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Disentangling Drivers of Metacommunity Structure for Small Mammals Throughout Paraguay

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ABSTRACT Paraguay is home to a unique precipitation gradient, receiving progressively more precipitation from east to west. It has previously been suggested that metacommunity structures for order Chiroptera assemble along precipitation gradients such as this one. Metacommunities have also been shown to assemble along other bioclimatic gradients such as temperature. This study seeks to expand upon other findings by using a larger dataset, partitioned bioclimatic variables, and more mammalian orders. It also seeks to determine how metacommunities assemble along this gradient in Paraguay, investigate the differences between different ecological metacommunity assemblages, and to further understand which bioclimatic variables have the greatest impact on these assemblages. For this study various geospatial and statistical analyses, using ArcGIS Pro and R, were performed to achieve the goals of this project. It was found that for all orders studied and all three orders combined, the east of the country generally had a greater alpha-diversity. It also found that Rodentia, Chiroptera, and all species combined exhibit a Clementsian metacommunity structure while order Didelphimorphia has a Gleasonian metacommunity structure. These metacommunities, generally form boundaries near the *Rio* Paraguay along the precipitation gradient, except for order Didelphimorphia which had a larger metacommunity in the north of the country, but in the south, the two smaller metacommunities formed a boundary along the *Rio* Paraguay and precipitation gradient as well. For all orders and all orders combined, every bioclimatic variable had a significant influence on metacommunity assembly, except for temperature seasonality for order Didelphimorphia. For Rodentia, Chiroptera, and all species combined it was determined that precipitation during the coldest month is the most influential bioclimatic variable for metacommunity assembly, for Didelphimorphia, it was longitude. Understanding the way these metacommunities are assembled and what variables influence them can also influence our understanding of how climate change and deforestation impact these species, improving conservation methods.

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INTRODUCTION

Paraguay is a landlocked country that is located between Brazil, Argentina, and Bolivia. Given its location various bioregions are present in the country (Ávila-Torres et al., 2018). It is also bisected by the *Rio* Paraguay, which limits the dispersal of species across it (de la Sancha et al., 2017). In the northwestern part of the country along the border of Argentina and Bolivia is the Dry Chaco, a dry forest experiencing little precipitation and one of the last dry forests on Earth because of deforestation (de la Sancha et al., 2021a). In the northeastern part of the country is the Pantanal (Ávila-Torres et al., 2018). The *Rio* Paraguay is hugged on both sides by the humid Chaco (Ávila-Torres et al., 2018). East of that is the inland part of the Atlantic Forest, a subtropical rainforest, also threatened by deforestation (de la Sancha et al., 2014). Despite the country being relatively flat, a precipitation gradient is still present with the driest part of the country receiving 500 mm of precipitation annually and the wettest, 1800 mm (Ruiz-Díaz et al., 2024).

Paraguay is also home to a unique combination of mammal species (de la Sancha et al., 2017). According to a previous checklist of the mammals of Paraguay there are 58 species from order Chiroptera, 56 species from order Rodentia, 20 species from order Carnivora, 18 species from order Didelphimorphia, 11 species from order Cingulata, 10 species from order Artiodactyla, 5 species from order Primates, 2 species from order Pilosa, and 1 species from order Lagomorpha (de la Sancha et al., 2017).

Metacommunities are formed from smaller ecological communities, meaning that they are communities of communities (Leibold et al., 2004). A whole host of factors can affect these metacommunities, how they function, which species are included, and their ranges (Leibold et al., 2004). Natural gradients such as those in Paraguay are typically important drivers of metacommunity structure (Stevens et al., 2007). However, other anthropogenic factors such as climate change may impact how these metacommunities are assembled (Eklöf et al., 2012). Grasping the metacommunity concept how they function, and which factors influence them, may provide insights for conservation. Metacommunities rely on an environmental gradient for coherence, meaning that they rely on the same environmental factors to define their range (Presley et al., 2023, Presley et al., 2010). Without coherence metacommunities will fall into either a checkerboard pattern or will be assembled randomly (Stevens et al., 2007). However, because Paraguay is essentially a large precipitation gradient, metacommunities should form along the gradient (Presley et al., 2023). Using further analysis, the other environmental factors most closely associated with the assembly of metacommunities can also be determined.

It has also been well documented in the literature that mammal species form ecological communities with one another, and this should also occur in Paraguay (Stevens et al., 2004). Order Chiroptera has already been shown to have a community structure on the bioregional level in Paraguay (Stevens, 2007).

