Universidade Federal da Grande Dourados
Faculdade de Ciências Exatas e Tecnologia

Traços Funcionais na Evolução e Estruturação de Florestas Estacionais
Functional Traits in the Evolution and Structuring of Seasonal Forests

Larissa Oliveira Vilela

Dourados 2024

Larissa Oliveira Vilela
Bióloga

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Functional Traits in the Evolution and Structuring of Seasonal Forests

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Nuestro Mundo

Nuestro mundo divino mundo te amo tanto
Con tus ríos y tus bosques me ilumino
Con mis ojos puedo ver tu belleza
Con tus plantas y animales maravillosos
Tus montañas y tus aguas cristalinas

Pachamama, madre tierra, madre de todo
Perdoname ya tus hijos que te hicieron daño
Pachamama, madre tierra, madre de todo
Curame ya tus hijos que te aman tanto

Espíritu de la vida ayúdanos
A curar y sanar el corazón
Cada uno puedo vivir en la luz
Vivir en paz y amor es el camino
Vivir en paz y amor te lo pido

Pachamama…

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RESUMO

Traços funcionais são atributos morfológicos, fisiológicos e comportamentais que influenciam o desempenho das plantas em seu ambiente, crucial para seu estabelecimento, sobrevivência e reprodução ao longo do tempo evolutivo. Esta tese investiga os traços funcionais das plantas lenhosas nas Florestas Estacionais de Mato Grosso do Sul, Brasil, explorando sua evolução, distribuição e impacto no funcionamento dos ecossistemas. O primeiro capítulo foca na análise do sinal filogenético dos traços funcionais, investigando a conservação e superdispersão desses atributos em diferentes fitofisionomias das Florestas Estacionais. Utilizando estatística D para estimar o sinal filogenético e a Análise de Correspondência (CA) para explorar padrões nas associações entre as variáveis. Foram identificados padrões distintos de conservação filogenética. Traços como o tamanho da flor e a síndrome de dispersão foram identificados como conservados, enquanto características como espinescência e capacidade de rebrota mostraram-se mais aleatórias ou superdispersas. Estes padrões refletem adaptações específicas a pressões seletivas, incluindo distúrbios e interações mutualísticas ao longo da evolução das comunidades vegetais. O segundo capítulo agrupa espécies em clusters com base em seus traços funcionais, analisa a sobreposição e as relações entre esses grupos funcionais em um espaço multivariado e busca entender a distribuição espacial das espécies dentro desses clusters em relação a fatores ambientais, como clima, pedologia e geomorfologia. Este capítulo destaca a importância de traços reprodutivos e florais na diferenciação dos clusters e a adaptação flexível das espécies às condições ambientais variáveis, revelando preferências por determinados ambientes topográficos e climáticos dentro do Mato Grosso do Sul. Esta tese contribui significativamente para o entendimento teórico e aplicado dos traços funcionais como elementos fundamentais na estruturação e dinâmica das comunidades vegetais das Florestas Estacionais. Ademais, estabelece uma base sólida para futuras pesquisas e iniciativas de conservação e restauração ecológica em ecossistemas similares, em face às mudanças ambientais globais.

Palavras-chave

Sinal filogenético, Adaptabilidade ecológica, Interações ecológicas, Restauração ecológica, Manejo ambiental, Resiliência ecológica

ABSTRACT

Functional traits are morphological, physiological, and behavioral attributes that influence plant performance in their environment, crucial for their establishment, survival, and reproduction over evolutionary time. This thesis investigates the functional traits of woody plants in the Seasonal Forests of Mato Grosso do Sul, Brazil, exploring their evolution, distribution, and impact on ecosystem functioning. The first chapter focuses on the analysis of the phylogenetic signal of functional traits, investigating the conservation and superdispersion of these attributes in different phytophysiognomies of Seasonal Forests. Using D statistics to estimate the phylogenetic signal and Correspondence Analysis (CA) to explore patterns in the associations between variables, distinct patterns of phylogenetic conservation were identified. Traits such as flower size and dispersal syndrome were identified as conserved, while characteristics such as spinescence and resprouting capacity showed more randomness or superdispersion. These patterns reflect specific adaptations to selective pressures, including disturbances and mutualistic interactions throughout the evolution of plant communities. The second chapter groups species into clusters based on their functional traits, analyses the overlap and relationships among these functional groups in a multivariate space, and seeks to understand the spatial distribution of species within these clusters in relation to environmental factors such as climate, soil, and geomorphology. This chapter highlights the importance of reproductive and floral traits in differentiating clusters and the flexible adaptation of species to variable environmental conditions, revealing preferences for specific topographic and climatic environments within Mato Grosso do Sul. This thesis significantly contributes to the theoretical and applied understanding of functional traits as fundamental elements in the structure and dynamics of plant communities in Seasonal Forests. Furthermore, it establishes a solid foundation for future research and initiatives in conservation and ecological restoration in similar ecosystems, in the face of global environmental changes.

Keywords
Phylogenetic signal, Ecological adaptability, Ecological interactions, Ecological restoration, Environmental management, Ecological resilience

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1 Apresentação

Esta tese explora os traços funcionais de espécies arbustivas e arbóreas presentes em Florestas Estacionais. Nesta apresentação, são descritos conceitualmente os traços funcionais, destacando as interações e efeitos ecológicos que podem ser mediados por eles, além das vantagens e desafios das abordagens baseadas nesses traços. Também é abordado como o estudo de atributos funcionais pode contribuir para a compreensão da história evolutiva das plantas e da formação e manutenção de comunidades, além de fornecer subsídios para restauração ecológica em larga escala nos trópicos e preencher lacunas teóricas ainda existentes. Finalmente, são contextualizadas as abordagens funcionais em Florestas Estacionais e evidenciado como esta tese pode contribuir para esses avanços.

Quando analisamos o processo de evolução dos organismos ao longo da história da vida na Terra, observamos uma série de características adaptativas selecionadas ao longo de suas histórias evolutivas. Tais características, resultantes de um longo processo de seleção natural, conferiram aos organismos a capacidade de sobreviver, se reproduzir e obter recursos nesses ambientes. À medida que essas características passam a influenciar o crescimento, sobrevivência e reprodução do indivíduo, bem como a mediar suas interações com o ambiente, podemos considerá-las como atributos ou traços funcionais (Caruso et al., 2020).

O termo "traço funcional" (*functional traits,* em inglês) tem inúmeras definições na literatura. Pode ser definido, em linhas gerais, como quaisquer atributos - sejam características morfológicas, bioquímicas, fisiológicas, estruturais, fenológicas ou comportamentais - que exerçam uma influência significativa no estabelecimento, sobrevivência e reprodução dos organismos, e que sejam expressas em fenótipos de organismos individuais, sendo estas consideradas relevantes para a resposta desses organismos ao ambiente e/ou seus efeitos nas propriedades do ecossistema (Díaz et al., 2013; Garnier et al., 2016; Reich et al., 2003; Violle et al., 2007).

A utilização de atributos funcionais permite organizar espécies ou indivíduos com funções ou respostas similares, *i.é*, cujos estados de atributos sejam semelhantes (Rosenfield & Müller, 2020). Os atributos funcionais podem ser classificados com base na relação atributo-ecossistema, em outros termos, se eles sofrem variação em resposta a mudanças ambientais ou se são capazes de afetar processos ecossistêmicos. Nesse sentido, os atributos funcionais podem ser denominados como atributos *resposta*, cujos valores ou estados se alteram em conformidade com características ambientais, ou atributos de *efeito*, que influenciam as funções ecológicas (Lavorel & Garnier, 2002; Rosenfield & Müller, 2020).

As plantas desenvolveram inúmeras estratégias no decorrer de suas histórias de vida para obterem sucesso em diversos ambientes da Terra. Entretanto, ainda são escassos os estudos voltados à compreensão da evolução por seleção natural dos traços funcionais de plantas ao longo de gerações (Caruso et al., 2020). No entanto, evidências demonstram padrões globais em relação às variações em plantas (Adler et al., 2014), tais como o espectro da economia da folha (Osnas et al., 2013; Wright et al., 2004) e da madeira (Chave et al., 2009) e a compensação entre tamanho e número de sementes (Moles & Westoby, 2006; Venable, 1992).

Por consequência, os atributos funcionais passaram a ser considerados como a melhor abordagem na compreensão geral preditiva de comunidades e ecossistemas (Adler et al., 2014). Graças à disponibilidade de informações em bases de dados globais, como o *TRY: Plant Trait Database* < https://www.try-db.org/> que contém cerca de 148.000 táxons de plantas e 6,9 milhões de registros de atributos (Kattge et al., 2020), e informações regionais (Rosenfield & Müller, 2020), as abordagens fundamentadas em atributos funcionais de plantas têm sido amplamente utilizadas (Adler et al., 2014) para predizer o resultado da assembleia de comunidades (Cornwell & Ackerly, 2009; Laughlin et al., 2012; Shipley et al., 2006), a dinâmica global da vegetação (Scholze et al., 2006) e a taxa dos processos ecossistêmicos (Díaz & Cabido, 2001; Eviner & Chapin III, 2003; Garnier et al., 2004; Lavorel & Garnier, 2002).

O conhecimento existente sobre atributos funcionais ainda se concentra em espécies de regiões temperadas (Carlucci et al., 2020; Hortal et al., 2015). Informações taxonômicas, ecológicas e fisiológicas básicas para um grande número de espécies nativas nos trópicos, bem como sobre atributos funcionais, ainda são ausentes (Aerts & Honnay, 2011), dificultando a recomposição de comunidades tropicais originalmente megadiversas (Carlucci et al., 2020). Apesar disso, a disponibilidade de dados atualmente permite compreender em certo nível como determinados atributos se associam a diferentes funções e estratégias ecológicas das plantas (*i.é*, espectros de características) (Díaz et al., 2016). Os atributos mais comumente medidos em plantas estão relacionados à aspectos foliares, reprodutivos, de crescimento e de raiz (Pérez-Harguindeguy et al., 2013; Rosenfield & Müller, 2020).

Nessa lógica, ao entendermos funções associadas a atributos funcionais, também compreendemos a história evolutiva das plantas, a formação e manutenção de comunidades, bem como os atributos que podem ser priorizados em ações de restauração visando a estruturação de comunidades com alta diversidade funcional. Ao separar as espécies em grupos funcionais, podem ser destacados os processos de maior interesse para as ações de restauração. A seleção de traços representa uma etapa importante, uma vez que certos traços funcionais podem responder a diferentes condições e recursos do ambiente, assim como provocar efeitos em processos ecológicos (Rosenfield & Müller, 2020).

Da perspectiva da restauração ecológica, o uso de atributos funcionais é considerado um desafio. É sabido que as trajetórias sucessionais são imprevisíveis e podem seguir múltiplas direções (Mesquita et al., 2015; Norden et al., 2015), tal qual a dinâmica dos ecossistemas de referência (Hiers et al., 2012) podem ser difíceis de prever ao longo do tempo. Além disso, uma espécie pode integrar mais que um grupo funcional e, desta forma, desempenhar diversas funções, em graus variados (Diaz et al., 2007), o que significa que seus diversos traços e múltiplos efeitos podem contribuir de forma independente ou conjunta no ecossistema (Carlucci et al., 2020; Gamfeldt et al., 2008).De acordo com Carlucci *et al. (*2020), as espécies acabam representando mais um "*continuum* multivariado" do que um cenário de espécies classificadas em grupos funcionais discretos.

As interações ecológicas, quando explicitamente vinculadas a atributos, podem ser quantificadas em diversos níveis de organização, de indivíduos até comunidades e ecossistemas (Díaz et al., 2016). Portanto, é fundamental escalonar atributos verificados em nível de organismo para outros níveis de organização, a fim de inferir ou compreender as funções que influenciam tais comunidades e ecossistemas (Rosenfield & Müller, 2020). Nesse sentido, mostram-se necessários estudos que forneçam informações sobre atributos vinculados a funções ecossistêmicas chave e que, dessa forma, possibilitem a definição de serviços e atributos funcionais prioritários para a restauração ecológica. É importante entender como atributos de efeito atuam na estruturação e manutenção da comunidade, garantindo a ela estabilidade e resiliência. Essas informações são imprescindíveis para a criação de estruturas quantitativas baseadas em atributos, que permitam a seleção de conjuntos de espécies nativas e suas abundâncias para áreas que estarão sujeitas a restauração. Além disso, ainda é necessário focar na obtenção de informações taxonômicas, ecológicas e fisiológicas básicas e de traços funcionais para espécies nativas de vegetações cujas características ainda são pouco conhecidas, como as Florestas Estacionais, por exemplo.

Esta tese apresenta o estudo de atributos funcionais de espécies arbustivas e arbóreas de Florestas Estacionais, um tipo de vegetação caracterizada pela sazonalidade (alternância de períodos chuvosos e secos) e pertencente ao domínio fitogeográfico da Mata Atlântica (Marques et al., 2021). Serão abordadas tanto as Florestas Estacionais Semideciduais, nas quais 20-50% das árvores perdem suas folhas no inverno, quanto as Florestas Estacionais Deciduais, onde mais de 50% das árvores perdem suas folhas no inverno (Marques et al., 2021), assim como Florestas de Transição para Savana Florestada ou para Floresta Ripícola.

Os capítulos desta tese foram redigidos em formato de artigos a serem submetidos a diferentes revistas, cada uma alinhada ao escopo de interesse dos estudos realizados (Appendix C). O primeiro capítulo, que se concentra em mensurar o sinal filogenético dos traços e compreender as principais convergências e divergências funcionais entre as fitofisionomias de Florestas Estacionais, será submetido à revista "*Functional Ecology*", que tem foco na área de atributos funcionais e ecologia, incluindo temas relevantes como a evolução dos organismos em relação aos traços funcionais e fenômenos ecológicos em uma escala mais abrangente. Neste capítulo, é analisado quais traços foram mais conservados e quais são mais aleatórios ou superdispersos nessas florestas, bem como se existem diferenças significativas entre elas. Além disso, busca-se compreender se as relações filogenéticas revelam padrões de evolução para os diferentes traços funcionais nessas comunidades.

O segundo capítulo, que agrupa espécies em "*clusters*" com base em seus traços funcionais e analisa sua relação com fatores ambientais, será submetido à revista "*Journal of Applied Ecology*", que publica artigos na interface entre ciência ecológica e o manejo do ambiente natural, especialmente em relação à conservação da biodiversidade e à aplicação prática de conhecimentos ecológicos. Nesse segundo capítulo, é analisada a sobreposição e relação desses grupos funcionais em espaço multivariado. Verifica-se também se as espécies pertencentes a esses clusters apresentam distribuições espaciais diferentes ao longo do domínio fitogeográfico e se essas distribuições estão (ou podem estar) relacionadas a fatores ambientais, como clima, solo e geomorfologia. Por fim, discute-se como a a interação desses *"clusters"* com os fatores ambientais, em um contexto de mudanças ambientais, e se estes podem influenciar a estabilidade e dinâmica da comunidade, e como o manejo adequado desses *"clusters"* pode ser aplicado em programas de restauração ecológica. Desse modo, esse estudo pode fornecer informações até então inexistentes sobre atributos funcionais em Florestas Estacionais, e também pode avançar no entendimento teórico dos grupos funcionais, suas interações, suas influências no funcionamento das comunidades.

1 Presentation

This thesis explores the functional traits of shrub and tree species present in Seasonal Forests. This presentation conceptually describes functional traits, highlighting the ecological interactions and effects they may mediate, as well as the advantages and challenges of trait-based approaches. It also discusses how studying functional attributes can contribute to understanding plant evolutionary history, the formation and maintenance of communities, and providing support for large-scale ecological restoration in the tropics while addressing existing theoretical gaps. Finally, it contextualises functional approaches in Seasonal Forests and illustrates how this thesis can contribute to these advancements.

When we examine the evolutionary process of organisms throughout Earth’s history, we observe a series of adaptive traits selected over their evolutionary paths. Such traits, resulting from a prolonged process of natural selection, have endowed organisms with the ability to survive, reproduce, and acquire resources in their environments. As these traits begin to influence an individual’s growth, survival, and reproduction, and mediate their interactions with the environment, they can be regarded as attributes or functional traits (Caruso et al., 2020).

The term "functional trait" has numerous definitions in the literature. In general terms, it can be defined as any attribute—whether morphological, biochemical, physiological, structural, phenological, or behavioural—that significantly influences the establishment, survival, and reproduction of organisms and is expressed in the phenotypes of individual organisms, considered relevant to their response to the environment and/or their effects on ecosystem properties (Díaz et al., 2013; Garnier et al., 2016; Reich et al., 2003; Violle et al., 2007).

Using functional traits allows for the organisation of species or individuals with similar functions or responses—those whose trait states are alike (Rosenfield & Müller, 2020). Functional traits can be classified based on their attribute-ecosystem relationship, in other words, whether they vary in response to environmental changes or can affect ecosystem processes. In this context, functional traits can be termed response traits, whose values or states change according to environmental conditions, or effect traits, which influence ecological functions (Lavorel & Garnier, 2002; Rosenfield & Müller, 2020).

Plants have developed numerous strategies throughout their life histories to succeed in various environments on Earth. However, studies focused on understanding the natural selection-driven evolution of plant functional traits across generations are still scarce (Caruso et al., 2020). Nevertheless, evidence demonstrates global patterns regarding plant variations (Adler et al., 2014), such as leaf economic spectrum (Osnas et al., 2013; Wright et al., 2004), wood density (Chave et al., 2009), and the trade-off between seed size and number (Moles & Westoby, 2006; Venable, 1992).

Consequently, functional traits have been considered the most promising approach in the overall predictive understanding of communities and ecosystems (Adler et al., 2014). Thanks to the availability of data in global databases, such as TRY Plant Trait Database <https://www.try-db.org/>, which contains about 148,000 plant taxa and 6.9 million trait records (Kattge et al., 2020), and regional information (Rosenfield & Müller, 2020), atrait-based approaches have been widely used (Adler et al., 2014) to predict community assembly outcomes (Cornwell & Ackerly, 2009; Laughlin et al., 2012; Shipley et al., 2006), global vegetation dynamics (Scholze et al., 2006), and the rate of ecosystem processes (Díaz & Cabido, 2001; Eviner & Chapin III, 2003; Garnier et al., 2004; Lavorel & Garnier, 2002).

Current knowledge on functional traits still primarily focuses on species from temperate regions (Carlucci et al., 2020; Hortal et al., 2015). Basic taxonomic, ecological, and physiological information for a large number of native species in the tropics, as well as information on functional traits, remains lacking (Aerts & Honnay, 2011), hindering the restoration of originally mega-diverse tropical communities (Carlucci et al., 2020). Nevertheless, the current availability of data enables an understanding, to some extent, of how certain traits are associated with different plant functions and ecological strategies (i.e., trait spectra) (Díaz et al., 2016). The most commonly measured plant traits relate to leaf, reproductive, growth, and root aspects (Pérez-Harguindeguy et al., 2013; Rosenfield & Müller, 2020).

In this framework, by understanding functions associated with functional traits, we also gain insight into plant evolutionary history, community formation and maintenance, as well as attributes that may be prioritised in restoration actions aimed at creating communities with high functional diversity. Grouping species into functional groups helps highlight processes of greater interest for restoration efforts. Trait selection represents an important step, since certain functional traits may respond differently to environmental conditions and resources, as well as affect ecological processes (Rosenfield & Müller, 2020).

From an ecological restoration perspective, the use of functional traits is still considered a challenge. Successional trajectories are known to be unpredictable and can follow multiple directions (Mesquita et al., 2015; Norden et al., 2015), just as reference ecosystem dynamics (Hiers et al., 2012) can be difficult to predict over time. Moreover, a species may belong to more than one functional group and thus perform various functions to varying degrees (Diaz et al., 2007), meaning their diverse traits and multiple effects can contribute independently or collectively to the ecosystem (Carlucci et al., 2020; Gamfeldt et al., 2008). According to Carlucci et al. (2020), species often represent more of a "*multivariate* continuum" than a scenario of species classified into discrete functional groups.

Ecological interactions, when explicitly linked to attributes, can be quantified at various levels of organisation, from individuals to communities and ecosystems (Díaz et al., 2016). Therefore, scaling up verified organism-level traits to other levels of organisation is crucial for inferring or understanding the functions that influence such communities and ecosystems (Rosenfield & Müller, 2020). In this regard, studies are needed that provide information on attributes linked to key ecosystem functions and, thus, enable the identification of priority services and functional attributes for ecological restoration. It is essential to understand how effect traits operate in structuring and maintaining the community, ensuring its stability and resilience. This information is essential for creating quantitative frameworks based on attributes, allowing the selection of native species assemblages and their abundances for areas subject to restoration. Furthermore, there is still a need to focus on obtaining basic taxonomic, ecological, and physiological information and functional traits for native species of vegetation whose characteristics are still poorly understood, such as Seasonal Forests, for example.

This thesis presents the study of functional traits of shrub and tree species in Seasonal Forests, a type of vegetation characterised by seasonality (alternation of rainy and dry periods) and belonging to the phytogeographic domain of the Atlantic Forest (Marques et al., 2021). Both Semi-deciduous Seasonal Forests, where 20-50% oof trees lose their leaves in winter, and Deciduous Seasonal Forests, where more than 50% of trees lose their leaves in winter (Marques et al., 2021), as well as Transition Forests to Forested Savannah or Riparian Forests, will be addressed.

The chapters of this thesis are written in the format of articles to be submitted to different journals, each aligned with the scope of the studies conducted (Appendix C). The first chapter, which focuses on measuring the phylogenetic signal of traits and understanding the main functional convergences and divergences among the phytophysiognomies of Seasonal Forests, will be submitted to the journal "*Functional Ecology*", which focuses on functional traits and ecology, including relevant topics such as organism evolution alongside functional traits and ecological phenomena on a broader scale. This chapter analyses which traits are more conserved and which are more random or overdispersed in these forests, and whether there are significant differences among them. Additionally, it seeks to understand whether phylogenetic relationships reveal evolutionary patterns for different functional traits in these communities.

The second chapter, which groups species into clusters based on their functional traits and examines their relationship with environmental factors, will be submitted to the journal "*Journal of Applied Ecology*", which publishes articles at the interface between ecological science and natural resource management, particularly concerning biodiversity conservation and the practical application of ecological knowledge. This second chapter analyses the overlap and relationship of these functional groups in multivariate space. It also examines whether the species within these clusters exhibit different spatial distributions across the phytogeographic domain and whether these distributions are (or could be) related to environmental factors such as climate, soil, and geomorphology. Finally, it discusses how the interaction of these clusters with environmental factors, in the context of environmental changes, might influence community stability and dynamics and how proper management of these clusters can be applied in ecological restoration programmes. Thus, this study could provide previously unavailable information on functional attributes in Seasonal Forests and advance theoretical understanding of functional groups, their interactions, and their influences on community functioning.

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Chapter 1

The traits phylogeny and its effects on the multifunctional structure of Brazilian's Seasonal Forests

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ABSTRACT

1. Functional traits are aspects of organisms that influence their establishment, survival, and reproduction, responding to environmental conditions and affecting ecosystem properties. The study of functional traits is crucial for understanding the structuring of plant communities and biological diversity in different environments.
2. We evaluated ten functional traits relevant to plant fitness in three types of Seasonal Forests in Mato Grosso do Sul, Brazil. We used *D statistics* to estimate phylogenetic signal and Correspondence Analysis (CA) to explore patterns in the associations between variables.
3. Each type of forest exhibited different degrees of phylogenetic conservation for each trait, indicating the influence of specific environmental and evolutionary factors in each context, providing insights into how such factors have shaped the evolution of plant communities in different forest ecosystems.
4. Flower size and dispersal syndrome were the conserved traits in the three forests examined, reflecting the close relationship between plants and pollinating and seed-dispersing organisms over evolutionary time.
5. Spinescence was characterised as an overdispersed trait in the Semideciduous Forests, as well as resprouting capacity, which was overdispersed in the Semideciduous and Transition Forests but random in the Deciduous Forests. This highlights the adaptation of plants to selective pressures related to disturbances such as cutting, herbivore grazing, or wildfires.
6. *Synthesis and applications*. The results demonstrate that different traits have evolved in distinct ways in the three forests analysed. Some traits are more conserved in one or more forests, while others are more random or dispersed. Correspondence Analysis (CA) satisfactorily explained the variance of functional traits along the dimensions of the biplot, capturing a significant portion of the total data variability. Our findings provide valuable insights into how functional traits can be used to understand the structure and dynamics of plant communities in different forest ecosystems.

KEYWORDS

functional traits, phylogenetic conservation, phylogenetic signal, seed dispersers, plant adaptation, seasonal forests, evolution of plant communities

A filogenia dos traços e seus efeitos na estrutura multifuncional em Florestas Estacionais

Larissa Oliveira Vilela

RESUMO

1. Traços funcionais são aspectos dos organismos que influenciam seu estabelecimento, sobrevivência e reprodução, respondendo às condições ambientais e afetando as propriedades do ecossistema. O estudo dos traços funcionais é crucial para entender a estruturação das comunidades vegetais e a diversidade biológica em diferentes ambientes.

2. Avaliamos dez traços funcionais relevantes para a aptidão das plantas em três tipos de Florestas Estacionais em Mato Grosso do Sul. Utilizamos a estatística *D* para estimar o sinal filogenético e a Análise de Correspondência (CA) para explorar padrões nas associações entre as variáveis.

3. Cada tipo de floresta exibiu diferentes graus de conservação filogenética para cada traço, indicando a influência de fatores ambientais e evolutivos específicos em cada contexto, fornecendo subsídios para entender como tais fatores moldaram a evolução das comunidades vegetais em diferentes ecossistemas florestais.

4. O tamanho da flor e a síndrome de dispersão foram os traços conservados nas três florestas examinadas, refletindo a estreita relação entre plantas e organismos polinizadores e dispersores de sementes ao longo do tempo evolutivo.

5. A espinescência foi caracterizada como um traço superdisperso nas Florestas Semidecíduas, assim como a capacidade de rebrota, superdispersa nas Florestas Semidecíduas e de Transição, mas aleatória nas Florestas Decíduas, destacando a adaptação das plantas a pressões seletivas relacionadas à distúrbios como corte, pastoreio de herbívoros ou incêndios florestais.

6. *Síntese e aplicações.* Os resultados demonstram que diferentes traços evoluíram de maneiras distintas nas três florestas analisadas. Alguns traços são mais conservados em uma ou mais florestas, enquanto outros são mais aleatórios ou dispersos. A Análise de Correspondência (CA) explicou satisfatoriamente a variância dos traços funcionais ao longo das dimensões do biplot, capturando uma parcela significativa da variabilidade total dos dados. Os nossos achados fornecem *insights* valiosos sobre como os traços funcionais podem ser usados para entender a estrutura e a dinâmica das comunidades vegetais em diferentes ecossistemas florestais.

PALAVRAS-CHAVE

traços funcionais, conservação filogenética, sinal filogenético, dispersores de sementes, adaptação das plantas, florestas estacionais, evolução das comunidades vegetais.

1 Introduction

The discussion on species distribution patterns and biological diversity in natural communities has been extensively explored for decades (Brown, 1995; Clements, 1916; Fisher et al., 1943; Gleason, 1927; MacArthur, 1960; MacArthur & Wilson, 1967; Preston, 1948). Comprehending the processes that drive variations in species composition, diversity, and abundance of competing species has been a key objective in Ecology (Kraft et al., 2007). Although it is known that the distribution of plants and their functional traits is not random (Cody & Diamond, 1975; Raunkiær, 2015), there is still limited knowledge about the mechanisms determining species composition in a community (Valladares et al., 2008). Significant gaps persist, such as the need to integrate functional traits and environmental factors (Hu et al., 2021; Holdaway et al., 2011), intra- and interspecific variation in traits (Kichenin et al., 2013), and the importance of interactions with soil microorganisms (Bever et al., 2010; Jíménez-Alfaro et al., 2016). According to Webb et al. (2002), many communities display non-random patterns of evolutionary relatedness among the species that comprise them, due to the interaction between phylogenetically conserved or convergent functional traits and ecological processes, such as environmental filters or competitive exclusion.

