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INTERAÇÕES ENTRE SERES HUMANOS E PLANTAS COMO DETERMINANTES PARA MONTAGEM DE COMUNIDADES VEGETAIS DA CAATINGA

Campina Grande, PB
2023

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Tese apresentada ao Programa de Pós-Graduação em Etnobiologia e Conservação da Natureza uma parceria entre as Universidades: Federal Rural de Pernambuco, Estadual da Paraíba, Federal de Pernambuco, como parte dos requisitos para obtenção do título de Doutora em Etnobiologia e conservação da Natureza.

Orientador: Sérgio de Faria Lopes (Universidade Estadual da Paraíba)
Co-orientador: Jorge Arturo Meave del Castillo) (Universidad Nacional Autónoma de México)

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Campina Grande PB

2023

Filha de agricultores, trabalhando com agricultores!

Dedico

Aos meus pais, Maria da Paz B. Ramos e João de Medeiros Ramos.

Em especial ao meu pai. Sua ausência deixou um vazio e a vida às vezes parece já não ter tanto sentido.

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Sumário

RESUMO

A complexa dinâmica dos ecossistemas, dada pela variação ao longo do tempo e espaço nas condições bióticas e abióticas, tem sido traduzida pela Ecologia, que ao longo do tempo tem ganhado força, complexidade e conectividade com diversas outras ciências, numa busca incessante em compreender os padrões que regem a abundância, composição e diversidade de espécies. No entanto, só recentemente, o papel dos seres humanos começou a ser incorporado nas explicações e previsões sobre essa dinâmica dos sistemas. Dentro desse contexto, o objetivo central desta tese foi compreender como ocorre a montagem de comunidades vegetais ao longo de gradientes climáticos submetidos a distintos distúrbios antrópicos crônicos no semiárido brasileiro. Para isso, buscamos também, integrar o conhecimento ecológico de populações humanas locais, sobre a utilização de espécies vegetais aos aspectos da Ecologia de comunidades vegetais, para determinar como características morfológicas e fisiológicas (traços funcionais) das plantas influenciam a seleção e uso de espécies por populações humanas locais. Nossos resultados revelam que as relações de uso e seleção de espécies tem severos efeitos na dinâmica dos sistemas sócio-ecológicos. Populações humanas locais selecionam as espécies vegetais de acordo com características importantes, como densidade da madeira, área foliar especifica, espussura foliar. Tal seleção exerce uma forte pressão de uso nas espécies mais desejáveis, o que pode afetar negativamente a dinâmica e resiliência do sistema. Nesse sentido, as comunidades vegetais dos estratos adulto e regenerante encontram-se com o desenvolvimento comprometidos, o que por sua vez, afetará o fornecimento de bens e serviços ecossistêmicos para as sociedades humanas, especialmente, aqueles que dependem diretamente desses recursos. A dinâmica das comunidades vegetais da Caatinga é portanto, um complexo resultante da interação entre fatores abióticos juntamente com a influência dos seres humanos que são agentes capazes de influenciar o funcionamento do ecossistema.

Palavras chave: Florestas secas, montagem de comunidades, conhecimento ecológico local, distúrbio antrópico crônico, precipitação, características funcionais.

1. INTRODUÇÃO GERAL

1.1 Objetivos e Questionamentos

A Caatinga é sem dúvida um ecossistema fascinante, e aprendi a admirá-la desde muito cedo. Desde a infância estive imersa dentro da Caatinga, fazendo parte desse ecossistema tão diverso, sou filha de agricultores do Cariri paraibano. Vivo até aqui as experiências, não apenas como uma jovem mulher cientista, mas antes de tudo sou uma caririzeira, e essas são as raízes que me sustentaram até aqui e sustentarão até o fim do ciclo terrestre. Os conhecimentos, práticas e crenças que antecedem o meu eu cientista exerceram forte influência no rumo dos meus interesses de pesquisa. Desde a infância, acompanhei meus pais na lida com as plantações (que acompanham o período chuvoso) e com a criação de rebanhos. Os conhecimentos, práticas, e os motivos pelos quais meus pais usavam determinadas plantas, enquanto outras eram excluídas sempre foi algo que me chamou atenção. Talvez era algo inato à minha pessoa, talvez foi algo que aprendi a admirar, através da observação, da relação intrínseca que meus pais desenvolveram com tudo que os cercava.

Prever como as atividades humanas, incluindo a seleção de espécies por sociedades rurais, influencia a montagem de comunidades vegetais pode ser um campo complexo. Tendo em vista que diversos fatores estão atuando ao longo do tempo e espaço. Isso se torna ainda mais complexo em ambientes heterogêneos, como é a Caatinga. As pesquisas na Ecologia tem seguido esse caminho e, um arcabouço teórico tem se formado, mostrando que o caminho para as respostas dos distúrbios antrópicos e perdas de biodiversidade é o modelo de sistemas socioecológicos (BENNETT *et al*., 2015; DÍAZ *et al*., 2011; LOPES, 2017). Uma estrutura útil para entender, prever e abordar a dinâmica de um "clima humano", no qual as sociedades humanas interagem diretamente com a biodiversidade e o ambiente em que vivem, em escala local e regional (HUDSON *et al*., 2020). Há reconhecimento de que ao longo de sua evolução, as sociedades humanas atuaram moldando os ecossistemas em que vivem. A medida que algumas espécies são selecionadas enquanto outras são excluídas, os humanos atuam como agentes causadores de mudanças (ELLIS, 2011).

Por um lado, sabe-se que as alterações ambientais causadas por atividades antrópicas conduzem mudanças severas na biodiversidade em todo o planeta. O que consequentemente, resulta em alterações nas propriedades dos ecossistemas, que por sua vez, afetam os benefícios que os humanos podem obter dos ecossistemas. Por outro lado, tais alterações resultam também em uma maior desigualdade social, isso porque as populações humanas que dependem diretamente da biodiversidade, têm o acesso e escolha desses recursos reduzidos, portanto, são essas as populações as mais afetadas pela perda de biodiversidade (DIAZ *et al*., 2006). Nesse cenário, há uma convergência para a necessidade de uma aliança entre distintas ciências, a fim de traçar caminhos para entender as ligações mútuas entre sistemas naturais e sociais e, assim, enfrentar os desafios da sustentabilidade (FIGUEROA; CALZADA; MEAVE, 2020). De fato, abordagens interdisciplinares exigem um acentuado esforço de pesquisa e, por vezes, os pesquisadores enfrentam uma série de desafios e barreiras para conduzir esse tipo de pesquisas (LOPES, 2017). Entretanto, essas abordagens permitiram traçar estratégias para melhoria na qualidade de vida de todos que compõem o planeta Terra (DÍAZ et al., 2011, 2018).

É preciso considerar que os desejos, as percepções e capacidades para selecionar componentes da biodiversidade variam dentro e entre os grupos humanos e, portanto, afetam de maneira distinta a biodiversidade (ALBUQUERQUE et al., 2018; CÁCERES et al., 2015). A abordagem através da teoria dos sistemas socioecológicos é uma ferramenta útil para entender, prever e abordar a dinâmica dos ecossistemas (FOLKE, 2006). Uma vez que, através dessa abordagem, é possível analisar como as sociedades humanas interagem diretamente com os demais componentes dos ecossistemas, em escala local e regional (FERNÁNDEZ-GIMÉNEZ et al., 2018; FOLKE, 2006).

Dessa forma, na presente tese busquei compreender como ocorre a montagem de comunidades vegetais ao longo de gradientes climáticos submetidos a distintos distúrbios antrópicos crônicos no semiárido brasileiro. Para alcançar uma compreensão mais detalhada sobre as interações entre seres humanos e plantas, integrei o conhecimento ecológico de populações humanas locais, sobre a utilização de espécies vegetais, aos aspectos da Ecologia de comunidades vegetais para determinar como características morfológicas e fisiológicas (traços funcionais) das plantas influenciam a seleção e uso de espécies por populações humanas da Caatinga. Dessa forma, busquei responder as seguintes questões: Como os distúrbios antrópicos crônicos afetam a estrutura, composição e diversidade dos componentes (estratos) da vegetação adulta e regenerante ao longo dos gradientes climáticos na Caatinga?; (2) Como as variáveis climáticas e ambientais interagem com os distúrbios antrópicos crônicos? (3) Como caracteristicas funcionais das plantas influenciam a seleção de plantas por populações humanas rurais?. A partir das respostas obtidas com esses questionamentos tornou-se possível elaborar um cenário detalhado sobre as respostas das comunidades vegetais as distintas combinações entre condições climáticas e distúrbios antrópicos crônicos. De modo que, ficaram evidentes algumas ameaças aos sistemas socioecológicos, bem como a resiliência da Caatinga. Além disso, chegamos a importantes achados sobre o papel das caracteristicas funcionais na seleção de plantas por populações humanas locais. Dessa forma, nesta tese estão apresentadas discussões importantes sobre os processos de montagem de comunidades vegetais, resiliência e a funcionalidade do ecossistema, todos sob a perspectiva da inclusão dos sistemas socioecológicos.

1.2 Estratégias de Pesquisa

Para alcançar nossos objetivos de pesquisa, buscamos elaborar um desenho amostral que atendesse o levantamento da vegetação, de variáveis ambientais, distúrbios antrópicos, bem como o levantamento etnobotânico. Inicialmente para construção do desenho amostral da pesquisa, foram elaborados mapas de precipitação e de cobertura vegetal. Para elaboração dos mapas, coletamos dados climáticos e imagens de satélite que cobrissem toda porção da microregião do Cariri. Para elaborar os mapas de cobertura vegetal, utilizamos o índice de vegetação por diferença normalizada (NDVI), que tem como *Proxy* estimar a biomassa e produtividade da vegetação, através do cálculo: NDVI = (Infra Vermelho – Vermelho) / (Infra Vermelho +Vermelho) (ROUSE *et al*., 1973), dado pelo Software Argis. O NDVI foi obtido a partir de imagens das bandas 4 e 5 do satélite Landsat 8, referentes a estação seca do ano de 2017 e obtidas no site eartherexplorer.usgs.gov. As bandas correspondem a proporção de luz refletidas pela vegetação detectadas por sensores, sendo designadas respectivamente como vermelho e infravermelho próximo. As imagens utilizadas foram registros da estação seca, pois é o momento mais favorável para mapear a vegetação de regiões secas. As imagens se referem ao ano de 2017. Os dados climáticos para região foram obtidos pelo banco mundial de dados climáticos *Word Clim*.

Após a elaboração dos mapas, foram definidas as áreas de interesse, incluindo áreas que estivessem localizadas em distintos níveis de precipitação, bem como áreas com diferentes níveis de cobertura vegetal. Buscamos considerar a variação ambiental em virtude da heterogeneidade ambiental da Caatinga. Posteriormente, a seleção de todos os pontos foi avaliada com visitas e observação de campo. Alguns pontos não condiziam com a cobertura vegetal esperada, por exemplo, ou áreas que sofreram alguma perturbação aguda e que tiveram toda cobertura vegetal retirada, foram descartados e selecionados novos pontos de interesse. Como uma restrição para seleção dos pontos amostrais, estabelecemos uma distância mínima de um raio de 2km entre os pontos. Consideramos esse tamanho do *buffer* para evitar a sobreposição e assim aumentar a independência entre as áreas. As áreas que investigamos estão todas localizadas na microregião do Cariri, porção central do estado da Paraíba, embora, em escala macro, essa região tenha algumas características em comum, em nossas pesquisas e viagens a campo observamos uma variação enorme nas formas vegetais, nos tipos de solo (dados não publicados) nos níveis e formas de pressão antrópica, bem como nas diferentes cosmovisões das comunidades locais da região estudada. Ao final, selecionamos um total de 21 áreas.

Para o levantamento da vegetação em cada área foram delimitadas parcelas de 50 por 20 metros. Realizamos o levantamento florístico e fitossociológico para o estrato adulto e regenerante. Para o estrato adulto, registramos também os indivíduos mortos. Em cada parcela sempre que possível, foram identificadas todas as espécies e coletado material vegetativo para identificação botânica, que ocorreu com auxílio de literatura e especialista na área (Figura 1). Afim de avaliar o efeito do aporte de serrapilheira no estrato regenerante, em todas as parcelas foram mensuradas o estoque de serrapilheira a partir da coleta de toda necromassa presente em cinco pontos de 1m x 1m ($1m^2$) cada, distribuídos aleatoriamente em cada parcela.

Para obtermos um gradiente de intensidade de distúrbio antrópicos, em cada parcela registramos métricas descritas como importantes indicadoras de distúrbios antropogênicos crônicos em Florestas Tropicais Secas (MARTORELL e PETERS, 2005). Utilizamos algumas métricas de medidas diretas que foram mensuradas na parcela e medidas indiretas baseadas no contexto geográfico que foram obtidas com auxílio de imagens de satélite utilizando o Software ArcGis 10.3. Com base nessas métricas, identificamos dois principais tipos de perturbação para caracterizar índices de distúrbio antrópico crônico: (1) Pressão do gado. Este distúrbio está relacionado à atividade dos herbívoros domésticos (gado, cavalos, burros, cabras e ovelhas) que pastejam e causam danos físicos no solo através do pisoteio nas parcelas; (2) Atividades humanas: este tipo de distúrbio se refere a marcas do uso da terra pelas pessoas, e são medidas indiretas relacionadas ao contexto geográfico. Utilizamos imagens de satélite para estimar os indicadores de pressão humana. Para coleta de dados sobre o conhecimento ecológico local selecionamos cinco áreas, de modo que abrangessem distintos níveis de cobertura vegetal e precipitação. Inicialmente mantivemos um primeiro contato com alguns moradores locais, nesse momento explicamos para eles os objetivos e como estava estruturada nossa pesquisa.

Figura 1. Primeira etapa da pesquisa. (A, B) Mensuração de impactos antrópicos. (C, D) Levantamento florístico e fitossociológico. (E, F) Processo de herborização de material vegetal para identificação.

Recorremos às associações rurais e agentes de saúde das comunidades rurais para fortalecer e garantir uma maior confiabilidade nas informações obtidas entre as populações locais e os pesquisadores. Para coleta de dados sobre o conhecimento ecológico local utilizamos um conjunto de técnicas complementares a fim de extrair o máximo das informações dos moradores locais (Figura 2). Inicialmente, fizemos perguntas sobre quais plantas eles conheciam e utilizavam para as diferentes categorias de uso que listamos. Em seguida, utilizávamos as técnicas da nova leitura, turnê guiada e recurso visual (ALBUQUERQUE *et al*., 2014). A técnica de nova leitura consistiu em o pesquisador enunciar oralmente as plantas citadas pelo participante, de forma a propiciar a recordação de mais plantas (ALBUQUERQUE *et al*., 2014). Utilizamos um recurso visual de fotografias em dois momentos diferentes: primeiro, para aqueles participantes que afirmaram não conhecer as plantas; e segundo, para os participantes que mencionaram esquecer no momento das entrevistas (MEDEIROS *et al*., 2014). As fotografias tinham imagens de frutas, folhas, flores e caules de plantas com o hábito de árvores e arbustos que foram registradas durante o levantamento da vegetação nas comunidades. Também realizamos visitas guiadas para verificar a identidade botânica das espécies mencionadas pelos participantes e para coletar material taxonômico (ALBUQUERQUE et al., 2014).

Figura 2. Levantamento de dados etnobotânicos. (A, B, C) Lista livre e técnicas da nova leitura. (D) Uso de recurso visual (fotografias). (E, F, G, H) Turnê guiada. (I) Equipe de pesquisadores com agropastor da comunidade Curral do meio, município de São João do Cariri, estado da Paraíba.

1.3 Estrutura da Tese

A tese é composta por cinco capítulos. De acordo com o modelo adotado pelo Programa de Pós-Graduação em Etnobiologia e Conservação da Natureza, o primeiro deles denomina-se "Fundamentação Teórica", onde apresento as principais temáticas envolvidas na tese. O capítulo II intitulado de "*Environmental factors modulate plant selection by local human populations in dry tropical forests"* corresponde a um capítulo de livro que foi publicado no livro *Ethnobotany of the Mountain Regions of Brazil* da editora Springer. O capítulo III que tem como título: *"Functional traits influencing selection and use of plant species by local human populations in the tropical dry Caatinga forest"* foi submetido a revista *Economic Botany*. O capítulo IV intitulado: "*The role of chronic anthropogenic disturbances in plant community assembly along a water stress gradient in Brazil's semiarid Caatinga region"* que foi publicado na revista *Forest Ecology and Management*. O capítulo V, que aborda as principais considerações finais da presente tese. E por fim, nos apêndices, apresento o registro de ocorrência de uma espécie vegetal encontrada nos levantamentos fitossociologicos. O artigo foi publicado na revista *Acta brasiliensis* e tem como titulo: *"First record of Cnidoscolus obtusifolius Pohl (Euphorbiaceae) for Paraíba State , northeastern Brazil"*

No segundo capítulo buscamos contextualizar e reunir algumas evidências sobre os efeitos de variáveis ambientais na seleção de espécies de plantas que populações humanas locais realizam. No terceiro capítulo, consideramos que o uso e seleção de espécies vegetais é um importante *driver* de mudanças nos ecossistemas, dessa forma compreender a dinâmica que rege esse processo é fundamental para compreender a dinâmica dos sistemas sociais e ecológicos. Dessa forma, buscamos integrar o conhecimento ecológico de populações humanas sobre a utilização de espécies vegetais, aos aspectos da Ecologia de comunidades vegetais, para compreender os fatores que influenciam a seleção de espécies de plantas pelas populações humanas locais. Demonstramos que os agropastores selecionam e utilizam as espécies de acordo com um conjunto de características mais adequadas ao fornecimento dos diferentes serviços ecossistêmicos que eles desejam. Portanto, as características funcionais das espécies de plantas são fatores importantes na seleção de espécies vegetais.