Orders Chiroptera, Rodentia, and Didelphimorphia are good models to demonstrate how metacommunities are formed along environmental gradients. In Paraguay, these are the three of the four largest orders of mammals by number of species (de la Sancha et al., 2017). Species from order Chiroptera belong to several trophic levels, with several families that generally have different diets, such as frugivory and insectivory (Stevens, 2007). This variety in diet within the order means that the order itself relies on a variety of ecosystems. Order Chiroptera also includes the only true flying mammals and despite their small size they have the potential for long distance dispersal or even migration (Varzinczack, 2020). This makes them great models to demonstrate metacommunity assembly in a country like Paraguay with diverse bioregions. By number of species, Rodentia is the most specious order of mammals in the world (Delaney et al., 2018). This makes them especially good models of study for ecological and biogeographical questions as to how metacommunities interact with environmental gradients. Rodentia like Chiroptera are both placental mammals, this means that their common ancestor diverged from marsupials about 160 million years ago (Upham et al., 2019). Order Didelphimorphia is also a good model to use for this study, because they are also a relatively diverse order, being the fourth largest mammalian order in Paraguay (de la Sancha et al., 2017). Didelphimorphia makes it possible to compare orders that are evolutionarily divergent, while still having similar body sizes to Rodentia (Fonseca et al., 2015). At the same they are also ecologically similar to Rodentia since most Didelphimorphia species are insectivores (Tarquini et al., 2020). Didelphimorphia in Paraguay also have smaller dispersal abilities, meaning they don't travel or migrate as far as other orders, such as Chiroptera (de la Sancha et al., 2020). These traits will provide a contrast with the Rodentia and Chiroptera (Stevens et al., 2007).

The aims of this study are to: 1) Understand the patterns of mammals along the environmental gradient in Paraguay; 2) Understand how ecological metacommunities assemble; 3) Understand the environmental variables that best explain these metacommunity patterns.

METHODS

Diversity Maps

To generate the alpha diversity maps (the richness, or the number of species in an area), shapefiles of the ranges of orders Chiroptera, Rodentia, and Didelphimorphia were downloaded from the Mammalian Diversity Database (Upham et al., 2022). These shapefiles were then imported into ArcGIS software and a workplace map was generated. A fishnet grid was then generated from 20° N, 95° W to 60° S, 30° W. To find the number of rows and columns the difference in degrees from the extreme points of the area were multiplied by four. This created a grid with 320 rows and 260 columns. When the fishnet grid was generated, a point layer of the centroid of each square was also generated. A spatial join was then performed, which added the latitude and longitude of the centroid of each square to the attribute table of the grid. A shapefile of South America from the University of Texas (International Boundary Collection, 2023) was then imported to the software. A “select by location” function was then performed to select the squares that intersected the shapefile of South America. The “create layer from selection” function was then run which created a new layer from just the squares that intersect South America. Another spatial join was then performed, the name and abbreviation of each country that intersected the squares of the grid was added to the attribute table.

Each order was then imported into a new map, which was named after each corresponding order. The grid of South America was pasted into each map. The order range shapefiles were then added from the same shared geodatabase into their corresponding map. A spatial join was then performed for each map joining the species range to the grid. The join was performed one to one, the scientific name and family fields were set to join using a comma as a delimiter. As spatial joins are performed, a join count field was also created, which is the number of joins created. This number is equal to the number of species in that square. The symbology of each map was generated using the same color scheme, a gradient starting with a pale yellow and ending with a deep purple. Using the graduated symbology option, the join count field was used with this color scheme. This created a grid map of South America where the pale yellow indicated little biodiversity and a dark purple indicated high biodiversity within that order.

The data from Paraguay were isolated using the “select by feature” tool and a new layer was created from that selection. Excel tables were then generated from these isolated Paraguay layers from ArcGIS to a .csv file. The pivottabler (Bailiss, 2023), dplyr (Wickham et al, 2023), and tidyr (Wickham et al, 2023) packages were used in R software to create presence-absence tables for Paraguay. These tables had each site, its latitude and longitude, as well as a 1, indicating presence of a species, or a 0, indicating the absence of a species.