Functional traits are aspects of organisms capable of influencing their establishment, survival, and reproduction, as well as responding to environmental conditions and affecting ecosystem properties (Díaz et al., 2013; Garnier et al., 2016; Reich et al., 2003; Violle et al., 2007). Leaf, reproductive, growth, and root traits are most commonly measured in plants (Kattge et al., 2020; Pérez-Harguindeguy et al., 2013; Rosenfield & Müller, 2020). Recently, plant functional ecology has expanded the spectrum of investigated functional traits, including belowground traits related to root economics (Carmona et al., 2021; Kramer-Walter et al., 2016; Weemstra et al., 2016), carbohydrate storage (Lubbe et al., 2021), mycorrhizal symbiosis (Bergmann et al., 2020), and floral and reproductive traits (E-Vojtkó et al., 2022; Roddy et al., 2019; Segrestin et al., 2020).

The comparison of functional traits and organism fitness primarily addresses ecological scales and processes, rather than evolutionary ones (Laughlin et al., 2020). However, the evolution of traits is expressed along the branches of organism phylogeny (Díaz et al., 2013), and the coordinated variation of functional traits in plants is manifested in correlations that reflect their shared evolutionary history (Kleyer & Minden, 2015; Murren, 2002, 2012). Evolutionarily related species tend to be ecologically similar and respond similarly to the selection, resulting in more similar values of functional traits in these species compared to those with distant relatedness and, therefore, showing phylogenetic signal (Ackerly, 2009; Freckleton et al., 2002; Harvey & Pagel, 1991). Thus, phylogenetic signal, i.e., the distribution of a functional trait among the species composing a community, can elucidate shared evolutionary history and help understand the processes that have shaped the spatial distribution of species over time.

In this context, our objective is to understand the evolutionary mechanisms associated with the development of functional traits in the woody flora of three different types of Seasonal Forests. By considering both phylogenetic information and the functional traits of species, we aim to address several key questions: Which traits are more conserved, and which are more random or overdispersed in each type of forest? Are there significant differences in the evolutionary patterns of these communities for different functional traits? What are the functional convergences and divergences among vegetation types? Are there correlations or associations among the evaluated traits? This information can contribute to a better understanding of how plant communities are structured and how different evolutionary and ecological factors may impact species composition and biodiversity in various environments. Our investigation is guided by two main hypotheses. First, we hypothesize that certain functional traits, particularly those related to plant-fauna interactions, exhibit signs of phylogenetic conservatism. Second, we predict that traits associated with resistance to disturbances —such as climate change, herbivory, and other environmental stresses— will show overdispersion in Seasonal Forests, reflecting the intense selective pressures present in these environments.

To test these hypotheses, we selected and collected data on ten essential functional traits for plant fitness, including leaf characteristics, spatial occupation, reproductive traits, floral traits, and survival attributes of the woody flora in three types of Seasonal Forests in the state of Mato Grosso do Sul. We used the D statistic (Fritz & Purvis, 2010) to estimate the phylogenetic signal, providing a deeper understanding of how these traits are distributed across the phylogeny of the studied species. Additionally, we employed Correspondence Analysis to explore and identify association patterns between variables, aiming to elucidate how such patterns vary among different forest types. The findings allowed us to understand that different forest types exhibit distinct patterns of phylogenetic conservation for various traits and provided insights into how historical and environmental factors have shaped the evolution of plant communities in different forest ecosystems.

2 Material and Methods

2.1 Data sources

We compiled data from 470 species, including trees, shrubs, cacti, and palms, listed by Damasceno-Junior et al. (2018) for the state of Mato Grosso do Sul, to gather the functional traits of woody species in Seasonal Forests. The species were classified based on their occurrence records in different phytophysiognomies, which include Deciduous Seasonal Forest, Semideciduous Seasonal

Forest, and Transition to Forested Savanna or Riparian Forest (referred to here as Transition Forest), as described by Damasceno-Junior et al. (2018). The plant families were classified according to the Angiosperm Phylogeny Group (APG IV, 2016), and botanical nomenclature was standardised according to the Flora e Funga do Brasil (2023) <floradobrasil.jbrj.gov.br>.

To obtain information on the functional traits of species within this assemblage, we collected data from various sources, including the TRY - Plant Trait Database <try-db.org> (Kattge et al., 2020), the BIEN - Botanical Information and Ecology Network database <bien.nceas.ucsb.edu/bien>, the CRIA - Centro de Referência em Informação Ambiental <cria.org.br> and the GBIF - Global Biodiversity Information Facility. Additionally, we sought information from the bibliographic sources listed in Supporting Information Table S1 for species lacking trait data in the databases above.

2.2 Functional Plant Traits

We considered only those that exhibited ecological relevance to select the functional traits that would impact plant fitness (Violle et al., 2007), as demonstrated in Table 1. In total, we selected ten traits, five of which were related to leaf characteristics and spatial occupation of the plants (such as the size of the adult plant (Hmax), stem specific density (SSD), vegetative phenology, leaf epidermal characteristics, and spinescence), four related to reproductive and floral characteristics (such as flower size and colour, pollination type, and dispersal syndrome), and one related to survival (plant resprouting capacity).

Table 1. Functional traits used in the analyses and their ecological significance.

Traits	Ecological significance	References
Size of the adult plant (Hmax)	Positively related to competitive ability (competition for light)	(E-Vojtkó et al., 2022)
Stem-specific density (SSD) or wood density (g.cm-3)	Climatic change resistance (drought resilience)	(Carlucci et al., 2020; Hacke et al., 2001; Laughlin, 2014)
Vegetative phenology	Reduction of herbivory and less loss of water and nutrients during drought	(Pringle et al., 2011)
Leaf epidermal characteristics	Climatic change resistance (protective function to high solar radiation and high temperatures)	(Moles et al., 2020)
Spinescence	Reduction of herbivory	(Hanley et al., 2007; Xu et al., 2020)
Flower size	Pollinator attraction and flower production cost	(Krizek & Anderson, 2013)
Flower colour	Pollinator attraction and flower production cost	(E-Vojtkó et al., 2022)
Pollination type	Related to pollinator dependency	(E-Vojtkó et al., 2022)
Dispersal syndrome	Related to dispersal fauna dependency	(Pijl, 1982; van Rheede van Oudtshoorn & van Rooyen, 1999)
Plant resprouting capacity	Disturbance resistance (fire resistance)	(Clarke et al., 2013; Moris et al., 2022)

2.3 Data analyses

We employed the "phylo.maker" function from the "V.PhyloMaker2" library (Jin & Qian,

2022) in the R software to generate phylogenetic trees for the species lists (Figure 1) and to understand the evolutionary relationships among the species. To estimate the phylogenetic signal, we utilised the *D* statistic (Fritz & Purvis, 2010), a metric developed to measure phylogenetic signal in binary data through the "phylo.d" function in the R-package "Caper" (Orme et al., 2018). The sum of changes in the estimated nodal values of a binary trait in a phylogeny (*D*) provides a measure of the phylogenetic signal for that trait (Fritz & Purvis, 2010).

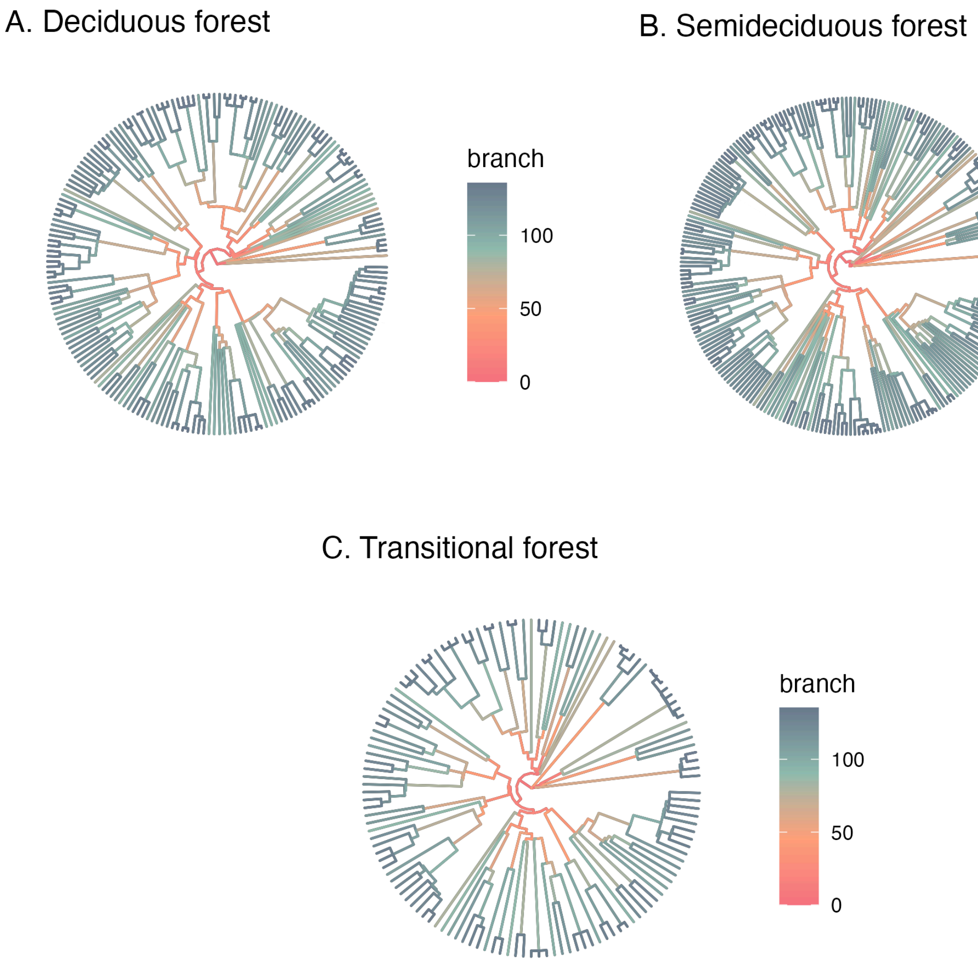

Figure 1. Phylogenetic trees of the species found in the phytogeographic regions of Seasonal Forests evaluated in this study.

The "phylo.d" function tests the estimated *D* value for significant distances in a random association and the expected clustering under the Brownian threshold evolution model. In other words, calculate the observed *D* for an attribute in a tree and compare it with the value of *D* found using the same number of simulations for the phylogenetic randomness model, where the trait values are randomly shuffled concerning the phylogeny tips and *D* is calculated; and for the Brownian threshold model, where a continuous attribute is developed along the phylogeny under a Brownian process and then converted into a binary attribute using a threshold that reproduces the relative prevalence of the observed trait. *D* values equal to 0 indicate a more clustered phylogenetic structure according to the Brownian threshold model, while values equal to 1 indicate a random phylogenetic distribution at the tips of the phylogeny (Fritz & Purvis, 2010). *D* values can also fall outside this range. When less than 0 ($D < 0$), they suggest that the trait is highly phylogenetically conserved, while values greater than 1 ($D > 1$) indicate that the trait is more overdispersed than expected by chance (Fritz & Purvis, 2010). Functional trait values were transformed into binary values according to their positive or negative relationship with their ecological significance (Table 2). Information on missing traits in the data table was excluded from the analysis using the "na.omit" function.

Table 2. Summary representation of the functional traits used in further analyses by transforming their values into a binary scale based on their ecological significance.

Low-value interpretation	Trait name	High-value interpretation
0. small	Size of the adult plant (Hmax)	1. medium and/or large
0. light woods and/or moderately dense woods	Stem-specific density (SSD) or wood density (g.cm-3)	1. dense woods and/or very dense woods
0. semi-deciduous and/or deciduous	Vegetative phenology	1. evergreen
0. glabrous	Leaf epidermal characteristics	1. hispid, lanate or very tomentose
0. not spiny	Spinescence	1. spiny
0. small and/or intermediate	Flower size	1. big
0. greenish	Flower colour	1. white or coloured
0. wind and/or water pollination	Pollination type	1. animal pollination
0. anemochorous and/or autochorous	Dispersal syndrome	1. zoochorous
0. absence	Plant resprouting capacity	1. presence or ambiguous

To explore and visualise the associations between categories of categorical variables in a low-dimensional space and identify patterns in the associations between the variables, we used Correspondence Analysis (CA). CA is a multivariate analysis instrumental when dealing with binary, nominal, or ordinal variables and when there are many cells in the contingency table dataset (Beh & Lombardo, 2014; Greenacre, 2017). We performed Correspondence Analysis on datasets from the three types of Seasonal Forests (Deciduous Forest, Semideciduous Forest, and Transitional Forest), using the R-package "FactoMineR" (Lê et al., 2008) for the "CA" function and the R-package "ggplot2" (Wickham, 2016) for the "plot.CA" function in the R software. The "CA" function calculates the contribution values of each species and each variable (or functional trait) and their associations. Before the analysis, the "na.omit" function was applied to remove any missing values in the data table. The chi-square test was performed to determine the presence or absence of statistically significant associations between the variables. All analyses mentioned above were conducted using the statistical software R version 4.1.1 (R Core Team, 2021) and RStudio Team (2022).

3 Results

We found that each type of forest exhibits different degrees of phylogenetic conservation for each trait, indicating the influence of specific environmental and evolutionary factors in each context, as detailed in Supporting Information Table S2 and Figure 2.

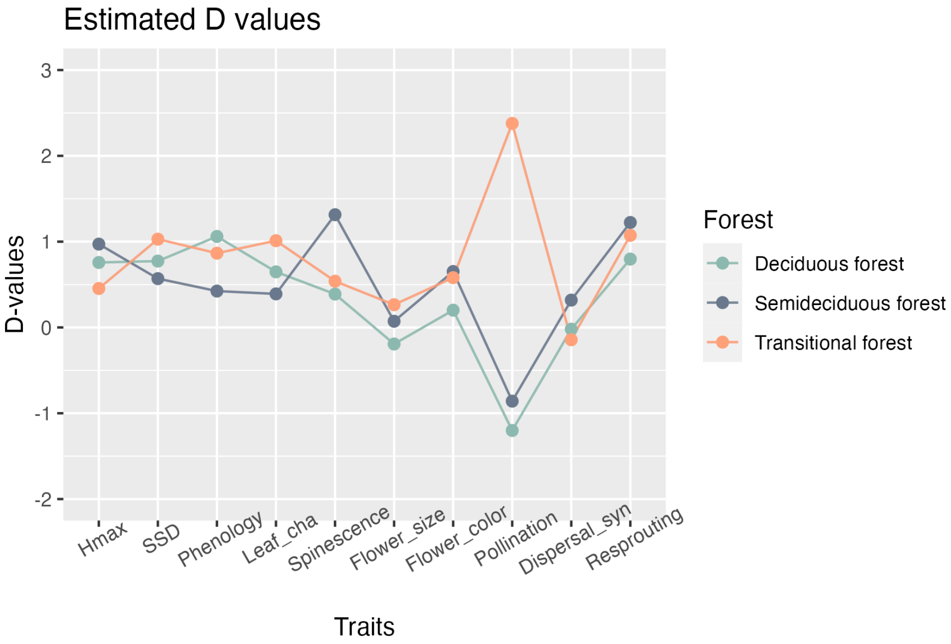

Figure 2. Estimated D values for each trait across three physiognomies of the seasonal forest. *D-values*, Fritz and Purvis's *D* (Fritz & Purvis, 2010). Values of *D* may range from <0 (highly conserved) to 0 (conserved according to the Brownian threshold model), to 1 (random), to >1 (overdispersed).

Regarding the analysed traits, it was observed that adult plant size (Hmax) showed moderate values of phylogenetic conservation for Transitional Forests (0,4540655) and more random values for Deciduous Forests (0,7571172) and Semideciduous Forests (0,9714001), suggesting that this characteristic is more conserved in Transitional Forests and more dispersed in the other two phytogeographic formations. Wood density (SSD) presented values greater than 1 for the Transitional Forest (1,028679) and close to 1 for the Deciduous Forest (0,7734552), indicating the random evolution of this trait. On the other hand, for the Semideciduous Forest, the value of SSD was less than 1 (0,5691683), suggesting that wood density is more conserved in this forest than in the others.

Regarding leaf traits, it was observed that leaf phenology and leaf epidermal characteristics (Leaf_cha) were more conserved in Semideciduous Forests than in the others, while spinescence proved to be an overdispersed trait. Leaf phenology was more random in Deciduous (1,060419) and Transitional Forests (0,8654366) but more conserved in Semideciduous Forests (0,4238272). The Leaf_cha trait had a value close to 1 and, therefore, more random in Transitional Forests (1,010963) and lower values in

Deciduous (0,6480734) and Semideciduous Forests (0,3911315). As for spinescence, this trait showed a moderate degree of phylogenetic conservation in Deciduous (0,3887693) and Transitional Forests (0,538733) but was overdispersed in Semideciduous Forests (1,313996).

The floral traits exhibited significant variations concerning the D values. Among them, flower size was one of the most conserved traits. The analysis demonstrated that flower size is highly conserved in Deciduous Forests (-0,1930143), while in Semideciduous Forests (0,0719513) and Transition Forests (0,2649111), it showed a degree of phylogenetic conservation. Regarding flower colour, values close to 0.5 were observed for Semideciduous Forests (0,6517187), and Transition Forests (0,5806129), and a D value closer to 0 was found in Deciduous Forests (0,2011635), indicating that, like size, flower colour is also more conserved in Deciduous Forests. Pollination showed the most disparate values among all traits, being highly conserved in Semideciduous Forests (-0,8589665) and Deciduous Forests (-1,200868) and overdispersed in Transition Forests (2,378267).

Finally, dispersal syndrome was conserved in Semideciduous Forests (0,3187124) and highly conserved in Deciduous Forests (-0,0200040) and Transition Forests (-0,1433094). On the another hand, resprouting capacity was found to be random in Deciduous Forests (0,7968552) and overdispersed in Semideciduous Forests (1.223328) and Transition Forests (1,073293). The results show that different traits evolved differently in the three analysed forests (Table S2, Figure 2). Some traits are more conserved in one or more forests, while others are more random or overdispersed.

The Correspondence Analysis (CA) results satisfactorily explained the variance of the functional traits along the biplot dimensions (Figure 3). In Deciduous Seasonal Forests, the cumulative percentage of variance explained by Dim.1 and Dim.2 together accounted for 34.518% of the total variation, capturing over one-third of the total data variability. In Semideciduous Seasonal Forests, Dim.1 and Dim.2 together explained 35.946% of the total variation. The cumulative percentage of explained variation when considering Dim.3 was 51.172%, showing the same results. In Transition Forests, Dim.1 and Dim.2 explain 39.665% of the total variation, while the first four dimensions (Dim.1 to Dim.4) explain 65.856%. From the fifth dimension onwards, the explained variation decreases significantly (Table S3).

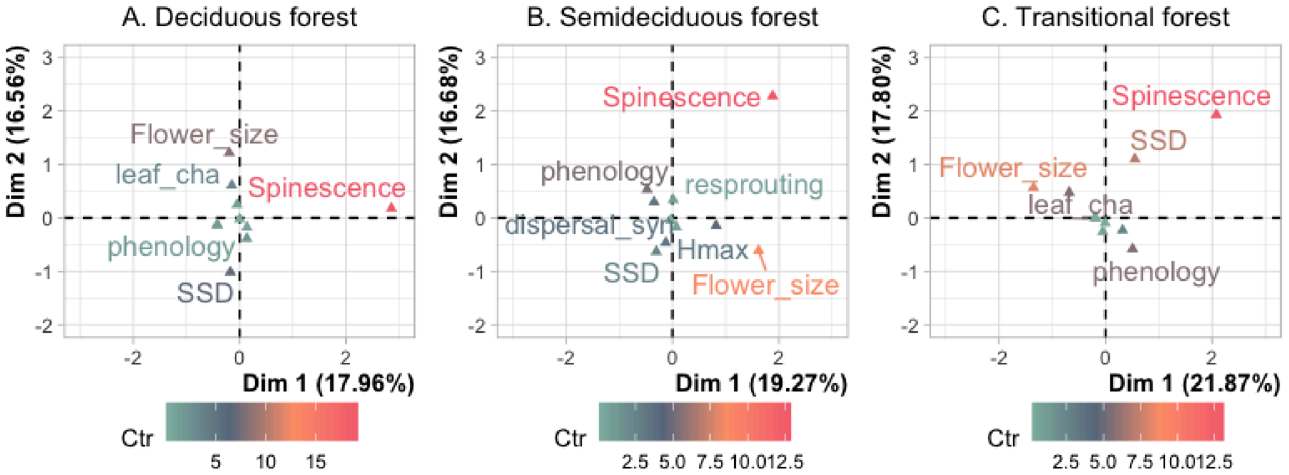

Figure 3. Correspondence Analysis (CA) factor map demonstrating the associations between variables for the three phytophysiognomies of the seasonal forest. The colour gradient represents the contribution of the variables.

The Correspondence Analysis (CA) plot depicts the correlations between variables within each vegetation type (Figure 3). Across all three phytophysiognomies, the relationship between variables and the dimensions of data variability in CA was similar. Among all environments, spinescence exhibited the highest relative contribution to the total data variability and played a crucial role in sample differentiation (Table S3). Traits such as SSD (Specific Leaf Area) and flower size also displayed high inertia values. Conversely, traits such as pollination, flower colour, and dispersal syndrome had lower relative contributions to the CA dimensions. The obtained chi-square test values for independence were 537.5066, 709.8971, and 408.6947, with p-values equal to 1 in all cases for Deciduous Seasonal Forests, Semi-deciduous Seasonal Forests, and Transition Forests, respectively. This result suggests that, at the significance levels considered, there is insufficient statistical evidence to claim that functional traits are dependent on one another.

4 Discussion

The phylogenetic signal of functional traits reflects the shared evolutionary history between species and their traits, demonstrating that certain traits are more important than others for the survival and adaptation of plants in specific environments (Cronk, 2004; Gurevitch et al., 2006). Our results indicate that functional traits of the studied plant assemblages differ regarding their phylogenetic clustering (Figure 2), having evolved in distinct and independent ways in the three examined forest ecosystems (Table S3). Some traits are more conserved in one or more forests, while others exhibit greater randomness or overdispersion.

The interpretation of the results support the formulated hypotheses. We identified significant phylogenetic conservation in traits such as flower size and dispersal syndromes, while characteristics such as spinescence and resprouting ability showed overdispersion patterns. These differences can shed light on how historical and environmental factors have shaped the evolution of these communities over time (Swenson et al., 2012; Webb et al., 2008).

A functionally conserved or highly conserved trait demonstrates that its evolution has occurred similarly in closely related phylogenetic species, and the evolution of this trait is influenced by both the shared evolutionary history among species and environmental filtering through abiotic factors (Bose et al., 2019; Helmus & Ives, 2012; Mayfield & Levine, 2010; Qian et al., 2014, 2017; Whitfeld et al., 2012). Analysis of the obtained *D* values (Figure 2) revealed that different types of forests exhibit distinct patterns of phylogenetic conservation for different traits. Flower size and dispersal syndrome were the most widely conserved traits in the three examined forests, suggesting that they play an important role in the survival and reproduction of the plant species present. This finding highlights the close relationship between plants and other organisms that play crucial roles in their evolution, such as pollinators and seed dispersers.

Correspondence Analysis (CA) revealed that flower size was also a significant and informative trait in the data structure (Figure 3), despite the absence of a significant relationship among the variables (Table S3). Flower size is a crucial characteristic in ecological contexts, as it impacts both the evolution and effectiveness of plant reproductive systems (Goodwillie et al., 2010; Krizek & Anderson, 2013; Sargent et al., 2007). This characteristic is significant because larger flowers generally contain more nectar and are more visible to pollinators (Blarer et al., 2002; Fenster et al., 2006). In plants that rely on cross-pollination, floral traits such as flower size are presumed to coevolve with pollinators (Goodwillie et al., 2010; Krizek & Anderson, 2013).

Regarding the dispersion syndrome, the observed conservatism indicates a tight relationship between dispersers and fruits that, throughout evolutionary time, has led to morphological convergences among plant species (Pijl, 1982). The evolution of fruit characteristics is highly responsive to mutualistic interactions with seed-dispersing frugivores - Seed Dispersal Syndrome Hypothesis (Valenta & Nevo, 2020). The high level of integration revealed by phylogenetic contrasts demonstrates that mutualistic frugivores can shape the phenotypic covariance of fleshy fruits (Valido et al., 2011), highlighting the conservatism of the phylogenetic niche (Crisp & Cook, 2012) and the importance of these interactions in the evolution of fleshy fruits and seed dispersal patterns.

Phylogenetic conservatism can indicate the presence of shared adaptations among closely related species under specific conditions, thus referred to as niche conservatism (Crisp & Cook, 2012;

Harvey & Pagel, 1991; Ricklefs, 2010; Webb et al., 2002). This phenomenon can be reinforced by the coexistence of closely related species in a physically stressful habitat, suggesting low competition for specific adaptations (Bruun et al., 2006; Callaway et al., 2002; Mienna et al., 2020). When species lineages tend to maintain their ecological niche-related traits over time, even after speciation events, it is referred to as the phenomenon of phylogenetic niche conservatism (Ackerly, 2003; Cooper et al., 2010; Crisp & Cook, 2012; Wiens et al., 2010). There is a debate in the literature as to whether phylogenetic niche conservatism is a process that structures communities and biomes or a pattern resulting from underlying causes, whether intrinsic or extrinsic (Crisp & Cook, 2012; Losos, 2008a, 2008b, 2011; Wiens & Graham, 2005). Wiens et al. (2010) argue that phylogenetic niche conservatism is a process because it can lead to other patterns, such as diversity gradients. However, the same processes may lead to phylogenetic niche conservatism and also generate other patterns (Cooper et al., 2010; Losos, 2011).

The type of pollination has also proven to be a highly conserved trait for Semideciduous Seasonal Forests and Deciduous Forests. This result suggests that, under the specific conditions of these particular forests, phylogenetically close species share adaptive similarities regarding the type of pollination, making this characteristic an important factor in the shared evolution of these species. In contrast, in Transition Forests, the type of pollination was an overdispersed trait. Unlike phylogenetic conservatism, which suggests the selection of species with similar traits and shared evolutionary histories due to abiotic factors and mild selective pressures (Bose et al., 2019; Helmus & Ives, 2012; Mayfield & Levine, 2010; Qian et al., 2014, 2017; Whitfeld et al., 2012), overdispersion is often associated with interspecific interactions, including competitive exclusion (Cavender-Bares et al., 2009; Webb et al., 2002) or facilitation (Valiente-Banuet & Verdú, 2007), as well as strong selective pressures or environmental filtering of ecologically important traits (Cavender-Bares et al., 2004; Das & Ratnam, 2022; Webb et al., 2002). Regarding pollination, the combination of interspecific facilitation and intra-specific competition among plants may promote their coexistence, suggesting that pollination can be a crucial factor in maintaining plant diversity as a niche axis, benefiting rare species and biodiversity maintenance (Bergamo et al., 2020; Feldman et al., 2004).