No quarto capítulo, buscamos verificar como os distúrbios antrópicos crônicos modulam a estrutura, composição e diversidade de comunidades vegetais adultos e regenerantes submetidas a distintas condições climáticas na Caatinga. Demonstramos que os distúrbios antrópicos crônicos são mais severos nas áreas mais áridas. A limitação hídrica dificulta a manutenção da dinâmica natural e restabelecimento das espécies após os distúrbios. O que resulta em uma comunidade menos desenvolvida, com baixa diversidade. O índice de pressão do gado foi negativamente relacionado ao diâmetro ao nível do solo, área basal, e diversidade no estrato adulto. Para o estrato regenerante, o estoque de serapilheira teve efeito mais forte na estrutura da comunidade regenerante, que é composto, principalmente, por espécies mais resistentes a distúrbios. Esses resultados revelam que a interação entre os distúrbios antrópicos crônicos e a baixa disponibilidade de água pode ter consequências drásticas na dinâmica da Caatinga.

E por fim, embora não esteja nos objetivos centrais da tese, apresento aqui um novo registro de ocorrência de uma espécie vegetal para o estado da Paraíba. Esse artigo surgiu a partir do levantamento fitossociologico, uma das etapas fundamentais desta tese. A partir desse achado fica evidente a importância dos levantamentos florísticos e fitossociológicos na região. A Caatinga compreende uma vasta área, com território equivalente a alguns países europeus, e elevada heterogeneidade ambiental, isso assegura que ainda temos muito a descobrir sobre a Caatinga, esse ecossistema tão heterogêneo e diverso, no contexto ecológico e social.

Abaixo descrito estão as referências bibliográficas dos produtos publicados da tese:

Capítulo II: Ramos, M.B., Pedrosa, K.M., de Faria Lopes, S., 2022. Environmental Factors Modulate Plant Selection by Local Human Populations in Dry Tropical Forests. Springer, Cham, pp. 1–13. https://doi.org/10.1007/978-3-030-47254-2_115-2.

Capítulo IV: Ramos, M.B., Maciel, M.G.R., Cunha, S.S. da, de Souza, S.M., Pedrosa, K.M., de Souza, J.J.L.L., González, E.J., Meave, J.A., Lopes, S. de F., 2023. The role of chronic anthropogenic disturbances in plant community assembly along a water availability gradient in Brazil's semiarid Caatinga region. For. Ecol. Manage. 538, 120980. https://doi.org/10.1016/J.FORECO.2023.120980

Nota: Ramos, M.B., Maciel, M.G.R., De Melo, J.I.M., Lopes, S. de F., 2020. First record of *Cnidoscolus obtusifolius* Pohl (Euphorbiaceae) for Paraíba State , northeastern Brazil. Acta Bras. 4, 187–190.

2. CAPÍTULO I: FUNDAMENTAÇÃO TEÓRICA

As comunidades ecológicas são definidas como uma organização no espaço e no tempo, compostas por um conjunto de populações que estão interconectados através das suas interações. Tais interações determinam os padrões de abundância, riqueza, composição, e por fim, o funcionamento das comunidades (VELLEND, 2010). A maneira como as espécies estão distribuídas no ambiente está diretamente ligada aos mecanismos de utilização dos recursos, e adaptação as condições ambientais (SILVERTOWN, 2004), além da influência de fatores biológicos, tais como predação, competição e a interferência antropogênica (DORNELAS, 2010). Todos esses fatores variam no espaço e no tempo e atuam sinergicamente na distribuição das espécies e na estruturação das comunidades vegetais (MEYNARD *et al.*, 2013; SANDE, VAN DER *et al.*, 2017; SILVA e SOUZA, 2018).

Apesar do vasto arcabouço teórico e empírico acumulado a respeito dos padrões de estruturação das comunidades, muitas lacunas permanecem abertas. A exemplo, do papel dos seres humanos como agentes de mudanças, que só recentemente passou a ser discutido, e apontado como importante covariável em todos os processos doravante apresentados (BOWLER *et al.*, 2020). Além disso, grande parte dos esforços se concentraram em florestas úmidas, o que permitiu a construção de um entendimento sobre os mecanismos e padrões que governam desde a dinâmica e crescimento das populações, até o desenvolvimento e estrutura das comunidades. No entanto, muitos desses padrões não podem ser aplicados efetivamente a outros ecossistemas, por exemplo as Florestas Tropicais Sazonalmente Secas (FTSS). Por essas razões, compreender os padrões de distribuição das espécies nos mais variados ambientes continua sendo uma questão fundamental na Ecologia vegetal.

As Florestas Tropicais Sazonalmente Secas (FTSS) são consideradas importantes componentes da vegetação tropical, possuem um conjunto de características particulares, a exemplo dos baixos regimes hídricos (<1.000 mm), acentuada sazonalidade, com estação seca que dura de 3 a 8 meses, além de altas taxas de evapotranspiração potencial (DEXTER *et al.*, 2018; MORO *et al.*, 2015), o que resulta em um conjunto de particularidades na estrutura, composição de espécies e dinâmica do sistema. Ao mesmo tempo em que a dinâmica hídrica exerce efeito modulador nesses ambientes, os distúrbios antrópicos crônicos atuam potencializando o stress hídrico (GIBB *et al.*, 2015) tornando o ecossistema vulnerável, devido as lentas taxas de recrutamento e crescimento dos vegetais (CALZADA *et al.*, 2018). No contexto de mudanças climáticas globais, até 2100 as Florestas Secas passarão por um aumento na evaporação e temperatura médias e, consequentemente, secas mais longas e severas que podem reduzir a produção líquida primária, induzir mudanças no crescimento anual da população e aumentar a probabilidade de extinção de espécies (SARMENTO; FRANCA, 2018).

Dentre as FTSS, a Caatinga é uma das maiores regiões semiáridas tropicais do mundo, abrangendo um polígono com aproximadamente 912,500 km^2 do território brasileiro (MORO *et al.*, 2015). Compreende um mosaico vegetacional dotado de uma grande variedade de fisionomias, condicionadas por uma série de fatores físicos e microclimáticos (APGAUA *et al.*, 2015; MORO *et al.*, 2016). A forte sazonalidade, com altas taxas de radiação solar, temperaturas elevadas, altos índices de evapotranspiração e baixos e irregulares índices pluviométricos caracterizam os principais determinantes para os padrões de crescimento e reprodução dos organismos vegetais (SILVA e SOUZA, 2018), atuando diretamente nos processos de regeneração e podendo limitar o recrutamento de árvores (RIBEIRO *et al.*, 2015).

Outra importante característica da Caatinga, é que apesar da severidade climática, cerca de 27 milhões de pessoas vivem nessa região, dependendo direta ou indiretamente dos recursos naturais, o que consequentemente remete no alto grau de degradação da região (ANTONGIOVANNI *et al.*, 2020). Considerando que as populações humanas estão espalhadas nos mais diversos ambientes e paisagens do mundo, é importante compreender que o modo de vida das pessoas que ocupam um determinado espaço natural pode fornecer informações imprescindíveis para estratégias de conservação da biodiversidade (HUNTINGTON 2011) e, nesse contexto, o conhecimento ecológico local (CEL) tem sido cada vez mais reconhecido como um componente importante para direcionar ações conservacionistas (BERKES; COLDING; FOLKE, 2000; LOPES, 2017). O conhecimento ecologico local se refere ao corpo de conhecimentos, práticas e crenças, que as populações humanas adquiriram partir da observação, uso e manejo dos recursos (BERKES *et al*. 2000). Tais conhecimentos podem ser transmitidos cuturalmente atraves das gerações e pode ser utilizado para entender como as sociedades humanas interagem com a natureza, levando em conta suas estratégias e interesses (FOLKE, 2000). Conectar o CEL ao Ecologia pode portanto, ajudar a desenvolver, de modo mais eficiente, soluções para o manejo dos recursos e garantir a sustentabilidade dos sistemas sócio ecológicos (BERKES; COLDING; FOLKE, 2000; DÍAZ et al., 2018; FOLKE, 2006).

Algumas pesquisas têm apontado que as populações humanas são capazes de reconhecer e selecionar indiretamente grupos de plantas com características similares, a depender do fim de sua utilização (BROWN *et al.*, 2011; CÁMARA-LERET *et al.*, 2017; PEDROSA *et al.*, 2021). Nota-se uma preferência por grupos de plantas com atributos funcionais que favorecem o uso da espécie para determinado fim (CÁMARA-LERET et al., 2017). Espécies de interesse para uso madeireiro, podem ser selecionadas por sua maior densidade, fato que reflete em um maior potencial energético (FARIAS *et al.*, 2007). Além disso, destaca-se a seleção feita pelos animais domesticados que acabam forrageando grupos de vegetais com maior palatabilidade, reduzindo a diversidade da mesma (CUNHA *et al.*, 2022; NIU *et al.*, 2016; NUNES *et al.*, 2016).

Montagem de comunidades vegetais em escala local

Do ponto de vista da montagem de comunidades, compreender os fatores que regem as comunidades vegetais é a base para o entendimento do funcionamento desses sistemas e, num cenário de mudanças climáticas globais, é possível prever como os ecossistemas responderão frente ao exponencial desenvolvimento das atividades antropogênicas (DORNELAS, 2010). Alguns fatores abióticos como, o clima, atuam em macro escala determinando padrões gerais de diversidade (VELLEND, 2010), por outro lado, em escala local, fatores como a altitude, topografia, relevo, profundidade, fertilidade, quantidade de matéria orgânica, umidade e textura do solo, atuam selecionando um conjunto de espécies com características morfofisiológicas adaptadas a um conjunto específico de condições ambientais (MÉNDEZ-TORIBIO *et al.*, 2016; RAMOS *et al.*, 2020)

Dentre as variáveis abióticas, o solo é um sistema dinâmico e complexo resultante de processos históricos e da ação combinada de fatores físicos, químicos e biológicos (JENNY; AMUNDSON, 1941). O solo desempenha um importante papel no crescimento, no sucesso reprodutivo de plantas, no desempenho relativo de plantas coexistentes, na composição, e produtividade da comunidade (GUREVITCH; SCHEINER; FOX, 2009). Por exemplo, a topografia, as propriedades físicas e químicas do solo são responsáveis por controlar as concentrações de nutrientes do solo, a retenção de umidade, além de apoiar ou limitar o crescimento da raiz, e influenciar a quantidade de água, oxigênio, e na drenagem do solo (MÉNDEZ-TORIBIO *et al.*, 2016; PUTTEN, VAN DER *et al.*, 2013). Em FTSS, o regime hídrico é considerado o principal filtro ambiental, refletindo não apenas na vegetação, mas também nas características dos solos, que são predominantemente pouco desenvolvidos, cascalhentos, rasos, ácidos à alcalinos e eutróficos (ARAÚJO FILHO *et al.*, 2017). Como resultado da baixa pluviosidade que minimiza a perda de nutrientes por lixiviação e proximidade do material de origem, ocasionando maior fertilidade natural dos solos (ARAÚJO FILHO *et al.*, 2017; ARRUDA *et al.*, 2015). Em FTSs, um dos atributos do solo que mais influenciam as plantas é a estrutura, que está relacionada ao arranjo físico de partículas do solo. Entre os atributos da estrutura do solo, a porosidade e a textura se destacam em FTSs por o influenciar o fluxo de água e ar dentro do solo, bem como a retenção de água e relações nutricionais (GUREVITCH; SCHEINER; FOX, 2009).

O entendimento do ambiente abiótico como modelador da distribuição de espécies é um dos conceitos mais primários e duradouros dentro da Ecologia (KRAFT *et al.*, 2015). O conceito de filtragem ambiental que temos atualmente é oriundo de estudos com vegetais e postulam que apenas as espécies que possuem fenótipos específicos para se estabelecer no ambiente vão persistir, enquanto outros menos adaptados a pressões do ambiente tem maior probabilidade de serem excluídas (LA RIVA, DE *et al.*, 2016). Como estratégias para coexistência, as plantas variam em suas características funcionais e, portanto, em sua preferência às condições ambientais (DUBUIS *et al.*, 2013; LAUGHLIN *et al.*, 2015). Dentre essas características funcionais, os teores de compostos fenólicos, teores de fibras, concentrações de nutrientes foliares, área foliar específica, massa seca foliar, densidade de madeira, altura média, diâmetro médio, respondem de maneira significativa as variações nas condições abióticas, e podem, portanto, fornecer informações valiosas sobre os processos de montagem das comunidades, bem como o funcionamento dos ecossistemas (MCGILL *et al.*, 2006; PETCHEY; GASTON, 2006).

Associado aos filtros ambientais e atuando em menor escala, fatores bióticos como as interações ecológicas (competição, mutualismo, facilitação e herbivoria), e pressão humana são determinantes na montagem das comunidades, estando diretamente relacionados a diferenciação de nicho e coexistência das espécies (LA RIVA, DE *et al.*, 2016; MIGUEL *et al.*, 2018). No caso das interações, o consumo de vegetais por parte dos herbívoros, por um lado, induz os vegetais a desenvolverem diversas estratégias de defesas, tais como, variações na morfologia, composição química e resistência física (DÍAZ *et al.*, 2007). Por outro lado, a pastagem por grandes herbívoros pode controlar o crescimento e a dominância de algumas espécies através do pastejo (NIU *et al.*, 2016). Dessa forma, competidores mais fracos conseguem coexistir com um conjunto de outras espécies, controlando e mantendo os padrões de riqueza da área (NIU *et al.*, 2016). Em regiões semiáridas, as espécies perenes, investem em compostos de carbono e menores concentrações de nitrogênio, o que lhes confere uma menor palatabilidade (SILVA; ESPÍRITO-SANTO, MORAIS, 2015). A herbivoria por animais domesticados está entre as métricas para mensuração de distúrbios antrópicos crônicos e tem efeitos severos nas comunidades vegetais (MARTORELL; PETERS, 2005). Na Caatinga, esses animais têm sido relatados como uma forte ameaça à riqueza e diversidade vegetal, em detrimento de seu intenso forrageio sobre espécies nativas (SCHULZ *et al.*, 2016, 2019).

Relações entre populações humanas e uso dos recursos naturais

Comprender a dinâmica da interações entre os seres humanos e meio ambiente tem sido campo de investigação de diversas ciências e, requer esforço combinado e integrado dos mais diversos campos científicos (ALBUQUERQUE; FERREIRA JÚNIOR, 2017; MILLENNIUM ECOSYSTEM ASSESSMENT, 2005). Nessa perspectiva, a Etnobiologia emerge como a ciência, que busca compreender as relações dinâmicas entre os povos, biota e ambientes (ALBURQUERQUE e MEDEIROS, 2013) e que pode conectar cientistas ambientais, gestores e grupos humanos que lidam diretamente com a biodiversidade (SMITH, 2009). Baseada em ciências como a Ecologia, Antropologia, e Psicologia, a Etnobiologia reflete sobre as inter-relações que populações humanas estabeleceram ao longo do espaço e do tempo com os animais, as plantas, e o ambiente físico, levando em consideração os vieses, crenças, cultura e religião dos povos em questão (ANDERSON *et al.*, 2011; WOLVERTON, 2013).

É sabido que ao longo de sua evolução os seres humanos manejaram diferentes formas de vida e recursos naturais, moldando o ambiente e utilizando os serviços ecossistêmicos de acordo com as variações sazonais, variabilidade dos preços, legislação e conflitos de interesse (DÍAZ *et al.*, 2011). Dessa forma, atuam como construtores de nicho, modificando o ambiente em que vivem (nicho) e o de outros organismos através de suas ações, podendo alterar também os processos de seleção natural (ELLIS, 2015; ODLING-SMEE; LALAND; FELDMAN, 2013). O que no princípio era um meio de subsistência, hoje expressa a capacidade humana de utilizar a biodiversidade, conduzindo a um crescimento exponencial nos desequilíbrios ambientais, o que consequentemente levou a uma diminuição dos recursos naturais (ELLIS; RAMANKUTTY, 2008).

Os distúrbios antropogênicos crônicos representam um perigo eminente as FTSS, levando um decréscimo drástico da biodiversidade e conduzindo ao colapso ecossistêmico. A coleta de lenha, exploração de produtos florestais não madeireiros e o pastoreio extensivo de gado representam excelentes exemplos de fatores que contribuem para as alterações negativas na função, composição e diversidade das FTSS, além de serem difíceis de detectar, tornando o problema ainda mais crítico. Os impactos antrópicos, podem ainda levar a perda de espécies com características funcionais específicas, que integram grupos funcionais responsáveis pela prestação de importantes serviços ecossistêmicos (DÍAZ *et al.*, 2011; LEBRIJA-TREJOS *et al.*, 2010). Em adição, a remoção contínua de biomassa florestal pode alterar a estrutura da vegetação (por exemplo, redução da densidade do caule e aumento da abertura do dossel), bem como condições microclimáticas (por exemplo, os ambientes mais quentes com solos mais degradados) (RIBEIRO *et al.*, 2015; SCHULZ *et al.*, 2016). Em conjunto, estas condições podem limitar o recrutamento / reprodução de alguns grupos funcionais de plantas, enquanto outros grupos podem experimentar aumentos no recrutamento e desempenho em todos os estágios ontogenéticos, resultando em substituição do tipo vencedor / perdedor (TABARELLI; PERES; MELO, 2012).

