These studies mainly focused on elucidating mating systems and evaluating genetic diversity (e.g., Zimmerman et al. 1994; Bessega et al. 2000; Ferreyra et al. 2007; Grossi et al. 2011; Pometti et al. 2011). Phylogeographic studies account for 25% of the total, whereas landscape genetics and molecular marker development are less represented, accounting for 16% and 8% of the studies, respectively. Phylogeography studies the processes that have shaped the geographic distribution of gene lineages (Avice 2000). Consequently, these studies tend to cover a wide range of species distributions and allow the detection of the spatial distribution of IGD and the historical biogeography

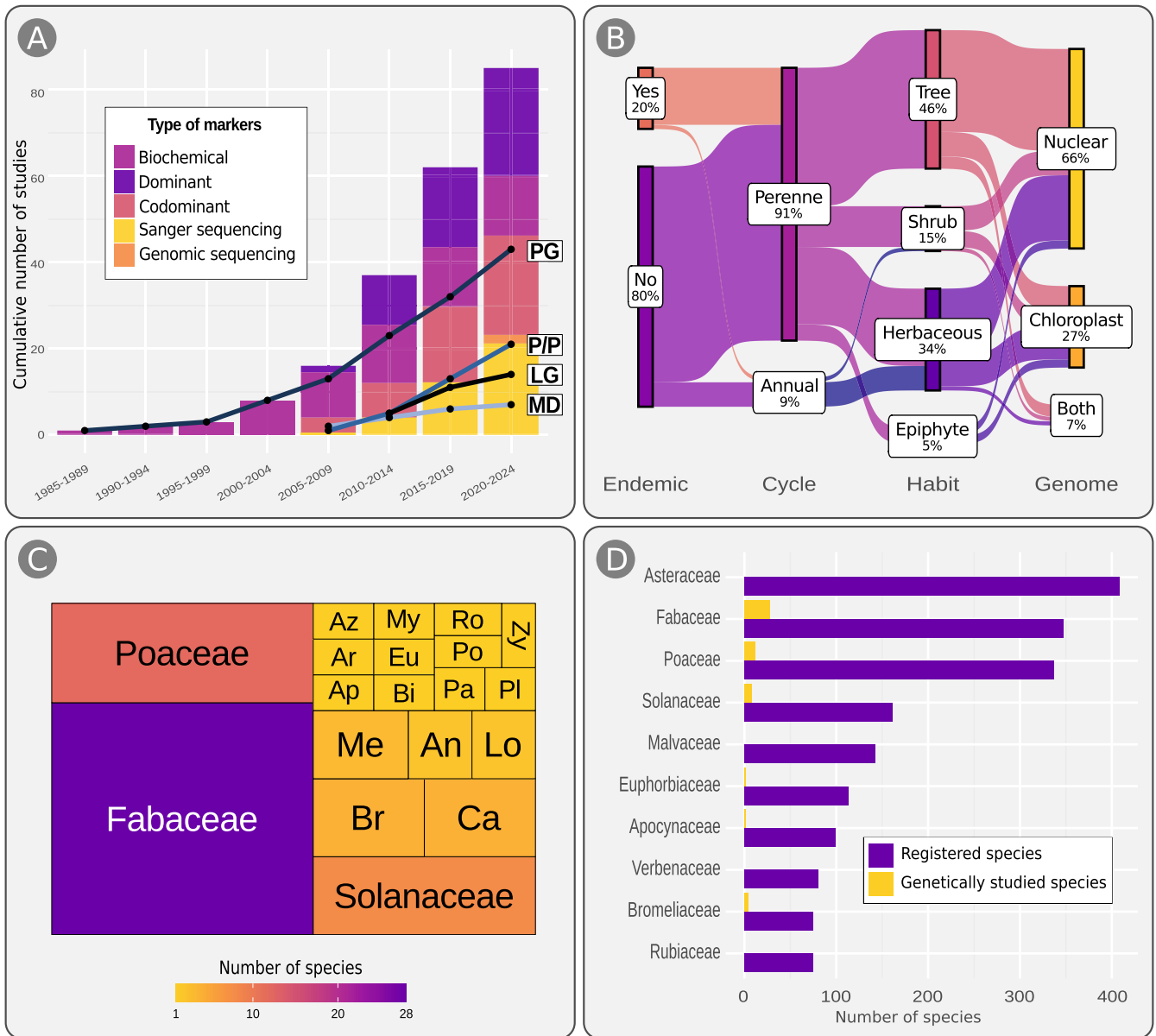


FIGURE 1 | Current knowledge of intraspecific genetic studies in the Gran Chaco. (A) Cumulative number of studies over time. The lines represent the number of studies employing four main approaches: LG, landscape genetics; MD, molecular markers development; P/P, phylogeography or phylogeny; PG, population genetics. Colours indicate the type of molecular marker used. (B) Alluvial plot illustrating the relationships between multiple categorical variables of the studied species and the type of DNA analysed. (C) Botanical families of the Gran Chaco. The colour and size of each rectangle represent the number of species studied. An, Anacardiaceae; Ap, Apocynaceae; Ar, Arecaceae; Az, Azollaceae; Bi, Bignoniaceae; Br, Bromeliaceae; Ca, Cactaceae; Eu, Euphorbiaceae; Lo, Loranthaceae; Me, Meliaceae; My, Myrtaceae; Pa, Passifloraceae; Pl, Plantaginaceae; Po, Podocarpaceae; Ro, Rosaceae; Zy, Zygophyllaceae. (D) The 10 most abundant families in the Gran Chaco, with the number of studied species in yellow, and the total number of species in violet.

of the region (Avisé 2004). This approach was first applied to Gran Chaco plants in 2008 (Caetano et al. 2008), and although its use has increased since then, it remains limited. Methodologically, most species were studied using nuclear DNA (66%), 27% were analysed using chloroplast DNA, and the remaining 7% involved both types of DNA (Figure 1B). The molecular markers used in the studies have evolved, transitioning from biochemical markers (e.g., allozymes and isozymes) to others such as dominant markers (e.g., RAPD, AFLP, ISSR), codominant markers (e.g., SSR, CAPS), Sanger-DNA sequences, and, more recently, genome-wide markers (e.g., SNPs obtained from RADseq). The implementation of

high-throughput sequencing technologies for intraspecific studies is still lagging in the region. To date, only two studies employing RADseq have been identified (Figure 1A), which could be related to the ongoing limitations in research funding for science in the countries of the Gran Chaco (Ciocca and Delgado 2017; Figure 1A).