When a trait displays random or overdispersed patterns, that is, it exhibits a low degree of phylogenetic aggregation (Webb et al., 2002), phylogenetically distant species may possess similar characteristics (Münkemüller et al., 2012; Pavoine & Ricotta, 2013). Low-stress abiotic environments, characterised by greater habitat heterogeneity and significant dispersal constraints, can contribute to an increase in overdispersion, which occurs when multiple functional groups or distinct evolutionary lineages are simultaneously present (Butterfield et al., 2013; Dias et al., 2020; Mienna et al., 2020; Wang et al., 2013). Compared to others, a higher diversity of overdispersed traits in Transition Forests demonstrates that this forest exhibits a wide range of ecological environments with different selective pressures, leading to a greater diversity of adaptive mechanisms among species.

In the Semideciduous Seasonal Forest, thorns in plants were an overdispersed characteristic that may have evolved as a defence mechanism and adaptation to avoid herbivory or protect leaves from large animals that feed on trees (Xu et al., 2020). It is essential to highlight that plant consumption by herbivorous mammals is one of the main factors driving vegetation dynamics worldwide (Huntly, 1991), which justifies its importance in the data structure for all forests evaluated by Correspondence Analysis (Figure 3). Furthermore, herbivorous mammals also exert an influence on the characteristics of plant thorns, such as their length, density, and distribution (Goheen et al., 2007; Karban & Myers, 1989; Young et al., 2003; Zhang et al., 2022).

Historical herbivory patterns explain a substantial portion of the current biogeographic variability in plant functional traits and ecosystem geographical distribution, highlighting the importance of the historical distribution of extinct neotropical megafauna in understanding the functional biogeography of plants and ecosystems (Dantas & Pausas, 2022). Although most of these animals were extinct by the end of the Pleistocene and the beginning of the Holocene (Owen-Smith, 2013), woody plants in herbivory-sustained ecosystems have developed morphological and physiological adaptations to minimize damage caused by large herbivores, known as anti-herbivory defense traits (Dantas & Pausas, 2020). Even though many of these traits have been lost in areas where selective pressure changed after megafauna extinction, some may have persisted as anachronistic features (Galetti et al., 2009; Janzen & Martin, 1982).

The resprouting capacity of plants was also an overdispersed characteristic in Semideciduous and Transitional Forests, appearing to be random in Deciduous Forests. Resprouting capacity is an extremely important trait whose different mechanisms have also emerged in response to strong selective pressures throughout the evolutionary history of plants, being closely linked to the plant's ability to recover after suffering damage caused by cutting, herbivore grazing, or wildfires (Clarke et al., 2013). Trees and shrubs possess resprouting mechanisms that allow them to regenerate tissues from buds in different plant parts, such as roots, stems, and branches (Clarke et al., 2013). Resprouting can vary significantly among plant species, influenced by physiological and genetic characteristics and factors such as the intensity and frequency of disturbances (Pausas & Keeley, 2014). Particularly in these forests, where wildfires are common, resprouting capacity is essential for plant survival (Abreu et al., 2022).

Our findings provide insights into understanding how historical and environmental factors have shaped the evolution of plant communities in different types of forest vegetation. The independence between traits and the relevance of certain functional traits over others for plant survival and adaptation in specific environments become evident. Additionally, distinct patterns of phylogenetic conservation for different traits were observed among the analysed forests. The traits most conserved across the three forests were flower size and dispersal syndrome, highlighting the inherent conservatism in the close relationship between plants, pollinators and seed dispersers, which play crucial roles in plant evolution.

The origins of the discrepant differences regarding the values found for the type of pollination need to be further studied, considering that the portion of the Atlantic Forest located in the state of Mato Grosso do Sul has recently been identified as a priority area for the protection of pollination networks and species interaction webs, which are essential for the survival and balance of ecological communities (Pereira et al., 2022). Moreover, the overdispersion found for spinescence in Semideciduous Seasonal Forests and for resprouting capacity indicates the solid selective pressure exerted by herbivory, cutting, or fire in these environments. These findings are consistent with the patterns of overdispersion described in the literature (Cavender-Bares et al., 2004; Das & Ratnam, 2022; Webb et al., 2002). The methodology presented here may be applied to explore other communities, enabling the expansion of knowledge about the complex interactions between evolutionary history, environmental filtering, and variation in functional traits, as well as mechanisms of coexistence and biodiversity maintenance in ecological communities.

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Supporting Information

Table S1. Literature from which additional functional trait information was obtained.

No	Reference
1	Barbosa, L. M. (2017). *Lista de espécies indicadas para restauração ecológica para diversas regiões do Estado de São Paulo.* Instituto de Botânica.
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Table S2. Estimated D values for each trait across three physiognomies of the seasonal forest.

Trait name	Deciduous forest	Semideciduous forest	Transitional forest
Hmax	0,7571172	0,9714001	0,4540655
SSD	0,7734552	0,5691683	1,028679
Phenology	1,060419	0,4238272	0,8654366
Leaf_cha	0,6480734	0,3911315	1,010963
Spinescence	0,3887693	1,313996	0,538733
Flower_size	-0,1930143*	0,0719513	0,2649111
Flower_color	0,2011635	0,6517187	0,5806129
Pollination	-1,200868*	-0,8589665*	2,378267
Dispersal_syn	-0,0200040*	0,3187124	-0,1433094*
Resprouting	0,7968552	1.223328	1,073293

Note: Functional distances between species were calculated separately for each characteristic. Values marked by an asterisk (*) denoting highly phylogenetically clustered traits.

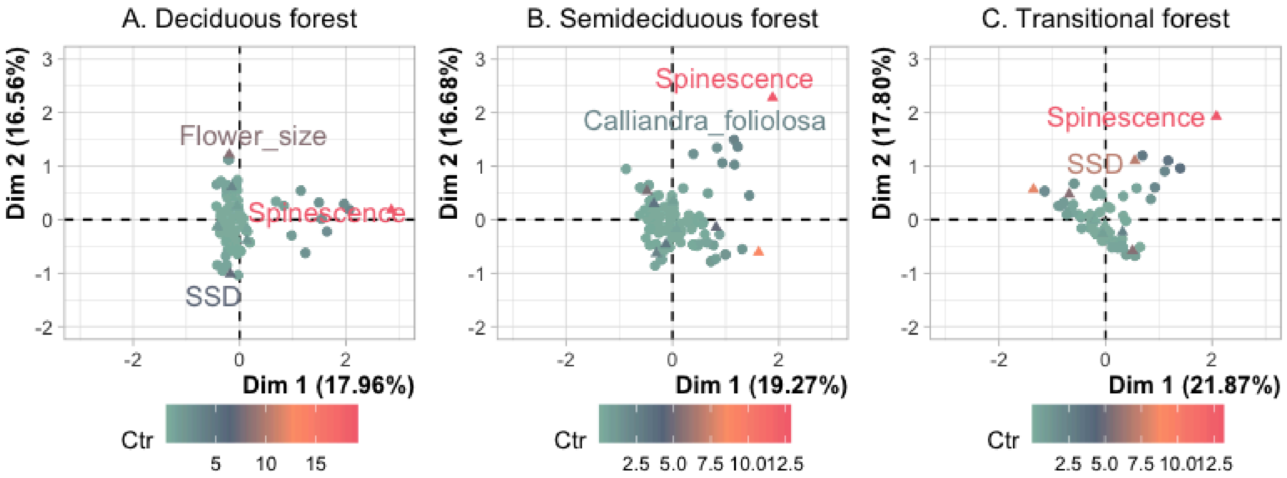

Figure S1. Correspondence Analysis (CA) factor map demonstrating the associations between variables and species for the three phytophysiognomies of the seasonal forest. The colour gradient represents the contribution of the variables.

Table S3. Correspondence Analysis (CA) results across three physiognomies of the seasonal forest.

Deciduous forest

The **chi-square** of independence between the two variables is equal to **537.5066** (p-value = 1).

Eigenvalues	**Dim.1**	**Dim.2**	**Dim.3**	**Dim.4**	**Dim.5**	**Dim.6**	**Dim.7**	**Dim.8**	**Dim.9**
Variance	0.227	0.209	0.195	0.171	0.134	0.116	0.097	0.092	0.022
%ofvar.	17.961	16.557	15.417	13.572	10.602	9.221	7.675	7.272	1.723
Cumulative%ofvar.	17.961	34.518	49.935	63.507	74.109	83.330	91.005	98.277	100.000

Rows(the10first)	**Iner*1000**	**Dim.1**	**ctr**	**cos2**	**Dim.2**	**ctr**	**cos2**	**Dim.3**	**ctr**	**cos2**
Astronium_urundeuva	10.734	-0.100	0.052	0.011	-0.246	0.341	0.066	0.741	3.310	0.600
Schinopsis_brasiliensis	13.642	-0.158	0.077	0.013	-0.576	1.117	0.171	0.875	2.775	0.396
Annona_coriacea	12.120	-0.056	0.013	0.002	0.694	2.164	0.373	0.064	0.020	0.003
Annona_cornifolia	10.682	-0.236	0.345	0.073	0.636	2.724	0.533	-0.196	0.278	0.051
Annona_emarginata	16.735	-0.042	0.006	0.001	0.742	1.855	0.232	-0.113	0.046	0.005
Annona_nutans	11.922	-0.220	0.252	0.048	0.496	1.382	0.242	-0.300	0.545	0.089
Aspidosperma_cuspa	19.851	-0.417	0.540	0.062	-0.850	2.435	0.256	0.327	0.386	0.038
Aspidosperma_polyneuron	9.929	-0.175	0.127	0.029	-0.161	0.116	0.024	-0.095	0.044	0.009
Aspidosperma_subincanum	11.340	-0.213	0.236	0.047	-0.568	1.812	0.334	0.465	1.304	0.224
Aspidosperma_tomentosum	12.445	-0.434	0.977	0.178	0.251	0.355	0.060	-0.371	0.831	0.130

Deciduous forest

Columns	**Iner*1000**	**Dim.1**	**ctr**	**cos2**	**Dim.2**	**ctr**	**cos2**	**Dim.3**	**ctr**	**cos2**
Hmax	115.010	0.135	0.940	0.019	-0.383	8.262	0.150	0.331	6.593	0.112
SSD	161.047	-0.175	0.855	0.012	-1.014	31.203	0.405	0.881	25.310	0.306
phenology	136.139	-0.417	5.588	0.093	-0.135	0.635	0.010	-0.776	22.515	0.322
leaf_cha	131.915	-0.149	0.756	0.013	0.610	13.789	0.218	0.144	0.830	0.012
Spinescence	208.192	2.852	84.277	0.917	0.178	0.357	0.004	-0.198	0.471	0.004
Flower_size	150.461	-0.194	0.898	0.014	1.218	38.370	0.533	0.443	5.456	0.071
Flower_color	80.362	-0.047	0.157	0.004	0.251	4.819	0.125	0.263	5.658	0.137
pollination	22.669	-0.003	0.001	0.000	-0.026	0.074	0.007	0.014	0.024	0.002
dispersal_syn	107.175	0.137	1.108	0.023	-0.175	1.962	0.038	-0.607	25.356	0.460
resprouting	148.784	-0.418	5.421	0.083	-0.125	0.528	0.007	-0.464	7.786	0.102

Semiciduous forest

The **chi-square** of independence between the two variables is equal to **709.8971** (p-value = 1).

Eigenvalues	**Dim.1**	**Dim.2**	**Dim.3**	**Dim.4**	**Dim.5**	**Dim.6**	**Dim.7**	**Dim.8**	**Dim.9**
Variance	0.224	0.194	0.177	0.162	0.129	0.117	0.069	0.063	0.028
%ofvar.	19.266	16.680	15.226	13.952	11.074	10.029	5.925	5.443	2.406
Cumulative%ofvar.	19.266	35.946	51.172	65.123	76.197	86.226	92.151	97.594	100.000

Rows(the 10 first)	**Iner*1000**	**Dim.1**	**ctr**	**cos2**	**Dim.2**	**ctr**	**cos2**	**Dim.3**	**ctr**	**cos2**
Astronium_fraxinifolium	12.199	0.154	0.087	0.016	-0.426	0.767	0.122	0.312	0.449	0.065
Astronium_graveolens	9.512	-0.207	0.125	0.029	-0.744	1.868	0.381	0.605	1.354	0.252
Spondias_mombin	3.496	-0.229	0.153	0.098	-0.216	0.157	0.087	0.046	0.008	0.004
Tapirira_guianensis	6.426	-0.604	0.801	0.279	0.597	0.904	0.273	-0.083	0.019	0.005
Annona_sylvatica	10.927	0.581	1.481	0.303	-0.052	0.014	0.002	-0.340	0.642	0.104
Unonopsis_guatterioides	11.835	0.352	0.453	0.086	0.003	0.000	0.000	-0.597	1.650	0.247
Xylopia_aromatica	9.728	0.502	1.288	0.296	0.067	0.026	0.005	-0.590	2.257	0.411
Aspidosperma_pyrifolium	5.008	-0.061	0.008	0.004	-0.514	0.670	0.259	0.064	0.011	0.004
Hancornia_speciosa	13.371	0.560	1.145	0.192	-0.084	0.030	0.004	-0.960	4.267	0.565
Tabernaemontana_catharinensis	4.587	-0.415	0.503	0.245	0.350	0.414	0.175	-0.133	0.066	0.025

Columns	**Iner*1000**	**Dim.1**	**ctr**	**cos2**	**Dim.2**	**ctr**	**cos2**	**Dim.3**	**ctr**	**cos2**
Hmax	96.024	-0.128	1.014	0.024	-0.462	15.350	0.310	0.185	2.677	0.049
SSD	156.067	-0.305	1.976	0.028	-0.630	9.734	0.121	0.937	23.544	0.267
phenology	109.760	-0.479	10.396	0.212	0.534	14.918	0.263	-0.116	0.773	0.012
leaf_cha	147.618	0.817	19.989	0.303	-0.143	0.709	0.009	0.398	5.997	0.072
Spinescence	184.476	1.880	23.247	0.282	2.283	39.610	0.416	1.466	17.892	0.172
Flower_size	162.273	1.618	34.434	0.475	-0.610	5.656	0.068	-1.032	17.742	0.193
Flower_color	63.427	0.073	0.371	0.013	-0.172	2.379	0.073	-0.120	1.260	0.035
pollination	28.671	-0.031	0.096	0.008	-0.044	0.224	0.015	0.016	0.032	0.002
dispersal_syn	74.093	-0.347	8.471	0.256	0.299	7.269	0.190	-0.004	0.001	0.000
resprouting	139.452	0.012	0.004	0.000	0.342	4.151	0.058	-0.880	30.080	0.382

Transitional forest

The **chi-square** of independence between the two variables is equal to **408.6947** (p-value = 1).

Eigenvalues	**Dim.1**	**Dim.2**	**Dim.3**	**Dim.4**	**Dim.5**	**Dim.6**	**Dim.7**	**Dim.8**	**Dim.9**
Variance	0.243	0.198	0.154	0.137	0.131	0.101	0.065	0.056	0.027
%ofvar.	21.868	17.797	13.896	12.295	11.793	9.096	5.852	5.015	2.387
Cumulative%ofvar.	21.868	39.665	53.561	65.856	77.649	86.745	92.597	97.613	100.000

Rows(the10first)	**Iner*1000**	**Dim.1**	**ctr**	**cos2**	**Dim.2**	**ctr**	**cos2**	**Dim.3**	**ctr**	**cos2**
Astronium_fraxinifolium	20.409	-0.151	0.128	0.015	0.550	2.077	0.201	-0.001	0.000	0.000
Tapirira_guianensis	11.042	0.553	1.028	0.226	-0.674	1.875	0.336	0.155	0.126	0.018
Annona_montana	15.605	-0.300	0.505	0.079	-0.151	0.156	0.020	0.361	1.145	0.113
Xylopia_aromatica	12.544	-0.465	1.692	0.327	0.043	0.018	0.003	0.511	3.222	0.396
Aspidosperma_australe	15.011	-0.504	0.854	0.138	0.094	0.037	0.005	-0.962	4.890	0.503
Aspidosperma_cylindrocarpon	9.549	-0.180	0.109	0.028	-0.265	0.289	0.060	-0.575	1.749	0.283
Himatanthus_obovatus	15.502	-0.266	0.237	0.037	-0.076	0.024	0.003	0.884	4.129	0.411
Dendropanax_cuneatus	9.479	0.388	0.675	0.173	-0.651	2.331	0.486	-0.294	0.611	0.099
Acrocomia_aculeata	30.840	0.851	4.860	0.383	0.384	1.214	0.078	0.534	3.014	0.151
Attalea_phalerata	7.764	0.311	0.433	0.135	-0.507	1.413	0.360	0.166	0.193	0.038

Transitional forest

Columns	Iner*1000	Dim.1	ctr	cos2	Dim.2	ctr	cos2	Dim.3	ctr	cos2
Hmax	115.263	-0.053	0.130	0.003	-0.258	3.854	0.066	-0.645	30.750	0.412
SSD	135.807	0.551	5.785	0.103	1.103	28.460	0.414	0.056	0.094	0.001
phenology	112.136	0.508	10.095	0.219	-0.579	16.140	0.284	0.294	5.335	0.073
leaf_cha	130.224	-0.684	15.714	0.293	0.477	9.367	0.142	-0.378	7.537	0.089
Spinescence	171.394	2.081	29.084	0.412	1.932	30.780	0.355	-0.077	0.062	0.001
Flower_size	157.280	-1.353	28.696	0.443	0.566	6.168	0.078	0.448	4.951	0.049
Flower_color	56.119	-0.205	2.779	0.120	-0.002	0.000	0.000	0.078	0.632	0.017
pollination	26.643	-0.009	0.007	0.001	-0.093	0.955	0.071	-0.111	1.769	0.102
dispersal_syn	76.738	0.319	6.853	0.217	-0.228	4.274	0.110	-0.001	0.000	0.000
resprouting	128.979	-0.179	0.857	0.016	-0.007	0.002	0.000	1.075	48.869	0.585

SI1. R code for (I) Generating phylogenetic trees using V.PhyloMaker2, (II) Calculating the D statistic for the phylogenetic structure of a binary variable, (III) Visualizing the generated phylogenetic trees, (IV) Creating Parallel Coordinates Visualization, and (V) Performing Correspondence Analysis and Visualization.

I. Generating phylogenetic trees using V.PhyloMaker2

```
library("V.PhyloMaker2")

example <- read.csv("species_list.csv")

tree <- phylo.maker(sp.list = example, tree = GBOTB.extended.TPL, nodes = nodes.info.1.TPL, scenarios = "S3")

write.tree(tree$scenario.3, "sample.tre")
```

II. Calculation of D statistic for the phylogenetic structure of a binary variable

```
library(caper)
library(phytools)
library(vegan)
library(geiger)

tree <- read.tree("tree")
plot(tree, cex=0.4)
tree$node.label <- NULL

traits <- read.csv("traits.csv")
head(traits)

spdata <- comparative.data(tree, traits, "species")

spdata2 <- na.omit(spdata)

variable <- spdata2$variable
PhyloD <- phylo.d(spdata2, binvar=variable)
print(PhyloD)  # Display the calculated D statistic

plot(PhyloD)
```

III. Generating the visualization of the generated phylogenetic trees

```
library(ggplot2)
library(ggtree)
library(cowplot)
library(gridExtra)
library(grid)
```

```
tree1 <- read.tree("arvore_decidual")
tree2 <- read.tree("arvore_semidecidual")
tree3 <- read.tree("arvore_transição")

color_palette <- c("#F67280", "#FFA07A", "#8FBBAF", "#6B7B8E")

title1 <- expression("A. Deciduous forest")
title2 <- expression("B. Semideciduous forest")
title3 <- expression("C. Transitional forest")

layer1 <- ggtree(tree2, layout = "circular") +
  geom_tree(aes(color = branch)) +
  ggtitle(title1) +
  scale_colour_gradientn(colours = color_palette)

layer2 <- ggtree(tree2, layout = "circular") +
  geom_tree(aes(color = branch)) +
  ggtitle(title2) +
  scale_colour_gradientn(colours = color_palette)

layer3 <- ggtree(tree3, layout = "circular") +
  geom_tree(aes(color = branch)) +
  ggtitle(title3) +
  scale_colour_gradientn(colours = color_palette)

plot <- arrangeGrob(
  arrangeGrob(layer1, layer2, ncol = 2),
  arrangeGrob(layer3, ncol = 1),
  ncol = 1)
grid.draw(plot)
```

IV. Parallel Coordinates Visualization

```
library(ggplot2)
library(GGally)
library(readr)

my_palette <- c("#8FBBAF", "#6B7B8E", "#F67280")

data <- read_csv("phylo.d.csv")

ggparcoord(data = data,
        columns = 2:11,
        alphaLines = 0.9,
        groupColumn = "Forest",
        showPoints = TRUE,
        scale = "globalminmax") +
  theme(axis.text.x= element_text(angle = 30, vjust = 1))+
  scale_color_manual(values = my_palette) +
  geom_point(size = 2) +
  scale_y_continuous(limits = c(-1, 3)) +
  labs(x = "Traits", y = "D-values") +
  ggtitle("Estimated D values")
```

V. Correspondence Analysis and Visualization

```
library(vegan)
library(FactoMineR)
library(factoextra)
library(ggplot2)
```

```
library(gridExtra)

create_plot <- function(my_ca, title) {
  plot.CA(my_ca, selectCol = 'contrib 15', selectRow = 'contrib 99',
          unselect = 0, cex = 1.1, cex.main = 1.1, cex.axis = 1.1, habillage = 'contrib',
          col.col = '#0D00FF', invisible = c('row')) +
    theme(legend.position = "bottom") +
    scale_x_continuous(limits = c(-3, 3)) +
    scale_y_continuous(limits = c(-2, 3)) +
    scale_color_gradientn(colors = c("#8FBBAF", "#6B7B8E","#FFA07A","#F67280")) +
    labs(title = title, fill = "contrib")
}

data1 <- na.omit(read.csv("traits_decidual.csv", header = TRUE, row.names = 1))
data2 <- na.omit(read.csv("traits_semidecidual.csv", header = TRUE, row.names = 1))
data3 <- na.omit(read.csv("traits_transicao.csv", header = TRUE, row.names = 1))

my_ca <- lapply(list(data1, data2, data3), CA)

titles <- c(expression("A. Deciduous forest"),
            expression("B. Semideciduous forest"),
            expression("C. Transitional forest"))

plots <- lapply(1:3, function(i) create_plot(my_ca[[i]], titles[i]))

grid.arrange(grobs = plots, ncol = 3)

create_species_plot <- function(my_ca, title) {
  plot.CA(my_ca, selectCol = 'contrib 15', selectRow = 'contrib 0',
          unselect = 0, cex = 1.1, cex.main = 1.1, cex.axis = 1.1, habillage = 'contrib',
          col.col = '#0D00FF') +
    theme(legend.position = "bottom") +
    scale_x_continuous(limits = c(-3, 3)) +
    scale_y_continuous(limits = c(-2, 3)) +
    scale_color_gradientn(colors = c("#8FBBAF", "#6B7B8E","#FFA07A","#F67280")) +
    labs(title = title, fill = "contrib")
}

species_plots <- lapply(1:3, function(i) create_species_plot(my_ca[[i]], titles[i]))

grid.arrange(grobs = species_plots, ncol = 3)

lapply(my_ca, summary)
```

Chapter 2

Woody Plant Functional Traits and Environmental Drivers of Community Structure in Brazilian's Seasonal Forests

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ABSTRACT

1. This study identifies the primary functional traits of woody flora in the Seasonal Forests of Mato Grosso do Sul, Brazil, addressing the gap in understanding how these traits influence community structuring. We classified species into functional clusters based on their traits, analyzed the relationships among these clusters in a multivariate space, and examined their spatial distribution in relation to climate, pedology, and geomorphology. These insights are crucial for informing effective conservation and restoration strategies in these forests.
2. Reproductive and floral traits were crucial in the differentiation and spatial distribution of functional clusters. Characteristics like floral symmetry, size, and color impact floral production cost and the attraction of pollinators, which in turn influences reproductive success.
3. Dispersal syndromes and adaptive fruit characteristics were fundamental in the formation of species clusters. The morphological properties of fruits influence dispersal mechanisms and interactions with dispersal agents. Dispersal methods, such as wind and animal dispersal, shape the spatial structure and diversity of plant communities.
4. The spatial distribution of functional clusters across the phytogeographic domain reveals a flexible adaptation of plant species to diverse environmental conditions. However, preferences for specific topographic environments, soil types, and climate categories are evident. Environmental factors, particularly climate, significantly influence the distribution of functional clusters.
5. *Synthesis and applications.* Our findings highlight the significant role of reproductive and floral characteristics in the differentiation and spatial distribution of functional clusters. Additionally, they underscore the importance of understanding the complex relationships between functional traits and environmental factors for effective conservation and management strategies. Promoting resilience and functional heterogeneity through species integration and considering critical environmental factors can increase ecological resilience, stability, and diversity, contributing to the development of restoration and maintenance practices for biodiversity in impacted ecosystems.

KEYWORDS

functional clusters, spatial distribution, environmental factors, reproductive traits, dispersal syndromes, ecological management, ecological resilience, biodiversity conservation

Traços Funcionais de Plantas Lenhosas e Fatores Ambientais na Estrutura das Comunidades em Florestas Estacionais

Larissa Oliveira Vilela

RESUMO

1. Este estudo identifica os principais traços funcionais da flora lenhosa nas Florestas Sazonais de Mato Grosso do Sul, Brasil, abordando a lacuna na compreensão de como esses traços influenciam a estruturação das comunidades. Classificamos as espécies em clusters funcionais com base em seus traços, analisamos as relações entre esses clusters em um espaço multivariado e examinamos sua distribuição espacial em relação ao clima, pedologia e geomorfologia. Esses insights são cruciais para informar estratégias eficazes de conservação e restauração nessas florestas.

2. Traços reprodutivos e florais foram cruciais na diferenciação e distribuição espacial dos clusters funcionais. Características como simetria floral, tamanho e cor das flores impactam o custo da produção floral e a atração de polinizadores, o que, por sua vez, influencia o sucesso reprodutivo.

3. Síndromes de dispersão e características adaptativas dos frutos foram fundamentais na formação dos clusters de espécies. As propriedades morfológicas dos frutos influenciam os mecanismos de dispersão e as interações com os agentes dispersores. Métodos de dispersão, como dispersão pelo vento e por animais, moldam a estrutura espacial e a diversidade das comunidades vegetais.

4. A distribuição espacial dos clusters funcionais por meio do domínio fitogeográfico sugere uma adaptação flexível das espécies de plantas a diversas condições ambientais. No entanto, são evidentes preferências por ambientes topográficos específicos, tipos de solo e categorias climáticas. Fatores ambientais, particularmente o clima, influenciam significativamente a distribuição dos clusters funcionais.

5. *Síntese e aplicações.* Nossos achados destacam o papel significativo das características reprodutivas e florais na diferenciação e distribuição espacial dos clusters funcionais. Além disso, ressaltam a importância de compreender as relações complexas entre características funcionais e fatores ambientais para estratégias eficazes de conservação e manejo. Promover resiliência e heterogeneidade funcional através da integração de espécies e considerando fatores ambientais críticos pode aumentar a resiliência ecológica, estabilidade e diversidade, contribuindo para o desenvolvimento de práticas de restauração e manutenção da biodiversidade em ecossistemas impactados.