Da mesma forma que outras regiões brasileiras, a Caatinga historicamente tem sido espaço para a criação de rebanhos, agricultura e extração de madeira para diversos fins, o que transformou a vegetação em um conjunto de manchas altamente modificadas e com áreas em processos de desertificação (ANTONGIOVANNI *et al.*, 2020; RIBEIRO *et al.*, 2015). Considerando que populações humanas locais detém um vasto conhecimento acerca da dinâmica dos sistemas, o entendimento das ameaças ao funcionamento desses ecossistemas requer a integração do conhecimento ecológico local com as questões da Ecologia das comunidades vegetais (LOPES, 2017). Diversos trabalhos foram realizados relatando uma variedade de plantas utilizadas pra distintas categorias de uso (ALBUQUERQUE, Ulysses Paulino et al., 2015; ALMEIDA, C. F. C. B. R. DE et al., 2005; C et al., 2018; ESTOMBA; LADIO, A.; LOZADA, 2006; FARIAS et al., 2007; GAOUE et al., 2016; LESO et al., 2017; LETCHER et al., 2015; MEDEIROS, DE et al., 2017; NUNES et al., 2016; RAMOS et al., 2008; SILVA OLIVEIRA, DA et al., 2015).No entanto, se faz necessário uma compreensão mais ampla, que mescle o conhecimento ecológico local e a Ecologia de comunidades (BENNETT et al., 2015; ISBELL et al., 2017; LOPES, 2017; PERIAGO et al., 2017).

3. CAPÍTULO II: Environmental factors modulate plant selection by local human populations in dry tropical forests

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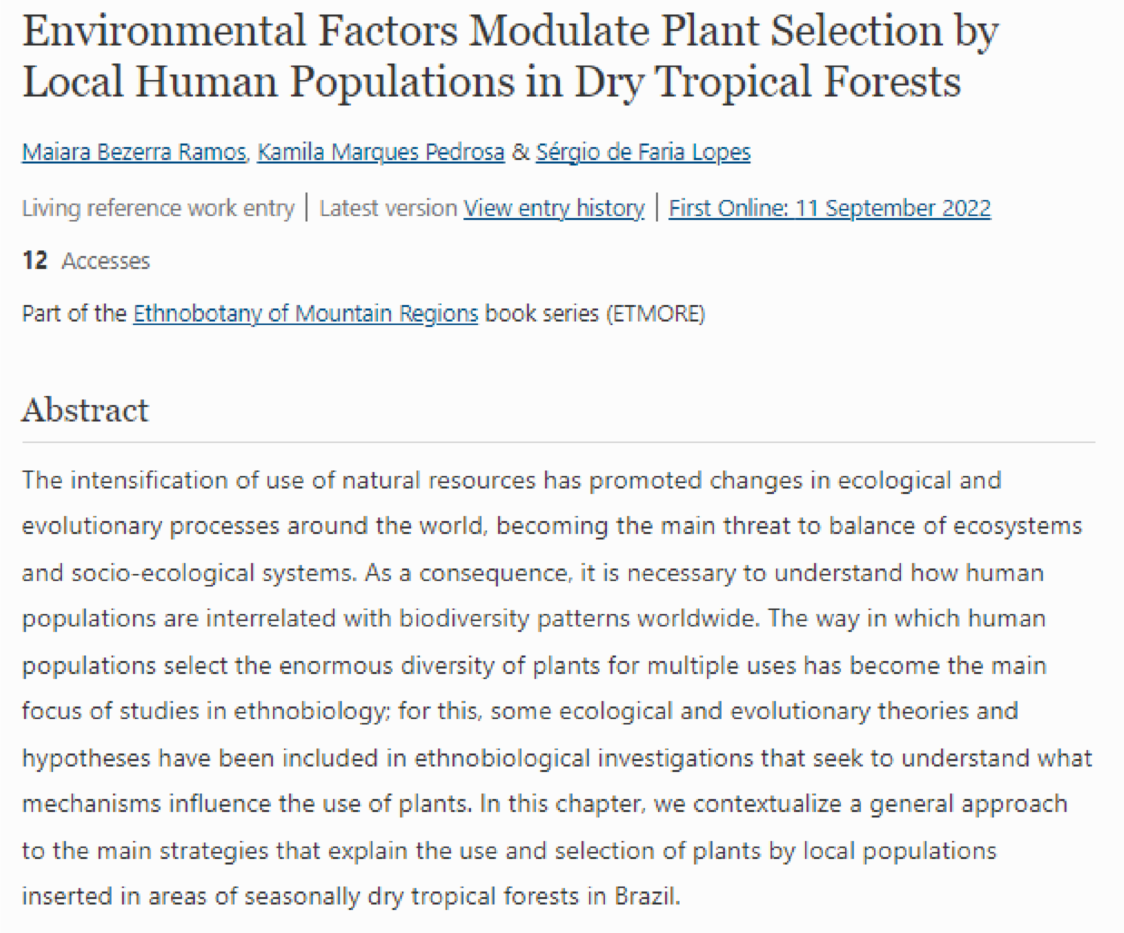

Environmental Factors Modulate Plant Selection by Local Human Populations in Dry Tropical Forests

Maiara Bezerra Ramos, Kamila Marques Pedrosa & Sérgio de Faria Lopes

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Abstract

The intensification of use of natural resources has promoted changes in ecological and evolutionary processes around the world, becoming the main threat to balance of ecosystems and socio-ecological systems. As a consequence, it is necessary to understand how human populations are interrelated with biodiversity patterns worldwide. The way in which human populations select the enormous diversity of plants for multiple uses has become the main focus of studies in ethnobiology; for this, some ecological and evolutionary theories and hypotheses have been included in ethnobiological investigations that seek to understand what mechanisms influence the use of plants. In this chapter, we contextualize a general approach to the main strategies that explain the use and selection of plants by local populations inserted in areas of seasonally dry tropical forests in Brazil.

Introduction

Natural resource exploitation by human beings dates from the most remote times, especially for the survival and perpetuation of our species (Clement et al. 2015). However, the way in which resources are exploited and selected is what marks human evolution and distinguishes us from other species (Albuquerque et al. 2015; Ellis 2015). By altering the environment, human beings have acted as niche builders, modifying the environment in which they live (niche) and that of other organisms, and may also alter natural selection processes (Sterelny 2007; Odling-Smee et al. 2013; Ellis 2015).

Throughout time and space, evolutionary forces have conditioned human beings to adapt to different ways of life and use of natural resources (Albuquerque et al. 2018). For example, the domestication of plants is a phenomenon which has enabled human groups to gain control over nature and predictability in provision of ecosystem services arising from plants (Ellis and Ramankutty 2008; Anderson et al. 2011; Smith 2011; Ellis 2015). However, what in the beginning was a means of subsistence today expresses the human capacity to dominate nature, causing these relationships to increase exponentially over time, which has consequently led to a continuous decrease in natural resources and changes in ecosystems (Clement et al. *2015*; Folke et al. *2021*).

Human populations are spread across the most diverse environments and landscapes in the world, from areas with high biodiversity to slightly different environments (Ellis *2015*). This suggests that local populations can exercise different forms of coexistence, use, and selection of plants in view of the different existing environmental factors (Naah and Guuroh *2017*; Folke et al. *2021*). Ethnobiology has emerged as a science in order to understand the dynamics of these interrelations, supported by biological and anthropological bases (Wolverton *2013*; Gaoue et al. *2017*), and which has devoted great efforts over the last few years in order to understand the criteria for species selection and structuring of human behavior through ecological and evolutionary bases (De Almeida et al. *2005*; Albuquerque et al. *2015*; Cáceres et al. *2015*; Savo et al. *2015*; Nunes et al. *2016*; Cámara-Leret et al. *2017*; Naah and Guuroh *2017*; Periago et al. *2017*; Teixidor-Toneu et al. *2018*; Molina-Venegas et al. *2020*; Pedrosa et al. *2021*).

New hypotheses have emerged with the inclusion of mechanisms and processes for the use and exploitation of resources, considering biases such as the environment and culture, as well as aspects such as biological and cultural evolution to understand the dynamics of human behavior in plant selection (Ellis and Ramankutty *2008*; Anderson et al. *2011*; Smith *2011*; Ellis *2015*). Environmental factors such as vegetation cover have been used as a predictor to explain how people know and use plants, and it is shown to be positively correlated to the degree of knowledge and use of woody trees (Lucena et al. *2012*; Gonçalves et al. *2016*), since knowledge and the selection criteria can be shaped depending on the supply of plants in the environment (Gaoue et al. 2016; Cunha *2020*). On the other hand, cultural factors such as the perception of organoleptic properties (odor and taste) reflect strategies which determine plant choice for a given use (Johns *1998*; Cámara-Leret et al. *2017*; Dai et al. *2017*).

Thus, environmental and cultural factors may reflect a cost/benefit ratio in the behavior of human groups (Ellis *2015*), especially in environments with certain environmental restrictions, as is the case of Dry Forests which are marked by the strong spatial and temporal irregularity of the rains. Faced with these conditions, human populations tend to develop a set of adaptive strategies to ensure their coexistence and use of plants in these environments. The strategies range from the choice of plants which have morphological attributes available throughout the year, to the consumption of similar plants for a specific use (Brown et al. *2011*; Nascimento et al. *2016*; Pedrosa et al. *2021*). These relationships provide human behavior development which emphasizes strategies to maximize energy expenditure when acquiring the resource. The study of these phenomena proposes thinking about the assumptions which influence the strategies for selecting and using plants. Thus, this chapter serves as a general introduction to the main information which comprises understanding strategies for managing and using plants by local populations located in dry tropical forests in Brazil.

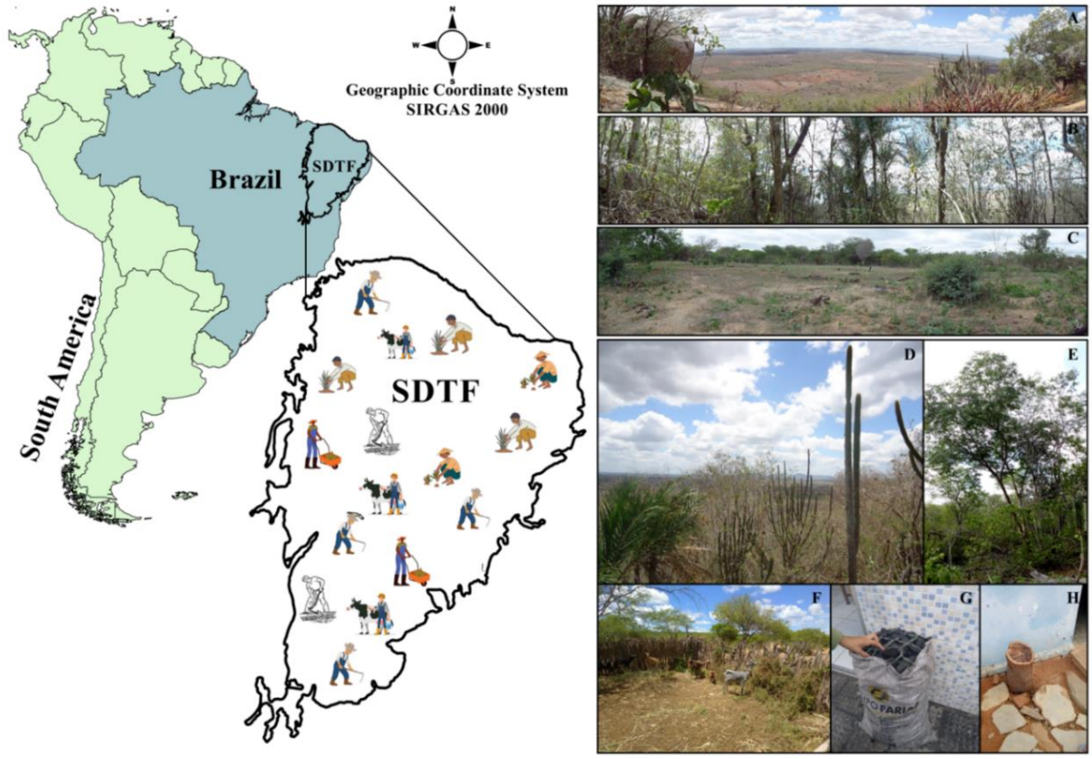

Fig. 1 Location map of Brazilian semiarid. Highlight the semiarid region with merely illustrative figures that represent different activities carried out by local populations. On the left side of figure, different types and uses of Caatinga vegetation. A, B, C, D, and E = images of vegetation, including areas of anthropized Caatinga. F = goats feeding, and fences built; G = coal production; H = production of technological artifacts. All uses from Caatinga species. (Photo: Humberto A. Almeida and Maiara B. Ramos)

Human Populations in the Caatinga – Human-Environment Interactions: The Past and the Present

The semi-arid region of Brazil is inserted within the domain of Seasonally Dry Tropical Forests (SDTF), called Caatinga (Fig.1). The Caatinga is considered one of the largest and most populous semi-arid regions in the world, occupying about 912,500 km2 of Brazilian territory (Moro et al. *2016*; Silva et al. *2018*). Its vegetation is strongly influenced by environmental filters which determine the assembly of plant communities (Pennington et al. *2018*; Fernandes et al. *2020*). The plant species have a set of morphophysiological adaptations to survive the conditions imposed by the low and irregular precipitation level which has the capacity to limit the development and distribution of plant species (Souza *2020*; Fernandes et al. *2020*). Chronic anthropic disturbances linked to the precipitation gradient also have a strong influence on the availability and richness of plants (Rito et al. *2017*; Silva and Souza *2018*). The Caatinga region historically had unrestrained extraction of its natural resources (Silva et al. *2018*). The anthropization process suggests that the anthropic impacts have been massive since the first colonial settlements (Souza and Souza *2016*). As the European conquest advanced in Brazil's semi-arid region, land donations through *sesmaria* letters promoted the settlement of these regions and the expansion of agricultural production (Melo *1998*).

The usage and occupation patterns of environments in the last four centuries in the Brazilian semi-arid region have stimulated the reproduction of inadequate agricultural and livestock techniques among the local populations for the semi-arid region, and which provide strong environmental changes. Historical evidence shows that the majority of requests for *sesmaria* letters were sent to farmers to allocate cattle in drier regions (Pereira *2008*). Cattle migration increased fires to remove the tree vegetation to create space for grass growth which served as potential forage (Pereira *2008*).

It is important to consider that the current species richness and distribution patterns are not only a result of climatic and environmental factors such as the relief and soil characteristics, but above all the result of these factors acting in conjunction with the influence of human activities (Silva and Souza *2018*; Antongiovanni et al. *2020*; Ramos et al. *2020*). Overgrazing and agriculture are currently considered the main agents causing biodiversity loss in these regions (Sobrinho et al. *2016*; Schulz et al. *2019*; Antongiovanni et al. *2020*). An aggravating factor for this scenario is that the synergistic effect between anthropic impacts and low rainfall regimes negatively contributes to the resilience of these ecosystems (Rito et al. *2017*). This happens through a delay in the establishment and recruitment of regenerating species which synchronously develop with the rainy season, which leads to a decrease in diversity (Marinho et al. *2016*; Souza *2020*).

The environmental characteristics of the semi-arid region generate several socioeconomic imbalances (Silva et al. *2018*). For example, the rain regime is considered a problem for the economic development and survival of the human population which depends on natural capital. As a consequence of this irregular rainfall, there is a shortage in the drinking water supply to some places in the semi-arid region (Montenegro and Ragab *2012*; Andrade et al. *2017*). The situation became even more aggravated by the failure to implement public policies for different reasons. First, government programs were developed with a lack of alignment between environmental and social issues (Silva et al. *2018*). Several adopted strategies failed due to a lack of articulation which considered environmental characteristics, for example, the insertion of *Prosopis juliflora* (Sw). D.C. as an alternative forest resource for fodder and wood production, but which further problematized the socio-environmental issues of the Brazilian semi-arid region (Andrade et al. *2009*). Second, most of these government programs made it possible for large landowners to benefit, which has culminated in growing social inequality in the region which has persisted for many years (Silva et al. *2018*). In addition, a lack of continuity in social programs which are compromised according to the historical-political moment (Dantas et al. *2020*). Some public policies have been implemented to tackle the drought phenomenon and assist the most vulnerable populations, but it is not a reality for the whole semi-arid and does not help to structure the population's economic independence (Mattos and May *2020*).

The Influence of the Environment on Plant Selection

The environmental context is one of the most tested predictor variables in ethnobiology; and, among the aspects related to the environment, the availability of plants has remained as one of the main hypotheses which guide research on the differential use of plants in socio-ecological systems. The first evidence in ethnobiology which verified the influence of the environment on knowledge emerged in the seminal study by Phillips and Gentry (*1993*), which was influenced by ecological ideas and explained how the appearance (abundance) of plants influenced herbivory (Fenny *1976*). The idea formulated in 1993 was that plants which are most used by human populations would be those most apparent in the environment. The appearance hypothesis suggested by these authors confirmed inductive observations that more abundant plants were more useful (Johns *1998*). The hypothesis suggested by Phillips and Gentry (*1993*) explained the use of quantitative techniques to test whether the use of plants by local populations was related to availability.