Metacommunity Analysis

To understand the metacommunity patterns and their relationship to bioclimatic variables the workflow from de la Sancha et al. 2014 was followed. To complete the metacommunity analysis as well as generate the metacommunity boundaries at each site, the metacom (Dallas, 2020) and vegan (Oksanen et al., 2022) packages were used in R. The presence absence table were then used to run the metacommunity analysis. The metacommunity structure as well as charts depicting presence and absence were generated. For each table, coherence, turnover, and clumping (Figure 1) were tested to identify the metacommunity structure as described by Presley et al. 2010. The matrices were reordinated via reciprocal averaging. Coherence was tested based on the number of embedded absences in the matrix which was then compared to a null distribution. Turnover was tested based on the number of species which were replaced along the gradient and then compared to a null distribution, or in other terms, the number of times one species replaces another between two sites (Presley et al., 2010). Clumping was tested via a Morista index which compared the observed pattern to an expected equiprobable distribution, boundary clumping is how species live in similar habitats in clumps rather than evenly spaced out (Presley et al., 2010).

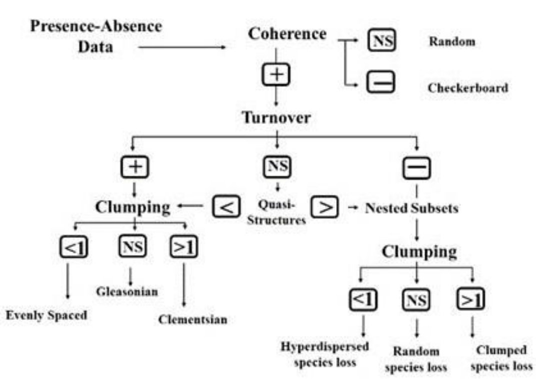

Figure 1. Flowchart describing how metacommunity structure is determined using the metacom R package, modified from de la Sancha et al., 2014.

Cluster Analysis

Using the fossil (Vavrek, 2011) R package dendrograms were generated for each order to visualize the relationship each site had with each other based on Sørensen similarity. Metacommunities were then identified on top of the top of the dendrogram based on the beta diversity of each order. Beta diversity is the ratio between regional (gamma) diversity and local (alpha) diversity. The beta diversity of each order was also calculated; this is the number of metacommunities from each order in Paraguay. The metacommunities were overlaid with boxes onto the dendrograms to visualize and identify similar sites.

Metacommunity Maps

The metacommunities and their corresponding sites were visualized on a map to determine the general metacommunity structure for each order in the country. To determine which site corresponded with each metacommunity, each site was labeled with a number according to the square they corresponded with and exported into a .csv file. This file was then able to be exported into ArcGIS and new maps were generated using the grid from earlier and with the metacommunity data from R.

Environmental Variables

To perform further analyses, bioclimatic variables were needed for each site. The centroids of each square in Paraguay were imported into ArcGIS. Then 30 second rasters were downloaded for 19 bioclimatic variables from WorldClim (Hijmans et al., 2005 worldclim.org). These rasters were then imported into ArcGIS as well. The “extract multi values to point” tool was then used to add data from each bioclimatic variable raster and assign it to each centroid. The centroid data was then exported into a .csv file.

Canonical Correspondence Analysis

A canonical correspondence analysis (CCA) was performed on the presence absence table. The resulting first CCA axis was compared to each bioclimatic variable using spearman correlation analysis in order to identify what variables best described the metacommunity structure. The CCA axes were generated for orders Chiroptera, Didelphimorphia, and Rodentia using the vegan R package.

Regression Tree Analyses

To identify the variable that best described the metacommunity structure, regression tree analyses were implemented. This approach is a multivariate analysis that does not require the traditional assumptions of more traditional statistical approaches, but still yields useful results (de la Sancha et al., 2020). In this analysis each node of the tree identifies the best predictor for each of the metacommunity structures and each following node identifies other variables based on their importance to predict the structure (de la Sancha et al., 2020). The regression trees were generated using the vegan package again, as well as the ape (Paradis et al, 2019), picante (Kembel, 2010), tree (Ripley, 2023), rpart (Therneau, 2022), and rpart.plot (Milborrow, 2022) packages. These were used to generate decision trees to view which variables had the biggest impact on metacommunity structure.

RESULTS

Diversity Maps

Using the previously generated files it was determined that there were 70 species from the order Chiroptera, 22 species from the order Didelphimorphia, and 64 from order the Rodentia in Paraguay. Species diversity in Paraguay for each order east of the *Rio* Paraguay is generally more diverse than west for all orders (Figure 2).