PALAVRAS-CHAVE

clusters funcionais, distribuição espacial, fatores ambientais, traços reprodutivos, síndromes de dispersão, manejo ecológico, resiliência ecológica, conservação da biodiversidade

1 Introduction

The Atlantic Forest is one of the most biodiverse and unique forest biomes on Earth (Marques et al., 2021; Mittermeier et al., 2004; Myers et al., 2000), being considered a biodiversity hotspot (Laurance, 2009). Over time, urbanization, industrialization, and the expansion of agricultural activities have significantly modified natural environments, leading to extensive fragmentation and habitat loss (da Fonseca, 1985; Joly et al., 2014), with forest cover now reduced to just 24.3% (MapBiomas Project, 2023). In recent years, Brazil has experienced a process of degradation of its environmental and social policies and institutions (Abessa et al., 2019; Ferrante & Fearnside, 2019; Oliveira & Araújo, 2020; Ruggiero et al., 2021), posing a significant risk to a historically threatened biome.

Large-scale global initiatives for restoration and reforestation have been promoted worldwide to partially reverse the processes and consequences involved (Chazdon & Brancalion, 2019; Rosa et al., 2021). The commitments made in recent years for the restoration of the Atlantic Forest are numerous, ranging from the Atlantic Forest Restoration Pact and the National Plan for Native Vegetation Recovery (Planaveg) to Brazil's nationally determined contribution to the Paris Climate Agreement and the United Nations Decade on Ecosystem Restoration (2021–2030). The science of restoration ecology and its applied practice of ecological restoration has been contributing to overcoming these challenges (Dobson et al., 1997; Nellemann et al., 2010; Perring et al., 2015; Suding et al., 2015). However, regrouping functional ecological communities after their degradation is challenging, and transforming commitments into restored landscapes requires planning (Brancalion & Holl, 2020; Holl & Brancalion, 2020).

A critical aspect of this planning involves understanding how the choice of species or groups of species can influence ecosystem structure and functioning. In this context, the approach based on functional traits emerges as a valuable strategy that can have lasting effects on plant communities and positive implications for restoration efforts. In general terms, "functional trait" can be defined as morphological, biochemical, physiological, structural, phenological, or behavioural characteristics significantly influencing establishment, survival, and reproduction. These traits are expressed in individual phenotypes and are considered relevant for organisms to respond to the environment and/or have effects on ecosystem properties (Díaz et al., 2013; Garnier et al., 2016; Reich et al., 2003; Violle et al., 2007). Ecosystem properties and community productivity depend on the functional traits of the species that compose them (Roscher et al., 2012). For this reason, functional traits are considered the best approach for the overall predictive understanding of communities and ecosystems (Adler et al., 2014), allowing the organisation of species or individuals into groups with similar functions or responses

(Rosenfield & Müller, 2020).

From this perspective, grouping species or functional groups with similar and relevant functional traits provides an adaptable framework for local context and restoration objectives (Laughlin, 2014). It is worth noting, however, that species often belong to more than one functional group, performing various functions at different levels (de Bello et al., 2010; Diaz et al., 2007), and their traits may contribute independently or jointly to the ecosystem (Carlucci et al., 2020; Gamfeldt et al., 2008). Thus, multiple functional traits reflect the diversity of ecosystem functions (Cadotte et al., 2011; Tsujii et al., 2020). Furthermore, communities with different species compositions can exhibit similar functionality (Laughlin et al., 2017), while communities predominantly composed of functionally similar species may not be resilient to environmental disturbances (Laughlin et al., 2018).

In recent years, traits have been employed to comprehend even the global dynamics of vegetation (Scholze et al., 2006) and the rate of ecosystem processes (Díaz & Cabido, 2001; Eviner & Chapin III, 2003; Garnier et al., 2004; Lavorel & Garnier, 2002). Although global databases such as the TRY Plant Trait Database (Kattge et al., 2020) contain information on functional traits, current knowledge is predominantly limited to species from temperate regions (Carlucci et al., 2020; Hortal et al., 2015) and much of the essential information for a large number of native tropical species is still lacking (Aerts & Honnay, 2011), or is still insufficient. For the Atlantic Forest, information on functional traits is scarce, focusing on tree species with small geographical distributions and no economic value (Petisco-Souza et al., 2020). The absence of basic information hampers the restoration of originally megadiverse tropical communities (Carlucci et al., 2020), particularly considering that the success of restoration efforts relies on the availability of taxonomic, ecological, physiological, and functional trait information for these species.

Knowledge about functional traits is indispensable for conserving and restoring biodiversity (Carlucci et al., 2020). Here, we focus on the functional traits of woody species in Seasonal Forests, a type of vegetation characterised by seasonality (alternation of rainy and dry periods) and belonging to the Atlantic Forest phytogeographic domain (Marques et al., 2021). Our analysis will encompass species from Semideciduous Seasonal Forests, where 20% to 50% of the trees shed their leaves in winter, and Deciduous Seasonal Forests, where more than 50% of the trees are deciduous (Marques et al., 2021), as well as species from Transition Forests to Forested Savannah or Riparian Forests.

The main objective of this study is to identify the key functional traits of the woody flora in the Seasonal Forests of the Mato Grosso do Sul state. Additionally, we aim to (i) group species into clusters based on their functional traits; (ii) analyze the relationships and overlaps among these functional groups in a multivariate space; and (iii) investigate the spatial distribution of species within these functional groups in Mato Grosso do Sul, examining potential correlations with environmental factors such as climate, pedology, and geomorphology. We expect to comprehend the functional traits that drive the formation of each functional cluster, the variations of traits within clusters, and the potential relationships between the spatial distribution of these clusters and environmental factors. This analysis will enable us to discuss how effective management of these clusters can be integrated into ecological restoration programs, with the goal of enhancing resilience and functional diversity in degraded areas.

2 Material and methods

2.1 Species list

To gather information on the functional traits of woody plant species in Seasonal Forests, data were compiled from 470 species, including trees, shrubs, cacti, and palms, listed by Damasceno-Junior et al. (2018) for the state of Mato Grosso do Sul. To classify the species, we utilised occurrence records provided by Damasceno-Junior et al. (2018), and we grouped the plants into three distinct phytophysiognomies: Deciduous Seasonal Forest, Semideciduous Seasonal Forest, and Transition to Forested Savannah or Riparian Forests, referred to here as Transition Forest. Families were organised according to the Angiosperm Phylogeny Group (APG IV, 2016). Additionally, botanical nomenclature was standardised according to the Flora e Funga do Brasil (2023) <floradobrasil.jbrj.gov.br>

2.2 Plant Functional Traits

We gathered information on the functional traits of species, which are related to essential aspects of their biology and ecology, and assigned presence and absence values to each trait (see Table 1). For this selection, we relied on previous studies (Fitter & Peat, 1994; Valladares et al., 2008), which were simplified to avoid ambiguities and overlapping concepts and definitions. The classification of wood density (SSD) followed the proposal by Jankowsky (1990) (Table 1). Regarding fruits, their classification regarding type, dehiscence, and adaptations for dispersal was mainly based on Barroso et al. (1999), which addresses the morphology of diaspores at the genus level, as well as the simplification of their work performed by Kuhlmann & Ribeiro (2016), also present in Kuhlmann & Fagg (2018a, 2018b) (Table S1). Regarding seed size, we used five qualitative categories according to Tabarelli & Peres (2002) and de Melo et al. (2006) (Table 1). The values of adult plant size (Hmax) were classified according to Stovall et al. (2019). Attributes related to plant survival, such as the ability to resprout and nitrogen fixation capacity, were also considered in this study.

Table 1. Definition of traits and groups of traits used in the study

Characteristics related to spatial occupation

Plant growth form	subshrub shrub tree palm
Size of adult plant (Hmax)	small (height < 15m) medium (15m - 30m) large (height > 30 m)
Plant phyllotaxis	alternate opposite
Stem epidermal characteristics	glabrous hispid lanate or very tomentose
Whole plant sexuality	monoic dioic hermaphrodite polygamous
Stem specific density (SSD) or wood density (g.cm-3)	light (density < 0,50 g.cm-3) moderately dense (0,51 g.cm-3 - 0,75 g.cm-3) dense woods (0,76 g.cm-3 - 0,95 g.cm-3) o very dense woods (density > 0,96 g.cm-3)

Characteristics related to foliar morphology

Vegetative phenology	evergreen semi-deciduous deciduous
Leaf compoundness	simple compound
Leaf epidermal characteristics	glabrous hispid lanate or very tomentose
Spinescence	absence presence

Characteristics related to reproduction and seed dispersal

Type of inflorescence	cymose racemose
Flower symmetry type (flower shape)	actinomorphic zygomorphic
Flower size	small (corolla < 5 mm) intermediate (5 mm - 20 mm) big (corolla > 20 mm)
Flower colour	brown-greenish white or coloured
Fruit dehiscence	indehiscent dehiscent
Fruit type	capsular follicular nucoid samaroid bacoid drupoid schizocarp arthrocarpal
Adaptation	fleshy adherent elaiosome aril pseudofruit resin mimetic seed plume winged light seeds explosive dehiscence
Seed size	very small (< 1 to 3 mm in length) or small (3.1 to 6 mm) medium (6.1 to 15 mm) large (15.1 to 30 mm) or very large (>30 mm in length)
Dispersal syndrome	anemochorous autochorous zoochorous
Dispersal agent	wind mammaliochory ornithochory myrmecochory chiropterochory mixed

Survival and nutrient-related traits

Plant nitrogen (N) fixation capacity	absence presence
Plant resprouting capacity	absence presence

2.3 Plant Functional Traits Database and species occurrence data

We obtained data on the functional traits (Table S2) from two databases: TRY - Plant Trait Database <try-db.org> (Kattge et al., 2020), global repository of plant characteristics, and BIEN - Botanical Information and Ecology Network database <bien.nceas.ucsb.edu/bien> through the R-package “R BIEN” (Maitner et al., 2018) in the statistical software R version 4.1.1 (R Core Team, 2021), using the RStudio Team environment (2022). Subsequently, we eliminated duplicate functional traits and outliers and calculated mean values, when necessary, for each species concerning the functional attribute. To complement the information on morphological characteristics and obtain data on species occurrence, we utilised two data sources: CRIA - Centro de Referência em Informação Ambiental <cria.org.br> and GBIF - Global Biodiversity Information Facility <gbif.org>. To access this information, we utilised the "rspecieslink" and "rgbif2" functions available in the R-package “plantR” (Lima et al., 2021) n the R statistical program. Next, we searched the literature (Table S3) for information on species that did not have attribute data in the abovementioned databases. Species without trait information were excluded from the analysis.

2.4 Clustering analysis and pattern identification

To identify patterns in the data and group species into different clusters based on their characteristics, we conducted a clustering analysis using the functional traits data of the Seasonal Forest species. Firstly, the data were preprocessed by excluding rows with missing values using the "na.omit" function and normalised using the "scale" function, transforming each variable into a mean of zero and a standard deviation of one. The clustering analysis was performed using the R-package "stats" by employing the "kmeans" function, which divides the species into groups based on their similarities. To determine the number of groups, we utilised the R-package "factoextra" (Kassambara & Mundt, 2020) with the "fviz_nbclust" function using the *gap statistic* method. A hierarchical clustering analysis was conducted using the "hcut" function, which generates a dendrogram illustrating the similarity relationships among the species. To extract the species list for each group, we used the group identification vector obtained from the "cutree" function and applied an anonymous function using "lapply" to obtain the species list for each group. Lastly, Principal Component Analysis (PCA) was performed using the R-package "stats" with the "prcomp" function, which reduces the dimensionality of the data and generates principal components that explain most of the data variance. PCA was carried out by phytophysiognomy to comprehend which variables had the greatest influence on cluster formation. All analyses were conducted in the statistical software R version 4.1.1 (R Core Team, 2021) within the RStudio Team environment (2022).

2.5 Geoprocessing and environmental data

To assess the spatial distribution of species composing the functional clusters across the Mato Grosso do Sul state, geoprocessing tools were employed to identify potential species distribution patterns concerning environmental factors. Utilising QGIS 3.30 software <qgis.org>, thematic maps were constructed incorporating geomorphological information (Figure S2), pedology data (Figure S3), and climate data (Figure S4) sourced from the Instituto Brasileiro de Geografia e Estatística (IBGE) <ibge.gov.br>. Occurrence data for the species obtained from CRIA and GBIF were exported and preprocessed to remove unnecessary information. In QGIS, this file was configured as a shapefile with a standardised coordinate reference system set to SIRGAS 2000 UTM Zone 18S. Geomorphological, pedology, and climate information were obtained from the Geosciences division of IBGE. Shapefile format data for these variables were acquired from IBGE and imported into QGIS. As these data covered the entire national territory, the GIS software's clipping tool was used to clip the layers and enhance the visibility of the study area. Attribute table information for each layer was saved, processed within QGIS, and utilised to verify correlations between clusters and environmental factors.

2.6 Data analysis

To identify patterns and trends in the data concerning different clusters and environmental variables, we employed the "ggparcoord" function from the R-package "GGally" (Schloerke et al., 2018) to generate parallel coordinate plots. To identify patterns of relationship and correlation among the data matrices, we utilised Multiple Factor Analysis (MFA) using the R-package "FactoMineR" (Lê et al., 2008). MFA is a multivariate technique based on the generalisation of Principal Component Analysis (PCA) aimed at analysing multiple sets of variable data collected on the same set of observations, providing a set of standard factorial scores and projecting each of the original data set to analyse communities and discrepancies (Abdi et al., 2013). MFA employs a factor analysis applied to the entire set of variables, where each group of variables is weighted, resulting in a canonical analysis (Escofier & Pages, 1994).

3 Results

3.1 Cluster analysis and general characterisation of resulting clusters

The optimal number of clusters established using the *gap statistic* technique for the Deciduous Seasonal Forest was determined as 2; for Semideciduous Seasonal Forest, it was determined as 4; and for Transition Forest, it was determined as 3 (Figure S1). The partitioning clustering plot identified the clusters for the three physiognomies (Figure 1).

Figure 1. Partitioning clustering plot showing the identified clusters of three seasonal forest phytophysiognomies using k-means clustering. The points on the plot represent plant samples, and their colours indicate which cluster each sample belongs to.

In Deciduous Forests, there is a significant differentiation among the clusters (Figure 1). The traits that contributed the most to the variance and formation of the clusters were related to fruit characteristics, flower characteristics, leaf characteristics, and seed dispersal (Figure 2). Cluster 1 (DC1) is mainly characterised by plants with indehiscent fruits, fleshy berries, or a fleshy aril surrounding the seeds, strongly associated with zoochoric dispersal by ornithochory and mammaliochory. These plants have simple leaves and glabrous stems, with actinomorphic flowers that are small and green. Cluster 2 (DC2), on the other hand, is primarily characterised by plants with dehiscent fruits, follicular and capsular, with the presence of winged expansions associated with anemochory. Plants in DC2 have compound leaves and white or colourful zygomorphic flowers.

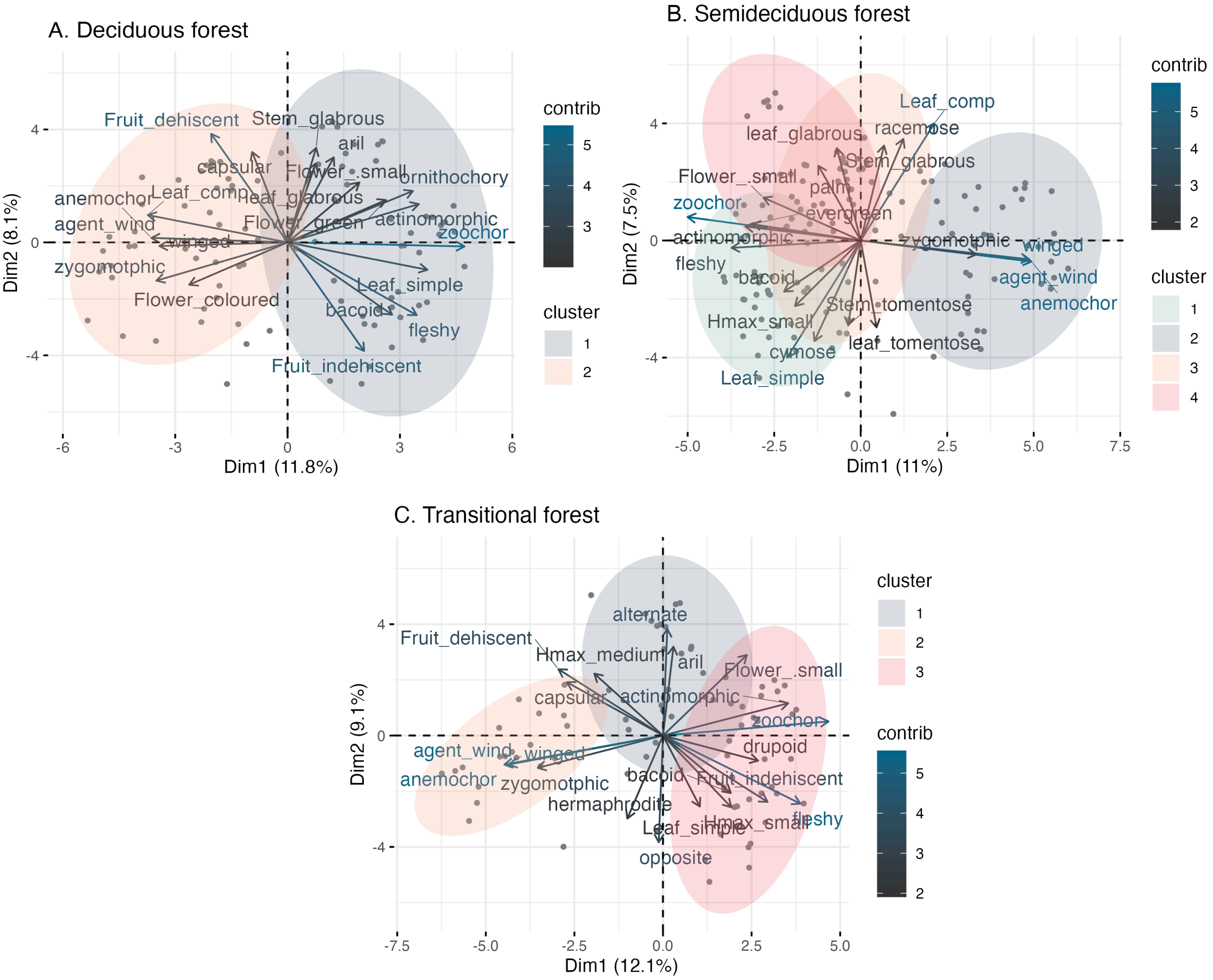

Figure 2. PCA biplot showing the main variables that explain the most variance in data grouped by each type of Seasonal Forest. The points represent the species, and the arrows indicate the variables' contribution to each cluster's formation. The elliptical areas highlight the high-density regions in each cluster.

The results indicated the presence of four distinct clusters (Figure 1) in the Semideciduous Forests. Cluster 3 (SC3) exhibits relationships with the other three clusters, particularly with Clusters 1 (SC1) and 4 (SC4), which also show overlaps between them and are distributed across the biplot dimensions primarily due to leaf composition. Cluster 2 (SC2) differs from the others, being more distant and sharing characteristics solely with SC3. The traits that contributed the most to the variance and formation of the clusters are related to reproductive aspects, involving fruits, their adaptations, and dispersal syndrome, as well as traits associated with flowers and epidermal characteristics of stems and leaves. SC1 is primarily characterised by small, evergreen plants with simple leaves, fleshy bacoid fruits, zoochorous dispersal, cymose inflorescences, and actinomorphic flowers. SC2 stands out from the other clusters by featuring plants with wing-like expansions associated with anemochory and zygomorphic flowers. The SC3 group shares characteristics with all clusters and is more heterogeneous regarding functional traits. This group consists of plants with simple leaves, tomentose stems and leaves, and plants with compound leaves, glabrous stems and leaves, racemose as well as cymose inflorescences, and drupoid fruits. Lastly, SC4 shares characteristics with SC1 and SC3 and primarily comprises small-flowered palms with glabrous leaves.

The Transition Forests were divided into three different clusters (Figure 1). Cluster 1 (TC1) exhibits similarities and shares attributes with Cluster 2 (TC2) but primarily with Cluster 3 (TC3). There are no characteristic similarities between the latter two. The variance and formation of the clusters were also related to reproduction-oriented attributes, such as fruit characteristics, adaptations, and seed dispersal. The first group, TC1, comprises medium-height species with compound and alternate leaves, small flowers, and adaptations involving fleshy and colourful arils surrounding the seeds. TC2, on the other hand, groups species with adaptations of wing-like expansions associated with anemochorous dispersal, dehiscent and capsular fruits, and flowers with zygomorphic symmetry. Finally, TC3 is represented by small plants with indehiscent, bacoid, and drupoid fruits, fleshy and associated with zoochorous dispersal. Additionally, the presence of species with small and actinomorphic flowers is observed.

3.2 Spatial distribution of clusters in the phytogeographic domain and their relationship with environmental factors

The analysis of the spatial distribution of species within functional clusters across the phytogeographic domain and the state of Mato Grosso do Sul revealed distinct patterns. Each cluster's predominant areas and zones of overlap were identified, highlighting the spatial organization of these clusters. In various proportions, the clusters exhibited remarkably similar distribution patterns across different categories of geomorphology, pedology, and climatic types (Figure 3). The clusters were predominantly distributed in regions characterised by Latossolo and Neossolo, primarily in Hills, Plains, and Depressions, with a hot and humid climate accompanied by 1 to 2 or 3 dry months or a sub-hot humid climate with 1 to 2 dry months.

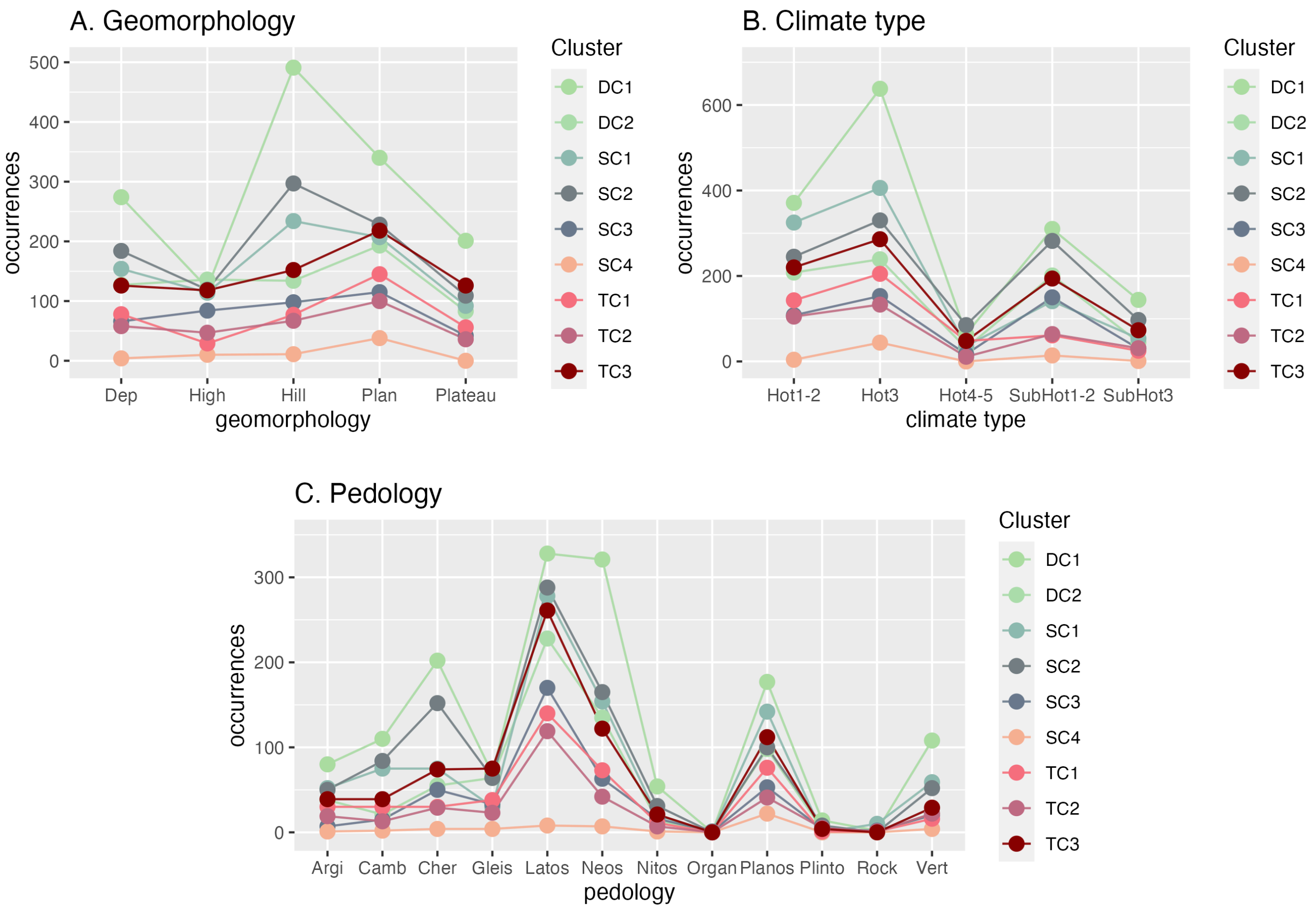

Figure 3. Distribution of clusters among the A. Geomorphology, B. Climate type and C. Pedology classes. In the geomorphology class, "Dep" represents Depressions, "High" represents Highlands, "Hill" represents Hills, "Plan" represents Plains, and "Plateau" represents Plateaus. In the climate type class, "Hot1-2" corresponds to Hot, humid (1 to 2 dm), "Hot3" corresponds to Hot, humid (3 dm), "Hot4-5" corresponds to Hot, semi-humid (4 to 5 dm), "SubHot1-2" corresponds to Sub-hot, humid (1 to 2 dm), and "SubHot3" corresponds to Sub-hot, humid (3 dm). Finally, in the pedology class, "Argi" stands for Argissolo, "Camb" stands for Cambissolo, "Cher" stands for Chernossolo, "Gleis" stands for Gleissolo, "Latos" stands for Latossolo, "Neos" stands for Neossolo, "Nitos" stands for Nitossolo, "Organ" stands for Organossolo, "Planos" stands for Planossolo, and "Plinto" stands for Plintossolo.

Although there are similarities in the distribution of species belonging to the clusters across environmental factors, significant differences influence the distribution of plant species. The Multiple Factor Analysis (MFA) based on geomorphology, pedology, and climate type data indicates that these factors strongly influence the clusters. Dim.1 explained the majority of the total variability (81.1%), followed by Dim.2 (7.0%) and Dim.3 (5.7%). The cumulative sum of eigenvalues shows that the first three dimensions explained 93.9% of the total variability. Geomorphology, pedology, and climate type exhibit high loadings on the first component (Dim.1), while the most significant loadings of the second component (Dim.2) are observed in pedology and climate (Figure S2, S3, and S4).

All variables have a strong positive correlation structure, demonstrating that they are highly interconnected (Table S5). The variables related to geomorphology and climate had a more significant contribution to the results of the MFA than the other variables associated with pedology (Figure 4b). Clusters TC1, TC2, and SC4, as well as DC2 and TC3, grouped in regions of the graph (Figure 4a), for example, exhibit more similar profiles concerning the considered variables than the remaining clusters.