Thus, the usage value model proposed in the appearance hypothesis has become an important measure for characterizing plant use. The technique was also corroborated by successive research (Lucena et al. *2012*; Maldonado et al. *2013*), and in most studies the assumptions indicate that apparent species tend to be more used by local populations as they are more likely to be experimented with, while less-apparent plants are less experimented with. This relationship started to be used by researchers as an indicator of important plants for people (Ribeiro et al. *2014*), and it shows that the frequency with which people keep using it is directly affected by the availability of plants (Gonçalves et al. *2016*).

An evidence pattern in dry forest regions assumes that the ecological parameters, relative dominance, and abundance of plants recorded in plant communities influence socio-ecological systems (Lucena et al. *2012*; Guerra et al. *2015*; Ribeiro et al. *2014*). Some studies select two distinct areas as predictor variables to access the plant communities, characterizing them as conserved areas (where there is no plant collection) and anthropic areas (plant collection area) (Lucena et al. *2012*; Ribeiro et al. *2014*). However, measuring conserved environments is a difficult task, since most environments have some level of anthropic impact (Menezes and Baldauf *2021*). Furthermore, as far as we know, studies reporting the use of these samples do not declare the level of human impact in environments classified as anthropic.

On the other hand, the use of spatial tools which can improve the validation of anthropogenic disturbance levels in environments is increasing. The changes in the vegetation cover have been used as a model to evaluate the anthropic impacts on the use of plants by rural communities (Naah and Guuroh *2017*). In a study with populations of sacred areas in Nepal, Kunwar et al. (*2020*) used remote-sensing images to analyze how the lost vegetation cover influenced the use of medicinal plants over the years. The authors realized that sacred practices were changing, especially when they noticed that areas with declining vegetation cover made it impossible to collect medicinal plants. (Kunwar et al. *2020*). Perhaps, providing direct information (i.e., biomass of domestic animals, collection of forest resources) and indirect information (i.e., satellite images, history of past uses) about anthropic characteristics present in ecological samples is an alternative to demonstrate how the ecological community influences knowledge with greater precision.

Human disturbances in Brazil's seasonally dry forest are a continuing reality. Timber extraction, collection of non-wood products, and livestock breeding are common practices among local human populations and represent chronic anthropic disorders, punctual and continuous disturbances in the environment (Martorell and Peters 2005; Antongiovanni et al. *2018*), which lead to decreases in the taxonomic, functional, and phylogenetic diversity patterns of plant communities (Coelho et al. *2020*; Rito et al. *2017*; Zorger et al. *2019*), and can cause direct and indirect impacts to local human populations who depend on forests (Díaz et al. *2011*).

Human-induced environmental changes have exposed diverse environments to high levels of degradation due to intense human activities (Leal et al. 2018; Antongiovanni et al. *2020*). The amount of fragmented landscapes without functional connectivity has had profound impacts on the biodiversity of dry forests (Calzada et al. *2018*; Antongiovanni et al. *2018*). The criteria for plant selection occur in detriment for several reasons. Human populations have developed several strategies when faced with changes in the landscape. Evidence of the influence of plant availability on local knowledge has served as a model to explain human behavior (Clement et al. *2015*; Cámara-Leret et al. *2017*). This assumption made the scientific community investigate how human behavior can be shaped according to environmental fluctuations (Díaz et al. *2011*, *2018*). Evidence suggests that the greater the heterogeneity of the environment in terms of plant availability leads to people demonstrating more specialized plant use behavior, since the environment enables a greater supply of plants to choose from. In contrast, people tend to exhibit generalist behavior in environments with less plant availability due to biological homogenization, as they concentrate their collections for available species (Albuquerque et al. 2013).

Human Populations in the Caatinga and Its Dynamics Over Time

It is necessary to consider that people use different strategies throughout the year to ensure safety in the use of a resource due to the climatic seasonality of the Brazilian semi-arid region (Albuquerque *2006*; Cunha *2020*). These strategies were verified and tested through some hypotheses in ethnobiology. The hypothesis of climatic seasonality strongly demonstrates how the knowledge of medicinal plants is shaped by the Caatinga vegetation seasonality (Albuquerque *2006*). Studies show that native plants which are available throughout the year are more widely used by local populations. On the other hand, herbaceous plants are less chosen for use because of their availability and because they are ephemeral and in line with precipitation periods (Albuquerque *2006*; Naah *2018*).

Some research has pointed out that human populations are able to recognize and select groups of plants with similar characteristics, depending on the purpose of their use (Brown et al. *2011*; Nunes et al. *2016*; Cámara-Leret et al. *2017*; Pedrosa et al. *2021*). Species of interest for wood use can be selected for their higher wood density, a fact which is reflected in greater energy potential (Lucena et al. 2007). In addition to the wood density, the efficiency offered by the plant is a positive criterion in selecting a species for combustible uses (Hora et al. *2021*). Likewise, Ramos et al. (*2015*) demonstrated that plants used for the production of technological artifacts had an undetermined replacement time. This may indicate a criterion in selecting plants with a certain functional characteristic to meet a specific use. In addition, that local populations perceive that domestic animals tend to forage groups of plants with greater palatability (Niu et al. *2016*; Cunha *2020*). This taxonomic selectivity enables us to observe that local populations select plants with specific functional characteristics (Cámara-Leret et al. *2017*; Cunha *2020*). Non-random plant selection is one of the most tested ideas in ethnobotany (Moerman *1979*, *1991*; Medeiros et al. *2015*; Ford and Gaoue *2017*; Muleba et al. *2021*), and it has contributed to pertinent answers on the usage pattern of plants. For example, the literature has shown that the chemical component is an attribute which can help to justify selecting medicinal plants and is perhaps due to the bioactive characteristics shared among themselves (Johns *1998*; Yessoufou et al. *2015*; Cámara-Leret et al. *2017*; Ford and Gaoue *2017*). This can refer to Moerman's explanations where he explains that species of the same family share characteristics due to their evolutionary kinship, which may in turn influence their physiology (Moerman *1991*; Pedrosa et al. *2021*). Selecting plants for use may be due to selecting a set of specific functional characteristics which present a phylogenetic convergence of species with specific traits (Brown et al. *2011*; Pedrosa et al. *2021*). This relationship has caused the scientific community to use phylogenetic inferences to understand the evolutionary history of plants which are useful for local populations (Cámara-Leret et al. *2017*; Garnatje et al. *2017*).

Predictions coined in evolutionary history are emerging as a tool to test whether the taxonomic signal in the use of plants translates into phylogenetic selectivity (Grace et al. *2015*). Phylogenetic methods enable exploring usage patterns of plants which are similar to each other (Lei et al. *2020*). Furthermore, the use of phylogenetic hypotheses in ethnobiology can overcome the limitation on investigations regarding plant selection. Despite little use until now, the use of phylogenies is relatively new in ethnobiology. However, it has recently gained momentum in the agreement that plant selection is not random (Dáaz et al. 2007; Brown et al. *2011*; Cámara-Leret et al. *2017*; Dai et al. *2017*; Leso et al. *2017*; Naah and Guuroh *2017*; Guzman and Molina *2018*; Lei et al. *2018*; Cunha *2020*; Lei et al. *2020*; Hora et al. *2021*; Molina-Venegas et al. *2021*; Pedrosa et al. *2021*).

Final Considerations

In summary, in this chapter we bring a general approach highlighting evidence of environmental factors that modulate the use and selection of plant species in the Caatinga.

This approach highlights the importance of ecological and evolutionary integration to social and cultural systems in order to understand how the dynamics of use and selection of plants occurs in local human communities. We believe that by integrating different views, a better understanding of the dynamics of ecosystems is possible, which is essential to ensure the current and future provision of ecosystem services for human populations, especially in a scenario of global change.

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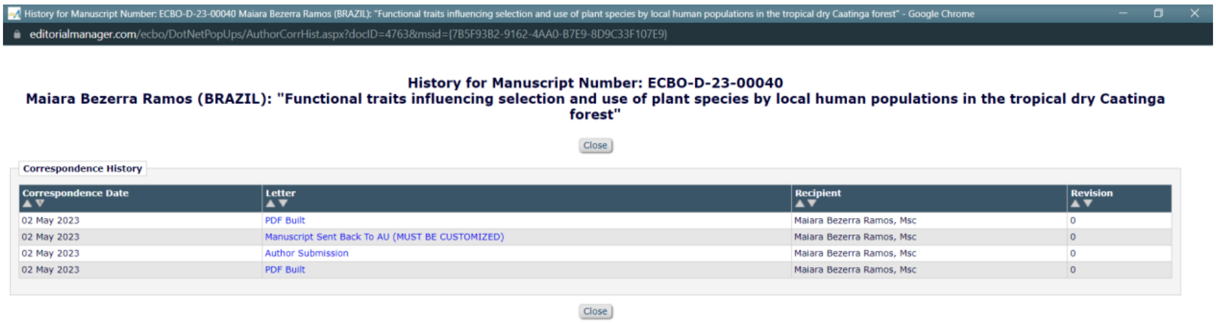
4. CAPÍTULO III: Functional traits influencing selection and use of plant species by local human populations in the tropical dry Caatinga forest

(Manuscrito submetido ao periódico Economic Botany)



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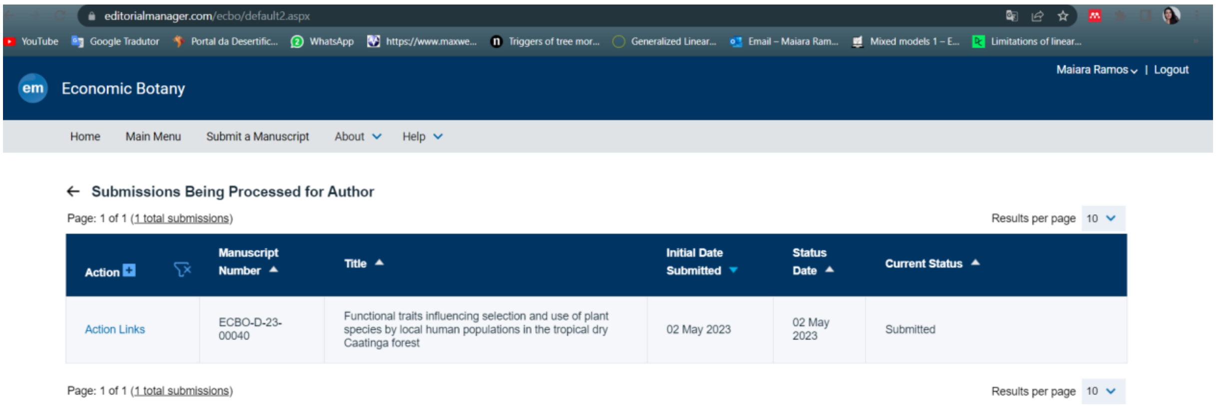

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Functional traits drive the selection of plant species used by agropastoralists in the Brazilian semiarid region

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Abstract

Biodiversity plays a key role in the well-being and sustenance of human life. Rural communities directly dependent on vegetation resources will likely be the most affected by the losses of goods and services provided by biodiversity. Here, we tested the hypothesis that plant functional traits drive the selection and use of plant species by agropastoralists in the Brazilian semiarid region. We approached agropastoralists from rural communities across a Caatinga area to gather information about local ecological knowledge. This information was contrasted with the functional trait attributes of plants used for fuel, construction and forage, which are the three most common categories of plant use in the study area. Our results confirm that agropastoralists select the plants they use in each use category according to functional trait attributes that they associate with desirable goods and services. For example, wood density emerged as a relevant plant functional trait for plant selection in the fuel and construction categories due to its relationship with durability. Our approach allowed us to identify the fundamental plant functional traits driving the selection of plants used by local

communities in the Caatinga.

Key words: ecosystem provision services, selective use, specific leaf area, wood density, plant height, stem diameter, ethnobotany

1. Introduction

The quality of life and well-being of the global human population largely depends on the timely and adequate provision of a variety of ecosystem goods and services by nature (Díaz et al. 2006; Cáceres et al. 2015). Ecosystem services are the benefits that people obtain from ecosystems, and are related to multiple biodiversity components (Díaz et al. 2006; Brauman et al. 2007). For example, vegetation provides a broad range of key ecosystem services (Díaz et al. 2007; Hassen et al. 2023), including food, fibers, fuel, biochemicals, medicines, regulation of climate and erosion, plant pollination, spiritual and religious values, recreation and ecotourism, cultural heritage values, photosynthesis and carbon uptake from the atmosphere, biomass, and nutrient cycling (Millennium Ecosystem Assessment 2005; Díaz et al. 2011). The humans have learned to use the diversity of organisms in a unique way, with an extraordinary capacity to alter ecological and evolutionary processes across the ecosystems (Ellis and Ramankutty 2008; Smith 2011; Ellis 2015), which today represents a threat to the persistence of the human species itself.

The theoretical framework of functional ecology helps understand species' responses to ecological interactions and environmental modifications due to global change, as well as the interplay between biodiversity and ecosystem properties (Diaz and Cabido 1997; Albert et al. 2010). Alterations in the provision of ecosystem services have direct impacts on the quality of life of humans and compromises our survival; therefore, it is necessary to assess the perceptions of the different social actors about ecosystem services and the components of functional diversity (Díaz and Cabido 2001).

The numerous plant species occurring in every region of the planet differ greatly in their functional trait attributes (de Bello et al. 2013; Luo et al. 2016). Such large functional diversity may play an important role in the selection process of species by local populations; at each time and place, the choice of sets of useful species, on the one hand, and undesirable species, on the other, may be guided depending on the type of use that people want to make of plants, and weighted by the abundance of the different species in the environment and their attractive or undesirable characteristics (Albuquerque and Oliveira 2007; Meuret and Provenza 2015).

Previous studies have examined the relationships between functional traits and plant selection. For example, when focusing on food, people mainly select plants with large fruits (Cámara-Leret et al. 2017), whereas when it comes to feeding their herds they rather value plants with high nutritional contents (Meuret and Provenza 2015; Nunes et al. 2016; Cunha et al. 2022). Management decisions made by agropastoralists are often based on plant characteristics, for example their phenological patterns, plant dimensions (e.g., height) and its casted shade, leaf density, and rooting patterns (Martin and Isaac 2015; Valencia et al. 2015). Similarly, there is evidence suggesting that people value woody plants with high wood density for fuel or construction (Ticktin 2004; Brown et al. 2011; Gaoue et al. 2016; Gonçalves et al. 2021a). Therefore, a functional trait-based approach can shed new light on the relationship between the functional trait attributes of useful plants and the fulfillment of different human needs, and to the dynamics of the provision and maintenance of ecosystem services (Brown et al. 2011; Díaz et al. 2011; Cámara-Leret et al. 2017; Kusumoto et al., 2020).

The observation, use, and management of biodiversity and the physical environment over millennia have led human societies to develop an enormous body of knowledge, practices, and beliefs, which is known as Local Ecological Knowledge (LEK) (Berkes et al.

2000). Therefore, the concept of LEK creates an important window of understanding about how human societies relate to biodiversity (Díaz et al. 2011; Lopes 2017). Connecting our knowledge on biodiversity and the provision of ecosystem services with societal interests is essential for the maintenance and sustainability of socio-ecological systems (Berkes et al. 2000; Folke 2006; Saynes-Vásquez et al. 2013; Pascual et al. 2017; Díaz et al. 2018).

The management of plants for various purposes such as subsistence agriculture and raising goats, sheep, and cattle reveals essential aspects of the LEK. This is true for the local populations of the Caatinga, which is the largest tropical semi-arid region in the New World and has a long history of colonization, changes in land use and interactions between humans and plants (Melo 2017; Antongiovanni et al. 2020). Despite previous efforts to investigate LEK of rural populations in Brazil's semiarid region (Farias et al. 2007; Ramos et al. 2008; Lucena et al. 2012; Gonçalves et al. 2016; Gonçalves et al. 2021b), important gaps persist regarding the selection criteria used by these populations, especially regarding the role of plant functional trait attributes (Cunha et al. 2022).

In this study, we examined the relationship between the functional trait attributes of plant species (sensu Violle et al. 2007, i.e., the different values or states that functional traits can take in a given species, population or individual) and the selection and use of plants by local human populations. To this end, we gathered data on LEK and on functional traits to delineate a functional profile of the preferred species used for fuel, construction, and forage by agropastoralists from the Brazilian semiarid. We hypothesized that for each primary use that people give to plants (i.e., fuel, construction and forage), humans based their selection on certain functional trait attributes, which ultimately results in a set of species that best meet the needs for each type of use. Specifically, we hypothesized that for fuel and construction uses stem traits would be more important for plant selection, whereas for plants used as forage leaf traits would be more important.

2. Materials and methods

2.1. Study area

We conducted the study in the Brazilian semiarid region, specifically in the central portion of Paraiba State. The study involved local human populations from five rural communities distributed across the region (Fig. 1). Regional climate is Bswh, i.e., hot, semi-arid (Alvares et al. 2013), with two well-defined seasons: a rainy period (March to July), and a period of drought (August to February). Total annual precipitation varies greatly in space and time, with records as low as 300 mm (the lowest average total annual precipitation in Brazil) and no higher than 750 mm, and high evapotranspiration rates (< 0.65) (Moro et al. 2015; Souza et al. 2020).