When assessing the status of each studied species, we found that the majority were not exclusive to the Gran Chaco, with only 20% being endemic to the region. Regarding functional traits, research has heavily focused on perennial plants, which account for 91% of the studied species (Figure 1B).

Research on trees was particularly prevalent, accounting for 46% of the studied species, a trend that may be expected since dry forests are the dominant vegetation (Cabrera 1951; Oyarzabal et al. 2018), and the study of woody species is often prioritised because of their economic and ecological relevance (Villagra 2000; Ruiz-Nieto et al. 2020; Pastorino and Marchelli 2021). Although the exact proportions of functional traits across the entire Gran Chaco flora remain unknown, floristic surveys conducted in part of the region—the Chaco mountain forest—reported 28 tree species and 41 annual herbs out of a total of 792 native vascular plant species (Giorgis et al. 2011). This suggests that the proportion of studied tree species could be higher than expected, given the actual floristic composition.

When comparing the number of species studied against the Gran Chaco plant species richness obtained from the Botanical Information and Ecology Network database (hereafter ‘BIEN database’, see Section S1), we found that the coverage of IGD studies in the region is extremely low. Specifically, the species coverage is only 2.14%, while the phylogenetic coverage—measured by the percentage of taxonomic families represented—is 9.95%. Kartzinel et al. (2025) reported that about 25% of all extant land plant species have reference DNA barcodes in public repositories, representing 83% of plant families. Although these genetic data do not necessarily enable the identification of IGD, they provide a useful reference, showing that the values found here for Gran Chaco are markedly lower than the reported global patterns. The IGD studies focused on a few families, including Fabaceae—mainly *Neltuma* (previously classified within *Prosopis*) and *Vachellia* (previously classified within *Acacia*)—as well as Poaceae and Solanaceae. These accounted for 37.8%, 16.2% and 10.8% of the total studies, respectively (Figure 1C). Notably, some of the most diverse families within Gran Chaco, such as Asteraceae and Malvaceae, are entirely unrepresented in IGD studies (Figure 1D). Plant family size generally predicts the amount of available genetic data (Kartzinel et al. 2025); thus, the underrepresentation of some of the most diverse families in the Chaco suggests a phylogenetic bias in research projects. Furthermore, no IGD studies focused on Gymnosperms and only one work focused on Pteridophytes, two taxonomic groups that are naturally scarce in the Gran Chaco (Enquist et al. 2016). The genetic knowledge gap in southern regions (Miraldo et al. 2016; Satler et al. 2021; Theodoridis et al. 2020) and particularly in the Gran Chaco (Guillory et al. 2024) has been identified for various organisms, primarily through studies on animal genetics. Our findings show that this pattern also applies to vascular plants, highlighting that the Gran Chaco remains largely overlooked in plant genetic datasets.

To understand common evolutionary trajectories of the Gran Chaco vegetation, it is essential to improve the taxonomic representation of species, ensuring the inclusion of all life forms. This is important, as both ecological characteristics and phylogenetic affinity are associated with intraspecific genetic patterns of species, and their responses to habitat or environmental changes (Chung et al. 2020; Milesi et al. 2024). Furthermore, the incorporation of genomic data in future studies will enhance the understanding of spatial biodiversity, local adaptation processes and the ecological dynamics

of the Chaco (Leigh et al. 2021; Guillory et al. 2024; Pearman et al. 2024).

3 | Spatial Patterns of Knowledge

The Gran Chaco is characterised by vast plains bordered by mountains to the west, and exhibits strong ecological heterogeneity shaped by climatic, geological and vegetational gradients (Prado 1993). It features an east–west precipitation gradient, distinguishing humid ecosystems in the east from dry ecosystems in the west, along with a north–south temperature gradient characterised by warmer conditions in the north (Cabrera 1951; Olson et al. 2001). To understand geographic patterns and potential sampling biases in research efforts across this diverse region, we analysed the collected genetic information using $\sim 100 \times 100$ km hexagonal grid cells. For each grid cell, we recorded the total number of species retrieved from the BIEN database, the number of species with IGD data, the road coverage (Section S2 and Figure S1), mean elevation and the geographic coordinates of the cell’s centroid. We also estimated the geographic distances from each centroid to institutions conducting research within the Gran Chaco (Section S2). We employed a distributional model using a Bayesian approach to account for counts with excess zeros, resulting in a zero-inflated Poisson (ZIP) model. The count component modelled the number of species with genetic data as a function of a spatial smooth term (spline on latitude and longitude) to account for spatial autocorrelation, along with elevation, road density, total species richness (BIEN), distance to institutions and grid cell area offset (Section S2). The zero-inflation component was modelled with a t term, with the same predictors used for the count component (Section S2).