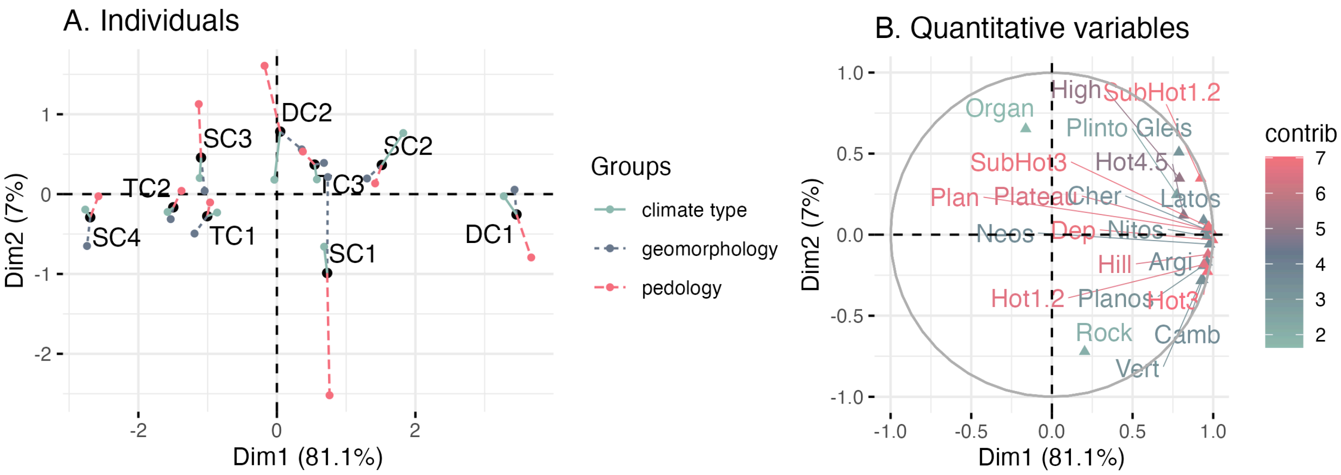

Figure 4. Multiple Factor Analysis (MFA): A. Individual factor map where points represent the centroid of clusters concerning Principal Component Analyses (PCA) of each group of variables. The colours used indicate different groups of variables, and the distance between the points represents their similarity or dissimilarity; B. Global PCA presents the correlation among multiple variables. The colours used indicate the contribution of each variable to the analysis, and the position of the points on the graph indicates the relationship between them.

Considering that the proximity of the points to the arrows indicates the contribution of these variables to the observed differences between groups, the observed patterns of association between environmental characteristics and the clusters suggest that each forest type presents a specific dynamic. The closer the point is to the arrow, the stronger the association between the variable and the respective cluster. Therefore, it is possible to observe that the different groups of variables have distinct strengths of influence among the different clusters.

4 Discussion

Although reproduction is one of the key aspects of individuals' fitness, reproductive and floral traits have played a secondary role in the ecology of functional traits and trait-based community assembly studies (E-Vojtkó et al., 2020). Nonetheless, the findings here reinforce the importance of traits associated with seed reproduction and dispersal in functional clusters' differentiation and spatial distribution. Floral characteristics, which play a crucial role in attracting pollinators and seed production (Faegri & Pijl, 1979), were particularly significant for the differentiation of clusters, especially in the species and physiognomies observed in this study. Floral symmetry, for instance, has been considered a determining factor in pollination syndromes (Ashworth et al., 2015; Rosas-Guerrero et al., 2014; Yoder et al., 2020). Additionally, flower size and colour directly affect the cost of flower production and, consequently, their ability to attract pollinators (E-Vojtkó et al., 2022; Krizek & Anderson, 2013).

Although in some species or habitats the relationship between fitness and floral traits may appear subtle, typically during the sexual reproduction phase of the plant life cycle, floral traits assume great importance for maximising reproductive success (Larson & Funk, 2016). This significance is partially attributed to the fact that larger flowers generally contain more nectar and are more visible to pollinators (Blarer et al., 2002; Fenster et al., 2006), have been associated with phenotypic selection for larger flowers (Zhao et al., 2020), and that flower colour components can serve as signalling cues for pollinators (Garcia et al., 2014; Horth et al., 2014; Lunau, 2000; Trunschke et al., 2021; Van Der Kooi et al., 2021; Verhoeven et al., 2018), which may increase visitation rates (Fenster et al., 2006; Krizek & Anderson, 2013) and, consequently, the probability of fertilisation.

The dispersal syndrome and fruits' adaptive characteristics played a crucial role in clustering species in all cases. These characteristics are closely related, as the morphological properties of fruits influence how they are dispersed and act as a selective barrier that restricts interaction with seed dispersal agents at the community level (Bender et al., 2018; Burns, 2013; Dehling et al., 2016; Olesen et al., 2011; Rojas et al., 2022). Dispersal is the only means by which plants can colonize new habitats; hence it is understandable that plants have evolved various physical methods to accomplish this task (Seale & Nakayama, 2020), being a fundamental process that shapes the spatial structure and diversity of plant communities (Morán-López et al., 2018). The distances over which seeds are dispersed are critical for examining the spatial patterns of seed dispersal and their implications for plant reproductive success and population structure (Heymann et al., 2012). The distances over which seeds are dispersed are critical for examining the spatial patterns of seed dispersal and their implications for plant reproductive success and population structure.

Plants with large seeds and fruits featuring attractive adaptations for fauna, for instance, rely on animals for their dispersal, whereas those with lighter and smaller seeds, along with adaptations such as wing-like expansions or plumes, are more easily dispersed by wind over long distances (Ghamari et al., 2010; Pijl, 1982; van Rheede van Oudtshoorn & van Rooyen, 1999). In tropical regions, where a significant portion of plants relies on vertebrates for seed dispersal, frugivores play a vital role in shaping plant communities, and their behavior can influence the spatial distribution of dispersed seeds and accelerate succession in planted stands compared to natural succession (De La Peña-Domene et al., 2014; Gopal et al., 2020).

The similarities in fruit characteristics have originated through complex evolutionary pathways in response to mutualistic interactions with dispersers - Dispersal Syndrome Hypothesis (DSH; Valenta & Nevo, 2020), and currently, they influence the interaction between species and dispersers (Blendinger et al., 2016; Dehling et al., 2016; González-Castro et al., 2015). The contributions of dispersal syndromes, fruit adaptations, and flower characteristics in shaping different clusters indicate that the plants of the phytophysiognomies in question have evolved to exploit different ecological niches in the region and underscore the importance of these traits in the structuring of these communities.

The DC2, SC2, and TC1 clusters, predominantly composed of anemochorous species, share characteristics such as wing expansions and zygomorphic flowers. In DC2 and TC1, the fruits are predominantly capsule-shaped, while in SC2 they are mostly samaroid. Anemochory, or wind dispersal, is highly frequent, particularly in drier and more open environments (Jara-Guerrero et al., 2011; Soons et al., 2004). Fruit modifications such as wing expansions primarily serve to enhance the diaspore's resistance to air, thus prolonging its flight time and expanding its capacity for wind-mediated transport (Eriksson & Kainulainen, 2011; Minami & Azuma, 2003; van Rheede van Oudtshoorn & van Rooyen, 1999; Zhang et al., 2014). The wings found in species belonging to clusters of anemochorous species aid in gliding when symmetrically arranged, and when arranged asymmetrically, they provide dynamic propulsion. This is why most tree species with winged diaspores are large (Minami & Azuma, 2003; van Rheede van Oudtshoorn & van Rooyen, 1999).

The remaining clusters, mostly composed of zoochorous species, also share characteristics such as small, actinomorphic flowers and mainly bacoid or drupoid fruits, fleshy or with fleshy aril surrounding the seeds. Zoochory is a phenomenon associated with forest environments, owing to the high diversity of frugivorous species in these habitats (Willson et al., 1990). To attract the dispersing species, properties such as colour, odour, and size play a determining role (Fahn & Werker, 1972). Adaptations such as the presence of fleshy and colourful aril surrounding the seeds and fleshy fruits fulfil the role of making the diaspore more attractive to fauna, particularly avian and mammalian frugivores (Evrard et al., 2019; Fleming & John Kress, 2011; Pijl, 1982; Skutch, 1980; Valenta & Nevo, 2020).

Regarding floral symmetry, zygomorphic flowers are associated with higher rates of diversification (O'Meara et al., 2016; Sargent, 2004; Vamosi & Vamosi, 2010) and are commonly considered more specialised than those with actinomorphic symmetry, which is regarded as an axiom of pollination ecology (Darwin, 1877; Endress, 2012; Stebbins, 1974; Takhtajan, 1981). Actinomorphic flowers, with their radial symmetry, are often associated with generalist pollinators due to easy access to nectar and pollen from all directions, attracting a wide range of pollinators, including bees, butterflies, and beetles, whereas zygomorphic flowers are typically specialized for pollination by specific pollinator species (Chapman et al., 2012; Lázaro et al., 2008). However, at both the global and community levels, plants with zygomorphic flowers tend to have fewer visitor species and, therefore, may be more susceptible to pollinator loss (Yoder et al., 2020).

The spatial distribution pattern of functional clusters throughout the phytogeographic domain in the state of Mato Grosso do Sul significantly contributes to understanding the determinants of the relationship between the floristic composition of these areas and various environmental factors. The presence of clusters in distinct geomorphological, pedological, and climatic categories (Figure 3) suggests a flexible adaptation of plant species to diverse environmental conditions. However, a preference for specific topographic environments (Plains, Hills, and Depressions), soil types (Latossolo and Neossolo regions), and climate types (hot and humid with 1 to 2 or 3 dry months, or sub-hot with 1 to 2 dry months) is evident. Despite this, the MFA indicated that these variables do not uniformly affect all clusters and that these groups of variables exert different levels of influence on each cluster. In most cases, climate was highly correlated with the clusters, serving as a crucial factor in determining their distribution.

The distribution and patterns of plant species are influenced by a multitude of environmental factors that interact to shape the composition and structure of plant communities. The influence of climate on plant species distribution has been extensively documented from early biogeographers (Humboldt & Bonpland, 1805) to contemporary ecologists (Bañares-de-Dios et al., 2022; Morueta-Holme & Svenning, 2018; Willig et al., 2003). Climate, particularly temperature and precipitation, is considered the primary factor controlling the distribution of plant species at a continental scale (Thompson et al., 2006) and influences the composition patterns of plant communities and species distribution in tropical communities (Bañares-de-Dios et al., 2022; Engelbrecht et al., 2007; Esquivel-Muelbert et al., 2017; Hawkins et al., 2003; Ter Steege et al., 2006; Woodward et al., 2004). Moreover, precipitation and temperature have been identified as significant drivers of the large-scale geographic distribution of species with fleshy fruits (Zhao et al., 2018). Understanding these dynamics is crucial for predicting how plant communities will respond to future environmental changes.

The distribution patterns of shrub and tree species are deeply influenced by climate, affecting the diversity, composition, and interactions of plant communities. Historical climatic conditions have a lasting influence on the distribution of shrubs and trees, highlighting the climate's impact on woody plant diversity (Loidi et al., 2021). Furthermore, both tree and shrub richness exhibit similar responses to climatic variables, indicating large-scale spatial autocorrelation patterns in response to climate (Speziale et al., 2010). Climate change poses a significant threat to ecosystems, altering species distribution and composition patterns and modifying the dynamics of plant communities, leading to changes in vegetation structure and biodiversity (Limpens et al., 2021; Mod & Luoto, 2016). Understanding the intricate relationships between climate and woody plant species is crucial for effective conservation and management strategies in the face of ongoing environmental changes.

The results underscore the importance of functional traits related to reproduction and dispersal in categorizing and understanding species within their distinct ecological clusters. The notable overlap and significant interrelation among functional groups in different clusters suggest that these groups are not strictly isolated but rather parts of a complex ecological *continuum*. The spatial distribution of species, correlated with specific environmental factors observed in this study, reinforces the need for targeted management strategies in ecological restoration programs. Climate and geomorphology emerge as determining factors, while soil characteristics also play an important role in the pattern of species distribution.

Promoting resilience and functional heterogeneity in the restoration of Seasonal Forests can be achieved by integrating species based on specific functional traits associated with seed reproduction and dispersal, and by considering critical environmental factors related to these species. For the studied sample universe, it is recommended to focus on functional traits such as fruit shape and size, which can influence dispersal effectiveness, and flower morphology, which affects attractiveness to pollinators. This approach can enhance ecological resilience by reducing vulnerability to environmental changes and the loss of specific pollinators, while promoting stability and ecological diversity. These recommendations are crucial for developing more effective and sustainable restoration practices, contributing to the recovery and maintenance of biodiversity in impacted ecosystems.

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Supporting Information

Table S1. Characterisation of fruit types according to Barroso (1999), Kuhlmann & Ribeiro (2016), and Kuhlmann & Fagg (2018a, 2018b).

	Fruit type	Characteristics
1	Capsular	Dry, dehiscent fruits formed by two or more carpels.
2	Follicular	Dry, dehiscent fruits formed by only one carpel.
3	Nucoid	Dry, indehiscent fruit.
4	Samaroid	Dry, indehiscent, winged fruits.
5	Bacoid	Fleshy fruits without the formation of a pit surrounding the seeds.
6	Drupoid	Fleshy fruits with the formation of a pit surrounding the seeds.
7	Schizocarp	Dry, indehiscent fruits segregate into smaller dispersion units.
8	Arthrocarpal	Fruit dry, indehiscent, uni carpellate, segregated into smaller units.

Table S2. Trait List and TraitID in the TRY database.

Trait_ ID	Trait name
917	Fruit width (diameter)
2934	Inflorescence type
2935	Flower symmetry type (flower shape)
29	Pollination syndrome
2940	Fruit dehiscence type
99	Fruit type
27	Seed length
28	Dispersal syndrome
1251	Plant vegetative phenology (leaf phenology)
17	Leaf compoundness
8	Plant nitrogen(N) fixation capacity
819	Plant resprouting capacity
4	Stem specific density (SSD) or wood density (stem dry mass per stem fresh volume)
24	Bark thickness
14	Leaf nitrogen (N) content organic per leaf dry mass
15	Leaf phosphorus (P) content per leaf dry mass
3086	Leaf area per leaf dry mass (specific leaf area, SLA or 1/LMA) petiole, rhachis and midrib excluded
660	Leaf nitrogen (N) content organic per leaf dry mass
15	Leaf phosphorus (P) content per leaf dry mass
33	Leaf photosynthesis rate per leaf area
3086	Leaf area per leaf dry mass (specific leaf area, SLA or 1/LMA) petiole, rhachis and midrib excluded

Table S3. List of literature from which additional functional trait information was obtained.

No	Reference
1	Barbosa, L. M. (2017). *Lista de espécies indicadas para restauração ecológica para diversas regiões do Estado de São Paulo.* Instituto de Botânica.
2	Barroso, G. M. (Org.). (1999). *Frutos e sementes: Morfologia aplicada à sistemática de dicotiledôneas.* UFV, Universidade Federal de Viçosa.
3	Carvalho, P. E. R. (2003). *Espécies arbóreas brasileiras* (1° ed., Vol. 1). Embrapa Informação Tecnológica.
4	Carvalho, P. E. R. (2006). *Espécies arbóreas brasileiras* (1° ed., Vol. 2). Embrapa Informação Tecnológica.
5	Carvalho, P. E. R. (2008). *Espécies arbóreas brasileiras.* (1° ed., Vol. 3). Embrapa Informação Tecnológica.
6	Carvalho, P. E. R. (2010). *Espécies arbóreas brasileiras* (1° ed., Vol. 4). Embrapa Informação Tecnológica.
7	Carvalho, P. E. R. (2014). *Espécies arbóreas brasileiras* (1° ed., Vol. 5). Embrapa Informação Tecnológica.
8	de Melo, F. P. L., Dirzo, R., & Tabarelli, M. (2006). Biased seed rain in forest edges: Evidence from the Brazilian Atlantic forest. *Biological Conservation,* 132(1), 50–60. https://doi.org/10.1016/j.biocon.2006.03.015
9	Fitter, A. H., & Peat, H. J. (1994). The Ecological Flora Database. *The Journal of Ecology,* 82(2), 415. https://doi.org/10.2307/2261309
10	Gomes, V. G. N., Sazima, M., Arruda, R., Fischer, E., & Araujo, A. C. (2021). Temporal Patterns of Pollination and Seed Dispersal in Capões of the Southern Pantanal. In G. A. Damasceno-Junior & A. Pott (Orgs.), *Flora and Vegetation of the Pantanal Wetland* (Vol. 18, p. 551–577). Springer International Publishing. https://doi.org/10.1007/978-3-030-83375-6_14
11	Gonçalves, E. G., & Lorenzi, H. (2011). *Morfologia Vegetal* (2° ed). Jardim Botânico Plantarum: Instituto Plantarum de Estudos da Flora Ltda.
12	Jankowsky, I. P., Chimelo, J. P., Cavalcante, A. A., Galina, I. C. M., & Nagamura, J. C. S. (1990). *Madeiras brasileiras.* Spectrum.
13	Kuhlmann, M., & Fagg, C. W. (2018a). *Frutos e sementes do Cerrado: Espécies atrativas para fauna* (2° ed., Vol. 1). Frutos atrativos do Cerrado.
14	Kuhlmann, M., & Fagg, C. W. (2018b). *Frutos e sementes do Cerrado: Espécies atrativas para fauna* (2° ed., Vol. 2). Frutos atrativos do Cerrado.
15	Lorenzi, H. (2020). *Árvores brasileiras manual de identificação e cultivo de plantas arbóreas nativas do Brasil* (8° ed., Vol. 1). Jardim Botânico Plantarum: Instituto Plantarum de Estudos da Flora Ltda.
16	Lorenzi, H. (2021). *Árvores brasileiras manual de identificação e cultivo de plantas arbóreas nativas do Brasil* (3° ed., Vol. 3). Jardim Botânico Plantarum: Instituto Plantarum de Estudos da Flora Ltda.
17	Lorenzi, H. (2022). *Árvores brasileiras: Manual de identificação e cultivo de plantas arbóreas nativas do Brasil* (6° ed., Vol. 2). Jardim Botânico Plantarum: Instituto Plantarum de Estudos da Flora Ltda.
18	Pott, A., & Pott, V. J. (1994). *Plantas do Pantanal*. Centro de Pesquisa Agropecuária do Pantanal, Serviço de Produção de Informação.
19	Ramírez, N., Barrios, Y., & Briceño, H. (2021). Correlations between morphological fruit types, fruit and seed colors, and functional groups. *Biota Neotropica*, 21(4), e20211238. https://doi.org/10.1590/1676-0611-bn-2021-1238
20	Souza, V. C., & Lorenzi, H. (2019). *Botânica sistemática: Guia ilustrado para identificação das famílias de Fanerógamas nativas e exóticas no Brasil, baseado em APG IV* (4o ed). Jardim Botânico Plantarum : Instituto Plantarum de Estudos da Flora Ltda.
21	Tabarelli, M., & Peres, C. A. (2002). Abiotic and vertebrate seed dispersal in the Brazilian Atlantic forest: Implications for forest regeneration. *Biological Conservation*, 106(2), 165–176. https://doi.org/10.1016/S0006-3207(01)00243-9
22	Valladares, F., Tena, D., Matesanz, S., Bochet, E., Balaguer, L., Costa-Tenorio, M., Tormo, J., & García-Fayos, P. (2008). Functional traits and phylogeny: What is the main ecological process determining species assemblage in roadside plant communities? J*ournal of Vegetation Science*, 19(3), 381–392. https://doi.org/10.3170/2008-8-18378
23	Wanderley, M. das G. L., Giulietti, A. M., Melhem, T. S., & Shepherd, G. J. (2005). *Flora fanerogâmica do Estado de São Paulo*. (Vol. 4). Editora RiMa.
24	Wanderley, M. das G. L., Giulietti, A. M., Melhem, T. S., & Shepherd, G. J. (2009). *Flora fanerogâmica do Estado de São Paulo.* (Vol. 6). Instituto de Botânica.

Figure S1. The optimal number of clusters for the three seasonal forest phytophysiognomies, determined using the *gap statistic* method.

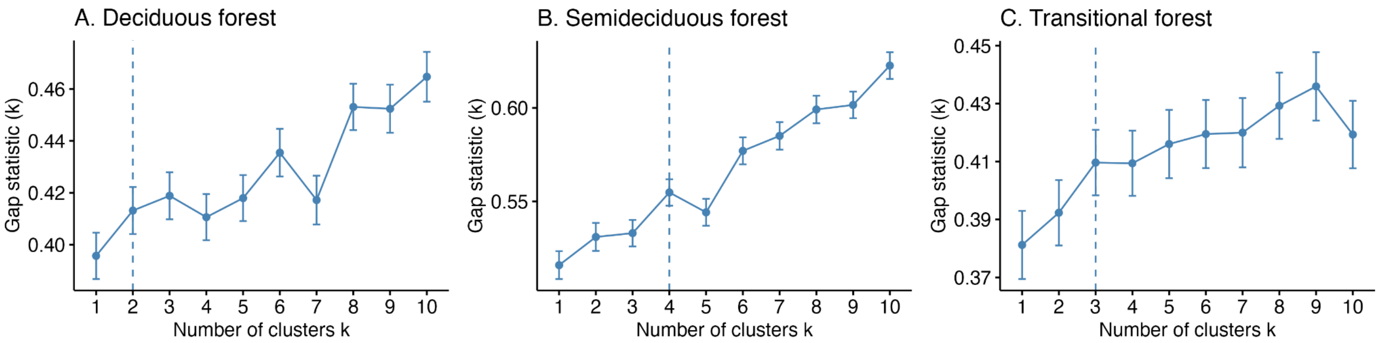

Table S4: Species grouped by Cluster, with a focus on those for which occurrence data is not available.

Cluster	**Species**	
SC1	*Allophylus_edulis*	
SC1	*Apuleia_leiocarpa*	
SC1	*Aspidosperma_pyrifolium*	
SC1	*Astronium_fraxinifolium*	
SC1	*Astronium_graveolens*	unavailable data
SC1	*Calycophyllum_multiflorum*	
SC1	*Cariniana_estrellensis*	
SC1	*Cedrela_fissilis*	
SC1	*Ceiba_speciosa*	
SC1	*Cordia_trichotoma*	
SC1	*Coutarea_hexandra*	
SC1	*Diplokeleba_floribunda*	
SC1	*Diptychandra_aurantiaca*	
SC1	*Gallesia_integrifolia*	
SC1	*Handroanthus_heptaphyllus*	
SC1	*Handroanthus_ochraceus*	
SC1	*Handroanthus_serratifolius*	
SC1	*Kielmeyera_coriacea*	
SC1	*Lafoensia_pacari*	
SC1	*Luehea_candicans*	
SC1	*Luehea_grandiflora*	
SC1	*Luehea_paniculata*	
SC1	*Machaerium_stipitatum*	
SC1	*Machaerium_villosum*	
SC1	*Peltophorum_dubium*	
SC1	*Plathymenia_reticulata*	
SC1	*Platypodium_elegans*	
SC1	*Simira_sampaioana*	unavailable data
SC1	*Sparattosperma_leucanthum*	
SC1	*Spondias_mombin*	unavailable data
SC1	*Sweetia_fruticosa*	
SC1	*Tabebuia_aurea*	
SC1	*Tabebuia_roseoalba*	
SC1	*Terminalia_argentea*	
SC1	*Terminalia_corrugata*	
SC1	*Terminalia_glabrescens*	
SC1	*Trema_micrantha*	
SC1	*Triplaris_gardneriana*	
SC2	*Aegiphila_integrifolia*	
SC2	*Agonandra_brasiliensis*	
SC2	*Aloysia_virgata*	
SC2	*Annona_sylvatica*	
SC2	*Apeiba_tibourbou*	unavailable data
SC2	*Blepharocalyx_salicifolius*	
SC2	*Brosimum_gaudichaudii*	
DC1	*Coutarea_hexandra*	
DC1	*Diatenopteryx_sorbifolia*	
DC1	*Dilodendron_bipinnatum*	
DC1	*Dimorphandra_mollis*	
DC1	*Diplokeleba_floribunda*	
DC1	*Enterolobium_contortisiliquum*	
DC1	*Guibourtia_hymenaeifolia*	
DC1	*Handroanthus_impetiginosus*	
DC1	*Handroanthus_serratifolius*	
DC1	*Helietta_apiculata*	
DC1	*Hymenaea_martiana*	
DC1	*Lachesiodendron_viridiflorum*	unavailable data
DC1	*Luehea_divaricata*	
DC1	*Machaerium_acutifolium*	
DC1	*Magonia_pubescens*	
DC1	*Maprounea_brasiliensis*	
DC1	*Maprounea_guianensis*	
DC1	*Ormosia_arborea*	
DC1	*Peltophorum_dubium*	
DC1	*Pilocarpus_pennatifolius*	
DC1	*Pseudobombax_grandiflorum*	
DC1	*Pseudobombax_longiflorum*	
DC1	*Pterogyne_nitens*	
DC1	*Samanea_tubulosa*	
DC1	*Sapium_glandulosum*	
DC1	*Sapium_haematospermum*	
DC1	*Schinopsis_brasiliensis*	unavailable data
DC1	*Senegalia_polyphylla*	
DC1	*Senegalia_tenuifolia*	
DC1	*Senna_spectabilis*	unavailable data
DC1	*Sterculia_apetala*	unavailable data
DC1	*Sterculia_striata*	
DC1	*Strychnos_pseudoquina*	
DC1	*Tabebuia_roseoalba*	
DC1	*Terminalia_fagifolia*	
DC1	*Trichilia_catigua*	
DC1	*Triplaris_americana*	unavailable data
DC1	*Zanthoxylum_caribaeum*	unavailable data
DC1	*Zanthoxylum_fagara*	unavailable data
DC1	*Zanthoxylum_rhoifolium*	unavailable data
DC1	*Zeyheria_montana*	
DC1	*Zygia_latifolia*	
DC2	*Agonandra_brasiliensis*	
DC2	*Andira_cujabensis*	
DC2	*Annona_coriacea*	

Cluster	Species	
SC2	*Cecropia_pachystachya*	
SC2	*Cestrum_schlechtendalii*	
SC2	*Chrysophyllum_marginatum*	
SC2	*Cordia_sellowiana*	
SC2	*Cordiera_sessilis*	
SC2	*Dendropanax_cuneatus*	
SC2	*Didymopanax_morototoni*	unavailable data
SC2	*Dipteryx_alata*	
SC2	*Erythroxylum_daphnites*	
SC2	*Eugenia_pyriformis*	
SC2	*Eugenia_subterminalis*	
SC2	*Garcinia_brasiliensis*	
SC2	*Guapira_opposita*	
SC2	*Guazuma_ulmifolia*	unavailable data
SC2	*Hancornia_speciosa*	
SC2	*Holocalyx_balansae*	
SC2	*Jacaratia_spinosa*	
SC2	*Leptobalanus_parvifolius*	
SC2	*Maclura_tinctoria*	
SC2	*Melicoccus_lepidopetalus*	
SC2	*Mimosa_bimucronata*	
SC2	*Myrcia_guianensis*	
SC2	*Myrcianthes_pungens*	
SC2	*Myrciaria_tenella*	
SC2	*Myrsine_guianensis*	
SC2	*Persea_willdenovii*	
SC2	*Piper_amalago*	
SC2	*Pouteria_torta*	
SC2	*Priogymnanthus_hasslerianus*	
SC2	*Prockia_crucis*	
SC2	*Psidium_sartorianum*	
SC2	*Psychotria_carthagenensis*	
SC2	*Randia_armata*	
SC2	*Rudgea_jasminoides*	
SC2	*Rudgea_viburnoides*	
SC2	*Simarouba_amara*	
SC2	*Siparuna_guianensis*	
SC2	*Sloanea_guianensis*	
SC2	*Sorocea_bonplandii*	
SC2	*Styrax_camporum*	
SC2	*Talisia_esculenta*	
SC2	*Tapirira_guianensis*	unavailable data
SC2	*Unonopsis_guatterioides*	
SC2	*Urera_baccifera*	unavailable data
SC2	*Vitex_cymosa*	
SC2	*Xylopia_aromatica*	
SC3	*Albizia_niopoides*	
SC3	*Alchornea_discolor*	
SC3	*Alchornea_glandulosa*	
SC3	*Alchornea_triplinervia*	
SC3	*Anadenanthera_peregrina*	
SC3	*Cabralea_canjerana*	
SC3	*Casearia_obliqua*	
SC3	*Casearia_sylvestris*	
SC3	*Copaifera_langsdorffii*	
SC3	*Croton_floribundus*	
SC3	*Croton_urucurana*	
SC3	*Enterolobium_contortisiliquum*	
SC3	*Erythrina_mulungu*	
SC3	*Geoffroea_spinosa*	
SC3	*Guarea_guidonia*	
SC3	*Guarea_kunthiana*	
SC3	*Guarea_macrophylla*	
SC3	*Guibourtia_hymenaeifolia*	