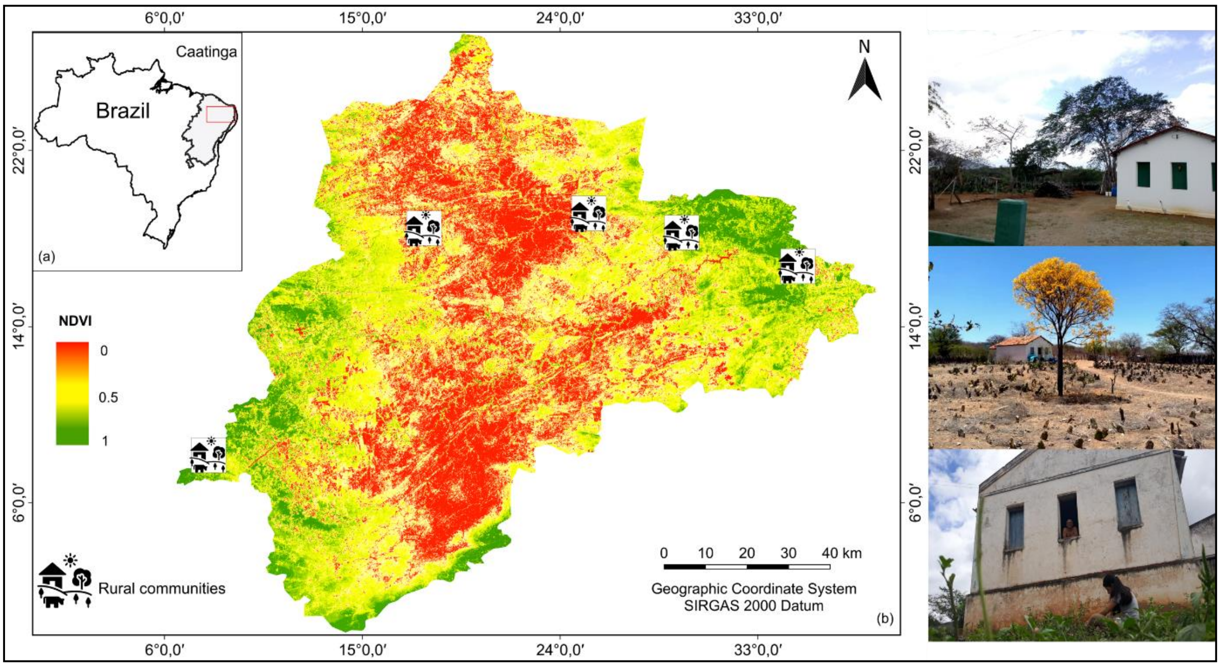

Fig. 1.

The prevailing vegetation is seasonally dry tropical forest, known in Brazil as Caatinga. The flora of this ecosystem encompasses many species with morpho-physiological adaptations to water deficit, including leaf area reduction, thick cuticles, presence of wax and trichomes on leaves, presence of spines and thorns, water-storing tissues, stomata closure mechanisms, CAM metabolism, and deciduousness (de Queiroz et al. 2018; Fernandes et al. 2020). The environmental variation across the region creates a vegetational mosaic with large differences in community structure and species richness and composition even over short distances (Moro et al. 2016; Silva and Souza 2018).

The study region comprises 31 subdivisions (*municípios*) hosting a total population of 190,367 inhabitants (15.45 inhabitants per km²), of which 90,030 people live in the rural environment. The human presence in the region dates to approximately 10,000 years BP (Souza et al. 2020). In the 19th century the region underwent strong modifications, when a wave of colonizers brought about the foundation of new population centers and the clearing of forest for agriculture, including cash crops such as cotton and sisal, and intensified the extraction of charcoal and firewood. During the same period extensive livestock farming expanded, using the native vegetation as a source of fodder (Silva et al. 2018).

2.2. Selection of rural communities and interviewees

The study sites were selected based on satellite imagery, precipitation maps and field surveys. We selected rural communities having different levels of vegetation cover and annual rainfall in order to represent a resource availability gradient, thus maximizing the amount of information on the use and selection of plant species. The degree of vegetation cover was assessed through the Normalized Difference Vegetation Index (NDVI), obtained with ArcGIS (Fig. 1). Satellite images were acquired in the dry season of 2017 (downloaded from eartherexplorer.usgs.gov: Rouse et al. 1974). Mean annual precipitation (MAP) data for each area were obtained from WorldClim (http://www.worldclim.org/), updated with monthly data and overall means for the 1970–2000 period, with a 30” (~1 km^2) spatial resolution (Hijmans et al. 2005). These data were collected with the ‘raster’ package (Hijmans 2021) in R (R Core Team 2019). MAP ranged among sites from 379 to 690 mm.

We approached local agropastoralists from the five rural communities for conducting interviews on plant use by them: Curral do Meio (São João do Cariri *minicípio,* 30 interviewees), Caiçara (Cabaceiras *município*, 32), Alto dos Cardeiros (Barra de Santana *município,* 24), Viveiro (São José dos Cordeiros *município*, 23), and Olho d'Agua (Monteiro *minicípio,* 11) (Fig.1). We defined agropastoralists as those people who make a living from family farming and raising small herds, and who possess ample experience with these activities. The rural economy of these communities has been traditionally dominated by cattle production (bovine, caprine and ovine) along with rain-fed subsistence agriculture, with maize, beans, sweet potatos, watermelon, and squash being the main cultivated produce (Ramos et al. 2023). Cattle is raised in an extensive format and the animals often roam freely in the native vegetation. Even though most households have gas ranges, firewood and wood for charcoal production are still gathered as part of the traditions of many inhabitants.

2.3. Data collection

The analyzes focused on plant use categories that are currently the most common in the region and are related to changes in vegetation patterns in our study area (Forage, Fuel, and Construction), and their respective use subcategories. During the interviews, the agropastoralists also mentioned characteristics (i.e., plant trait attributes) that, in their view, rendered some plants to be less preferred or even rejected by them; thus we were able to also gathered information on plants apparently not being used (and classified them as 'not used'). By combining information on LEK and functional ecology, we were able to delineate a functional profile for plants undergoing high use pressure and for those suffering little pressure of use.

Initially, we approached the study communities through informal conversations with the first people we had contact with. These people were usually at their work sites, either tending animals or their plantations. In these conversations we disclosed our research objectives and, following a snowball sampling technique (Bailey, 1994), asked them to recommend us other neighbors involved in agriculture and livestock-related activities that were considered equally experienced, and who had lived in the community for long times. The process was repeated until saturation or until reaching the desired sample size. In total we conducted 120 interviews with agropastoralists (men and women) over 12 months of field work (April 2019–February 2020). Information on plant use and knowledge was obtained by asking the interviewee to freely list as many plants as possible (Albuquerque et al. 2014) for each main use category (Fodder, Fuel, Construction). Next, we used semi-structured formats to collect information about local knowledge. Thereafter, we inquired about the characteristics of each species, which prompted them to remember and mention other useful species. The interviews were supplemented with other research techniques, such as participatory observation, walks through the forest around the homes and in places used to gathering resources, as well as the use of visual stimuli, i.e. using photographs of plants occurring in the region (Albuquerque et al. 2014; Medeiros et al. 2014). For each use category, the agropastoralists mentioned some visual and/or tactile attributes, such as leaf texture, size, and thickness, phenology, nutritional quality, aromas in leaves or stems, presence of oils or latex, trunk thickness, wood hardness, and the arrangement of wood fibers. In addition, interviewees highlighted their preferred plants as well as those they do not like, and justified their preferences and selection criteria. A plant species was classified as ‘preferred’ if at least 20% of respondents agreed with such classification; the remaining species were classified as ‘common’ (Valencia et al. 2015).

When more than one part of the same plant was associated with a particular use, we made a separate record for each plant part. For example, interviewee 1 stated the use of leaves, fruits, flowers and bark of *Cenostigma pyramidale* as fodder (three different applications). Regarding unused plants, we asked which species were in this category and asked them to justify this judgment by listing characteristics that make it useless or unattractive.

The walks through the forest with the interviewees allowed un to supplement the information on vernacular names and plant uses, and to collect specimens of species that could not be identified in the field. These specimens were deposited at the Manoel Arruda Camara Herbarium (ACAM, Universidad Estadual da Paraíba) for future reference. Initial taxonomic identifications were done with the help of local and regional floristic studies (Araujo et al. 2010; Cabral et al. 2013); later, names of plant taxa were verified using Flora do Brasil (The Angiosperm Phylogeny Group 2016).

2.4. Functional trait selection

To analyze the association between LEK and the functional traits of plant species used by the agropastoralists, we integrated a dataset containing these two types of information. Based on these information, we first established broad associations with important functional traits recorded in the literature; this allowed us to selected eight functional traits for which there were data available in the literature: maximum stem diameter, maximum plant height, wood density, leaf thickness, leaf area, specific leaf area, and leaf nitrogen content. For the few species that lacked information on these functional trait attributes, we assigned the mean value of all congeneric species. Trait values (i.e., attributes) were extracted from specialized literature (peer-reviewed articles, dissertations, and academic theses that have collected functional traits). In addition, we retrieved data available in the TRY database (https://www.try-db.org/TryWeb/Home.php). We used the standardized values given, which had been converted to uniform units of traits.

2.5. Data analysis

First, we defined functional groups of the plant species rcorded through the interviews through a cluster analysis using a matrix containing the eight selected plant functional traits for each species. The dendrogram was constructed based on a Gower dissimilarity matrix with the UPGMA (Unweighted Pair-Group Method using Arithmetic Avarages) clustering method. Determination of the functional groups was made with the NbClust package (Charrad et al. 2014), which offers 30 indices to determine the best number of classes and suggests to the user what the best clustering scheme is. The clusters so produced were used as vectors to be represented in a principal component analysis (PCA). Next, to evaluate each use category, indicated by agropastoralists, we constructed generalized linear models (GLM) by using the number of mentions for each use category as response variables and the plant functional traits as predictor variables. To prevent problems derived from multicollinearity among predictor variables, we calculated the variance inflation factor (VIF) for each of them with the *car* package (Sugawara and Nikaido 2014). All variables included in our models had VIF values < 4, suggesting independence among them (Bondell and Reich 2008). We also tested correlations between all predictor variables. For count variables a negative binomial distribution was used (Crawley 2007). Finally, we applied a model selection procedure based on the sample corrected Akaike Information Criterion (AICc); models with ΔAICc < 2 were considered equally supported and capable of explaining the variation of the response variable. A total of 147 models were constructed for the total set of response variables (Fuel, Construction, Fodder, and Not Used). All analysis were performed in R ver. 3.6.0 (R Core Team, 2019).

3. Results

3.1. Classification of plants by agropastoralists

We recorded a total of 4,938 mentions of use for 82 plant species distributed among 71 genera and 24 families (Appendix A). The largest number of mentions of use corresponded to the Forage category (2,673 mentions; 72 species), and this was followed by the Construction (1,103 mentions, 42 species) and Fuel (1,070 mentions, 50 species) categories; in turn, 32 plant species were mentioned (84 mentions) as not having any use as they lacked useful characteristics for any use category (Fig. 2; Appendix A).

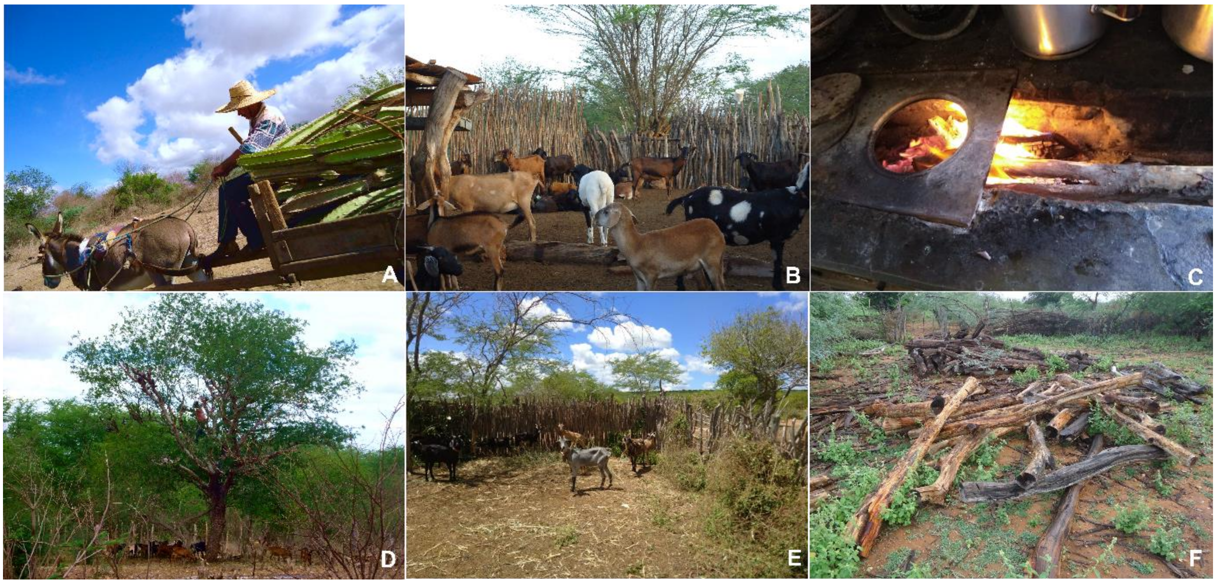

Fig. 2.

3.2. Preferred plants by agro-pastoralists

Agropastoralists select plants within each use category according to the traits whose attributes they associate with desirable goods and services, *e.g.*, leaf texture, size and wood hardness, deciduousness, protein content, tree height and diameter, and wood quality (Table 1).

Table 1. Attributes mentioned by interviewed agro-pastoralists from the semiarid region of Brazil.

Use category	**Attributes**	
	Positive	**Negative**
Fuel	Abundant ember production	Toxic smoke
	Hot ember	Soft wood
	Little waste production	The fire dies out readily
	Combustion power	Produces much waste
	Lasting ember	Short longevity
	Dark wood	Noisy snapping
	Abundant crumbs	Unpleasant smell during combustion
	Little smoke production	
	Hard wood	Wet wood
	Pleasant smell	Produces much smoke
	Ignition	
	High fire durability	
	High durability of the flame	
Construction	Fast growth	Low longevity and durability
	Dark color	Soft wood
	High longevity and durability	Light and light-colored wood
	Heavy wood	Twisted wood
Fodder	Leaves with high vitamin content	Bitter
	Increases milk production	Bad smell
	Helps animals to fatten	Produces helminthiasis (worm infestation)
	Sprouts	

Nice smell	Astringent (caustic) leaves
Soft leaves	Toxic foliage
Thin and tender leaves	
Velvety leaves	
Sweet	
Prevents helminthiasis	
Smooth leaves	

Among the total number of species mentioned in the interviews, there is a set of preferred species within each use category (Table 2). We recorded 29 indicators used by agropastoralists to describe good-quality plants in each category and 18 indicators to describe low-quality plants whose use is avoided. Some indicators for the Forage category were related to the intrinsic characteristics of the plants, other indicators highlighted the behavior of the cattle, and a last group highlighted the effects and impacts of Forage plants on cattle's health.

A large proportion of the interviewees (83.2 %) expressed a preference for some plant species, and 12 species were mentioned as preferred in all use categories. Fifteen species were mentioned in each of the Construction and Fuel categories, and 29 species were pointed as preferred for Fodder. Regarding those species with a shared preference among categories, *Cenostigma pyramidale* and *Mimosa ophthalmocentra* stood out with 307 and 281 mentions, respectively (Table 2).

Agropastoralists also stated that some species are less preferred, based on attributes such as hard and bitter leaves in the case of Fodder use, and too soft wood for Fuel and Construction uses (Table 1). Regarding the Construction category, specifically for the uses in the trough and hedge subcategories, the interviewees select species with low wood density, according to the literature, unlike the other uses within this category.

Table 2. Checklist of preferred species, with their numbers of mentions in each use category. Use categories: Fuel, Cons (Construction), and Fodder. The figures in the last column (%) represent the overall percentage preference of each species mentioned by the interviewees.