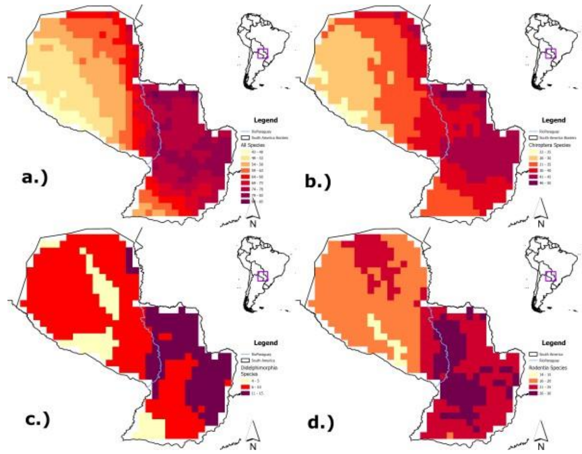

Figure 2. Map displaying diversity patterns of mammals in Paraguay including a.) All species (Chiroptera, Didelphimorphia, and Rodentia), b.) Chiroptera, c.) Didelphimorphia, and c.) Rodentia. Lighter shades of yellow represent lower alpha diversity while dark purple represents higher alpha diversity.

Metacommunity Analysis

Metacommunity analysis revealed that orders Rodentia and Chiroptera in Paraguay had Clementsian metacommunity structure while Didelphimorphia had Gleasonian structure. All species combined also exhibited Clementsian structure (Figure 3). All orders and all orders combined have a coherence p-value less than 0.05, as well as a positive coherence value. All four also had a turnover p-value less than 0.05 as well a positive turnover value. Didelphimorphia has a clumping p-value greater than 0.05 meaning that it has a Gleasonian metacommunity structure. Gleasonian metacommunity structure means that individuals within a species will be less reliant on its community. Rodentia, Chiroptera, and all species combined have a clumping p-value of less than 0.05 and a clumping index greater than 1, meaning that they have a Clementsian metacommunity structure. Clementsian metacommunity structure means that individuals in a species are more dependent on one another (see Appendix, Table 1).

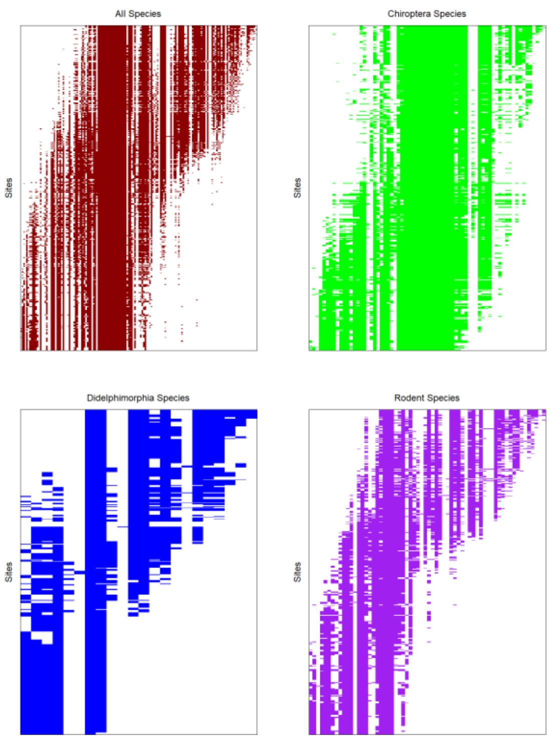

Figure 3. Metacommunity structure of Rodentia in Paraguay using presence absence data.

Cluster Analyses

The beta diversity was 2 for Chiroptera, 3 for Didelphimorphia, 3 for Rodentia, and 2 for all species combined. Similarity between sites varied by order (Figure 4) The boxes on the dendrograms represent the unique metacommunity. The Chiroptera metacommunities form a boundary near, but not corresponding to, the *Rio* Paraguay. Didelphimorphia has a large metacommunity in the north of the country, with two smaller metacommunities on opposite sides of the *Rio* Paraguay. Rodentia follows a very similar pattern as Chiroptera, however there is one site in the southwest corner of the country that forms its own metacommunity. All species combined also follow a similar pattern to that of Rodentia and Chiroptera (Figure 5).