Cluster	Species	
DC2	*Annona_cornifolia*	
DC2	*Annona_emarginata*	
DC2	*Annona_nutans*	
DC2	*Campomanesia_xanthocarpa*	
DC2	*Celtis_iguanaea*	
DC2	*Celtis_spinosa*	
DC2	*Cestrum_mariquitense*	
DC2	*Chrysophyllum_gonocarpum*	
DC2	*Chrysophyllum_marginatum*	
DC2	*Diospyros_inconstans*	
DC2	*Erythroxylum_cuneifolium*	
DC2	*Erythroxylum_pelleterianum*	
DC2	*Eugenia_florida*	
DC2	*Genipa_americana*	
DC2	*Guapira_areolata*	
DC2	*Hieronyma_alchorneoides*	
DC2	*Maclura_tinctoria*	
DC2	*Myrcia_bella*	
DC2	*Myrcia_tomentosa*	
DC2	*Myrciaria_delicatula*	
DC2	*Myrsine_gardneriana*	
DC2	*Palicourea_tomentosa*	unavailable data
DC2	*Pouteria_torta*	
DC2	*Priogymnanthus_hasslerianus*	
DC2	*Randia_armata*	
DC2	*Sapindus_saponaria*	unavailable data
DC2	*Sideroxylon_obtusifolium*	
DC2	*Syagrus_romanzoffiana*	unavailable data
DC2	*Urera_caracasana*	unavailable data
TC1	*Aspidosperma_australe*	
TC1	*Aspidosperma_cylindrocarpon*	
TC1	*Astronium_fraxinifolium*	
TC1	*Bowdichia_virgilioides*	
TC1	*Callisthene_fasciculata*	
TC1	*Cariniana_estrellensis*	
TC1	*Combretum_leprosum*	
TC1	*Handroanthus_heptaphyllus*	
TC1	*Handroanthus_serratifolius*	
TC1	*Himatanthus_obovatus*	
TC1	*Luehea_divaricata*	
TC1	*Machaerium_paraguariense*	
TC1	*Pseudobombax_marginatum*	
TC1	*Qualea_parviflora*	
TC1	*Terminalia_glabrescens*	
TC1	*Triplaris_americana*	unavailable data
TC1	*Vochysia_cinnamomea*	
TC1	*Vochysia_divergens*	
TC1	*Vochysia_haenkeana*	
TC2	*Albizia_niopoides*	
TC2	*Alchornea_castaneifolia*	
TC2	*Casearia_aculeata*	
TC2	*Casearia_gossypiosperma*	
TC2	*Casearia_sylvestris*	
TC2	*Cecropia_pachystachya*	
TC2	*Copaifera_langsdorffii*	
TC2	*Cupania_vernalis*	
TC2	*Curatella_americana*	
TC2	*Dilodendron_bipinnatum*	
TC2	*Enterolobium_contortisiliquum*	
TC2	*Guarea_guidonia*	
TC2	*Guazuma_ulmifolia*	unavailable data
TC2	*Hymenaea_courbaril*	
TC2	*Inga_vera*	
TC2	*Mabea_fistulifera*	

Cluster	**Species**	
SC3	*Inga_laurina*	
SC3	*Inga_marginata*	
SC3	*Lachesiodendron_viridiflorum*	unavailable data
SC3	*Margaritaria_nobilis*	
SC3	*Matayba_elaeagnoides*	
SC3	*Matayba_guianensis*	
SC3	*Pilocarpus_pennatifolius*	
SC3	*Protium_heptaphyllum*	
SC3	*Protium_spruceanum*	
SC3	*Sterculia_striata*	
SC3	*Swartzia_jorori*	
SC3	*Tabernaemontana_catharinensis*	
SC3	*Trichilia_clausseni*	
SC3	*Trichilia_hirta*	unavailable data
SC3	*Zanthoxylum_caribaeum*	unavailable data
SC3	*Zanthoxylum_fagara*	unavailable data
SC3	*Zanthoxylum_petiolare*	unavailable data
SC3	*Zanthoxylum_rhoifolium*	unavailable data
SC3	*Zanthoxylum_riedelianum*	
SC4	*Acrocomia_aculeata*	
SC4	*Attalea_speciosa*	unavailable data
SC4	*Copernicia_alba*	
SC4	*Euterpe_edulis*	
SC4	*Syagrus_oleracea*	
SC4	*Syagrus_romanzoffiana*	unavailable data
DC1	*Aloysia_virgata*	
DC1	*Amburana_cearensis*	
DC1	*Anadenanthera_colubrina*	
DC1	*Aspidosperma_cuspa*	unavailable data
DC1	*Aspidosperma_polyneuron*	unavailable data
DC1	*Aspidosperma_subincanum*	
DC1	*Aspidosperma_tomentosum*	
DC1	*Astronium_urundeuva*	
DC1	*Balfourodendron_riedelianum*	
DC1	*Bauhinia_cheilantha*	
DC1	*Bauhinia_longifolia*	
DC1	*Bauhinia_ungulata*	
DC1	*Calycophyllum_multiflorum*	
DC1	*Casearia_gossypiosperma*	
DC1	*Casearia_rupestris*	
DC1	*Casearia_sylvestris*	
DC1	*Ceiba_samauma*	
DC1	*Combretum_leprosum*	
DC1	*Commiphora_leptophloeos*	unavailable data
DC1	*Copaifera_martii*	
DC1	*Cordia_glabrata*	

Cluster	**Species**	
TC2	*Maprounea_guianensis*	
TC2	*Ormosia_arborea*	
TC2	*Protium_heptaphyllum*	
TC2	*Protium_spruceanum*	
TC2	*Samanea_tubulosa*	
TC2	*Siparuna_guianensis*	
TC2	*Tapirira_guianensis*	unavailable data
TC2	*Trichilia_elegans*	
TC2	*Trichilia_pallida*	
TC2	*Xylopia_aromatica*	
TC3	*Acrocomia_aculeata*	
TC3	*Andira_inermis*	
TC3	*Annona_montana*	
TC3	*Attalea_speciosa*	unavailable data
TC3	*Byrsonima_coccolobifolia*	
TC3	*Byrsonima_verbascifolia*	
TC3	*Campomanesia_guazumifolia*	
TC3	*Chomelia_pohliana*	
TC3	*Chrysophyllum_marginatum*	
TC3	*Copernicia_alba*	
TC3	*Cordiera_sessilis*	
TC3	*Crateva_tapia*	unavailable data
TC3	*Dendropanax_cuneatus*	
TC3	*Erythroxylum_cuneifolium*	
TC3	*Eugenia_florida*	
TC3	*Eugenia_myrcianthes*	
TC3	*Eugenia_uniflora*	unavailable data
TC3	*Genipa_americana*	
TC3	*Guettarda_viburnoides*	
TC3	*Hieronyma_alchorneoides*	
TC3	*Nectandra_cissiflora*	
TC3	*Nectandra_megapotamica*	
TC3	*Ouratea_castaneifolia*	
TC3	*Palicourea_crocea*	
TC3	*Palicourea_deflexa*	unavailable data
TC3	*Palicourea_tomentosa*	unavailable data
TC3	*Pouteria_gardneri*	
TC3	*Prockia_crucis*	
TC3	*Psidium_guineense*	
TC3	*Salacia_elliptica*	
TC3	*Sapindus_saponaria*	unavailable data
TC3	*Sideroxylon_obtusifolium*	
TC3	*Simarouba_amara*	
TC3	*Vitex_cymosa*	
TC3	*Ximenia_americana*	unavailable data

Figure S2. Geomorphology map displaying the geographical distribution of species belonging to each functional cluster across different geomorphological classes in the state of Mato Grosso do Sul.

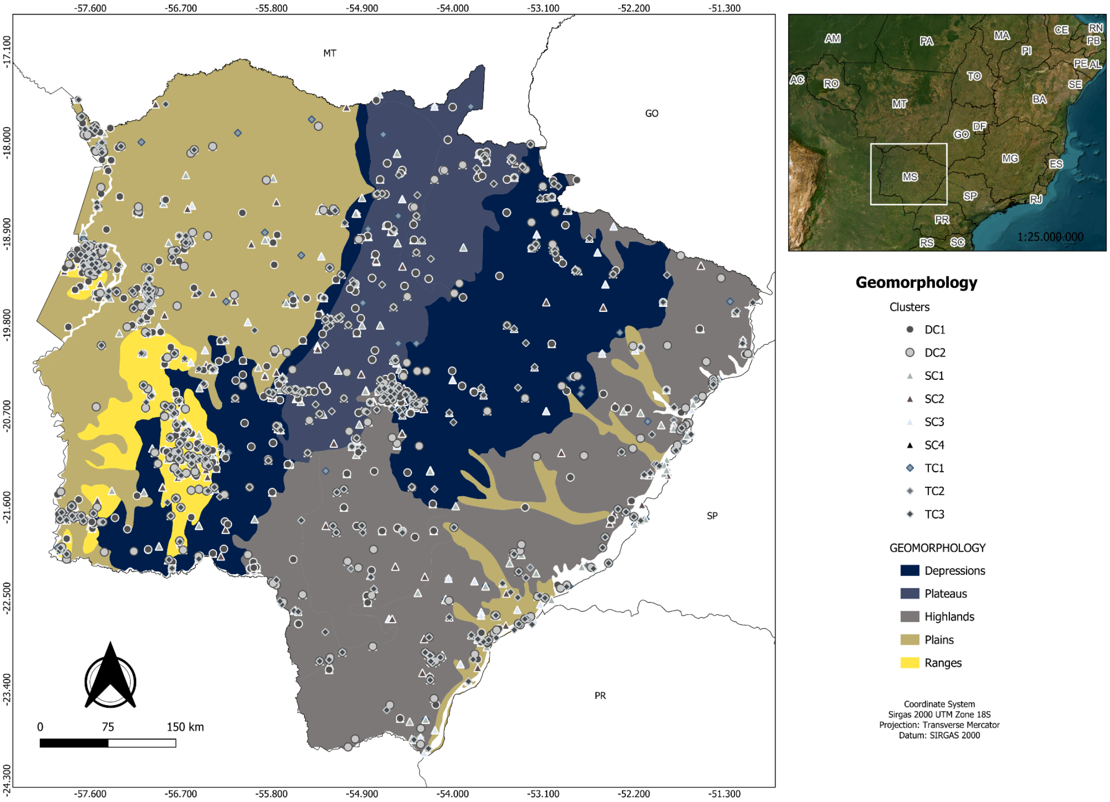

Figure S3. Climate type map showing the geographical distribution of species belonging to each functional cluster across different climate types in the state of Mato Grosso do Sul.

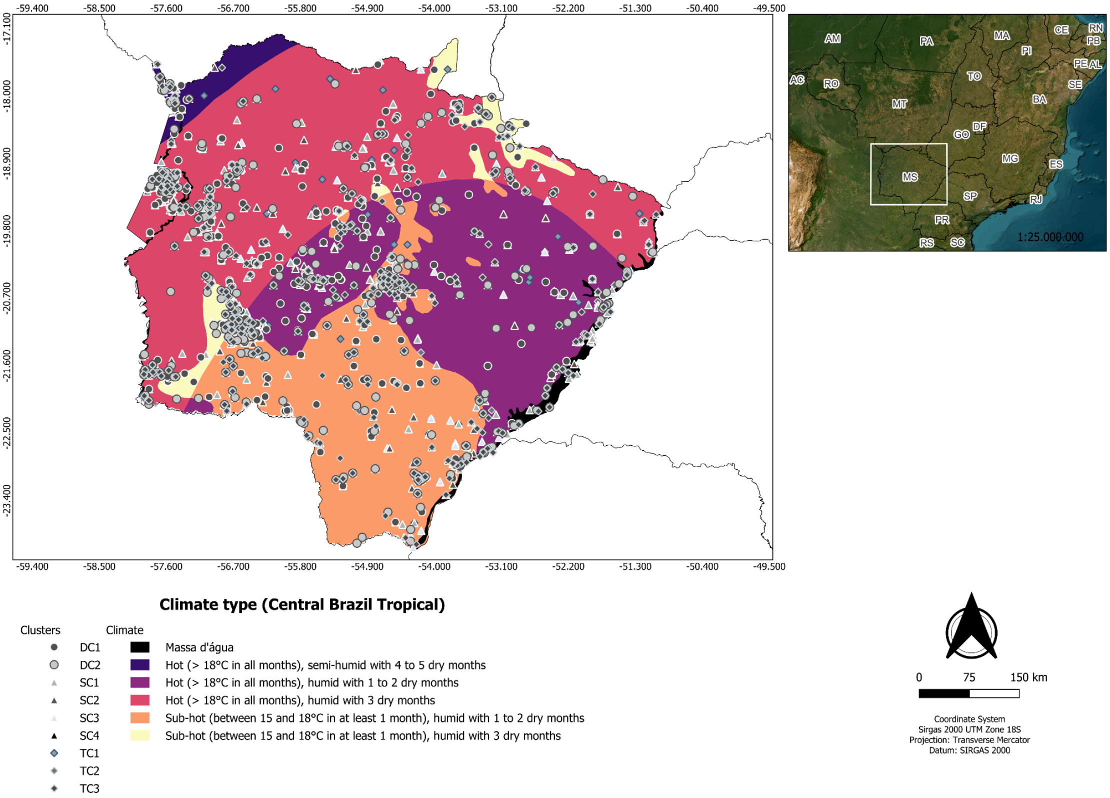

Figure S4. Pedology map illustrating the geographical distribution of species belonging to each functional cluster across different soil classes in the state of Mato Grosso do Sul.

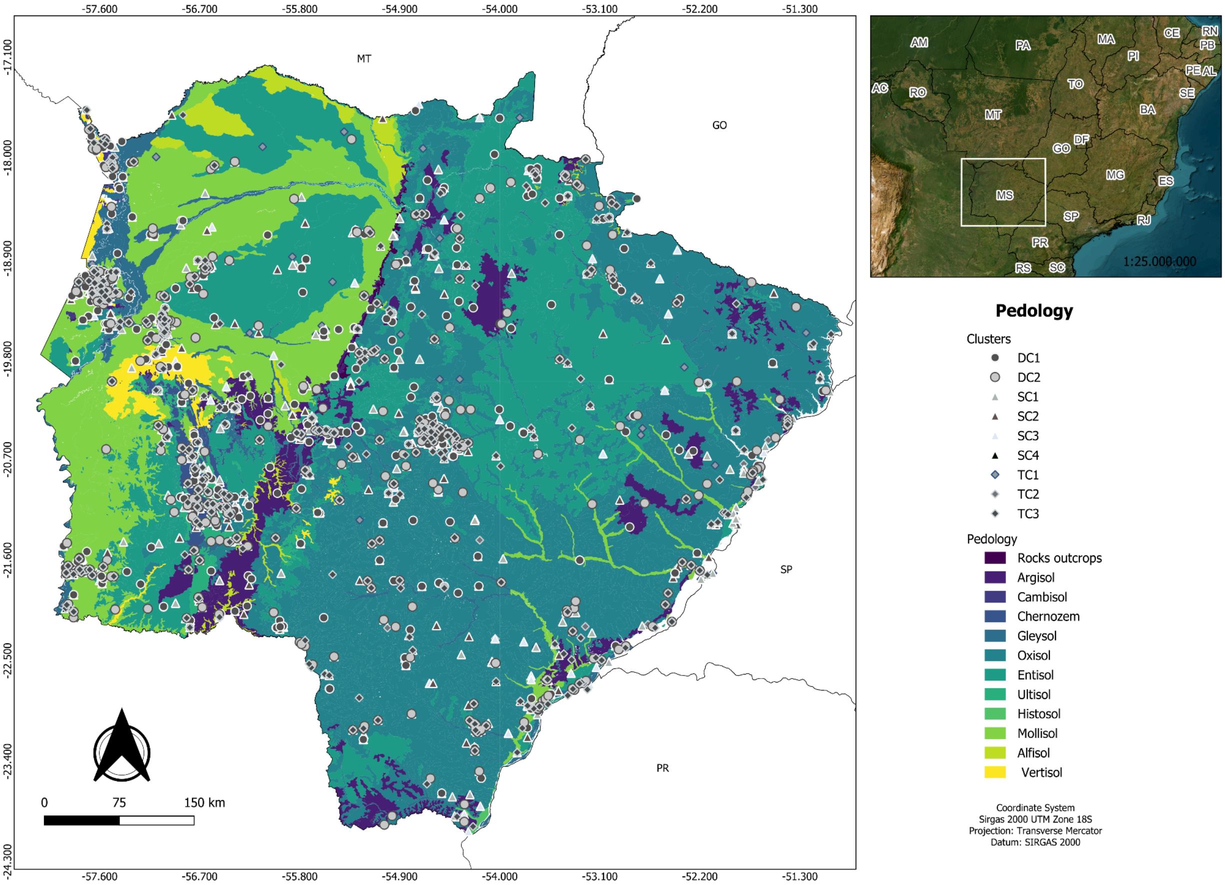

Table S5. MFA results for the different clusters and environmental variables of pedology, geomorphology, and climate type for the state of Mato Grosso do Sul.

Eigenvalues	**Dim.1**	**Dim.2**	**Dim.3**	**Dim.4**	**Dim.5**	**Dim.6**	**Dim.7**	**Dim.8**
Variance	2.978	0.258	0.211	0.120	0.057	0.029	0.010	0.008
% of var.	81.126	7.023	5.740	3.258	1.545	0.794	0.285	0.228
Cumulative % of var.	81.126	88.149	93.889	97.147	98.692	99.486	99.772	100.000

Groups	**Dim.1**	**ctr**	**cos2**	**Dim.2**	**ctr**	**cos2**	**Dim.3**	**ctr**	**cos2**
geomorphology	0.992	33.312	0.977	0.031	11.849	0.001	0.051	24.261	0.003
pedology	0.993	33.345	0.935	0.176	68.108	0.029	0.123	58.343	0.014
climate type	0.993	33.343	0.976	0.052	20.043	0.003	0.037	17.396	0.001

Individuals	**Dim.1**	**ctr**	**cos2**	**Dim.2**	**ctr**	**cos2**	**Dim.3**	**ctr**	**cos2**
DC1	3.460	44.657	0.958	-0.255	2.794	0.005	-0.409	8.818	0.013
DC2	0.048	0.009	0.002	0.783	26.421	0.577	0.614	19.905	0.355
SC1	0.726	1.966	0.233	-0.988	42.076	0.432	0.846	37.719	0.316
SC2	1.515	8.562	0.764	0.365	5.746	0.044	-0.439	10.154	0.064
SC3	-1.095	4.477	0.662	0.457	8.988	0.115	0.337	6.001	0.063
SC4	-2.695	27.101	0.957	-0.290	3.624	0.011	-0.407	8.744	0.022
TC1	-1.006	3.773	0.658	-0.276	3.289	0.050	-0.317	5.306	0.065
TC2	-1.496	8.352	0.909	-0.165	1.178	0.011	-0.251	3.320	0.026
TC3	0.544	1.104	0.367	0.369	5.884	0.169	0.026	0.035	0.001

Continuous variables (the 10 first)	**Dim.1**	**ctr**	**cos2**	**Dim.2**	**ctr**	**cos2**	**Dim.3**	**ctr**	**cos2**
Dep	0.996	7.379	0.992	-0.032	0.086	0.001	0.000	0.000	0.000
High	0.790	4.648	0.625	0.348	10.378	0.121	0.465	22.771	0.217
Hill	0.968	6.966	0.937	-0.122	1.274	0.015	-0.104	1.130	0.011
Plan	0.989	7.274	0.978	0.023	0.045	0.001	0.036	0.137	0.001
Plateau	0.973	7.045	0.947	0.028	0.065	0.001	-0.046	0.223	0.002
Argi	0.962	3.632	0.925	-0.169	1.303	0.029	0.014	0.011	0.000
Camb	0.935	3.436	0.875	-0.277	3.489	0.077	-0.089	0.444	0.008
Cher	0.954	3.577	0.910	0.033	0.049	0.001	-0.209	2.429	0.044
Gleis	0.787	2.435	0.620	0.509	11.754	0.259	0.021	0.024	0.000
Latos	0.940	3.473	0.884	0.089	0.358	0.008	0.256	3.629	0.065

SI1. R code for (I) Performing Clustering analysis and Visualization, (II) Hierarchical Cluster Analysis and Species list by Cluster, (III) Performing Principal Component Analysis (PCA) and Visualization, (IV) Species Occurrence Data Download and Save, (V) Creating Parallel Coordinates Visualisation, and (VI) Multiple Factor Analysis (MFA) and Visualization

I. Clustering analysis and Visualisation

```
library(factoextra)
library(ggplot2)
library(dendextend)
library(gridExtra)
library(ggpubr)

load_and_preprocess <- function(file) {
  data <- read.csv(file)
  clean_data <- na.omit(data)
  species_names <- clean_data[, 1]
  normalized_data <- scale(clean_data[, -1])
  str(clean_data)
  cat(paste("Missing values in", file, ":", any(is.na(normalized_data))), "\n")
  cat(paste("Infinite values in", file, ":", any(is.infinite(normalized_data))), "\n")
  cat(paste("NaN values in", file, ":", any(is.nan(normalized_data))), "\n")
  summary(normalized_data)
  head(normalized_data)
  return(list(species_names = species_names, normalized_data = normalized_data))
}

decidual_data <- load_and_preprocess("decidual.csv")
semidecidual_data <- load_and_preprocess("semidecidual.csv")
transitional_data <- load_and_preprocess("transição.csv")

titles <- c(expression("A. Deciduous forest"),
          expression("B. Semideciduous forest"),
          expression("C. Transitional forest"))

number_of_clusters <- function(data, title) {
  plot <- fviz_nbclust(data, kmeans, method = "gap_stat") +
    labs(title = title)
  print(plot)
}

set.seed(123)
```

```
clusters_decidual <- number_of_clusters(decidual_data$normalized_data, titles[1])
clusters_semidecidual <- number_of_clusters(semidecidual_data$normalized_data, titles[2])
clusters_transitional <- number_of_clusters(transitional_data$normalized_data, titles[3])

clusters<-grid.arrange(clusters_decidual, clusters_semidecidual, clusters_transitional, ncol = 3)

ggsave("Number of clusters.png", plot = clusters, width = 12, height = 3, units = "in", dpi = 300)

perform_kmeans <- function(data, num_clusters) {
  kmeans_result <- kmeans(data, num_clusters, nstart = 25)
}

results <- mapply(function(data, k) perform_kmeans(data, k),
               list(decidual_data$normalized_data, semidecidual_data$normalized_data,
transitional_data$normalized_data),
               c(2, 4, 3), SIMPLIFY = FALSE)

data_list <- list(decidual_data$normalized_data, semidecidual_data$normalized_data,
transitional_data$normalized_data)

clustering_list <- lapply(seq_along(results), function(i) {
  fviz_cluster(results[[i]], data = data_list[[i]], repel = TRUE,
            palette = c("#6B7B8E", "#F8b195", "#F67280", "#8FBBAF"),
            ggtheme = theme_minimal(), main = titles[i])
})

ggsave("Clustering decidual.png", plot = clustering_list[[1]], width = 5, height = 4, units = "in", dpi = 300)
ggsave("Clustering semidecidual.png", plot = clustering_list[[2]], width = 5, height = 4, units = "in", dpi =
300)
ggsave("Clustering transitional.png", plot = clustering_list[[3]], width = 5, height = 4, units = "in", dpi = 300)
```

II. Hierarchical Cluster Analysis and Species list by Cluster:

```
res_decidual <- hcut(decidual_data$normalized_data, k = 2, stand = TRUE)
res_semidecidual <- hcut(semidecidual_data$normalized_data, k = 4, stand = TRUE)
res_transitional <- hcut(transitional_data$normalized_data, k = 3, stand = TRUE)

dend_decidual <- as.dendrogram(as.hclust(res_decidual))
dend_semidecidual <- as.dendrogram(as.hclust(res_semidecidual))
dend_transitional <- as.dendrogram(as.hclust(res_transitional))

configure_dendrogram <- function(dend, species_names, colors, k) {
  labels(dend) <- species_names
  dend <- color_branches(dend, k = k, col = colors)
  dend <- color_labels(dend, k = k, col = colors)
  return(dend)
}

dend_decidual <- configure_dendrogram(as.dendrogram(as.hclust(res_decidual)),
decidual_data$species_names, c("#6B7B8E", "#F8b195"), k = 2)
dend_semidecidual <- configure_dendrogram(as.dendrogram(as.hclust(res_semidecidual)),
semidecidual_data$species_names, c("#8FBBAF", "#6B7B8E", "#F8b195", "#F67280"), k = 4)
dend_transitional <- configure_dendrogram(as.dendrogram(as.hclust(res_transitional)),
transitional_data$species_names, c("#8FBBAF", "#6B7B8E", "#F67280"), k = 3)

visualize_dendrogram <- function(dend, title) {
  fviz_dend(dend, rect = TRUE, cex = 0.5, k_colors = c("#6B7B8E", "#F8b195", "#F67280", "#8FBBAF"), main =
title, horiz = TRUE)
}
```

```
cluster_dend_decidual <- visualize_dendrogram(dend_decidual, titles[1])
cluster_dend_semidecidual <- visualize_dendrogram(dend_semidecidual, titles[2])
cluster_dend_transitional <- visualize_dendrogram(dend_transitional, titles[3])

cluster_ids_decidual <- cutree(res_decidual, k = 2)
cluster_ids_semidecidual <- cutree(res_semidecidual, k = 4)
cluster_ids_transitional <- cutree(res_transitional, k = 3)

species_lists <- list(
  lapply(1:2, function(i) decidual_data$species_names[cluster_ids_decidual == i]),
  lapply(1:4, function(i) semidecidual_data$species_names[cluster_ids_semidecidual == i]),
  lapply(1:3, function(i) transitional_data$species_names[cluster_ids_transitional == i])
)

save_cluster_to_csv <- function(cluster_list, directory, forest_type) {
  dir.create(directory, showWarnings = FALSE)

  for (i in seq_along(cluster_list)) {
    cluster_species <- cluster_list[[i]]
    cluster_df <- data.frame(Species = unlist(cluster_species))

    csv_filename <- file.path(directory, sprintf("%s Cluster %d.csv", forest_type, i))

    write.csv(cluster_df, csv_filename, row.names = FALSE)
  }
}

output_dir <- "~/Desktop/Occurrence data/"
save_cluster_to_csv(species_lists[[1]], output_dir, "Decidual")
save_cluster_to_csv(species_lists[[2]], output_dir, "Semidecidual")
save_cluster_to_csv(species_lists[[3]], output_dir, "Transitional")
```