Species	**Fuel**	**Cons**	**Fodder**	**%**
Cenostigma pyramidale (Tul.) Gagnon & G.P.Lewis	62	13	26	68.08
Croton blanchetianus Baill.	1	18	20	52.13
Mimosa tenuiflora (Willd.) Poir.	28	15	21	45.75
Astronium urundeuva (M.Allemão) Eng.	21	10	18	38.30
Mimosa ophthalmocentra Mart. ex Benth.	20	24	12	37.23
Prosopis juliflora (Sw.) DC.	16	10	17	31.92
Aspidosperma pyrifolium Mart.	4	16	6	23.40
Ziziphus joazeiro Mart.	0	0	21	20.21
Spondias tuberosa Arruda	0	0	18	17.02
Piptadenia retusa P.G.Ribeiro, Seigler & Ebinger	5	2	12	15.96
Cynophalla flexuosa (L.) J.Presl	0	1	13	10.64
Schinopsis brasiliensis Engl.	6	1	4	10.64
Anadenanthera colubrina (Vell.) Brenan	8	2	1	9.57
Bauhinia cheilantha (Bong.) Steud	1	3	5	7.45
Sideroxylon obtusifolium (Roem. & Schult.) T.D.Penn.	0	0	6	6.38
Combretum leprosum Mart.	28	2	2	4.26
Croton heliotropiifolius Kunth	1	2	0	3.19
Ceiba glaziovii Kuntze k. Schum	0	0	2	2.13
Lippia grata Schauer	0	1	1	2.13
Mimosa arenosa (Willd.) Poir.	1	0	1	2.13
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore	0	0	2	2.13
Commiphora leptophloeos (Mart.) J.B.Gillett	0	0	1	1.06

Euphorbia tirucalli L.	0	0	1	1.06
Lantana camara L.	0	0	1	1.06
Leucaena leucocephala (Lam.) de Wit	0	0	1	1.06
Lachesiodendron viridiflorum (Kunth) P.G.Ribeiro, L.P. Queiroz & Luckow	0	0	1	1.06
Melochia tomentosa L.	0	0	2	1.06
Mimosa lewisii Barneby	1	0	0	1.06
Mimosa paraibana Barneby	0	0	1	1.06
Pseudobombax marginatum (A.St.-Hil., Juss. & Cambess.) A.Robyns	0	0	1	1.06
Senna spectabilis (DC.) H.S.Irwin & Barneby	4	0	2	1.06

3.3. Relationships between local preferences and functional traits

The functional dendrogram rendered three major groups plus a minor one of species according to their functional trait attributes (Fig. 3a). At the opposite (upper and lower) ends of the dendrogram are species that cluster together based on the functional similarity in the measured plant traits. These two groups include species mentioned in the Fodder category, along with species that are not used. *Ziziphus joazeiro* and *Spondias tuberosa*, for example, are included in the red group, at the lower end of the dendrogram, and these are the two most frequently cited species in the Fodder category (Table 2), thus being highly preferred by the agropastoralists. However, species with low preference for Fuel and Construction uses were also present in the same group, such as *Manihot glaziovii* and *Jatropha mollisima* (Fig. 3a), both mentioned as having poor quality wood and other little desirable characteristics such as producing “excessive smoke” and “weak fire”. Importantly, all species included in the red cluster were mentioned as used for Fodder and are associated with high specific leaf area and leaf thickness values (Fig. 3b). At the upper end of the dendrogram (blue cluster) are concentrated most low-preferred species in all use categories (Fig. 3a); ten of them are shared across all use categories (Appendix A). In the central part of the dendrogram (black cluster) *Cenostigma pyramidale*, *Prosopis juliflora*, *Astronium urundeuva*, *Schinopsis brasiliensis*, *Anadenanthera colubrina* and *Tabebuia aurea* are present (Fig. 3a), all of them being among the 20 most frequently mentioned species in the study, mainly in the Fuel and Construction categories (Appendix A). This cluster is associated with height, stem diameter, wood density and leaf dry mass (Fig. 3 b) and encompasses species that differ considerably in terms of their functional profiles. Finally, the last cluster (yellow) only included one species (*Clusia paralicola*), which has high leaf thickness and was mentioned a single time in the interviews.

In general, the dendrogram revealed that many of the plant species recorded in the interviews have multiple uses, in addition to a lower selectivity for the fodder category compared to the other uses.

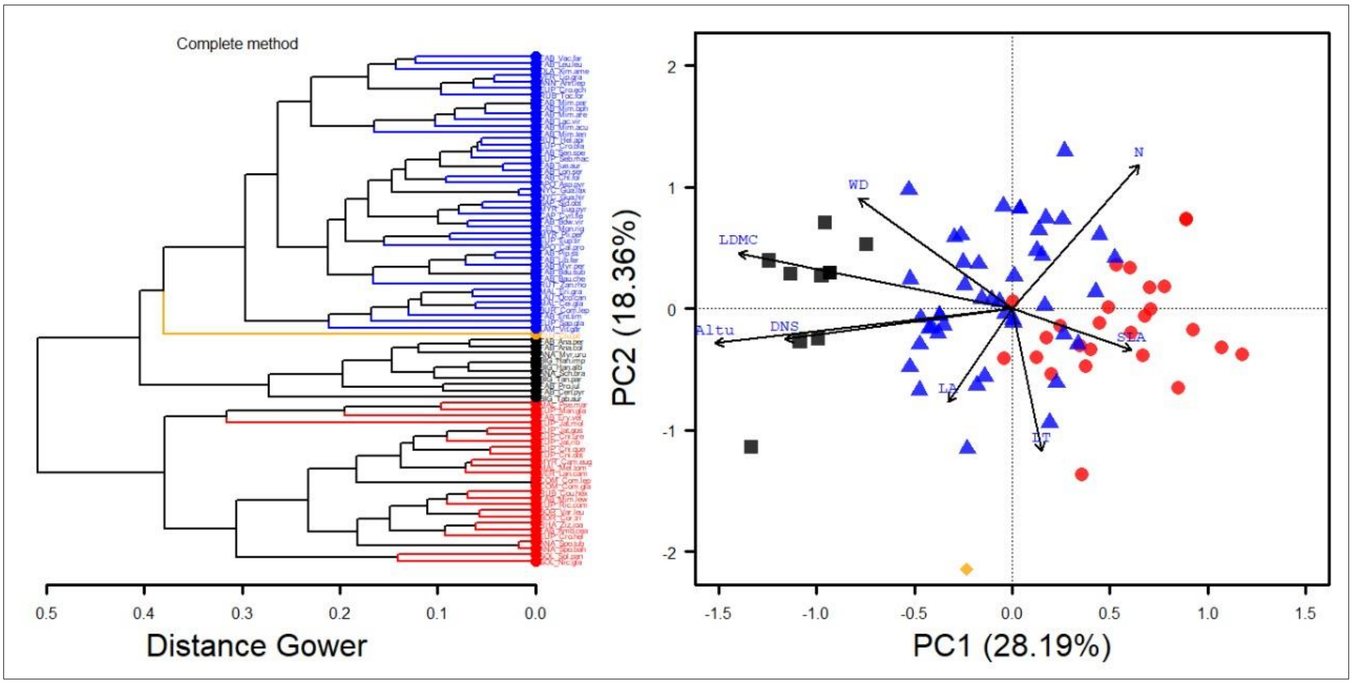

Fig. 3.

The assessment of functional traits of the plant species mentioned in the interviews showed that despite being interrelated, as revealed by the PCA (Fig. 3b), the different traits tend to be associated with different uses. The best models support these results. In general, wood density (WD) and maximum diameter (Dmax) were strong predictors of plant selection for Fodder, Fuel and Construction uses (Table 3), as these traits were included in all best models (Appendix B).

The selected models fitted to evaluate the role of plant traits associated to Fodder use revealed 16 equally plausible models (with leaf area, specific leaf area, leaf thickness and nitrogen concentration). The best model (ΔAICc = 0) included three factors, namely maximum diameter and wood density (with positive effects), and specific leaf area (with a negative effect) on plant selection for Fodder, indicating that plants with high specific leaf area, values tend to be under-consumed or less preferred as forage.

Notably, for wood-related uses, no model selected included mean height. We included this trait in the modeling because we had anticipated this to be an important predictor of wood use. Fuel, a use category that encompasses species in the firewood and charcoal use subcategories, was best described by three models. The first one included mean diameter, wood density (both functional traits being linked to wood quality) and leaf area, all with positive effects. The second-best model contained, in addition to wood density and mean diameter, leaf area and leaf nitrogen content, with positive and negative effects, respectively, suggesting that plants with high nitrogen contents are not preferred for Construction. For the Construction use category, three models were equally plausible, two of them including two terms (first model, maximum diameter and wood density; second model, maximum diameter and leaf dry matter content), whereas the last model included wood density, maximum diameter and leaf dry matter, all with positive effects.

The condition of not being used recorded for some plants seems to be determined by high leaf area and specific leaf area values, both of them being predictor variables included in the two best models selected to explain the plants mentioned as Not used. The first model, in addition to these two traits (positive effects), included the mean diameter (with a negative effect), suggesting that low-diameter plants do not offer many benefits.

Table 3. Best-supported generalized linear models (GLM) fitted to analyze the relationship between functional traits of plants mentioned by interviewed agropastoralists and the use they make of them, in the semi-arid region of Brazil. Dmax, maximun diameter (cm); LA, leaf area (cm²); SLA, specific leaf area (mm² mg^{-1}); WD, wood density (g cm^{-3}).

Response variable (Use category)	**Predictor variable (Plant trait)**	**Estimate**
Fuel	Dmax	0.483
	DM	0.708
	AF	0.348
Construction	Dmax	0.636
	DM	0.500
Forage	Dmax	0.649
	DM	0.208
	SLA	-0.442
Not used	Dmax	-0.282
	AF	0.293
	AFE	0.529

4. Discussion

Our study provides valuable information about the patterns of use of plant species in the environmentally heterogeneous semiarid region of Brazil Our findings reinforce the intrinsic relationships between rural populations and the plant species of the Caatinga, and shed light on the relationships within the functional traits/ecosystem services/LEK triad. Our results confirm the importance of plant functional traits in decision making about the use and management of plant species. Selection by rural human populations always considers the benefit/resource use maximization ratio(Gaoue et al. 2017; Albuquerque et al. 2019; Cunha et al. 2022). Nevertheless, some relationships between the use of plant species and their functional traits are not so clear, and thus we explore here some paths to understand them.

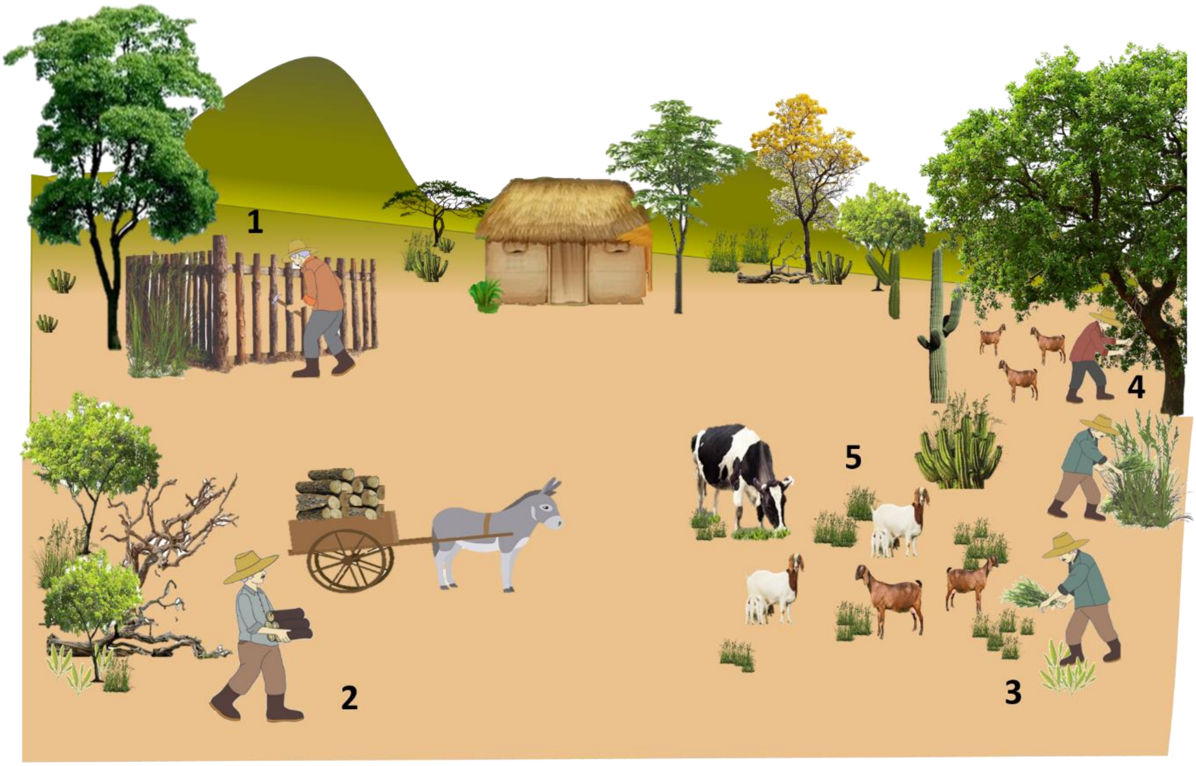

Fig. 4.

4.1. Plant use and selection by rural communities

The largest number of mentions for the Fodder category reinforces the dependence of local populations on local biodiversity elements for the nourishment of livestock herds in the Caatinga. Also, it reveals the magnitude of LEK about the behavior and preferences of animals related to sources of forage and demonstrates the great versatility in the use of plant parts, apontada, como uma estratégia para otimização no uso dos recursos (Linstädter et al. 2013). Among the species mentioned for Fodder, *Cenostigma pyramidalis* stands out, as it emerged as one of the most highly preferred species by ruminants (Cunha et al. 2022). This legume is characterized by high leaf protein content, an important indicator of nutritional quality (Chettri and Sharma 2009; Nunes et al. 2015). Moreover, the high regional abundance of this species appears to be related to its high frequency of mentions of use, since some ecosystem services largely depend on the characteristics of the dominant species (Santos et al. 2009; Araujo et al. 2010; Díaz et al. 2011; Ramos et al. 2023).

The numbers of plant species mentioned for the Construction and Fuel use categories, were similarly low. This may be a consequence of the gradual increase in the socioeconomic status of local populations, which seems to be leading to some abrupt changes in the dependence on plant use for those categories. For example, at present cooking gas is widely used in the region as a domestic source of energy, including the homes of all interviewees (personal observations). Yet, several cultural and spatial factors still require using native species for fuel (Hora et al. 2021; Pedrosa et al. 2022). *Cenostigma pyramidalis* was also highlighted in the Fuel category, which may be related to its high wood density, as well as the low moisture content reported by the interviewees (Table 1).

The knowledge that agropastoralists have about herd behavior and plant traits related to their selection as fodder has been much emphasized (Molnár et al. 2020). The specificity and variety of this use promotes a growing body of knowledge with a high level of detail. People develop intrinsic relationships with their environment from experiences and observations; this relationship provides them with an ever growing body of information and peculiar understandings (Naah and Guuroh 2017), allowing them to maximize resource use based on plant functional traits of the species, weighted by their availability. Notably, the criteria defining the preferences are many and variable among use categories (Cámara-Leret et al. 2017).

4.2. Functional traits involved in plant species preferences of agropastoralists

Based on a qualitative approach, Caatinga agropastoralists seem to be able to distinguish plant species according to their functional traits, relating them to the perceived quality of the used species, including high palatability, combustion power, and wood density (Table 1). For the Fodder category, leaf dry matter content was included in the second-best model; this is interesting, as this trait has been linked to a quality attribution to resources (Chettri and Sharma 2009). *Spondias tuberosa*, one of the preferred species for Fodder, stood out for the versatility of the parts used (leaves, branches, and especially fruits); according to the agropastoralists, the sweet flavor of its fruits is highly appreciated by ruminants. Interestingly, and considering all plant traits analyzed, this species belongs to the group of species positively associated with specific leaf area.

Overall, agropastoralists mentioned their preference for plant species with bigger diameter and higher wood density but smaller leaf area and, by contrast, their tendency to reject plants with larger leaf area and specific leaf area, and thicker leaves. Native plant diversity provides human populations with a range of critical ecosystem goods and services (Díaz et al. 2007; Brown et al. 2011). However, the way people benefit from these services varies according to their perceptions, needs, and ability to access and select the different species (Díaz et al. 2011; Nunes et al. 2016; Cunha et al. 2022). In arid and semi-arid ecosystems in particular, maintaining the provision of ecosystem services requires a deep understanding of forest resource dynamics (Linstädter et al. 2013), due to the different strategies of plants species selection and use. In the case of Fodder use, the consumption of different plant parts reveals the choice of different plant traits for a single purpose.

Several studies have reported people’s preferences for some species for Fodder, Fuel and Construction, with quality and availability being the main drivers of such preferences (Chettri and Sharma 2009; Nunes et al. 2015; Cámara-Leret et al. 2017; Gonçalves et al. 2021a; Hora et al. 2021). For Fodder use, for example, palatability was a significant criterion, as it relates to greater acceptability by ruminants. Regarding the Construction and Fuel categories, respectively, wood durability, combustion potential, and flame duration are the most relevant criteria (Santos et al. 2009; Marquez-Reynoso et al. 2017; Hora et al. 2021).

Agropastoralists often select plants for Construction through the judgement of functional traits related to wood quality, such as wood density and stem diameter, for example. This means that, by adopting the strategy of selecting plants with greater durability, they avoid the need to frequently replenish their stocks. However, this judgement also results in plant use being more heavily concentrated on a small set of highly durable species, which can exert strong pressure on them, progressively leading to their population decline and slowly increasing the pressure on lower quality species to replace them. Therefore, the perception of durability is a major factor in the selection of species, and it plays an important role for burning fuel, as well as in the daily dynamics of the life of rural populations (Santos et al. 2009; Marquez-Reynoso et al. 2017). By using more durable species, it is likely that more time can be spent on other activities such as herding, housework, or farming.

The positive relationship between wood density and all use categories examined here highlights how important this plant trait is for selecting plant species in the Caatinga, especially for rural constructions, which is the subcategory that received the largest number of mentions in the Construction category (Table 2). This relationship is also supported by the regional availability of high-wood density species, such as *Cenostigma pyramidale, Mimosa tenuiflora* and *M. ophthalmocentra* (Araujo et al. 2010). Considering that high wood density is a conservative water use attribute(Poorter et al. 2019; Romero et al. 2020; Romero et al. 2022), in dry environments it is expected that there will be a dominance of these species and consequently a greater exploitation.

The classification of several species as not used reinforces the specificity in selecting plants possessing desirable characteristics; plants with high specific leaf area, and high leaf area along with smaller stem diameters are clearly unattractive and thus do not seem to be useful for rural populations in the Caatinga; notable examples of this situation are *Jatropha molissima*, *J. ribifolia*, and *Cnidoscolus urens*.