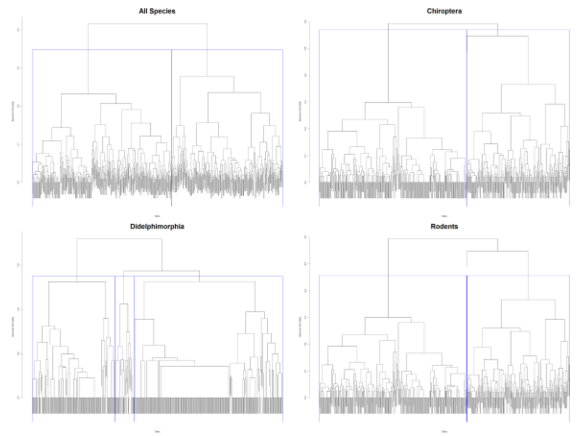

Figure 4. Dendrograms describing metacommunity structure for each order, as well as all species combined. Nodes represent different species while the end of each line corresponds to a site. The boxes overlaid are the metacommunities.

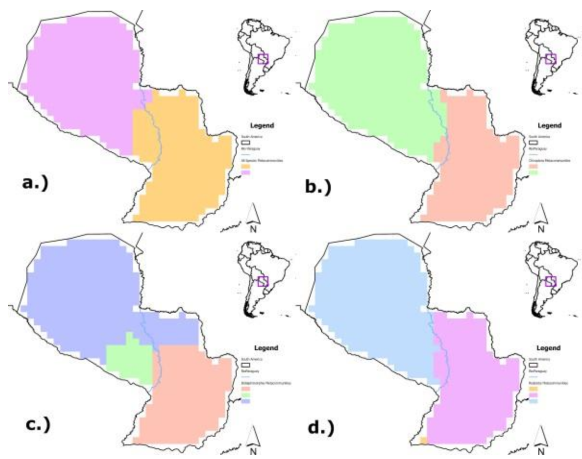

Figure 5. Map displaying metacommunity boundaries of mammals in Paraguay including
a.) All species (Chiroptera, Didelphimorphia, and Rodentia), b.) Chiroptera, c.) Didelphimorphia, and c.) Rodentia. Different colors represent the different metacommunities.

CCA

All orders tested had a significant correlation with every bioclimatic variable, with the exception of temperature seasonality and Didelphimorphia. For order Didelphimorphia the strongest correlations were with precipitation of the driest month, precipitation of the driest quarter, and longitude. For orders Rodentia and Chiroptera the strongest correlations were with the precipitation of the driest quarter (see Appendix, Table 2).

Regression Trees

Using a regression tree analysis, all 19 bioclim variables as well as latitude and longitude were used to compare the magnitude of influence that they had on the first CCA axis. It was determined that metacommunity structure from order Chiroptera and Rodentia are influenced most by precipitation in the coldest month, while order Didelphimorphia metacommunity structure is most influenced by latitude. All species combined had the same results as Rodentia. For all species, precipitation in the coldest month was also the most influential bioclimatic variable as well, followed by longitude and precipitation seasonality (Figures 6 and 7).

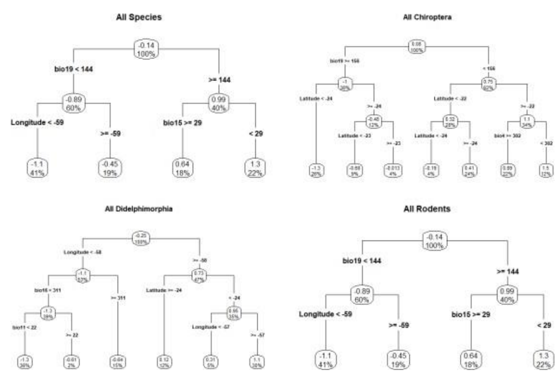

Figure 6. Regression trees displaying the best explanatory variables for all orders combined, Chiroptera, Didelphimorphia, and Rodentia

DISCUSSION

The metacommunity framework has been used in this study to explore structure, relationship with bioclimatic variables, and any influences from the *Rio* Paraguay. Metacommunities are formed from smaller ecological communities but vary in the way that different species are assembled within each community (Leibold et al., 2004). In the past the metacommunity concept has been used to determine factors that influence the assembly of species along an elevational gradient (Willig et al., 2019). A similar study analyzed how environmental conditions affected bat assemblies in Paraguay (Presley et al., 2009). The metacommunity analysis helps us better understand how larger groups of species and inter-community relationships work and are informed by environmental factors (Stevens et al., 2007).