III. Principal Component Analysis (PCA) and Visualization

```
calculate_and_visualize_pca <- function(data, title, results) {
  pca_result <- prcomp(data)

  fviz_eig(pca_result)

  fviz_pca_biplot(pca_result, col.var = "contrib", select.var = list(contrib = 20), repel = TRUE,
                gradient.cols = c("gray20", "deepskyblue4"),
                geom.ind = "point", pointsize = 1, col.ind = "#758184") +
    labs(title = title) +
    stat_ellipse(aes(fill = as.factor(results[["cluster"]])),
               level = 0.95, geom = "polygon", alpha = 0.25) +
    scale_fill_manual(values = c("#6B7B8E", "#F8b195", "#F67280", "#8FBBAF"), name = "cluster")
}

PCA_decidual<- calculate_and_visualize_pca(decidual_data$normalized_data, titles[1], results[[1]])
PCA_semidecidual<-calculate_and_visualize_pca(semidecidual_data$normalized_data, titles[2], results[[2]])
PCA_transitional<-calculate_and_visualize_pca(transitional_data$normalized_data, titles[3], results[[3]])

ggsave("PCA decidual.png", plot = PCA_decidual, width = 5, height = 4, units = "in", dpi = 300)
ggsave("PCA semidecidual.png", plot = PCA_semidecidual, width = 5, height = 4, units = "in", dpi = 300)
ggsave("PCA transitional.png", plot = PCA_transitional, width = 5, height = 4, units = "in", dpi = 300)
```

IV. Species Occurrence Data Download and Save

```
install.packages(c("remotes", "rgbif2", "rspecieslink"))
```

```
remotes::install_github("LimaRAF/plantR")
remotes::install_github("liibre/Rocc")

library(remotes)
library(rgbif2)
library(rspecieslink)
library(plantR)
library(Rocc)

download_and_save_data <- function(csv_path_list, cluster_type) {
  all_data <- list()

  for (i in seq_along(csv_path_list)) {
    csv_path <- csv_path_list[[i]]

    species_list <- read.csv(csv_path, header = FALSE)[, 1]

    cat("\nSpecies in Cluster", i, " (", cluster_type, "):\n")
    cat(paste(species_list, collapse = ", "), "\n")

    cluster_data <- lapply(species_list, function(species) {
      occs <- rspeciesLink(species = species)
      gbif <- rgbif2(species = species)

      data.frame(
        Species = species,
        Occs = I(list(occs)),
        GBIF = I(list(gbif))
      )
    })

    all_data[[i]] <- do.call(rbind, cluster_data)
    write.csv(all_data[[i]], paste0("cluster_", i, "_", tolower(cluster_type), "_data.csv"), row.names = FALSE)
  }
}

csv_paths <- list(
  "Decidual Cluster 1.csv",
  "Decidual Cluster 2.csv",
  "Semidecidual Cluster 1.csv",
  "Semidecidual Cluster 2.csv",
  "Semidecidual Cluster 3.csv",
  "Semidecidual Cluster 4.csv",
  "Transitional Cluster 1.csv",
  "Transitional Cluster 2.csv",
  "Transitional Cluster 3.csv"
)

download_and_save_data(csv_paths[1:2], "Decidual")
download_and_save_data(csv_paths[3:6], "Semidecidual")
download_and_save_data(csv_paths[7:9], "Transitional")
```

V. Creating Parallel Coordinates Visualisation

```
library(ggplot2)
library(GGally)
library(readr)

my_palette <- c("#abdda4", "#ACDEAA", "#8FBBAF","#758184", "#6B7B8E",
```

```
            "#F8b195", "#F67280", "#C06c84", "darkred")

dados <- read_csv("variaveis.csv")

plot_parallel_coordinates <- function(data, columns, y_limits, x_label, y_label, title) {
  ggparcoord(data = data,
             columns = columns,
             alphaLines = 0.9,
             groupColumn = "Cluster",
             showPoints = TRUE,
             scale = "globalminmax") +
    scale_color_manual(values = my_palette) +
    geom_point(size = 3) +
    scale_y_continuous(limits = y_limits) +
    labs(x = x_label, y = y_label) +
    ggtitle(title)

}

geomorphology<-plot_parallel_coordinates(dados, 2:6, c(-4, 500), "geomorphology", "occurrences", "A. Geomorphology")
pedology<-plot_parallel_coordinates(dados, 7:18, c(-4, 350), "pedology", "occurrences", "C. Pedology")
climate<-plot_parallel_coordinates(dados, 19:23, c(-4, 700), "climate type", "occurrences", "B. Climate type")

ggsave("A. Geomorphology.png", plot = geomorphology, width = 4.5, height = 3, units = "in", dpi = 300)
ggsave("C. Pedology.png", plot = pedology, width = 6, height = 3, units = "in", dpi = 300)
ggsave("B. Climate type.png", plot = climate, width = 4.5, height = 3, units = "in", dpi = 300)
```

VI. Multiple Factor Analysis (MFA) and Visualisation

```
install.packages(c("FactoMineR", "factoextra", "dplyr", "ggplot2", "rlang"), dependencies = TRUE)
library(FactoMineR)
library(factoextra)
library(dplyr)
library(ggplot2)
library(rlang)
library(readr)

dados_mfa <- na.omit(read.csv("variaveis.csv", row.names =  1))

res_mfa <- MFA(dados_mfa, group = c(5, 12, 5), type = rep("s", 3),
               name.group = c("geomorphology", "pedology", "climate type"),
               graph = FALSE, ncp = 5)
summary(res_mfa)

MFAind <- fviz_mfa_ind(res_mfa, partial = "all", repel = TRUE, palette = c("#8FBBAF",
"#6B7B8E","#F67280")) + ggtitle("A. Individuals")
MFAvar <- fviz_mfa_var(res_mfa, "quanti.var", col.var = "contrib",
                       gradient.cols = c("#8FBBAF", "#6B7B8E","#F67280"),
                       col.var.sup = "violet", repel = TRUE,
                       geom = c("point", "text")) + ggtitle("B. Quantitative variables")

ggsave("A. Individuals.png", plot = MFAind, width = 5, height = 3, units = "in", dpi = 300)
ggsave("B. Quantitative variables.png", plot = MFAvar, width = 5, height = 3, units = "in", dpi = 300)
```

APPENDICES

Appendix A - Table 1. Vegetal species evaluated in the study, along with their respective forest of occurrence denoted by the abbreviations DF: Deciduous Forest, SF: Semideciduous Forest, and TF: Transitional Forest, as well as their conservation statuses based on the CNCFlora's red list (Centro Nacional de Conservação da Flora). Where, NE: Not Evaluated, DD: Data Deficient, LC: Least Concern, NT: Near Threatened, VU: Vulnerable, EN: Endangered, CR: Critically Endangered, EW: Extinct In The Wild, EX: Extinct, and NA: (not available) missing data. Extracted from Damasceno-Junior et al. (2018).

Family	**id**	**SpeciesName**	DF	SF	TF	CNCflora
Acanthaceae	1	*Justicia hassleri (*Lindau) V.A.W.Graham	x			NE
	2	*Ruellia angustiflora* (Nees) Lindau ex Rambo	x			NE
	3	*Ruellia brevifolia* (Pohl) C.Ezcurra	x			NE
Achatocarpaceae	4	*Achatocarpus praecox* Griseb.	x	x		LC
Anacardiaceae	5	*Astronium fraxinifolium* Schott		x	x	LC
	6	*Astronium graveolens* Jacq.		x		LC
	7	*Astronium urundeuva* (M.Allemão) Engl.	x			LC
	8	*Lithraea molleoides* (Vell.) Engl.	x			NE
	9	*Schinopsis brasiliensis* Engl.	x			LC
	10	*Schinus terebinthifolia* Raddi	x			NE
	11	*Spondias mombin* L.		x		NE
	12	*Tapirira guianensis* Aubl.		x	x	NE
Annonaceae	13	*Annona coriacea* Mart.	x			LC
	14	*Annona cornifolia* A.St.-Hil.	x			NE
	15	*Annona emarginata* (Schltdl.) H.Rainer	x			LC
	16	*Annona montana* Macfad.			x	NE
	17	*Annona nutans* (R.E.Fr.) R.E.Fr.	x			NE
	18	*Annona sylvatica* A.St-Hil.		x		NE
	19	*Duguetia furfuracea* (A.St.-Hil.) Saff.	x		x	NE
	20	*Unonopsis guatterioides* (A.DC.) R.E.Fr.		x		NE
	21	*Xylopia aromatica* (Lam) Mart		x	x	LC
Apocynaceae	22	*Aspidosperma australe* Müll.Arg.			x	LC
	23	*Aspidosperma cuspa* (Kunth) S.F.Blake ex Pittier	x			NE
	24	*Aspidosperma cylindrocarpon* Müll.Arg.			x	LC
	25	*Aspidosperma polyneuron* Müll.Arg	x			NT
	26	*Aspidosperma pyrifolium* Mart.		x		NE
	27	*Aspidosperma subincanum* Mart.	x			NE
	28	*Aspidosperma tomentosum* Mart.	x			LC
	29	*Hancornia speciosa* Gomes.		x		NE
	30	*Himatanthus obovatus* (Müll.Arg.) Woodson			x	NE
	31	*Tabernaemontana catharinensis* A.DC.		x		NE
	32	*Tabernaemontana siphilitica* (L.f.) Leeuwenb.		x		NE
Araliaceae	33	*Dendropanax cuneatus* (DC.) Decne. & Planch.		x	x	LC
	34	*Didymopanax morototoni* (Aubl.) Decne. & Planch.		x		NE
Arecaceae	35	*Acrocomia aculeata* (Jacq.) Lodd		x	x	NE
	36	*Allagoptera leucocalyx* (Drude) Kuntze			x	NE
	37	*Attalea phalerata* Mart. ex Spreng.		x	x	LC
	38	*Attalea speciosa* Mart. ex Spreng.		x	x	NE
	39	*Copernicia alba* Morong ex Morong & Britton		x	x	NE

Family	id	SpeciesName	DF	SF	TF	CNCflora
	40	*Desmoncus orthacanthos* Mart.		x		NE
	41	*Euterpe edulis* Mart.		x		VU
	42	*Syagrus oleracea* (Mart.) Becc.		x		NE
	43	*Syagrus romanzoffiana* (Cham.) Glassman	x	x		LC
Asparagaceae	44	*Cordyline spectabilis* Kunth & C.D. Bouché		x		NE
Asteraceae	45	*Dasyphyllum brasiliense* (Spreng.) Cabrera	x	x		NE
	46	*Koanophyllon simillimum* (B.L.Rob.) R.M.King & H.Rob.	x			NE
	47	*Lessingianthus obscurus* (Less.) H.Rob.	x			NE
Bignoniaceae	48	*Handroanthus heptaphyllus* (Vell.) Mattos		x	x	LC
	49	*Handroanthus impetiginosus* (Mart. ex DC.) Mattos	x			NT
	50	*Handroanthus ochraceus* (Cham.) Mattos		x		NE
	51	*Handroanthus serratifolius* (A.H.Gentry) S.Grose	x	x	x	NE
	52	*Sparattosperma leucanthum* (Vell.) K. Schum.		x		NE
	53	*Tabebuia aurea* (Silva Manso) Benth. & Hook.f. ex S.Moore		x		NE
	54	*Tabebuia nodosa* (Griseb.) Griseb.	x			NE
	55	*Tabebuia roseoalba* (Ridl.) Sandwith	x	x		NE
	56	*Zeyheria montana* Mart.	x			LC
Burseraceae	57	*Commiphora leptophloeos* (Mart.) J.B. Gillett	x			NE
	58	*Protium heptaphyllum* (Aubl.) Marchand		x	x	DD
	59	*Protium spruceanum* (Benth.) Engl.		x	x	NE
Cactaceae	60	*Brasiliopuntia brasiliensis* (Willd.) A.Berger	x	x		LC
	61	*Cereus bicolor* Rizzini & A.Mattos	x	x		NE
	62	*Cleistocactus baumannii* (Lem.) Lem.	x			NE
	63	*Harrisia balansae* (K.Schum.) N.P.Taylor & Zappi	x			NE
	64	*Pereskia sacharosa* Griseb.		x		NE
	65	*Praecereus euchlorus* (F.A.C.Weber) N.P.Taylor	x			NE
Calophyllaceae	66	*Kielmeyera coriacea* Mart.		x		NE
Cannabaceae	67	*Celtis iguanaea* (Jacq.) Sarg.	x			NE
	68	*Celtis spinosa* Spreng.	x			NE
	69	*Trema micrantha* (L.) Blume		x		NE
Capparaceae	70	*Anisocapparis speciosa* (Griseb.) Conejo & Iltis	x			NE
	71	*Cappariocordis tweediana* (Eichler) Conejo & Iltis		x		NE
	72	*Capparidastrum coimbranum* (Cornejo & Iltis) Cornejo & Iltis.	x	x		NE
	73	*Crateva tapia* L.			x	NE
	74	*Cynophalla mattogrossensis* (Pilg.) Cornejo & Iltis	x			NE
	75	*Cynophalla retusa* (Griseb.) Cornejo & Iltis	x			NE
Caricaceae	76	*Jacaratia corumbensis* Kuntze.	x			NE
	77	*Jacaratia spinosa* (Aubl.) A.DC.		x		LC
Celastraceae	78	*Monteverdia ilicifolia* (Mart. ex Reissek) Biral	x			NE
	79	*Salacia elliptica* (Mart.) Peyr.			x	NE
Chrysobalanaceae	80	*Couepia uiti* (Mart. & Zucc.) Benth. ex Hook.f.			x	NE
	81	*Hirtella gracilipes* (Hook.f.) Prance		x	x	NE
	82	*Leptobalanus parvifolius* (Huber) Sothers & Prance		x		NE
Cleomaceae	83	*Melidiscus giganteus* (L.) Raf.		x		NE
Clusiaceae	84	*Garcinia brasiliensis* Mart.		x		NE
	85	*Garcinia gardneriana* (Planch. & Triana) Zappi		x		NE
Combretaceae	86	*Combretum duarteanum* Cambess.	x			NE
	87	*Combretum leprosum* Mart.	x		x	NE
	88	*Terminalia argentea* Mart.		x		LC

Family	id	SpeciesName	DF	SF	TF	CNCflora
	89	*Terminalia corrugata* (Ducke) Gere & Boatwr.		x		NE
	90	*Terminalia fagifolia* Mart.	x			NE
	91	*Terminalia glabrescens* Mart.		x	x	NE
Cordiaceae	92	*Cordia americana* (L.) Gottschling & J.S.Mill.	x	x		NE
	93	*Cordia brasiliensis* (I.M.Johnst.) Gottschling & J.S.Mill.	x			NE
	94	*Cordia ecalyculata* Vell.		x		NE
	95	*Cordia glabrata* (Mart.) A.DC.	x			NE
	96	*Cordia naidophila* I.M. Johnst.	x			NE
	97	*Cordia sellowiana* Cham		x		NE
	98	*Cordia trichotoma* (Vell.) Arráb. ex Steud.		x		NE
	99	*Varronia grandiflora* Desv.		x		NE
Dilleniaceae	100	*Curatella americana* L.			x	NE
Ebenaceae	101	*Diospyros inconstans* Jacq.	x			LC
	102	*Diospyros tetrasperma* Sw.		x		NE
Elaeocarpaceae	103	*Sloanea guianensis* (Aubl.) Benth.		x		NE
Erythroxylaceae	104	*Erythroxylum anguifugum* Mart.			x	LC
	105	*Erythroxylum cuneifolium* (Mart.) O.E. Schulz	x		x	NE
	106	*Erythroxylum daphnites* Mart.		x		NE
	107	*Erythroxylum pelleterianum* A.St.-Hil.	x			LC
Euphorbiaceae	108	*Acalypha villosa* Jacq	x			NE
	109	*Actinostemon klotzschii* (Didr.) Pax		x		NE
	110	*Adelia membranifolia* Chod. & Hassl.		x		NE
	111	*Alchornea castaneifolia* (Willd.) Anderson			x	NE
	112	*Alchornea discolor* Poepp.		x		NE
	113	*Alchornea glandulosa* Poepp. & Endl.		x		NE
	114	*Alchornea triplinervia* (Spreng.) Müll. Arg.		x		NE
	115	*Cnidoscolus cerv*i Fern.Casas	x			NE
	116	*Cnidoscolus cnicodendron* Griseb.	x			NE
	117	*Croton argenteus* L.		x		NE
	118	*Croton bonplandianus* Baill.		x		NE
	119	*Croton corumbensis* S.Moore		x		NE
	120	*Croton floribundus* Spreng.		x		NE
	121	*Croton gracilipes* Baill.	x	x		NE
	122	*Croton sellowii* Baill.		x		NE
	123	*Croton urucurana* Baill.		x		NE
	124	*Gymnanthes klotzschiana* Müll.Arg.		x		NE
	125	*Jatropha elliptica* (Pohl) Oken		x		NE
	126	*Jatropha weddeliana* Baill.	x			NE
	127	*Mabea fistulifera* Mart.			x	NE
	128	*Manihot anomala* Pohl			x	NE
	129	*Maprounea brasiliensis* A.St.-Hil.	x			NE
	130	*Maprounea guianensis* Aubl.	x		x	NE
	131	*Microstachys daphnoides* (Mart.) Müll. Arg.		x		NE
	132	*Philyra brasiliensis* Klotzsch	x	x		NE
	133	*Pleradenophora membranifolia* (Müll. Arg.) Esser & A. L. Melo	x			NE
	134	*Sapium glandulosum* (L.) Morong.	x			NE
	135	*Sapium haematospermum* Müll. Arg.	x			NE
	136	*Sapium obovatum* Klotzsch ex Müll. Arg.			x	NE
	137	*Sebastiania brasiliensis* Spreng.	x			NE

Family	**id**	**SpeciesName**	DF	SF	TF	CNCflora
	138	*Sebastiania ramosissima* (A. St.-Hil.) A. L. Melo & M. F. Sales		x		NE
Fabaceae	139	*Acosmium cardenasii* H.S.Irwin & Arroyo	x			NE
	140	*Albizia niopoides* (Spruce ex Benth.) Burkart		x	x	LC
	141	*Amburana cearensis* (Allemão) A.C. Sm.	x			NT
	142	*Anadenanthera colubrina* (Vell.) Brenan	x			NE
	143	*Anadenanthera peregrina* (L.) Speg.		x		NE
	144	*Andira cujabensis* Benth.	x			NE
	145	*Andira inermis* (W.Wright) Kunth ex DC.			x	NE
	146	*Apuleia leiocarpa* (Vogel) J.F.Macbr		x		VU
	147	*Bauhinia cheilantha* (Bong.) Steud.	x			NE
	148	*Bauhinia leptantha* Malme			x	VU
	149	*Bauhinia longifolia* (Bong.) Steud.	x			NE
	150	*Bauhinia mollis* (Bong.) D.Dietr.	x	x		NE
	151	*Bauhinia pentandra* (Bong.) Vogel ex Steud.	x		x	NE
	152	*Bauhinia pulchella* Benth.		x		NE
	153	*Bauhinia rufa* (Bong.) Steud.		x		NE
	154	*Bauhinia ungulata* L.	x			NE
	155	*Bowdichia virgilioides* Kunth			x	NT
	156	*Calliandra foliolosa* Benth.		x		NE
	157	*Calliandra parviflora* (Hook. & Arn.) Speg.	x			NE
	158	*Chloroleucon tortum* (Mart.) Pittier		x		NT
	159	*Copaifera langsdorffii* Desf.		x	x	NE
	160	*Copaifera martii* Hayne	x			NE
	161	*Dalbergia cuiabensis* Benth.	x			LC
	162	*Dalbergia frutescens* (Vell.) Britton	x	x		NE
	163	*Dimorphandra mollis* Benth.	x			NE
	164	*Dipteryx alata* Vog.		x		LC
	165	*Diptychandra aurantiaca* (Mart.) Tul.		x		NE
	166	*Enterolobium contortisiliquum* (Vell.) Morong	x	x	x	NE
	167	*Erythrina mulungu* Mart.		x		NE
	168	*Geoffroea spinosa* Jacq.		x		NE
	169	*Guibourtia hymenaeifolia* (Moric.) J.Léonard	x	x		NE
	170	*Holocalyx balansae* Micheli		x		NE
	171	*Hymenaea courbaril* L.			x	LC
	172	*Hymenaea martiana* Hayne	x			LC
	173	*Inga laurina* (Sw.) Willd.		x		LC
	174	*Inga marginata* Willd.		x		NE
	175	*Inga vera* Willd.			x	NE
	176	*Lachesiodendron viridiflorum* (Kunth) P.G. Ribeiro, L.P. Queiroz & Luckow	x	x		NE
	177	*Leptolobium dasycarpum* Vogel		x		NE
	178	*Libidibia paraguariensis* (D. Parodi) G.P. Lewis	x			NE
	179	*Lonchocarpus sericeus* (Poir.) Kunth ex DC.	x			NE
	180	*Lonchocarpus variabilis* R.R.Silva & A.M.G.Azevedo	x			NA
	181	*Machaerium acutifolium* Vogel	x			NE
	182	*Machaerium eriocarpum* Benth.	x			NE
	183	*Machaerium hirtum* (Vell.) Stellfeld	x			NE
	184	*Machaerium paraguariense* Hassl.			x	LC
	185	*Machaerium stipitatum* (DC.) Vogel		x		NE
	186	*Machaerium villosum* Vog.		x		LC

Family	id	SpeciesName	DF	SF	TF	CNCflora
	187	*Mimosa adenocarpa* Benth.			x	NE
	188	*Mimosa bimucronata* (DC.) Kuntze		x		NE
	189	*Mimosa debilis* Humb. & Bonpl. ex Willd.		x		NE
	190	*Mimosa glutinosa* Malme			x	NE
	191	*Mimosa pigra* L.		x	x	NE
	192	*Mimosa polycarpa* Kunth		x		NE
	193	*Mimosa weddelliana* Benth.			x	NE
	194	*Mimosa xavantinae* Barneby	x			NE
	195	*Muellera nudiflora* (Burkart) M.J. Silva & A.M.G. Azevedo		x		NE
	196	*Myroxylon balsamum* Druce		x		NE
	197	*Ormosia arborea* (Vell.) Harms	x		x	NE
	198	*Parapiptadenia rigida* (Benth.) Brenan	x			NE
	199	*Parkinsonia praecox* (Ruiz & Pav. ex Hook.) J. Hawkins	x	x		NE
	200	*Peltophorum dubium* (Spreng.) Taub.	x	x		NE
	201	*Pityrocarpa moniliformis* (Benth.) Luckow & R.W.Jobson			x	NE
	202	*Plathymenia reticulata* Benth.		x		LC
	203	*Platypodium elegans* Vogel		x		NE
	204	*Prosopis rubriflora* Hassl.		x		NE
	205	*Prosopis ruscifolia* Griseb.	x			NE
	206	*Pterogyne nitens* Tul.	x			LC
	207	*Samanea tubulosa* (Benth.) Barneby & J.W. Grimes	x		x	NE
	208	*Senegalia polyphylla* (DC.) Britton & Rose	x			NE
	209	*Senegalia tenuifolia* (L.) Britton & Rose	x			NE
	210	*Senna pendula* (Humb. & Bonpl. ex Willd.) H.S. Irwin & Barneby		x	x	NE
	211	*Senna pilifera* (Vogel) H.S. Irwin & Barneby	x			NE
	212	*Senna silvestris* (Vell.) H.S. Irwin & Barneby		x		NE
	213	*Senna spectabilis* (Vog.) Irw. et Barn.	x			NE
	214	*Senna splendida* (Vogel) H.S.Irwin & Barneby		x		NE
	215	*Sesbania virgata* (Cav.) Pers.		x	x	NE
	216	*Swartzia jorori* Harms.		x		NE
	217	*Sweetia fruticosa* Spreng.		x		NE
	218	*Tachigali rugosa* (Mart. ex Benth.) Zarucchi & Pipoly	x			NT
	219	*Vachellia caven* (Molina) Seigler & Ebinger	x			NE
	220	*Vachellia farnesiana* (L.) Wight & Arn.	x		x	NE
	221	*Zapoteca formosa* (Kunth) H. Hern.	x			NE
	222	*Zygia latifolia* (L.) Fawc. & Rendle	x			NE
Heliotropiaceae	223	*Myriopus maculatus* (Jacq.) Feuillet	x			NE
Lacistemataceae	224	*Lacistema hasslerianum* Chodat		x	x	NE
Lamiaceae	225	*Aegiphila integrifolia* (Jacq.) Moldenke		x		NE
	226	*Aegiphila verticillata* Vell.	x			NE
	227	*Vitex cymosa* Bertero ex Spreng.		x	x	NE
Lauraceae	228	*Cinnamomum triplinerve* (Ruiz & Pav.) Kosterm.		x		LC
	229	*Licaria triandra* (Sw.) Kosterm.		x		LC
	230	*Nectandra angustifolia* (Schrad.) Nees & Mart.			x	LC
	231	*Nectandra cissiflora* Nees			x	LC
	232	*Nectandra cuspidata* Nees & Mart.			x	NE
	233	*Nectandra gardneri* Meisn.		x	x	NE
	234	*Nectandra hihua* (R & P.) Rohwer	x			LC
	235	*Nectandra megapotamica* (Spreng.) Mez			x	NE

Family	**id**	**SpeciesName**	DF	SF	TF	CNCflora
	236	*Nectandra psammophila* Nees			x	LC
	237	*Ocotea diospyrifolia* (Meisn.) Mez		x	x	NE
	238	*Ocotea lancifolia* (Schott) Mez	x			LC
	239	*Ocotea minarum* (Nees & C. Mart.) Mez	x	x		NE
	240	*Ocotea velloziana* (Meisn.) Mez			x	NE
	241	*Persea willdenovii* Kosterm.		x		LC
Lecythidaceae	242	*Cariniana estrellensis* (Raddi) Kuntze		x	x	NE
Loganiaceae	243	*Strychnos pseudoquina* A.St.-Hil.	x			NE
Lythraceae	244	*Adenaria floribunda* Kunth		x		NE
	245	*Lafoensia pacari* A. St.-Hil.		x		LC
Malpighiaceae	246	*Bunchosia paraguariensis* Nied.	x			NE
	247	*Byrsonima clausseniana* A. Juss.		x		NE
	248	*Byrsonima coccolobifolia* Kunth			x	LC
	249	*Byrsonima cydoniifolia* A. Juss.			x	NE
	250	*Byrsonima verbascifolia* (L.) Rich.			x	NE
	251	*Ptilochaeta nudipes* Griseb.	x			NE
Malvaceae	252	*Apeiba tibourbou* Aubl.		x		NE
	253	*Bastardiopsis densiflora* (Hook. & Arn.) Hassl.		x		NE
	254	*Byttneria rhamnifolia* Benth.		x		NE
	255	*Ceiba pubiflora* (A. St.-Hil.) K. Schum.	x	x		NE
	256	*Ceiba samauma* (Mart.) K. Schum.	x			NE
	257	*Ceiba speciosa* (A. St.-Hil.) Ravenna		x		NE
	258	*Guazuma ulmifolia* Lam		x	x	NE
	259	*Helicteres guazumifolia* H.B.K.	x			NE
	260	*Helicteres lhotzkyana* (Schott & Endl.) K.Schum.	x	x		NE
	261	*Herissantia nemoralis* Brizicky		x		LC
	262	*Luehea candicans* Mart.		x		LC
	263	*Luehea divaricata* Mart.	x		x	NE
	264	*Luehea grandiflora* Mart. & Zuch		x		NE
	265	*Luehea paniculata* Mart.		x		NE
	266	*Pseudabutilon aristulosum* (K.Schum.) Krapov.	x			NE
	267	*Pseudabutilon benense* (Britton) Fryxell	x			NE
	268	*Pseudobombax grandiflorum* (Cav.) A. Robyns	x			LC
	269	*Pseudobombax longiflorum* (Martius & Zucc.) A. Robyns	x			NE
	270	*Pseudobombax marginatum* (A. St.-Hil.) A. Robyns			x	LC
	271	*Sterculia apetala* Karst	x			NE
	272	*Sterculia striata* A. St.-Hil. & Naudin	x	x		NE
	273	*Wissadula hernandioides* (L.Hér.) Garcke	x			NE
Melastomataceae	274	*Clidemia biserrata* DC.		x		NE
	275	*Clidemia bullosa* DC.			x	NE
	276	*Miconia albicans* (Sw.) Steud.		x		NE
	277	*Miconia ibaguensis* (Bonpl.) Triana	x			NE
	278	*Miconia nervosa* (Sm.) Triana	x			NE
	279	*Mouriri elliptica* Mart.	x			NE
	280	*Tococa guianensis* Aubl.		x		NE
Meliaceae	281	*Cabralea canjerana* (Vell.) Mart.		x		NE
	282	*Cedrela fissilis* Vell.		x		VU
	283	*Guarea guidonia* (L.) Slemer		x	x	NE
	284	*Guarea kunthiana* A.Juss.		x		NE