We found that 33% of grid cells lack IGD studies, and 22% present data for only one species (Figure 2A). The IGD studies are unevenly distributed across the region, with research effort concentrated in specific areas. Results of the ZIP model (Section S2, Table S3) showed that mean elevation ($\beta = 0.18$, 95% CI = 0.01–0.36) and road density ($\beta = 0.23$, 95% CI = 0.06–0.4) were positively associated with the number of species analysed, while distance to institutions had a significant negative effect ($\beta = -0.21$, 95% CI = -0.34 to -0.05) (Figure 2B). Total species richness from BIEN showed a positive but non-significant trend in the count component, while significantly reducing the probability of structural zeros ($\beta = -1.20$, 95% CI = -2.06 to -0.38). These results indicate that IGD-studied species are concentrated in more accessible areas (with more roads and closer to institutions) and at higher elevations; sites with greater floristic richness are more likely to have been sampled. Spatial smooths further revealed geographic structure, with large unsampled or poorly sampled areas concentrated in the northern Gran Chaco, particularly in Paraguay and Bolivia (Figure 2A and Figure S2).

The absence of genetic studies in the northern Gran Chaco is particularly concerning, as these areas have experienced significant habitat loss due to agriculture and livestock grazing (Piquer-Rodríguez et al. 2018; Fernández et al. 2020). The semiarid ecosystems within the Gran Chaco, particularly in Paraguay, are experiencing the most intense land-use change

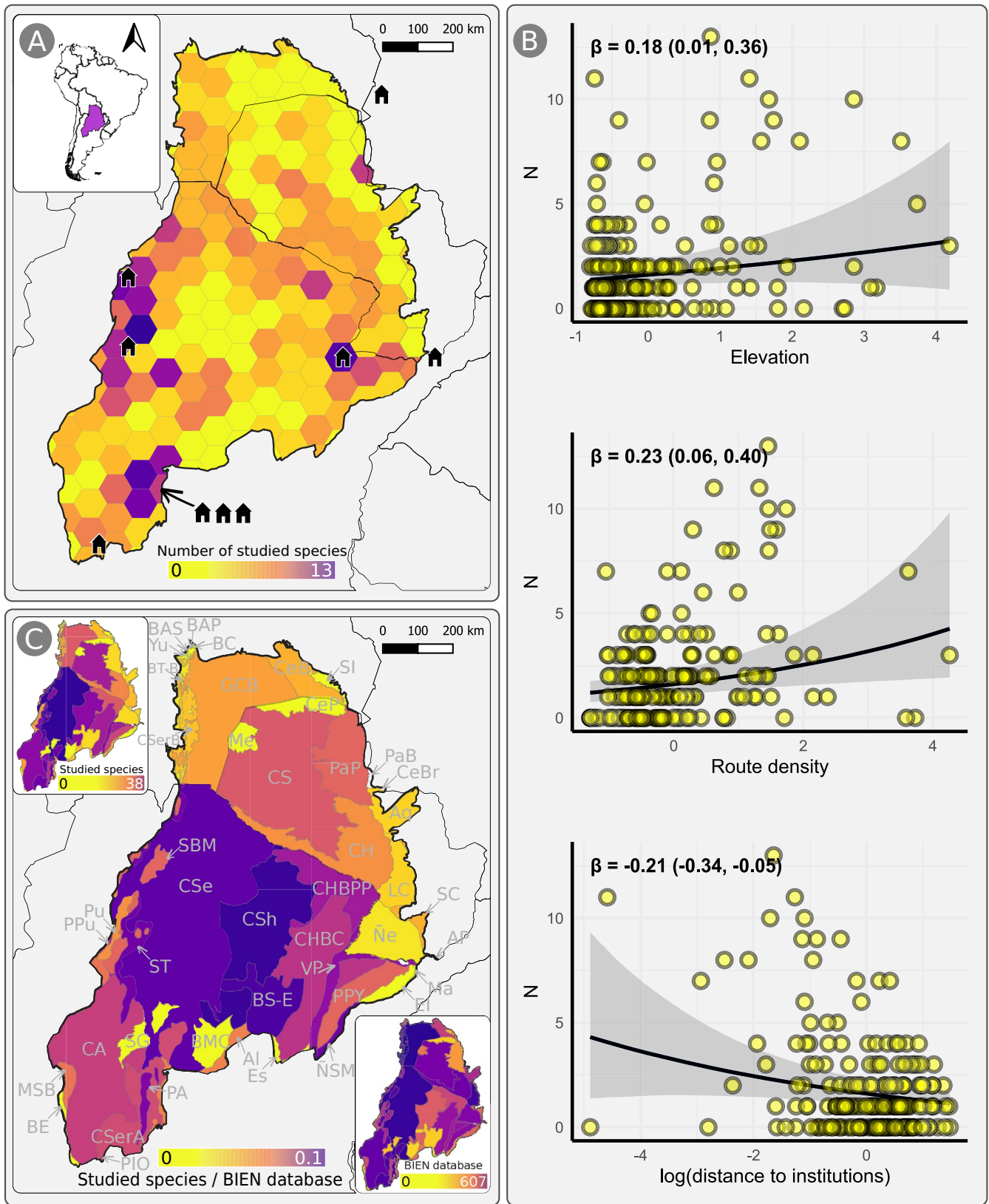


FIGURE 2 | Legend on next page.

(Vallejos et al. 2015; de la Sancha et al. 2021). This lack of IGD knowledge leaves us without a baseline for assessing potential genetic erosion across an entire region increasingly impacted by

human activities (Hoban et al. 2020). Thus, the northern and central Gran Chaco regions should be among the priority areas for new genetic data collection.