Through this study it was determined that orders Chiroptera and Rodentia as well as all species combined have Clementsian metacommunity structure in Paraguay, while order Didelphimorphia has Gleasonian metacommunity structure. It was also determined that metacommunity structures of orders Chiroptera and Rodentia and all species combined are influenced most by precipitation in the coldest month, while order Didelphimorphia metacommunity structure is most influenced by longitude. Because of the similarities in metacommunity structure, Clementsian, and being most influenced by the same bioclimatic variable there may be some evidence to suggest that orders Chiroptera and Rodentia metacommunities are assembled more similarly than previously thought. This could also be reinforced by looking at the maps of metacommunities in Paraguay. Chiroptera has two distinct metacommunities in Paraguay, but Rodentia has three. However, one of the Rodentia metacommunities is only present in one site in the far south of the country. The two major Rodentia metacommunities and the two Chiroptera metacommunities show similar boundaries along the *Rio* Paraguay which also runs along the precipitation gradient (Figure 7). This is further reinforced considering that when all species were compiled into the same dataset the results mirrored the results from orders Chiroptera and Rodentia. When all species were combined the metacommunity structure maps, regression tree, metacommunity type, and CCA analyses all yielded very similar results for these two orders. Order Didelphimorphia is different from the other two since it has a Gleasonian metacommunity structure and is most influenced by longitude, rather than a bioclimatic variable directly.
However, because of the precipitation gradient present in Paraguay, a correlation with longitude is perhaps associated with another variable that is not influenced by precipitation.

The metacommunity maps for all species combined, Chiroptera, and Didelphimorphia displayed a boundary near the *Rio* Paraguay, potentially indicating that the river limits the dispersal abilities of these animals and may prevent them from assembling metacommunities across the river. The dispersal abilities of these animals may have been a limiting factor in their ability to build metacommunities across the river. Didelphimorphia did not exhibit a boundary along the river for all three metacommunities; the two southernmost metacommunities did, but the northern metacommunity did span across the river. The *Rio* Paraguay flows in the north to south direction, along the precipitation gradient also present in the country (Ruiz-Díaz et al, 2024), potentially providing an alternative reason as to why metacommunities do not coincide with the river.

Stevens et al. (2009) studied metacommunity structure for the order Chiroptera in Paraguay, based on field data and found that Chiroptera exhibits Clementsian metacommunity structure. The same study also found that for all bat species, temperature as well as precipitation correlated with metacommunity assembly, which is also what this study found (Stevens et al., 2009). This also aligns with what is found for all species combined as well as order Rodentia. The findings from Stevens et al. (2009) do not align with what was found in this study for order Didelphimorphia. Unlike Chiroptera, this study found that Didelphimorphia correlated significantly with precipitation as well as temperature. The only difference is that Didelphimorphia has a Gleasonian metacommunity structure, not Clementsian. There were three key differences in the way that this study and the 2009 study were conducted. First, this study relied on open-source distribution maps for every order, while Stevens et al. (2009) relied on field data. Second, this study partitioned precipitation and temperature into multiple variables, such that metacommunities were not compared to just precipitation and temperature, but rather 19 bioclimatic variables. The other key difference is that Stevens et al. (2009) partitioned Chiroptera by their diet, while this study did not. This resulted in the 2009 study having different results for each trophic group. For example, aerial insectivore metacommunities were not as strongly correlated with temperatures as frugivore metacommunities. In future studies orders Chiroptera and Rodentia could be broken down into their respective families and then be compared to the larger order to determine which, if any, environmental variables influence the assembly of metacommunities within each family.

Paraguay has a precipitation gradient with the east of the country receiving more than three times more precipitation than parts of the west of the country (Ruiz-Díaz et al, 2024),with all precipitation related bioclimatic variables having a p-value > 0.05. This means that precipitation, in the case of metacommunity structure in orders Chiroptera and Rodentia, are most influenced by precipitation in the coldest month. Order Didelphimorphia metacommunity structure is also affected by precipitation, though less so than orders Rodentia and Chiroptera.

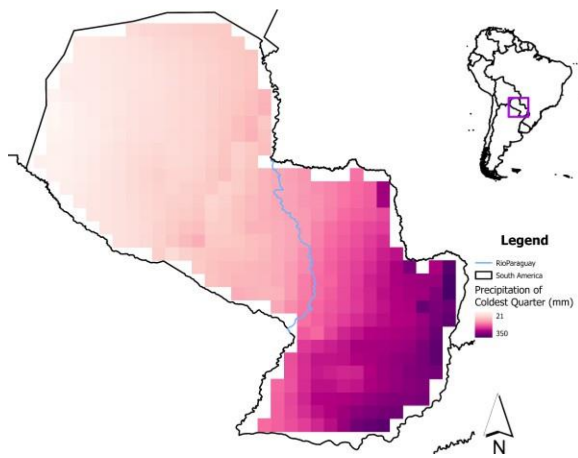

Figure 7. Map displaying precipitation during the wettest quarter. Darker shades represent higher precipitation.