4.3 Implications for conservation

Some agropastoralists expressed the concern that the availability of some preferred plant species has declined considerably over recent years, for example *Astronium urundeuva* and *Schinopsis brasiliensis*. These species were frequently reported as preferred (Table 3) for having characteristics suggested to be the best for their use as wood. Nevertheless, the current abundance of these two species is very low (Ramos et al. 2023), which has resulted in other plant species replacing them and becoming the preferred ones for this use. Such a shift is in agreement with the ecological appearance hypothesis that predicts that because the most apparent (visible) plants are more susceptible to herbivory, the most abundant useful plants experience greater pressure of use (Gaoue et al. 2016; Lucena et al., 2012; Gonçalves et al., 2016).

Two contrasting opinions are curretnly debated in this regard. On the one hand, there is a view that the pressure derived from plant use has little effect on the abundance of dominant species, especially those with resprouting capacity, so that they would not be affected significantly, as is the case of *Croton blanchetianus*, *Cenostigma pyramidale* and *Aspidosperma pyrifolium*, all of which reproduce successfully under the environmental conditions prevailing in some areas (Ramos et al. 2020; Gonçalves et al. 2021b; Ramos et al. 2023). On the other hand, the use history of these plant species reveals severe and constant pressures (Singh 1998; Silva et al. 2018), and considering the region's climatic severity, many areas of the Caatinga have not been able to recover from the impacts (Schulz et al. 2019; Antongiovanni et al. 2020), which may be leading to a decline in in the populations of some species and, consequently, to the collapse of the ecosystem due to inadequate management (Molnár et al. 2020). In the global scenario, cattle grazing comprises the most common land use (Travers et al. 2018), and consequently it is one of the activities that most strongly affect both the land and the species of the local biodiversity. For these reasons, grazing can compromise economic activities, especially in arid and semi-arid regions (Schulz et al. 2019).

The information produced in this study provides new insight into resource management; selective exploitation of plant resources is a growing problem that permeates across different forest systems (Ellis 2015). Intense and short-term pressures critically threaten resource regeneration and require urgent changes in the exploitation of ecosystems (Díaz et al. 2007; Brown et al. 2011).

Conclusion

Overall, the advantage of the integration of the information on plant traits with LEK allowed a better understanding of the complexity of human-biodiversity relationships of Caatinga. Our results lead to the conclusion that the functional plant traits are critical in decision-making for the selection of plant species for each primary use (i.e., fuel, construction and forage). Therefore, this approach represents a potentially powerful tool for understanding the provision of ecosystem services to human societies, allowing an exchange of information between researchers, resource managers and biodiversity conservation agencies. Will enhance our capacity to make a sound management of biodiversity and its conservation of Caatinga.

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Ethics declarations

The study was approved by the Research Ethics Committee of Centro Universitário UNIFACISA (appraisal No: 010713/2019; certificate of presentation for ethical review No. 07564918.2.0000.5175). Before starting data collection *in situ*, we explained our research objectives to the informants, and made clear to them that all information would be treated confidentially. We did this to get their consent before the interviews started and also to establish a relationship of trust with them. We obtained oral consent from those who agreed to participate, and later they signed the free and informed consent form.

Competing Interests

The authors declare no competing interests.

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Author contributions

MBR: Investigation, Conceptualization, Data acquisition (field work), Data analysis, Writing- Original draft preparation, Visualization, Writing - Review and Editing, Project administration.

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MGRM, SSC, SMS, and KMP Investigation, Conceptualization, Data acquisition (field work), Data analysis, Writing - Review and Editing.

JAM: Conceptualization, Data analysis, Visualization, Writing- Original draft preparation, Writing - Review and Editing.

SFL: Conceptualization, Data analysis, Funding acquisition, Supervision, Project administration, Visualization, Writing - Review and Editing.

Data Availability

N/A

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Figure Captions

Fig. 1. Location of the study area and vegetation cover map of the Cariri region, Paraíba State, NE Brazil, in the Caating realm (shaded). The icons indicate the location of the rural communities included in the study. The map was created using ArcGIS 10.5.1 (ESRI, https://www.esri.com). Images on the right side of the figure exemplify the livelihoods of the pastoralists living in this region.

Fig. 2. Different plant uses made by agropastoralists of the Cariri region, Paraiba State, NE Brazil. (A) Agropastoralist with branches of *Cereus jamacaru* used as fodder for the herds during the dry season. (B) Herds confined in pens made with stems of *Croton blanchetianus* and *Aspidosperma pyrifolium.* (C) Wood stove. (D) Agropastoralist cutting braches of *Schinopsis brasiliensis* to feed the herds. (E) Herds confined in a pen being fed by agropastoralists with native plant species. (E) *Prosopis juliflora* timber used for rural construction.

Fig. 3. Multivariate analyses of the species used by agropastoralists in the Cariri region and their functional traits. **(A)** UPGMA dendrogram for 82 species with functional traits mentioned by the interviewed agropastoralists. **(B)** PCA ordination of the trait functional space. The vectors represent functional traits: LDMC, leaf dry matter content; Height, maximum height; BD, basal diameter; WD, wood density; LT, Leaf thickness; LA, Leaf area; SLA, Specific leaf area; N, Leaf nitrogen.

Fig. 4. Agropastoralists knowledge of plant services. Daily life agropastoralists in where plants products play a central role: (1) Agropastoralists using Croton blanchetianus, Aspidosperma pyrifolium, Astronium urundeuva for fence construction. (2) Agropastoralists using Cenostigma pyramidale, Croton blanchetianus, Mimosa ophthalmocentra, for fuel. (3, 4) Agropastoralists supplying Mimosa tenuiflora, Schinopsis brasiliensis, and Ziziphus joazeiro branches to the herds. (5) Herds grazing freely through the Caatinga vegetation.

4. CAPÍTULO IV: The role of chronic anthropogenic disturbances in plant community assembly along a water availability gradient in Brazil's semiarid Caatinga region

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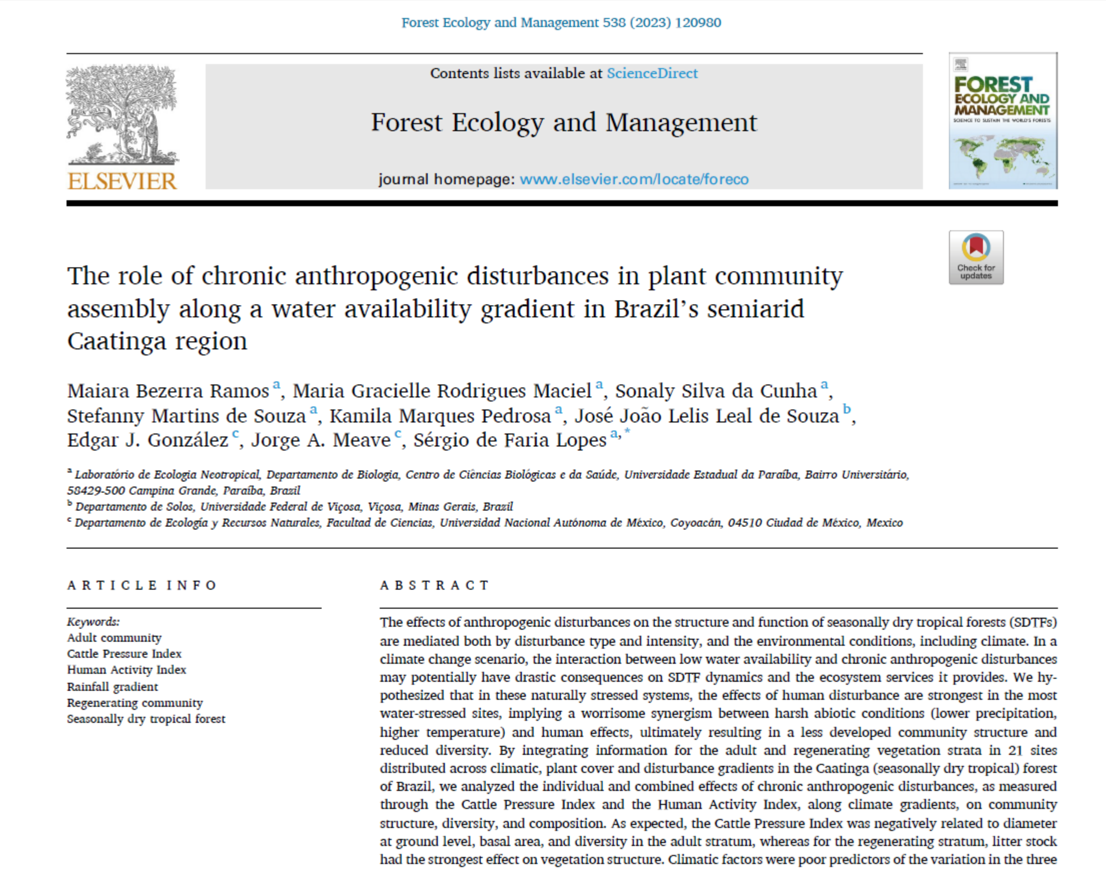

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The role of chronic anthropogenic disturbances in plant community assembly along a water availability gradient in Brazil's semiarid Caatinga region

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ABSTRACT

The effects of anthropogenic disturbances on the structure and function of seasonally dry tropical forests (SDTFs) are mediated both by disturbance type and intensity, and the environmental conditions, including climate. In a climate change scenario, the interaction between low water availability and chronic anthropogenic disturbances may potentially have drastic consequences on SDTF dynamics and the ecosystem services it provides. We hypothesized that in these naturally stressed systems, the effects of human disturbance are strongest in the most water-stressed sites, implying a worrisome synergism between harsh abiotic conditions (lower precipitation, higher temperature) and human effects, ultimately resulting in a less developed community structure and reduced diversity. By integrating information for the adult and regenerating vegetation strata in 21 sites distributed across climatic, plant cover and disturbance gradients in the Caatinga (seasonally dry tropical) forest of Brazil, we analyzed the individual and combined effects of chronic anthropogenic disturbances, as measured through the Cattle Pressure Index and the Human Activity Index, along climate gradients, on community structure, diversity, and composition. As expected, the Cattle Pressure Index was negatively related to diameter at ground level, basal area, and diversity in the adult stratum, whereas for the regenerating stratum, litter stock had the strongest effect on vegetation structure. Climatic factors were poor predictors of the variation in the three

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ABSTRACT

The effects of anthropogenic disturbances on the structure and function of seasonally dry tropical forests (SDTFs) are mediated both by disturbance type and intensity, and the environmental conditions, including climate. In a climate change scenario, the interaction between low water availability and chronic anthropogenic disturbances may potentially have drastic consequences on SDTF dynamics and the ecosystem services it provides. We hypothesized that in these naturally stressed systems, the effects of human disturbance are strongest in the most water-stressed sites, implying a worrisome synergism between harsh abiotic conditions (lower precipitation, higher temperature) and human effects, ultimately resulting in a less developed community structure and reduced diversity. By integrating information for the adult and regenerating vegetation strata in 21 sites distributed across climatic, plant cover and disturbance gradients in the Caatinga (seasonally dry tropical) forest of Brazil, we analyzed the individual and combined effects of chronic anthropogenic disturbances, as measured through the Cattle Pressure Index and the Human Activity Index, along climate gradients, on community structure, diversity, and composition. As expected, the Cattle Pressure Index was negatively related to diameter at ground level, basal area, and diversity in the adult stratum, whereas for the regenerating stratum, litter stock had the strongest effect on vegetation structure. Climatic factors were poor predictors of the variation in the three true diversity measures (${}^{0}D$, ${}^{1}D$, and ${}^{2}D$) of the regenerating community. Our results revealed important cross-site differences in both vegetation strata over a small range of climatic variation. We conclude that the most stressful conditions associated with a very low precipitation regime enhance the effects on chronic disturbances, gradually driving SDTF communities into new alternative states and rendering these environments more prone to desertification.

Keywords: Adult community • Cattle Pressure Index • Human Activity Index • Rainfall gradient • Regenerating community • Seasonally dry tropical forest

1. Introduction

Plant community assembly is the integrated result of the complex interplay among multiple abiotic and biotic factors operating at different spatio-temporal scales (HilleRisLambers et al., 2012; Vellend and Agrawal, 2010). Although this topic has long been central in ecological research, the implications of anthropogenic activities, including chronic disturbances, have only recently gained recognition as drivers of plant community assembly, both locally and globally (Ellis, 2015). Chronic disturbances consist in the continuous removal of relatively small amounts of biomass from ecosystems through different human activities, including the extraction of firewood and timber, and medicinal, ornamental, and fodder plants (Martorell and Peters, 2005; Singh, 1998). Collectively, these activities cause subtle, albeit constant, alterations with long-term effects in the plant community (Arnan et al., 2018; Jara-Guerrero et al., 2021). Depending on their intensity, anthropogenic chronic disturbances can strongly affect community composition and diversity (Eldridge et al., 2018; Jara-Guerrero et al., 2021; Marinho et al., 2016; Ribeiro et al., 2015; Schulz et al., 2019; Travers et al., 2018), the structure of both the adult and regenerating vegetation components (Derroire et al., 2016; Marinho et al., 2016; Schulz et al., 2016), and the functional and phylogenetic diversity of plant communities (Martínez-Blancas et al., 2018; Ribeiro et al., 2016; Zorger et al., 2019), ultimately putting the provision of ecosystem services at risk (Antongiovanni et al., 2020; Díaz et al., 2011).

The effects of chronic anthropogenic disturbances (CAD) are particularly worrisome in seasonally dry tropical forests (SDTF), mainly because of their potential to intensify climate change effects on plant communities (Arroyo-Rodríguez et al., 2017; Chaturvedi et al., 2017). Northeastern Brazil hosts the most extensive SDTF of the New World (Pennington et al., 2018). Locally known as Caatinga, this vegetation type covers over 912,500 km^2; it hosts a flora with a high level of endemism and a large variety of plant communities, whose geographic distribution is mainly determined by climatic, relief, geology, and edaphic heterogeneity (Apgaua et al., 2015; Moro et al., 2015; Silva et al., 2017). Despite representing a substantial proportion of Brazil's territory (ca. 11 %), for a long time the Caatinga was largely overlooked in the academic and political spheres (Miles 2006), which has delayed our understanding of this ecosystem's dynamics when compared to others such as the Amazon rain forest, for example (Santos et al., 2011).

The Caatinga is also characterized by complex and long-standing relationships between humans and biodiversity (Melo, 2017). Nearly 27 million people inhabit the region, which results in strong anthropogenic disturbance gradients, with a variable distribution in time and space (Antongiovanni et al., 2020). Cattle is the main anthropogenic disturbance type in the region (Silva et al., 2017). Domesticated herbivores like goats, oxen, and sheep graze freely on the native vegetation at rates apparently beyond viable limits (Silva et al., 2017). These herbivores have a broad generalist diet as they feed upon the leaves, fruits, barks, and cladodes of adult plants, as well as on seedlings and saplings (Cunha et al., 2022). Consequently, cattle reduce the accumulation of soil litter, affect plant community composition, structure, and diversity, inhibit plant regeneration, and promote desertification due to increased soil exposure (Almeida et al., 2020; Marinho et al., 2016; Schulz et al., 2016). The complexity of chronic anthropogenic disturbances remains insufficiently explored (Antongiovanni et al., 2020; Arnan et al., 2018); notwithstanding important efforts made in this direction, little is known about the isolated effects of different disturbance metrics in dry ecosystems (Jara-Guerrero et al., 2021; Marinho et al., 2016). In the Caatinga, such complexity of disturbances interacts in unclear ways with the variety and heterogeneity of socioecological systems (Pedrosa et al., 2022; Silva et al., 2018). For instance, human populations in different environmental contexts may differ in their species selection strategies (Cunha et al., 2020; Naah and Guuroh, 2017).

Precipitation and soil water retention play relevant roles in this ecosystem, acting as strong environmental filters and driving plant community distribution within the Caatinga realm (Moro et al., 2015; Silva and Souza, 2018). Habitats with higher water availability are associated with higher plant biomass, a variable exerting a strong influence on recruitment success in SDTF, as seedlings rarely become established on exposed soil (Chazdon, 2003; Marinho et al., 2016). Hence, the semi-arid plant systems are highly vulnerable to climate change (Werneck et al., 2011) and its potential synergy with human activities (Arroyo-Rodríguez et al., 2020; Gibb et al. 2015; Rito et al. 2017a). Hence, the interplay of the high environmental heterogeneity of the Caatinga with the different forms of anthropic disturbances requires sustained efforts from scientists to advance our understanding of the dynamics and functioning of this highly threatened ecosystem.

In this study, we addressed the following questions: (1) How do chronic anthropogenic disturbances affect the structure, composition, and diversity of the adult and the regenerating vegetation components (strata) along climatic gradients in the Caatinga?, and (2) How do climatic variables interact with anthropogenic disturbances? We hypothesized that in these naturally stressed systems the effects of human disturbance are stronger in drier places than in wetter places, implying a worrying synergism between harsh abiotic conditions (lower precipitation, higher temperature) and human effects. Water availability in this forest does not only depend on precipitation but also on temperature, as this variable is involved in water loss from the system through evapotranspiration. Accordingly, we expected the effect of CAD to be stronger in areas of lower precipitation, higher temperature, or higher evapotranspiration. We predicted that under drier conditions the adult community would be less developed, i.e. that it would comprise smaller trees, and host lower diversity; similarly, the regenerating community should also have a low diversity and have a less developed structure under these conditions. Conversely, we predicted that forests occurring in areas with higher water availability (either higher precipitation or lower temperature and lower evapotranspiration) should display a better regenerating capacity and maintain higher species diversity, even when subjected to human disturbance. We also predicted that in drier areas, anthropic disturbances would enhance tree death in the forest canopy.