FIGURE 2 | Spatial patterns of knowledge and ecoregional knowledge gaps in the study of intraspecific genetic diversity of plants in the Gran Chaco. (A) Number of species studied per grid cell. The locations of the research institutes within the Gran Chaco and the surrounding area are shown with a black house silhouette. (B) Partial effect of the standardized elevation (top), route density (middle) and distance to institutions (bottom) on the number of studied species per grid cell (N), according to the ZIP model. The estimated coefficients (β) and their corresponding 95% confidence intervals are shown for each independent variable. Solid lines represent the fitted predictions. Shadows indicate the 95% confidence intervals for the predictions. (C) Species richness and studied species by ecoregion. Main central map: Ratio of species studied to species recorded in the BIEN database by ecoregion; Top map: Number of studied species by ecoregion; Bottom map: Number of species recorded in the BIEN database by ecoregion. Full names of ecoregions are provided in Table S1.

4 | Gaps in Ecoregional Knowledge

Although often regarded as a single phytogeographic region (Cabrera 1951), the Gran Chaco is home to several ecoregions, each with unique geographic, environmental and floristic characteristics (Ibisch and Mérida 2003; Mereles et al. 2013; Oyarzabal et al. 2018; IBGE 2019). These regions have not been equally explored and studied regarding IGD (Figure 2, see details in Section S3 and Table S4), and knowledge of the genetic diversity of Gran Chaco plant species is spatially biased. In the Argentine Chaco ecoregions, 4.4 species have been genetically studied for every 100 species recorded in the BIEN database, while in Bolivia and Paraguay, this proportion drops to 1.1 species for every 100.

Ecoregions that are predominantly Chacoan (see Table S4)—such as the *Chaco Seco* (CS in Figure 2D) and *Chaco Húmedo* (CH) in Paraguay, the *Chaco Semiárido* (CSe) and *Chaco Árido* (CA) in Argentina, and the *Gran Chaco Boliviano* (GCB) in Bolivia—harbour hundreds of species, yet show a limited number of species studied using any type of genetic diversity approach (Figure 2D). For instance, although the Paraguayan CS includes over 300 plant species in the BIEN database, only 11 have been genetically studied (3.4%). Similarly, the GCB in Bolivia hosts more than 550 species, but only eight have been the focus of genetic studies (1.4%). Some transitional ecoregions—such as *Selva de Transición* (ST) in Argentina or *Aquidabán* (Aq) in Paraguay—exhibit moderate levels of species richness but also lack sufficient genetic data, while other areas like *Médanos* (Me; Paraguay), *Salinas Grandes* (SG) and *Bañados de Mar Chiquita* (BMC) (Argentina) show no documented studies, despite containing dozens of georeferenced species (Figure 2D). Even ecoregions with relatively higher sampling proportions, like the *Chaco Subhúmedo* (CSh) in Argentina (10.6%), account for only a few species overall. In addition, the proportion of species genetically studied in each ecoregion may be lower than we report here, since the BIEN database might not fully capture the actual species distributions, and some species present in the ecoregion may not be recorded. This uneven knowledge landscape reflects both spatial and taxonomic biases in plant genetic research. Most research efforts are clustered in a few areas, leaving large portions of the Gran Chaco—especially those in Bolivia and Paraguay—poorly represented or absent in the IGD literature (Figure 2A–D).

The gaps that we have identified in IGD research show that we are missing critical opportunities to understand how genetic diversity is structured across key ecoregions of the Gran Chaco, each representing distinct environmental gradients and habitat types. Likewise, limited genetic data hinders our

ability to reconstruct the historical biogeographic processes that shaped current species distributions across the Chaco, from the arid western margins to the more humid and transitional eastern zones. These gaps are particularly concerning given the presence of regional endemisms that may harbour unique genetic lineages (e.g., Moreno et al. 2018; Aguilar et al. 2020; Scaldaferrro et al. 2023), potentially critical for understanding speciation (e.g., Turchetto et al. 2014; Giudicelli et al. 2019), local adaptation (e.g., endemic species adapted to hyper-xeric conditions in *Médanos* or saline soils in *Salinas Grandes*), or for informing conservation prioritisation (e.g., Almirón et al. 2022; Camps et al. 2024). Without broader and more representative sampling, we risk overlooking not only the hidden evolutionary histories of Chacoan flora but also the adaptive strategies that have enabled these species to survive in one of South America's harshest environments. Moreover, limited sampling constrains our ability to explore floristic affinities between the Chaco and surrounding regions, particularly with the Seasonally Dry Tropical Forests that encircle much of the Chacoan domain (e.g., Caetano et al. 2008; Castello et al. 2016).

5 | Conclusion

Our findings reveal significant knowledge gaps in IGD research on Gran Chaco plant species, affecting the vast majority of taxonomic and ecological groups and a large proportion of the ecoregions, particularly those that are remote or less accessible. Despite being the second-largest continuous forest in South America and harbouring high ecological heterogeneity, the Gran Chaco remains vastly underrepresented in IGD studies. We overlook entire evolutionary lineages, unique population structures and irreplaceable reservoirs of diversity that have been shaped by long-term ecological and geological processes (Chung et al. 2023; Guillory et al. 2024). This lack of data limits the identification of diversification centres, historical refugia or the ability to anticipate species' responses to environmental change (e.g., López Lauenstein et al. 2013; Camps et al. 2018; Almirón et al. 2022; Baranzelli et al. 2022; Scaldaferrro et al. 2023). Moreover, this knowledge is essential to propose priority areas for protection and conservation that safeguard IGD (Gallo et al. 2009). The genetic signatures stored in the DNA of Chacoan plants encode stories of persistence, migration and diversification; stories that are fundamental to reconstructing South America's biogeographic past and essential for anticipating its ecological future.