The highly significant correlation between precipitation and metacommunity assembly as well as other significant correlations between other bioclimatic variables may also mean that metacommunities form along the different biomes in Paraguay. In the west of the country is the Dry Chaco, a dry forest experiencing little precipitation and for every order tested, there existed a unique metacommunity in the west of the country (de la Sancha et al, 2021). In the east of the country is the inland part of the Atlantic Forest, a subtropical forest that receives far more precipitation that the west (de la Sancha et al, 2014, Ruiz-Díaz et al, 2024). It is also clear that each order tested formed a metacommunity in this wetter region of the country. Precipitation during the coldest month being the most influential bioclimatic variable for Chiroptera and Didelphimorpia may be influenced by the limited amount of precipitation the country receives. According to Ruiz-Díaz et al, 2024, the coldest month is also the driest month, meaning that food may be in limited supply for these animals, meaning they have to live in their most optimal habitats to survive.

Precipitation also has a significant impact on vegetation in Paraguay (Ruiz-Díaz et al, 2024), with the east of the country having more vegetation than the west of the country. Since vegetation is essential for most mammals, alpha-diversity as well as metacommunities forming along this precipitation gradient makes sense, as in some ways it is also a vegetation gradient.

Both the Chaco in the west and the Atlantic Forest in the east are experiencing extreme levels of deforestation (de la Sancha et al., 2021a; de la Sancha et al., 2021b). Deforestation leads to fragmented habitats, as well as less overall habitat for animals to live in. However, despite deforestation in the Brazilian Atlantic Forest, Rodent metacommunities have been shown to maintain their biogeographic level structure, despite localized extinction (de la Sancha et al., 2014). There has not been extensive research that studies the relationship between deforestation in the Chaco Forest nor in the inland Atlantic Forest and metacommunity structure.

Dispersal capabilities may differ depending on the order. Chiroptera has high dispersal abilities (Stevens, 2007), while order Didelphimorphia has little dispersal ability (de la Sancha et al, 2020). Order Rodentia is more complicated. Within this study most species fell either into subfamily Sigmodontinae or suborder Hystrycomorpha (Keast, 1998; de la Sancha et al., 2017). The difference between Chiropteran dispersal abilities and Didelphimorphian dispersal abilities may be part of the reason as to why they have different beta-diversities and therefore different metacommunity structure. As order Rodentia is so diverse, it also has a diverse dispersal ability. A study from 2022 encompassing 89% of all rodent species determined that a nonlinear relationship exists between rodent dispersal and body size (Fourcade et al., 2022). The scope of this 2022 study has not yet determined a statistically significant relationship between dispersal abilities and metacommunities, so testing a hypothesis involving rodent dispersion and metacommunity may have to be its own study. This makes assessments of metacommunity structure based on dispersal abilities difficult for order Rodentia.

Open-source data is a key part of this study. All data used in this study was open source. Much of the data analysis was performed using open-source software as well. Open-source data provides the opportunity for everyone to test their own hypotheses and access to publish. Increasing our understanding of the intricacies of ecology is important as threats from climate change and anthropogenic land use increase.

One of the limitations of this study was relying very heavily on open-source data for all the analyses. None of the data were collected by anyone directly affiliated with this study. It does come from a peer-reviewed source, however. This study could be improved in the future if a higher resolution fishnet grid was generated. This would make this study more precise but would require more computing power. Other areas for improvement would be partitioning the larger orders, Chiroptera and Rodentia, into families and running analyses on those families. Further analysis could also involve other orders of mammals in Paraguay. Orders Carnivora, Cingulata, and Artiodactyla all have a presence in Paraguay as well (de la Sancha et al., 2017).

Conclusion

The metacommunity concept has been useful in this study as it has improved our understanding of how orders Chiroptera, Didelphimorphia, and Rodentia form communities, biodiversity, and are impacted by bioclimatic variables in Paraguay. Paraguay has been an excellent country to study because of its precipitation gradient (Ruiz-Díaz et al, 2024). This improved understanding may help future studies using other mammalian orders or by further partitioning orders Rodentia and Chiroptera. Understanding the way these metacommunities are assembled and what variables influence them can also influence our understanding of how climate change and deforestation impact these species, improving conservation methods.