Family	**id**	**SpeciesName**	DF	SF	TF	CNCflora
	285	*Guarea macrophylla* Vahl		x		NE
	286	*Trichilia catigua* A. Juss.	x			NE
	287	*Trichilia clausseni* C.DC.		x		NE
	288	*Trichilia elegans* A.Juss.			x	NE
	289	*Trichilia hirta* L.		x		LC
	290	*Trichilia pallida* Sw.			x	NE
	291	*Trichilia stellato-tomentosa* Kuntze	x	x		VU
Menispermaceae	292	*Abuta grandifolia* (Mart.) Sandwith		x		NE
Moraceae	293	*Brosimum gaudichaudii* Trec.		x		NE
	294	*Ficus adhatodifolia* Schott ex Spreng.	x			NE
	295	*Ficus broadwayi* Urb.		x		LC
	296	*Ficus calyptroceras* (Miq.) Miq.	x	x		LC
	297	*Ficus carautana* L.J. Neves & Emygdio			x	EN
	298	*Ficus citrifolia* Mill.		x		NE
	299	*Ficus crocata* (Miq.) Miq.			x	NE
	300	*Ficus elliotiana* S.Moore		x		NE
	301	*Ficus eximia* Schott	x			LC
	302	*Ficus insipida* Willd.		x		NE
	303	*Ficus lagoensis* C.C. Berg & Carauta	x			NE
	304	*Ficus obtusifolia* Kunth	x			NE
	305	*Ficus pertusa* L. f.		x		NE
	306	*Maclura tinctoria* (L.) D.Don ex Steud.	x	x		NE
	307	*Sorocea bonplandii* (Baill.) Burger		x		NE
	308	*Sorocea guilleminiana* Gaudich.			x	VU
	309	*Sorocea sprucei* (Baill.) J.F. Macbr.			x	LC
Myrtaceae	310	*Blepharocalyx salicifolius* (Kunth) O. Berg		x		LC
	311	*Campomanesia guazumifolia* (Cambess.) O.Berg			x	NE
	312	*Campomanesia xanthocarpa* O. Berg.	x			LC
	313	*Eugenia aurata* O. Berg		x		LC
	314	*Eugenia bimarginata* DC.	x			NE
	315	*Eugenia egensis* DC.		x	x	NE
	316	*Eugenia florida* DC.	x		x	LC
	317	*Eugenia modesta* DC.			x	NE
	318	*Eugenia myrcianthes* Nield.			x	NE
	319	*Eugenia pitanga* (O. Berg.) Kiaersk.		x		NE
	320	*Eugenia pyriformis* Cambess.		x		NE
	321	*Eugenia repanda* O. Berg		x		NE
	322	*Eugenia subterminalis* DC.		x		LC
	323	*Eugenia uniflora* L.			x	NE
	324	*Eugenia uruguayensis* Cambess.		x		NE
	325	*Myrcia bella* Cambess.	x			NE
	326	*Myrcia guianensis* (Aubl.) DC.		x		LC
	327	*Myrcia neolucida* A.R.Lourenço & E.Lucas		x		NE
	328	*Myrcia selloi* (Spreng.) N.Silveira	x			NE
	329	*Myrcia splendens* (Sw.) DC.	x			NE
	330	*Myrcia tomentosa* (Aubl.) DC.	x			NE
	331	*Myrcianthes pungens* (O .Berg) D. Legrand.		x		LC
	332	*Myrciaria delicatula* (DC.) O. Berg	x			NE
	333	*Myrciaria tenella* (DC.) O. Berg		x		DD

Family	**id**	**SpeciesName**	DF	SF	TF	CNCflora
	334	*Plinia peruviana* (Poir.) Govaerts			x	NE
	335	*Psidium acutangulum* DC.	x			NE
	336	*Psidium guineense* Sw.			x	NE
	337	*Psidium hians* Mart. ex DC.		x		NE
	338	*Psidium kennedyanum* Morong.	x		x	NE
	339	*Psidium sartorianum* (O. Berg) Nied.		x		LC
Nyctaginaceae	340	*Bougainvillea glabra* Choisy		x		NE
	341	*Bougainvillea infesta* Griseb.		x		NA
	342	*Guapira areolata* (Heimerl) Lundell	x			NE
	343	*Guapira opposita* Vell.		x		NE
	344	*Neea hermaphrodita* S. Moore	x		x	NE
	345	*Pisonia zapallo* Griseb.		x		NE
	346	*Reichenbachia paraguayensis* (D.Parodi) Dugand & Daniel	x			NE
Ochnaceae	347	*Ouratea castaneifolia* (DC.) Engl.			x	NE
	348	*Ouratea purpuripes* S. Moore		x		NE
Olacaceae	349	*Dulacia papillosa* (J.O. Rangel) Sleumer	x			NE
Oleaceae	350	*Priogymnanthus hasslerianus* (Chodat) P.S. Green	x	x		NE
Opiliaceae	351	*Agonandra brasiliensis* Miers ex Benth. & Hook. f.	x	x		NE
Phyllanthaceae	352	*Hieronyma alchorneoides* Allemão	x		x	NE
	353	*Margaritaria nobilis* L.f.		x		LC
	354	*Savia dictyocarpa* Müll.Arg.		x		LC
Phytolaccaceae	355	*Gallesia integrifolia* (Spreng.) Harms		x		NE
	356	*Phytolacca dioica* L.		x	x	NE
	357	*Seguieria aculeata* Jacq.		x		NE
	358	*Seguieria americana* L.	x			LC
Picramniaceae	359	*Picramnia latifolia* Tul.	x			NE
	360	*Picramnia ramiflora* Planch.		x		NE
Piperaceae	361	*Piper aduncum* L.		x	x	NE
	362	*Piper amalago* L.		x		NE
	363	*Piper arboreum* Aubl.	x	x	x	NE
	364	*Piper cuyabanum* C. DC.		x		NE
	365	*Piper gaudichaudianum* Kunth.		x		NE
	366	*Piper glabratum* Kunth		x		NE
	367	*Piper hispidum* Sw.		x		NE
	368	*Piper peltatum* L.			x	NE
	369	*Piper tuberculatum* Jacq.			x	NE
Polygonaceae	370	*Coccoloba cujabensis* Wedd.			x	NE
	371	*Coccoloba parimensis* Benth.		x		NE
	372	*Ruprechtia laxiflora* Meisn.		x		NE
	373	*Ruprechtia triflora* Griseb.		x		NE
	374	*Triplaris americana* L.	x		x	NE
	375	*Triplaris gardneriana* Wedd.		x		NE
Primulaceae	376	*Clavija nutans* (Vell.) B. Ståhl		x	x	NE
	377	*Myrsine gardneriana* A.DC.	x			NE
	378	*Myrsine guianensis* (Aubl.) Kuntze		x		NE
Rhamnaceae	379	*Rhamnidium elaeocarpum* Reiss.	x	x		NE
	380	*Sarcomphalus mistol* (Griseb.) Hauenschild		x		NE
Rubiaceae	381	*Calycophyllum multiflorum* Griseb.	x	x		NE
	382	*Calycophyllum spruceanum* (Benth.) Hook. f. ex K. Schum.	x			NE

Family	id	SpeciesName	DF	SF	TF	CNCflora
	383	*Chomelia pohliana* Müll.Arg.			x	NE
	384	*Cordiera sessilis* (Vell.) Kuntze		x	x	NE
	385	*Coussarea hydrangeifolia* (Benth.) Müll.Arg.	x			LC
	386	*Coutarea hexandra* (Jacq.) K. Schum.	x	x		NE
	387	*Ferdinandusa speciosa* (Pohl) Pohl		x	x	NE
	388	*Genipa americana* L.	x		x	LC
	389	*Guettarda viburnoides* Cham. & Schltdl.			x	NE
	390	*Palicourea crocea* (Sw.) Roem. & Schult.			x	NE
	391	*Palicourea deflexa* (DC.) Borhidi			x	NE
	392	*Palicourea marcgravii* A. St.-Hil.	x			NE
	393	*Palicourea rigida* Kunth	x			NE
	394	*Palicourea tomentosa* (Aubl.) Borhidi	x		x	NE
	395	*Psychotria carthagenensis* Jacq.		x		NE
	396	*Randia armata* (Sw.) DC.	x	x		NE
	397	*Rudgea jasminoides* (Cham.) Müll. Arg.		x		VU
	398	*Rudgea viburnoides* (Cham.) Benth.		x		NE
	399	*Sabicea aspera* Aubl.	x		x	NE
	400	*Simira hexandra* (S.Moore) Steyerm.	x	x		NE
	401	*Simira sampaioana* (Standl.) Steyerm.		x		NE
	402	*Tocoyena formosa* (Cham. & Schltdl.) K. Schum.		x	x	NE
Rutaceae	403	*Balfourodendron riedelianum* (Engl.) Engl	x			NT
	404	*Esenbeckia almawillia* Kaastra	x	x		NE
	405	*Esenbeckia amazonica* Kaastra		x		NE
	406	*Galipea ciliata* Taub.		x		NE
	407	*Helietta apiculata* Benth.	x			NE
	408	*Helietta puberula* R.E. Fr.		x		NE
	409	*Pilocarpus pennatifolius* Lem.	x	x		NE
	410	*Zanthoxylum caribaeum* Lam.	x	x		NE
	411	*Zanthoxylum fagara* (L.) Sarg.	x	x		NE
	412	*Zanthoxylum petiolare* A. St.-Hil. & Tul.		x		LC
	413	*Zanthoxylum rhoifolium* Lam.	x	x		NE
	414	*Zanthoxylum riedelianum* Engl.		x		NE
	415	*Zanthoxylum rigidum* Humb. & Bonpl. ex Willd.		x		NE
	416	*Zanthoxylum sprucei* Engl.		x		NE
Salicaceae	417	*Banara arguta* Briq.	x			NE
	418	*Casearia aculeata* Jacq.			x	NE
	419	*Casearia gossypiosperma* Briq.	x		x	LC
	420	*Casearia obliqua* Spreng.		x		NE
	421	*Casearia rupestris* Eichler	x			NE
	422	*Casearia sylvestris* Sw.	x	x	x	NE
	423	*Prockia crucis* P. Browne ex L.		x	x	NE
	424	*Xylosma venosa* N.E.Br.	x		x	NE
Sapindaceae	425	*Allophylus edulis* (A. St.-Hill.) Radlk.		x		NE
	426	*Allophylus pauciflorus* Radkl.	x		x	NE
	427	*Averrhoidium paraguaiense* Radlk.		x		NE
	428	*Cupania castaneaefolia* Mart.			x	NE
	429	*Cupania vernalis* Cambess.			x	NE
	430	*Diatenopteryx sorbifolia* Radlk.	x			NE
	431	*Dilodendron bipinnatum* Radlk.	x		x	LC

Family	**id**	**SpeciesName**	DF	SF	TF	CNCflora
	432	*Diplokeleba floribunda* N.E. Br.	x	x		NE
	433	*Magonia pubescens* A. St.-Hil.	x			LC
	434	*Matayba elaeagnoides* Radlk.		x		NE
	435	*Matayba guianensis* Aubl.		x		NE
	436	*Melicoccus lepidopetalus* Radlk.		x		NE
	437	*Sapindus saponaria* L.	x		x	NE
	438	*Talisia esculenta* (A. St.-Hil.) Radlk.		x		NE
Sapotaceae	439	*Chrysophyllum gonocarpum* (Mart. & Eichler) Engl.	x			NE
	440	*Chrysophyllum marginatum* (Hook. & Arn.) Radlk.	x	x	x	NE
	441	*Pouteria gardneri* (Mart. & Miq.) Baehni			x	NE
	442	*Pouteria torta* (Mart.) Radlk.	x	x		LC
	443	*Sideroxylon obtusifolium* (Roem. & Schult.) T.D. Penn.	x		x	LC
Simaroubaceae	444	*Castela tweedii* Planch.	x			EN
	445	*Simarouba amara* Aubl.		x	x	NE
Siparunaceae	446	*Siparuna brasiliensis* (Spreng.) A.DC.		x		LC
	447	*Siparuna guianensis* Aubl.		x	x	NE
Solanaceae	448	*Capsicum baccatum* L.		x		NE
	449	*Cestrum mariquitense* Kunth	x			NE
	450	*Cestrum obovatum* Sendtn.			x	NE
	451	*Cestrum schlechtendalii* G. Don		x		NE
	452	*Cestrum strigilatum* Ruiz & Pav.	x		x	NE
	453	*Solanum acerifolium* Dunal	x			NE
	454	*Solanum mauritianum* Scop.		x		NE
	455	*Solanum riparium* Pers.			x	NE
	456	*Vassobia breviflora* (Sendtn.) Hunz.	x			NE
Styracaceae	457	*Styrax camporum* Pohl		x		NE
Trigoniaceae	458	*Trigonia boliviana* Warm.			x	NE
Ulmaceae	459	*Phyllostylon rhamnoides* (J. Poiss.) Taub.	x			NT
Urticaceae	460	*Cecropia pachystachya* Trécul		x	x	NE
	461	*Urera baccifera* (L.) Gaudich.		x		NE
	462	*Urera caracasana* (Jacq.) Gaudich. ex Griseb.	x			NE
Verbenaceae	463	*Aloysia virgata* (Ruiz & Pav.) Pers.	x	x		NE
Violaceae	464	*Pombalia atropurpurea* (A.St.-Hil.) Paula-Souza	x			NE
Vochysiaceae	465	*Callisthene fasciculata* Mart.			x	NE
	466	*Qualea parviflora* Mart.			x	NE
	467	*Vochysia cinnamomea* Pohl			x	NE
	468	*Vochysia divergens* Pohl			x	NE
	469	*Vochysia haenkeana* (Spreng.) Mart.			x	NE
Ximeniaceae	470	*Ximenia americana* L.			x	NE

Appendix B - Table 2. Consulted databases in TRY database.

Dataset_ID	Dataset	Reference
305	Araucaria Forest Database	Higuchi, P.; Silva, A.C. (2013). Araucaria Forest Database.
89	ArtDeco Database	Cornwell, W. K., Cornelissen, J. H. C., Amatangelo, K., Dorrepaal, E., Eviner, V. T., Godoy, O., Hobbie, S. E., Hoorens, B., Kurokawa, H., Pérez-Harguindeguy, N., Quested, H. M., Santiago, L. S., Wardle, D. A., Wright, I. J., Aerts, R., Allison, S. D., van Bodegom, P., Brovkin, V., Chatain, A., … Westoby, M. (2008). Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecology Letters*, *11*(10), 1065–1071. https://doi.org/10.1111/j.1461-0248.2008.01219.x
431	BAAD: a biomass and allometry database for woody plants	Falster, D. S., Duursma, R. A., Ishihara, M. I., Barneche, D. R., FitzJohn, R. G., Vårhammar, A., Aiba, M., Ando, M., Anten, N., Aspinwall, M. J., Baltzer, J. L., Baraloto, C., Battaglia, M., Battles, J. J., Bond-Lamberty, B., van Breugel, M., Camac, J., Claveau, Y., Coll, L., … York, R. A. (2015). BAAD: A Biomass And Allometry Database for woody plants: Ecological Archives E096-128. *Ecology*, 96(5), 1445–1445. https://doi.org/10.1890/14-1889.1
79	BIOME-BGC Parameterization Database	White, M. A., Thornton, P. E., Running, S. W., & Nemani, R. R. (2000). Parameterization and Sensitivity Analysis of the BIOME–BGC Terrestrial Ecosystem Model: Net Primary Production Controls. *Earth Interactions*, *4*(3), 1–85. https://doi.org/10.1175/1087-3562(2000)004<0003:PASAOT>2.0.CO;2
57	Categorical Plant Traits Database	unpub.
345	CIRAD Selmet Tree LNC Sahel	unpub.
106	Climbing Plants Trait Database	Gallagher, R. V., Leishman, M. R., & Moles, A. T. (2011). Traits and ecological strategies of Australian tropical and temperate climbing plants: Trait comparisons of tropical and temperate climbers. *Journal of Biogeography*, *38*(5), 828–839. https://doi.org/10.1111/j.1365-2699.2010.02455.x
176	Climbing plants trait dataset	Gallagher, R. V., & Leishman, M. R. (2012). A global analysis of trait variation and evolution in climbing plants. *Journal of Biogeography*, *39*(10), 1757–1771. https://doi.org/10.1111/j.1365-2699.2012.02773.x
184	Cold Tolerance, Seed Size and Height of North American Forest Tree Species	unpub.
74	Costa Rica Rainforest Trees Database	Chain-Guadarrama, A., Imbach, P., Vilchez-Mendoza, S., Vierling, L. A., & Finegan, B. (2018). Potential trajectories of old-growth Neotropical forest functional composition under climate change. *Ecography*, *41*(1), 75–89. https://doi.org/10.1111/ecog.02637
74	Costa Rica Rainforest Trees Database	Finegan, B., Peña-Claros, M., de Oliveira, A., Ascarrunz, N., Bret-Harte, M. S., Carreño-Rocabado, G., Casanoves, F., Díaz, S., Eguiguren Velepucha, P., Fernandez, F., Licona, J. C., Lorenzo, L., Salgado Negret, B., Vaz, M., & Poorter, L. (2015). Does functional trait diversity predict above-ground biomass and productivity of tropical forests? Testing three alternative hypotheses. *Journal of Ecology*, *103*(1), 191–201. https://doi.org/10.1111/1365-2745.12346
74	Costa Rica Rainforest Trees Database	Finegan, B., Peña-Claros, M., de Oliveira, A., Ascarrunz, N., Bret-Harte, M. S., Carreño-Rocabado, G., Casanoves, F., Díaz, S., Eguiguren Velepucha, P., Fernandez, F., Licona, J. C., Lorenzo, L., Salgado Negret, B., Vaz, M., & Poorter, L. (2015). Does functional trait diversity predict above-ground biomass and productivity of tropical

		forests? Testing three alternative hypotheses. *Journal of Ecology*, *103*(1), 191–201. https://doi.org/10.1111/1365-2745.12347
74	Costa Rica Rainforest Trees Database	unpub.
263	Costa Rican Tropical Dry Forest Trees	Powers, J. S., & Tiffin, P. (2010). Plant functional type classifications in tropical dry forests in Costa Rica: Leaf habit versus taxonomic approaches: Leaf habit and functional traits of dry forest trees. *Functional Ecology*, *24*(4), 927–936. https://doi.org/10.1111/j.1365-2435.2010.01701.x
274	Crown Architecture Database	unpub.
288	CTFS Luquillo Forest Dynamics Plot	Swenson, N. G., Stegen, J. C., Davies, S. J., Erickson, D. L., Forero-Montaña, J., Hurlbert, A. H., Kress, W. J., Thompson, J., Uriarte, M., Wright, S. J., & Zimmerman, J. K. (2012). Temporal turnover in the composition of tropical tree communities: Functional determinism and phylogenetic stochasticity. *Ecology*, *93*(3), 490–499. https://doi.org/10.1890/11-1180.1
288	CTFS Luquillo Forest Dynamics Plot	Swenson, N. G., Anglada-Cordero, P., & Barone, J. A. (2011). Deterministic tropical tree community turnover: Evidence from patterns of functional beta diversity along an elevational gradient. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1707), 877–884. https://doi.org/10.1098/rspb.2010.1369
48	Dispersal Traits Database	unpub.
75	ECOQUA South American Plant Traits Database	Blanco, C., Sosinski, E., Santos, B., Silva, M., & Pillar, V. (2007). On the overlap between effect and response plant functional types linked to grazing. *Community Ecology*, *8*(1), 57–65. https://doi.org/10.1556/ComEc.8.2007.1.8
75	ECOQUA South American Plant Traits Database	Duarte, L. da S., Carlucci, M. B., Hartz, S. M., & Pillar, V. D. (2007). Plant dispersal strategies and the colonization of Araucaria forest patches in a grassland-forest mosaic. *Journal of Vegetation Science*, *18*(6), 847–858. https://doi.org/10.1111/j.1654-1103.2007.tb02601.x
75	ECOQUA South American Plant Traits Database	Müller, S. C., Overbeck, G. E., Pfadenhauer, J., & Pillar, V. D. (2007). Plant Functional Types of Woody Species Related to Fire Disturbance in Forest–Grassland Ecotones. *Plant Ecology*, *189*(1), 1–14. https://doi.org/10.1007/s11258-006-9162-z
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112	Panama Plant Traits Database	Wright, S. J., Kitajima, K., Kraft, N. J. B., Reich, P. B., Wright, I. J., Bunker, D. E., Condit, R., Dalling, J. W., Davies, S. J., Díaz, S., Engelbrecht, B. M. J., Harms, K. E., Hubbell, S. P., Marks, C. O., Ruiz-Jaen, M. C., Salvador, C. M., & Zanne, A. E. (2010). Functional traits and the growth–mortality trade-off in tropical trees. *Ecology*, *91*(12), 3664–3674. https://doi.org/10.1890/09-2335.1
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35	Reich-Oleksyn Global Leaf N, P Database	Reich, P. B., Oleksyn, J., & Wright, I. J. (2009). Leaf phosphorus influences the photosynthesis–nitrogen relation: A cross-biome analysis of 314 species. *Oecologia*, *160*(2), 207–212. https://doi.org/10.1007/s00442-009-1291-3
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	Traits Database	https://doi.org/10.1111/j.1469-8137.2008.02715.x
33	Tropical Rainforest Traits Database	Poorter, L., & Bongers, F. (2006). Leaf traits are good predictors of plant performance across 53 rain forest species. *Ecology*, *87*(7), 1733–1743. https://doi.org/10.1890/0012-9658(2006)87[1733:LTAGPO]2.0.CO;2
460	TRY Categorical Traits Dataset (update 2018)	unpub.
313	Wood carbon content database	Thomas, S. C., & Martin, A. R. (2012). Data from: Carbon content of tree tissues: a synthesis (Version 1, p. 145803 bytes) [Data set]. Dryad Digital Repository. https://doi.org/10.5061/DRYAD.69SG2
368	Wood traits of trees and lianas from the Brazilian Atlantic Forest	unpub.
241	Xylem Functional Traits (XFT) Database	Choat, B., Jansen, S., Brodribb, T. J., Cochard, H., Delzon, S., Bhaskar, R., Bucci, S. J., Feild, T. S., Gleason, S. M., Hacke, U. G., Jacobsen, A. L., Lens, F., Maherali, H., Martínez-Vilalta, J., Mayr, S., Mencuccini, M., Mitchell, P. J., Nardini, A., Pittermann, J., … Zanne, A. E. (2012). Global convergence in the vulnerability of forests to drought. *Nature*, *491*(7426), 752–755. https://doi.org/10.1038/nature11688
241	Xylem Functional Traits (XFT) Database	Choat, B., Jansen, S., Brodribb, T. J., Cochard, H., Delzon, S., Bhaskar, R., Bucci, S. J., Feild, T. S., Gleason, S. M., Hacke, U. G., Jacobsen, A. L., Lens, F., Maherali, H., Martínez-Vilalta, J., Mayr, S., Mencuccini, M., Mitchell, P. J., Nardini, A., Pittermann, J., … Zanne, A. E. (2012). Global convergence in the vulnerability of forests to drought. *Nature*, *491*(7426), 752–755. https://doi.org/10.1038/nature11690
241	Xylem Functional Traits (XFT) Database: Nature Subset	Choat, B., Jansen, S., Brodribb, T. J., Cochard, H., Delzon, S., Bhaskar, R., Bucci, S. J., Feild, T. S., Gleason, S. M., Hacke, U. G., Jacobsen, A. L., Lens, F., Maherali, H., Martínez-Vilalta, J., Mayr, S., Mencuccini, M., Mitchell, P. J., Nardini, A., Pittermann, J., … Zanne, A. E. (2012). Global convergence in the vulnerability of forests to drought. *Nature*, *491*(7426), 752–755. https://doi.org/10.1038/nature11689
190	Yasuni Ecuador Leaves	Kraft, N. J. B., Valencia, R., & Ackerly, D. D. (2008). Functional Traits and Niche-Based Tree Community Assembly in an Amazonian Forest. *Science*, *322*(5901), 580–582. https://doi.org/10.1126/science.1160662

Appendix C - Aims and Scope: Functional Ecology - British Ecological Society

Functional Ecology publishes high-impact papers that enable a mechanistic understanding of ecological pattern and process from the organismic to the ecosystem scale. Because of the multifaceted nature of this challenge, papers can be based on a wide range of approaches. Thus, manuscripts may vary from physiological, genetics, life-history, and behavioural perspectives for organismal studies to community and biogeochemical studies when the goal is to understand ecosystem and larger scale ecological phenomena. We believe that the diverse nature of our journal is a strength, not a weakness, and we are open-minded about the variety of data, research approaches and types of studies that we publish. Certain key areas will continue to be emphasized: studies that integrate genomics with ecology, studies that examine how key aspects of physiology (e.g., stress) impact the ecology of animals and plants, or vice versa, and how evolution shapes interactions among function and ecological traits. Ecology has increasingly moved towards the realization that organismal traits and activities are vital for understanding community dynamics and ecosystem processes, particularly in response to the rapid global changes occurring in earth’s environment, and Functional Ecology aims to publish such integrative papers.

Aims and Scope: Journal of Applied Ecology - British Ecological Society

Journal of Applied Ecology publishes novel, broad-reaching papers on the interface between ecological science and the management of the natural environment. We cover all ecological realms and themes in applied ecology, with a focus on addressing the acute global challenges of mitigating and adapting to climate change, conserving biodiversity, and promoting nature’s multifaceted contributions to people. We are particularly interested in articles that use ecological science to inform the policies and practices that (i) mitigate the impact of major anthropogenic stressors, such as habitat loss and ecosystem degradation, invasives, climate change, fire, overexploitation, etc, and (ii) show how nature can be managed to improve well being and sustainability in natural and modified systems.

While we focus primarily on studies involving free-living and non agricultural species, we consider papers involving cultivated species (e.g. crops), domestic species (e.g. livestock), or managed species (e.g. honey bees or farmed fish) as long as they have implications for the management of the natural environment.

We aim to be inclusive of novel approaches and non-standard research, and welcome a range of article types (e.g. reviews, practitioner’s perspectives, policy directions, and forum articles challenging existing work); contributions with a methodological focus that have strong potential to change the way applied ecology is conducted; and studies testing ideas outside of field settings, such as laboratory experiments and modeling, as long as they advance the discipline of applied ecology and provide recommendations that inform the management of the natural environment.