One of the most striking biases identified in this review is the disproportionate focus on woody perennials, with herbaceous and shrubby species remaining largely underrepresented. To address

this gap, expanding IGD studies in the Gran Chaco should prioritise the inclusion of underrepresented key botanical families, such as Asteraceae, Poaceae, Malvaceae and Euphorbiaceae, that are dominated by herbaceous and shrubby species (e.g., Giorgis et al. 2021). Additionally, the current reliance on nuclear DNA markers highlights an underuse of genomic approaches and plastidial sequences. Genomic approaches could provide deeper insights into demographic history, phylogeography and adaptation, enabling more comprehensive reconstructions of evolutionary patterns across different/diverse plant lineages (Strasburg et al. 2012; Chung et al. 2023). Meanwhile, IGD studies based on plastid DNA could provide important data using methods that are often faster and more cost-effective than those applied to nuclear genomes. Spatial biases in IGD research are also evident, with studies clustering in areas with more roads and near research institutions, leaving vast areas of potentially high biodiversity. This limits our ability to detect novel genetic patterns and increases the risk of overlooking unique evolutionary lineages. Overcoming these limitations requires targeted sampling in less accessible regions and stronger collaborations with local researchers and institutions, which would enhance regional research capacity, reduce logistical biases and ensure long-term, evidence-based conservation strategies (Mace and Purvis 2008; Andrello et al. 2022).

The knowledge gaps we have identified also hinder conservation efforts, as IGD is critical for assessing species' adaptive potential under increasing environmental pressures. Some authors suggest that even the most optimistic scenario of diversity loss still leads to catastrophic inbreeding, substantial declines in fitness, and reduced evolutionary capacity (Frankham 2022; Hoban et al. 2023). These scenarios reinforce the urgency of establishing a robust IGD baseline for the Gran Chaco, a remarkable and increasingly threatened biome, known for its ecological, social and cultural significance. Beyond the regional perspective, these gaps reflect a global challenge: plant IGD is systematically underrepresented across many of the world's most biodiverse but understudied biomes. Recent studies (e.g., Shaw et al. 2025) demonstrate that genetic erosion is a widespread phenomenon with profound consequences for ecological resilience and human well-being. Addressing these gaps in the Gran Chaco is therefore not only a regional conservation priority but also a crucial contribution towards meeting international biodiversity targets and safeguarding the evolutionary potential of plants at a global scale.

Author Contributions

M.L.G., G.A.C., A.N.S., A.C., M.C.A. and M.C.B. conceived the study. All authors contributed to data compilation. M.L.G., G.A.C., A.N.S. and M.C.B. performed the analyses. M.L.G., G.A.C. and M.C.B. wrote the first draft of the manuscript. All authors contributed to the revision and approved the final version of the manuscript.

Acknowledgements

We thank the National Council for Scientific and Technological Research (CONICET) Argentina, of which most of the authors are researchers or technical assistants. This work was supported by the National Ministry of Science and Technology (CONICET; PIBAA-28720210100101CO to M.C.B., PIP-11220210100320CO to A.C., PIP-11220210100536CO to M.C.A.), the Scientific and Technological Research Fund (FONCYT;

PICT 2020-00602 to M.L.G., PICT-3050 to A.C., PICT-2021-273 to M.C.A.) and the Secretariat of Science and Technology-National University of Cordoba (SECyT-UNC; PIP-33620230100570CB). We thank Dr. Seth Daniel Musker who was very helpful with his suggestions for the analyses. We thank the Reviews Editor, Joanna Freeland, and anonymous reviewers for their suggestions that helped improve the study.

Funding

This work was supported by the National Ministry of Science and Technology (CONICET; PIBAA-28720210100101CO to M.C.B., PIP-11220210100320CO to A.C., PIP-11220210100536CO to M.C.A.), the Scientific and Technological Research Fund (FONCYT; PICT 2020-00602 to M.L.G., PICT-3050 to A.C., PICT-2021-273 to M.C.A.), and the Secretariat of Science and Technology-National University of Cordoba (SECyT-UNC; PIP-33620230100570CB).

Disclosure

Benefits Sharing Statement: This review identifies gaps in publicly available intraspecific genetic data for South American plant species, highlighting opportunities for non-commercial benefit sharing through inclusive research and regional collaboration.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All datasets and analysis code will be deposited in the CONICET institutional repository (Repositorio Institucional CONICET Digital): <https://ri.conicet.gov.ar/>.

References

- Aguilar, D. L., M. C. Acosta, M. C. Baranzelli, et al. 2020. "Ecophylogeography of the Disjunct South American Xerophytic Tree Species *Prosopis chilensis* (Fabaceae)." *Biological Journal of the Linnean Society* 129, no. 4: 793–809.
- Almazroui, M., M. Ashfaq, M. N. Islam, et al. 2021. "Assessment of CMIP6 Performance and Projected Temperature and Precipitation Changes Over South America." *Earth Systems and Environment* 5: 155–183.
- Almirón, N. E., G. M. V. do Pico, A. Cosacov, E. N. Paredes, G. A. R. Dobladez, and V. G. S. Neffa. 2022. "The Geography of *Aspidosperma quebracho-blanco* Vulnerability, an Emblematic Species of the South American Gran Chaco." *Forest Ecology and Management* 523: 120503.
- Andrello, M., C. D'Aloia, A. Dalongeville, et al. 2022. "Evolving Spatial Conservation Prioritization With Intraspecific Genetic Data." *Trends in Ecology & Evolution* 37: 553–564.
- Avise, J. C. 2000. *Phylogeography: The History and Formation of Species*. Harvard University Press.
- Avise, J. C. 2004. "What Is the Field of Biogeography, and Where Is It Going?" *Taxon* 53, no. 4: 893–898.
- Baranzelli, M. C., A. Cosacov, N. Rocamundi, et al. 2020. "Volcanism Rather Than Climatic Oscillations Explains the Shared Phylogeographic Patterns Among Ecologically Distinct Plant Species in the Southernmost Areas of the South American Arid Diagonal." *Perspectives in Plant Ecology, Evolution and Systematics* 45: 125542.
- Baranzelli, M. C., A. Cosacov, S. M. Sede, M. V. Nicola, and A. N. Sérsic. 2022. "Anthropocene Refugia in Patagonia: A Macrogenetic Approach to Safeguarding the Biodiversity of Flowering Plants." *Biological Conservation* 268: 109492.
- Baumann, M., M. Piquer-Rodríguez, V. Fehlenberg, G. Gavier Pizarro, and T. Kuemmerle. 2016. "Land-Use Competition in the South