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APPENDIX

	Coherence		Turnover		Clumping		Result
	Abs	p	Turnover	p	Index	p	Metacommunity Structure
Chiroptera	8786	0.0000	7312604	0.0000	3.33	0.0000	Clementsian
Didelphimorphia	2234	0.0000	1589531	0.0032	2.60	0.0868	Gleasonian
Rodentia	6104	0.0000	16167560	0.0000	6.72	0.0000	Clementsian
All Species	19694	0.0000	61746980	0.0000	4.56	0.0000	Clementsian

Table 1. Results from metacommunity analysis.

	Chiroptera		Didelphimorphia		Rodentia		All Species	
	p-values	Correlation Coefficient	p-values	Correlation Coefficient	p-values	Correlation Coefficient	p-values	Correlation Coefficient
Bio1	0.0000	-0.75	0.0000	-0.73	0.0000	-0.75	0.0000	-0.79
Bio2	0.0000	-0.79	0.0000	-0.80	0.0000	-0.79	0.0000	-0.76
Bio3	0.0000	-0.52	0.0000	-0.54	0.0000	-0.52	0.0000	-0.59
Bio4	0.0357	0.09	0.0527	0.09	0.0357	0.09	0.0000	0.19
Bio5	0.0000	-0.90	0.0000	-0.88	0.0000	-0.90	0.0000	-0.88
Bio6	0.0000	-0.34	0.0000	-0.30	0.0000	-0.34	0.0000	-0.41
Bio7	0.0000	-0.46	0.0000	-0.48	0.0000	-0.46	0.0000	-0.38
Bio8	0.0000	-0.77	0.0000	-0.75	0.0000	-0.77	0.0000	-0.80
Bio9	0.0000	-0.72	0.0000	-0.66	0.0000	-0.72	0.0000	-0.75
Bio10	0.0000	-0.77	0.0000	-0.77	0.0000	-0.77	0.0000	-0.79
Bio11	0.0000	-0.63	0.0000	-0.61	0.0000	-0.63	0.0000	-0.68
Bio12	0.0000	0.96	0.0000	0.93	0.0000	0.96	0.0000	0.97
Bio13	0.0000	0.90	0.0000	0.91	0.0000	0.90	0.0000	0.91
Bio14	0.0000	0.97	0.0000	0.94	0.0000	0.97	0.0000	0.98
Bio15	0.0000	-0.96	0.0000	-0.92	0.0000	-0.96	0.0000	-0.98
Bio16	0.0000	0.88	0.0000	0.89	0.0000	0.88	0.0000	0.88
Bio17	0.0000	0.98	0.0000	0.94	0.0000	0.98	0.0000	0.99

	Chiroptera		Didelphimorphia		Rodentia		All Species	
Bio18	0.0000	0.83	0.0000	0.85	0.0000	0.83	0.0000	0.84
Bio19	0.0000	0.97	0.0000	0.94	0.0000	0.97	0.0000	0.98
Latitude	0.0000	-0.77	0.0000	-0.75	0.0000	-0.77	0.0000	-0.83
Longitude	0.0000	0.96	0.0000	0.94	0.0000	0.96	0.0000	0.96

Table 2. P-values and correlation Coefficients of CA1 score with bioclim variables for Chiroptera, Didelphimorphia, and Rodentia. Bio1 is Annual Mean Temperature, Bio2 is Mean Diurnal Range, Bio3 is Isothermality, Bio4 is Temperature Seasonality, Bio5 is Max Temperature of Warmest Month, Bio6 is Min Temperature of Coldest Month, Bio7 is Temperature Annual Range, Bio8 is Mean Temperature of Wettest Quarter, Bio9 is Mean Temperature of Driest Quarter, Bio10 is Mean Temperature of Warmest Quarter, Bio11 is Mean Temperature of Coldest Quarter, Bio12 is Annual Precipitation, Bio13 is Precipitation of Wettest Month, Bio14 is Precipitation of Driest Month, Bio15 is Precipitation Seasonality, Bio16 is Precipitation of Wettest Quarter, Bio17 is Precipitation of Driest Quarter, Bio18 is Precipitation of Warmest Quarter, and Bio19 is Precipitation of Coldest Quarter.