- American Chaco." In *Land Use Competition: Ecological, Economic and Social Perspectives*, edited by J. Niewöhner, A. Bruns, P. Hostert, et al., 215–229. Springer International Publishing.
- Bessega, C., L. Ferreyra, N. Julio, S. Montoya, B. Saidman, and J. C. Vilardi. 2000. "Mating System Parameters in Species of Genus *Prosopis* (Leguminosae)." *Hereditas* 132, no. 1: 19–27.
- Bouza, M. E., A. Aranda-Rickert, M. M. Brizuela, et al. 2016. "Economics of Land Degradation in Argentina." In *Economics of Land Degradation and Improvement—A Global Assessment for Sustainable Development*, edited by E. Nkonya, A. Mirzabaev, and J. von Braun, 291–326. Springer.
- Cabrera, A. L. 1951. "Territorios fitogeográficos de la República Argentina." *Boletín de la Sociedad Argentina de Botánica* 4: 21–65.
- Caetano, S., D. Prado, R. T. Pennington, et al. 2008. "The History of Seasonally Dry Tropical Forests in Eastern South America: Inferences From the Genetic Structure of the Tree *Astronium urundeuva* (Anacardiaceae)." *Molecular Ecology* 17, no. 13: 3147–3159.
- Camps, G. A., A. Cosacov, A. R. Verga, and A. N. Sérsic. 2024. "Employing Scientific Evidence Through Synthetic Indices to Support Management and Conservation Policies for an Endangered Tree of the Gran Chaco." *Journal for Nature Conservation* 81: 126698.
- Camps, G. A., E. Martínez-Meyer, A. R. Verga, A. N. Sérsic, and A. Cosacov. 2018. "Genetic and Climatic Approaches Reveal Effects of Pleistocene Refugia and Climatic Stability in an Old Giant of the Neotropical Dry Forest." *Biological Journal of the Linnean Society* 125, no. 2: 401–420.
- Castello, L. V., M. H. Barfuss, W. Till, L. Galetto, and J. O. Chiapella. 2016. "Disentangling the *Tillandsia capillaris* Complex: Phylogenetic Relationships and Taxon Boundaries in Andean Populations." *Botanical Journal of the Linnean Society* 181, no. 3: 391–414.
- Chung, M. Y., J. Merilä, J. Li, et al. 2023. "Neutral and Adaptive Genetic Diversity in Plants: An Overview." *Frontiers in Ecology and Evolution* 11: 1116814.
- Chung, M. Y., S. Son, S. Herrando-Moraira, et al. 2020. "Incorporating Differences Between Genetic Diversity of Trees and Herbaceous Plants in Conservation Strategies." *Conservation Biology* 34, no. 5: 1142–1151.
- Ciocca, D. R., and G. Delgado. 2017. "The Reality of Scientific Research in Latin America; an Insider's Perspective." *Cell Stress & Chaperones* 22, no. 6: 847–852.
- Convention on Biological Diversity (CBD). 2022. "Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity: Kunming-Montreal Global Biodiversity Framework Decision XV/4."
- de la Sancha, N. U., S. A. Boyle, N. E. McIntyre, et al. 2021. "The Disappearing Dry Chaco, One of the Last Dry Forest Systems on Earth." *Landscape Ecology* 36: 2997–3012.
- Des Roches, S., L. H. Pendleton, B. Shapiro, and E. P. Palkovacs. 2021. "Conserving Intraspecific Variation for Nature's Contributions to People." *Nature Ecology & Evolution* 5, no. 5: 574–582.
- Enquist, B. J., R. Condit, R. K. Peet, M. Schildhauer, and B. M. Thiers. 2016. "Cyberinfrastructure for an Integrated Botanical Information Network to Investigate the Ecological Impacts of Global Climate Change on Plant Biodiversity." *PeerJ Preprints* 4: e2615v2.
- Fernández, P. D., T. Kuemmerle, M. Baumann, et al. 2020. "Understanding the Distribution of Cattle Production Systems in the South American Chaco." *Journal of Land Use Science* 15, no. 1: 52–68.
- Ferreyra, L. I., C. Bessega, J. C. Vilardi, and B. O. Saidman. 2007. "Consistency of Population Genetics Parameters Estimated From Isozyme and RAPDs Dataset in Species of Genus *Prosopis* (Leguminosae, Mimosoideae)." *Genetica* 131: 217–230.
- Fonseca, E. M., T. A. Pelletier, S. K. Decker, D. J. Parsons, and B. C. Carstens. 2023. "Pleistocene Glaciations Caused the Latitudinal Gradient of Within-Species Genetic Diversity." *Evolution Letters* 7: 331–338. <https://doi.org/10.1002/evl3.344>.
- Frankham, R. 2022. "Evaluation of Proposed Genetic Goals and Targets for the Convention on Biological Diversity." *Conservation Genetics* 23, no. 5: 865–870.
- Gallo, L. A., P. Marchelli, L. Chauchard, and M. Gonzalez Penalba. 2009. "Knowing and Doing: Research Leading to Action in the Conservation of Forest Genetic Diversity of Patagonian Temperate Forests." *Conservation Biology* 23, no. 4: 895–898.
- Giorgis, M. A., A. M. Cingolani, F. Chiarini, et al. 2011. "Composición florística del Bosque Chaqueño Serrano de la provincia de Córdoba, Argentina." *Kurtziana* 36, no. 1: 9–43.
- Giorgis, M. A., M. V. Palchetti, R. Morera, M. Cabido, J. O. Chiapella, and A. M. Cingolani. 2021. "Flora vascular de las montañas de Córdoba (Argentina): características y distribución de las especies a través del gradiente altitudinal." *Boletín de la Sociedad Argentina de Botánica* 56, no. 3: 327–345.
- Giudicelli, G. C., C. Turchetto, M. C. Teixeira, and L. B. Freitas. 2019. "Morphological and Genetic Characterization in Putative Hybrid Zones of *Petunia axillaris* Subsp. *axillaris* and Subsp. *parodii* (Solanaceae)." *Botanical Journal of the Linnean Society* 191, no. 3: 353–364.
- Grossi, M. A., N. Julio, C. N. Gardenal, J. Di Rienzo, and G. Funes. 2011. "Genetic Variability in *Apurimacia dolichocarpa* (Fabaceae), a Narrow Endemic Species of Córdoba Hills, Argentina." *Annales Botanici Fennici* 48, no. 1: 21–28.
- Guillory, W. X., F. de Meiros Magalhães, F. E. A. Coelho, et al. 2024. "Geoclimatic Drivers of Diversification in the Largest Arid and Semi-Arid Environment of the Neotropics: Perspectives From Phylogeography." *Molecular Ecology* 33: e17431.
- Hoban, S., M. Bruford, J. D. U. Jackson, et al. 2020. "Genetic Diversity Targets and Indicators in the CBD Post-2020 Global Biodiversity Framework Must Be Improved." *Biological Conservation* 248: 108654.
- Hoban, S., M. W. Bruford, J. M. da Silva, et al. 2023. "Genetic Diversity Goals and Targets Have Improved, but Remain Insufficient for Clear Implementation of the Post-2020 Global Biodiversity Framework." *Conservation Genetics* 24, no. 2: 181–191.
- Hoban, S., I. Paz-Vinas, R. E. Shaw, et al. 2024. "DNA-Based Studies and Genetic Diversity Indicator Assessments Are Complementary Approaches to Conserving Evolutionary Potential." *Conservation Genetics* 25: 1147–1153.
- IBGE. 2019. "Biomass e sistema costeiro-marinho do Brasil 1:250.000."
- Ibsch, P., and G. Mérida. 2003. *Biodiversidad: la riqueza de Bolivia: estado de conocimiento y conservación*. Fundación Amigos de la Naturaleza.
- Kartzinel, T. R., H. K. Hoff, T. J. Divoll, et al. 2025. "Global Availability of Plant DNA Barcodes as Genomic Resources to Support Basic and Policy-Relevant Biodiversity Research." *Molecular Ecology* 34: e17712.
- Kuemmerle, T., M. Altrichter, G. Baldi, et al. 2017. "Forest Conservation: Remember Gran Chaco." *Science* 355, no. 6324: 465.
- Leigh, D. M., C. B. van Rees, K. L. Millette, et al. 2021. "Opportunities and Challenges of Macrogenetic Studies." *Nature Reviews Genetics* 22, no. 12: 791–807.
- López Lauenstein, D. A., M. E. Fernández, and A. R. Verga. 2013. "Drought Stress Tolerance of *Prosopis chilensis* and *Prosopis flexuosa* Species and Their Hybrids." *Trees* 27: 285–296.
- Mace, G. M., and A. Purvis. 2008. "Evolutionary Biology and Practical Conservation: Bridging a Widening Gap." *Molecular Ecology* 17, no. 1: 9–19.

- Mereles, F., J. L. Cartes, R. P. Clay, et al. 2013. "Análisis cualitativo para la definición de las ecorregiones de Paraguay occidental." *Paraguaria Natural* 1, no. 2: 12–20.
- Milesi, P., C. Kastally, B. Dauphin, et al. 2024. "Resilience of Genetic Diversity in Forest Trees Over the Quaternary." *Nature Communications* 15, no. 1: 8538.
- Miraldo, A., S. Li, M. K. Borregaard, et al. 2016. "An Anthropocene Map of Genetic Diversity." *Science* 353, no. 6307: 1532–1535.
- Moglia, G., and A. M. Giménez. 1998. "Rasgos anatómicos característicos del hidrosistema de las principales especies arbóreas de la región chaqueña Argentina." *Investigación Agraria, Sistemas y Recursos Forestales* 7, no. 1–2: 53–71.
- Morello, J., S. D. Matteucci, A. F. Rodríguez, and M. E. Silva. 2012. *Ecorregiones y complejos ecosistémicos argentinos. Primera edición*. Orientación Gráfica Editora.
- Moreno, E. M. S., L. B. de Freitas, P. R. Speranza, and V. G. Solís Neffa. 2018. "Impact of Pleistocene Geoclimatic Events on the Genetic Structure in Mid-Latitude South American Plants: Insights From the Phylogeography of Turnera Sidoides Complex (Passifloraceae, Turneroideae)." *Botanical Journal of the Linnean Society* 188, no. 4: 377–390.
- Naumann, N. 2006. *Atlas del Gran Chaco Sudamericano*. Sociedad Alemana de Cooperación Técnica (GTZ). ErreGé & Asoc.
- Olson, D. M., E. Dinerstein, E. D. Wikramanayake, et al. 2001. "Terrestrial Ecoregions of the World: A New Map of Life on Earth: A New Global Map of Terrestrial Ecoregions Provides an Innovative Tool for Conserving Biodiversity." *Bioscience* 51, no. 11: 933–938.
- Oyarzabal, M., J. Clavijo, L. Oakley, et al. 2018. "Unidades de vegetación de la Argentina." *Ecología Austral* 28, no. 1: 40–63.
- Pastorino, M. J., and P. Marchelli. 2021. *Low Intensity Breeding of Native Forest Trees in Argentina*. Springer.
- Pearman, P. B., O. Broennimann, T. Aavik, et al. 2024. "Monitoring of Species' Genetic Diversity in Europe Varies Greatly and Overlooks Potential Climate Change Impacts." *Nature Ecology & Evolution* 8, no. 2: 267–281.
- Piquer-Rodríguez, M., V. Butsic, P. Gärtner, et al. 2018. "Drivers of Agricultural Land-Use Change in the Argentine Pampas and Chaco Regions." *Applied Geography* 91: 111–122.
- Pometti, C. L., J. C. Vilardi, and B. O. Saidman. 2011. "Mating System Parameters and Genetic Structure in Argentinean Populations of *Acacia caven* (Leguminosae, Mimosoideae)." *Plant Systematics and Evolution* 292: 25–32.
- Prado, D. E. 1993. "What Is the Gran Chaco Vegetation in South America? I. A Review. Contribution to the Study of Flora and Vegetation of the Chaco. V." *Candollea* 48: 145–172.
- Rudbeck, A. V., M. Sun, M. Tietje, et al. 2022. "The Darwinian Shortfall in Plants: Phylogenetic Knowledge Is Driven by Range Size." *Ecography* 2022, no. 8: e06142.
- Ruiz-Nieto, J., J. Hernández-Ruiz, J. Hernández-Marín, et al. 2020. "Mesquite (*Prosopis* spp.) Tree as a Feed Resource for Animal Growth." *Agroforestry Systems* 94: 1139–1149.
- Satler, J. D., B. C. Carstens, R. C. Garrick, and A. Espíndola. 2021. "The Phylogeographic Shortfall in Hexapods: A Lot of Leg Work Remaining." *Insect Systematics and Diversity* 5, no. 5: 1.
- Scaldfarfero, M. A., A. Sérsic, A. A. Romanutti, and M. C. Acosta. 2023. "Mountains as Refugia in the Dry Chaco: Phylogeography and Species Distribution Modelling of the Southernmost Chilli Pepper, *Capsicum chacoense* Hunz. (Solanaceae)." *Biological Journal of the Linnean Society* 140, no. 1: 130–148.
- Schröder, J. M., L. P. Ávila Rodríguez, and S. Günter. 2021. "Research Trends: Tropical Dry Forests: The Neglected Research Agenda?" *Forest Policy and Economics* 122: 102333.
- Sérsic, A. N., A. Cosacov, A. A. Cocucci, et al. 2011. "Emerging Phylogeographical Patterns of Plants and Terrestrial Vertebrates From Patagonia." *Biological Journal of the Linnean Society* 103, no. 2: 475–494.
- Shaw, R. E., K. A. Farquharson, M. W. Bruford, et al. 2025. "Global Meta-Analysis Shows Action Is Needed to Halt Genetic Diversity Loss." *Nature* 638: 704–710.
- Sork, V. L. 2016. "Gene Flow and Natural Selection Shape Spatial Patterns of Genes in Tree Populations: Implications for Evolutionary Processes and Applications." *Evolutionary Applications* 9: 291–310.
- Strasburg, J. L., N. A. Sherman, K. M. Wright, L. C. Moyle, J. H. Willis, and L. H. Rieseberg. 2012. "What Can Patterns of Differentiation Across Plant Genomes Tell Us About Adaptation and Speciation?" *Philosophical Transactions of the Royal Society B: Biological Sciences* 367, no. 1587: 364–373.
- Theodoridis, S., D. A. Fordham, S. C. Brown, S. Li, C. Rahbek, and D. Nogues-Bravo. 2020. "Evolutionary History and Past Climate Change Shape the Distribution of Genetic Diversity in Terrestrial Mammals." *Nature Communications* 11, no. 1: 2557.
- Turchetto, C., N. J. Fagundes, A. L. Segatto, et al. 2014. "Diversification in the South American Pampas: The Genetic and Morphological Variation of the Widespread *Petunia axillaris* Complex (Solanaceae)." *Molecular Ecology* 23, no. 2: 374–389.
- Turchetto-Zolet, A. C., F. Pinheiro, F. Salgueiro, and C. Palma-Silva. 2013. "Phylogeographical Patterns Shed Light on Evolutionary Process in South America." *Molecular Ecology* 22, no. 5: 1193–1213.
- Vallejos, M., J. N. Volante, M. J. Mosciaro, L. M. Vale, M. L. Bustamante, and J. M. Paruelo. 2015. "Transformation Dynamics of the Natural Cover in the Dry Chaco Ecoregion: A Plot Level Geo-Database From 1976 to 2012." *Journal of Arid Environments* 123: 3–11.
- Verga, A., and D. López Lauenstein. 2020. "Subtropical Dry Forests: The Main Forest Ecoregion of Argentina." In *Low Intensity Breeding of Native Forest Trees in Argentina: Genetic Basis for Their Domestication and Conservation*, 217–243. Springer International Publishing.
- Villagra, P. E. 2000. "Aspectos ecológicos de los algarrobales argentinos." *Multequina* 9, no. 2: 35–51.
- Xiong, Y., Y. Zhao, Y. He, et al. 2024. "Current Progress and Future Prospects for Understanding Genetic Diversity of Seed Plants in China." *Biological Diversity* 1, no. 1: 13–21.
- Zimmerman, W. J., C. J. Simon, I. Watanabe, and K. Krawczyk. 1994. "Collection of *Azolla microphylla* in Paraguay and Its Characterization by Allozymes and DNA-RAPDs." *American Fern Journal* 84, no. 3: 86–93.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** mec70187-sup-0001-AppendixS1.pdf.