2. Material and methods

2.1. Study area

The study was conducted in the Cariri Velhas region, Paraíba state, NE Brazil (Fig. 1). Landscapes in the Cariri Velhas (ca. 11,225 km^2) are typical of the semi-arid Brazilian region and stand out for having the lowest precipitation regime in the country, so that it is recognized as a desertification core (Tomasella et al., 2018). Regional climate is hot, semi-arid (Bswh type; Álvares et al., 2013), and markedly seasonal, with a short rainy period of ca. four months (March to July) and a longer dry season (August to February); evaporation rates are high (< 0.65). Superimposed to the seasonal variation, precipitation also shows large interannual variability, with total annual precipitation ranging from 300 to 700 mm. Elevation ranges from 350 to 1,100 m a.s.l. at the summits of mountains and granitoid *inselbergs* (Moro et al., 2016; Souza et al., 2020). Soils are mainly hyper-eutrophic, gravelly, shallow, and incipient, with nine soil classes recorded for the region (Santos et al., 2011). The dominant vegetation type is the seasonally dry tropical forest, known in Brazil as Caatinga. The flora of these communities embodies numerous species having morpho-physiological adaptations in response to water availability (Queiroz et al., 2017; Fernandes et al., 2020). Relatively short trees dominate the Caatinga, mostly attaining heights of ca. 10 m, along with numerous species of shrubs, cacti, and bromeliads (Fernandes et al., 2020).

Chronic anthropogenic disturbance has been widespread in the Cariri Velhas since the 16th century when the European colonizers conquered the Brazilian North-East and learned to use Caatinga as a source of fodder for the newly introduced cattle. At present, agriculture and extensive cattle ranching are the main economic activities, both having strong effects on vegetation attributes, apparently overrunning the system’s carrying capacity (Marinho et al., 2016).

2.2. Selection of study sites and environmental gradients

To assess vegetation attributes along environmental and disturbance gradients, we selected 21 sites based on satellite imagery for the 2017 dry season (accessed through the SA Explorer search tool of the United States Geological Survey), precipitation maps, and field trips. The selected sites represent a range of vegetation cover development (as determined by the Normalized Difference Vegetation Index or NDVI), precipitation, and anthropic disturbances (Fig. 1), but were restricted to a 354–751 m asl elevational range. Sites difficult to access or where the vegetation had been recently removed were discarded and new ones were selected. NDVI is a proxy of photosynthetic activity intensity and thus provides a rough assessment of vegetation condition (Rouse et al., 1974); in the study region, NDVI ranged from 0.13 to 0.73 (Appendix A).

At each site, one 1000-m² (50 × 20 m) plot was established to sample the adult stratum of the vegetation. These plots were subdivided into 100 m^2 (10 × 10 m) subplots to sample the regenerating stratum. A minimum distance of 1 km between circular buffers (2-km radius; 12.56 km^2 in area) around the plots was set to maximize between-site independence.

2.3. Evaluation of vegetation attributes

Vegetation sampling was conducted in the rainy season of 2019. To examine the effects of environmental gradients on current vegetation structure while gaining insight into future vegetation development, we distinguished two vegetation components, namely the adult and the regenerating strata. The adult stratum comprised all individual trees and shrubs occurring in the 50 × 20 m plot that were alive or dead (but still standing) with heights ≥ 1 m and stem diameter at ground level (DGL) ≥ 3 cm (Rodal et al., 2008). In turn, the regenerating stratum included those individuals with DGL between 0.5 and 2.9 cm and heights < 1 m. This latter stratum was sampled in four randomly selected 10 × 10 m (100-m^2) subplots at each site (Rodal et al., 1992). Tree height was measured with a 12-m tall, graduated pole; the heights of a few trees taller than this pole were estimated visually.

Whenever possible, species identities were recorded in the field; otherwise, we collected samples for inspection by trained botanists or comparison with vouchers deposited at the Manuel de Arruda Câmara Herbarium (HACAM; Universidade Estadual da Paraíba). Species nomenclature and synonymy were verified in the Flora do Brasil data bank. Family classification of species followed APG IV (The Angiosperm Phylogeny Group et al., 2016).

2.4. Predictor variables

We assessed two groups of predictor variables. The first group represented environmental variables and included mean annual precipitation (MAP) and mean annual temperature (MAT), two fundamental variables considered broad indicators of climatic conditions (Hijmans et al., 2005), along with mean annual evapotranspiration (MAE) and Köppen’s Aridity Index (AI), calculated as (Quan et al., 2013):

$$AI = MAP/(MAT + 33).$$

We used the *raster* and *sp* packages (Hijmans, 2021; Pebesma and Bivand, 2005) to manipulate raster data within R. Litter stock (LS) was an additional environmental variable measured in each plot by collecting all necromass accumulated on the ground in five 1-m^2 (1 × 1 m) subplots randomly distributed in the plot. Litter samples were dried in a forced-air oven at 65 °C for 24 h and weighed in a precision balance to obtain litter dry matter (Appendix A). The mean annual precipitation of each plot ranged from 379 a 690 mm year.

The second group of predictive variables represented human-related factors and included nine metrics considered good indicators of chronic human disturbance in dry environments (Martorell and Peters, 2005), including SDTF (Arnan et al., 2018; Appendix A). Four of these were assessed directly in the plots, whereas the remaining five were derived from the geographical context or extracted from satellite images in the circular buffer around each plot. Based on these metrics, we assessed two main disturbance types to calculate two chronic anthropogenic disturbance indices, one related to cattle pressure and the other to human activity.

Cattle pressure is related to grazing intensity by domesticated herbivores (cattle, horses, donkeys, goats, and sheep) at the sites. To assess this disturbance, at each site we tallied all droppings of cattle (cows), equines (horses and donkeys), and goats/sheep in the 10 × 10 m plots (Appendix A). We then collected, dried, and weighed three dropping samples for each of these groups to calculate mean weight by plot and to estimate total biomass of bovine, equine, and goats/sheep feces by plot. In addition, soil compaction was assessed by measuring bulk density on undeformed soil samples collected from the surface soil horizon and the horizon immediately underneath, through the volumetric ring and balloon methods (Teixeira et al., 2017).

The second disturbance type is related to human activity and is expressed as signs of land use left behind by people. These were recorded as indirect measures from the geographical context based on satellite imagery. First, to assess proximity to human habitation we recorded the distance from each plot's center to the closest house and the closest urban center (city or town). In addition, housing density (number of houses per unit area) and land use were evaluated in buffers around the plots. Land use was defined as the percent cover of the land devoted to agriculture, pasture, residential areas, and human infrastructure; land use and trail density were visually estimated in a smaller 100-m radius buffer.

We integrated the different variables used to measure each disturbance type into a single, comprehensive metric by calculating two indices: the Cattle Pressure Index (CPI) and the Human Activity Index (HAI). Both CPI and HAI were calculated using the following general formula (Legendre and Legendre, 1998; Blüthgen et al., 2012):

$$I_j = \frac{1}{n}\sum_{i=1}^{n}\frac{y_{i,j} - y_{i,\min}}{y_{i,\max} - y_{i,\min}} \times 100$$

where I_j represents either CPI or HAI in plot j, $y_{i,j}$ is the observed value for the disturbance metric i in plot j, $y_{i,\min}$ is the minimum observed value for the disturbance metric i across all plots, $y_{i,\max}$ is the maximum observed value for the disturbance metric i across all plots, and n is the number of individual disturbance metrics included in the respective index (CPI or HAI).

2.5. Response variables

At each site, we estimated the following response variables for both the adult and regenerating strata: mean diameter at ground level (DGL; cm), mean tree height (H; m), mean tree height of the tallest trees in the canopy, i.e., those included in the uppermost decile at each site (HD10; m or cm, depending on the stratum), basal area (BA; m^2), abundance of individuals (Abu), and true diversity measures (Hill numbers, see below). In addition, for the adult stratum we also calculated the fraction of standing dead individuals (FDI).

Community diversity measures were based on cover-based estimators (Chao and Jost, 2012). Sample coverage was very high (> 95%) in all sites, both for the adult and regenerating strata, indicating an adequate sampling effort and confirming that diversity estimations were not biased due to between-plot differences in sample coverage (Chao and Jost, 2012; Chao et al., 2014). To assess diversity in the two above-defined vegetation strata we calculated true diversity values (Hill numbers) by integrating rarefaction and extrapolation curves. We used Hill numbers of three orders (q): $q = 0$ diversity (${}^0D$, species richness), which is insensitive to species abundances and thus gives disproportionate weight to rare species; $q = 1$ diversity (${}^1D$, exponential Shannon entropy), which is roughly interpreted as the number of common species, as it weights species according to the relative abundances in the community; and $q = 2$ diversity (${}^2D$, inverse Simpson concentration), which favors the most abundant species (Jost, 2006; 2007). True diversity values were calculated with the iNEXT package (Hsieh et al., 2016). Community homogeneity was assessed through the Evenness Factor (EF), which represents the proportion of dominant species in the community (Jost, 2010):

$EF = {}^2D/{}^0D$

2.6 Assessing the effects of predictor variables on response variables

To assess the effects of predictor variables on response variables from the adult and regenerating strata, we constructed generalized linear models (GLM) with the *glm* function. In addition to the four climatic variables described above, models for the regenerating community also included litter stock (LS) as predictor variable. We used Gaussian and Gamma distributions for the positive, continuous variables (DGL, HD10, BA, ^1D, ^2D), with the identity and log link functions for the former distribution, and the log link function for the latter. For count variables (Abundance and ^0D) a negative binomial distribution was used (Crawley, 2007).

For each response variable, we fitted models that included one, two or three predictor variables (factors), in addition to a null model (i.e., excluding all predictor variables), with the following general structure:

$$y = f(\beta_0)$$

$$y = f(\beta_0 + \beta_1 \cdot x_1)$$

$$y = f(\beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2)$$

$$y = f(\beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \beta_3 \cdot x_1 \cdot x_2)$$

$$y = f(\beta_0 + \beta_1 \cdot x_1 + \beta_2 \cdot x_2 + \beta_3 \cdot x_3)$$

where y is any of the 10 response variables of the adult stratum and nine of the regenerating stratum, x_i is any of the six predictor variables of the adult stratum or seven of the regenerating stratum, and f is the link function associated with each response variable. By considering all possible combinations of predictor variables, we fitted 51 models for each response variable for the adult stratum, and 78 models for each response variable for the regenerating stratum (the number of fitted models differed between strata due to the inclusion of the extra predictor [LS] for the regenerating stratum). We assessed multicollinearity among predictor variables with the variance inflation factor (VIF) with the *car* package (Fox and Weisberg, 2019); all variables included in our models had VIF < 4, suggesting independence between them (Bondell and Reich, 2008). Next, we performed a model selection procedure based on the sample corrected Akaike Information Criterion (AICc); models with ΔAICc < 2 were considered equally supported and capable of explaining the variation of the response variable. To assess the importance of factors in describing each response variable, we performed a relative importance variable analysis using the AICc values, following Burnham & Anderson (2002). One plot was considered an outlier because of its abnormally high temperature record and thus was removed from the modeling.

To identify the influence of predictor variables (both environmental and anthropic) on species composition of the adult and regenerating strata, we performed a Non-Metric Multidimensional Scaling (NMDS) ordination with the metaMDS function in the *vegan* package (Oksanen et al., 2015). We first tested for significant differences in vegetation composition based on a Bray-Curtis dissimilarity matrix (Anderson, 2001; McCune et al., 2002). Species abundances were square root-transformed to minimize the influence of the most abundant ones (Kindt and Coe, 2005). Then, we fitted the environmental variables on the NMDS ordination axes with the *envfit* function. This function estimated the strength and direction of the maximum relation between NMDS configuration and the environmental variables, and thus allowed us to test the effects of predictor variables on species composition. The linear fit of the variables on the NMDS axes was calculated, and its significance ($\alpha = 0.05$) assessed with a randomization test based on 999 permutations.

All analyses were performed in R version 3.6.0 (R Core Team, 2019).

3. Results

3.1. Community structure and diversity

For the adult stratum, we recorded a total of 4,501 individuals in the 21 sites (mean ± SD by site, 214.3 ± 68.7 individuals) representing 71 species (19 with unknown specific identities and thus treated as morphospecies) and 21 families. This figure for total abundance includes 1,285 dead individuals (Table 1, Appendix C). The most speciose families were Fabaceae (16 species) and Euphorbiaceae (10 species) (Appendix C). Observed per plot species richness (^{0}D) ranged between 5 and 35 species (Table 1). This implies an almost 7-fold difference between the least diverse site (Site 7), located centrally in the study area, and the most diverse one (Site 13), located in its western part. Other vegetation attributes also showed large cross-site variation: stem density ranged from 132 to 451 plants per 1000 m^{-2}, and maximum and mean diameters ranged from 27.4 to 87.9 cm, and between 6.8 to 15.4 cm, respectively. In turn, mean height ranged from 1.8 (site 7) to 7 m (site 17) (Table 1); likewise, canopy height (HD10) was very heterogeneous, ranging from 3 m at Site 6 to the largest recorded value of 12.7 m at Site 5.

The total number of individuals recorded in the regenerating stratum was 1,648, among which 40 species and 18 families were represented (Appendix C). Again, Fabaceae (9 species) and Euphorbiaceae (7) were the most speciose families. There were enormous cross-site differences in the abundance of individuals in this stratum, with values ranging from 10 (Site 5) to 264 (Site 20) individuals per site. Finally, ranges for mean height and diameter at ground level were 37.9 to 72.3 cm and 0.7 to 1.9 cm, respectively (Table 1).

3.1. Environmental factors affecting adult community structure and diversity

A total of 51 models were fitted to explain the variation of the different attributes of the adult community. After identifying those models with the best fit (ΔAIC < 2), we selected one model for each response variable (ΔAIC = 0; Appendix B). The Cattle Pressure Index (CPI), mean annual precipitation (MAP), mean annual temperature (MAT), mean annual evapotranspiration (MAE), aridity index (AI) and their interactions were important predictors of all response variables along the environmental gradients examined (Appendix B). Overall, the selected models pointed to a key role of impacts caused by livestock on the adult community structure and diversity, as indicated by the inclusion of CPI in most selected models (Figs. 2 and 3).

The variation of the adult stratum structure was most strongly influenced by the individual effects of the predictor variables, except for the fraction of standing dead individuals which was also best described by a single model containing MAT, AI, and MAT: AI (Fig. 3; Appendix B). The abundance of live individuals and basal area were best described by a single model that only included CPI as predictor (Fig. 2).

Community height (measured both through HD10 and mean height) was not only best described by MAP, MAE, and AI, but also influenced by CPI and HAI. By contrast, mean diameter at ground level was not affected by any predictor variable. As expected, the three true diversity measures (${}^0D$, ${}^1D$, and ${}^2D$) were strongly affected by CPI (Fig. 2; Appendix B). Between-predictor interactions were only included in the best models for ${}^0D$ and ${}^1D$. In turn, MAP, MAT, MAE, and AI were included in the best models for ${}^0D$ and ${}^1D$ (Fig. 2) with significant effects, suggesting an important role of climate on diversity variation. In turn, ${}^2D$ was influenced by HAI along with MAT, according to the best model for this variable.

3.2. Environmental factors affecting regenerating community structure and diversity

We compared the 78 models that were fitted to explain the variability of the regenerating stratum. Overall, litter stock was the factor having the strongest effect (Fig. 2), particularly for response variables related to vegetation structure, as it was the most frequently included in the best supported models (Appendix B). The importance of CPI seems to be shared between the adult and the regenerating communities, since this factor was present in most selected models (Fig. 4 and Appendix B).

Interestingly, climatic predictors had both positive and negative effects, and therefore they had a weak power to explain the variation in the three true diversity measures (${}^0D$, ${}^1D$, and ${}^2D$) of the regenerating community (Appendix B). Regarding community structure, climatic variables were infrequently included in the best models, suggesting for them a weak influence on the regenerating community (Fig. 2).

3.3. Species composition

The NMDS ordination revealed a gradual change in community composition across the study region. Site distribution on the ordination space revealed the segregation of areas with low (left) and high (right) precipitation (Fig. 5). Among the predictor variables analyzed for the adult stratum, CPI was significantly related with species composition ($R^2 = 0.29$; $P = 0.048$) (Table 2), while mean annual precipitation presented a trend, albeit non-significant ($R^2 = 0.25$; $P = 0.077$) (Table 2).

Croton blanchetianus, *Cenostigma pyramidale*, *Aspidosperma pyrifolium* and *Mimosa ophthalmocentra* were the most abundant species, mainly in the most impacted sites, and they were also widely distributed along the environmental gradients. By contrast, *Cnidoscolus obtusifolius*, *Erythroxylum* sp., *Maytenus rigida*, *Sebastiania macrocarpa*, *Senegalia bahiensis*, *Senegalia* sp., *Schinopsis brasiliensis*, and *Ziziphus joazeiro* were only recorded in sites with the highest precipitation, and all of them had a low abundance.

Community composition of the regenerating stratum was significantly related with CPI ($R^2 = 0.55$; $P = 0.003$) and litter stock ($R^2 = 0.54$; $P = 0.001$) (Fig. 5, Table 2). *Tacinga palmadora*, *Aspidosperma pyrifolium*, *Cenostigma pyramidale, Jatropha mollissima* and *M. ophthalmocentra* were the most abundant species in the regenerating stratum (Appendix C). *T.*

palmadora and *A. pyrifolium* also stood out because of their very large mean diameters.

4. Discussion

Here, we report an integrated analysis of the adult and regenerating components of Caatinga plant communities subjected to natural and anthropic influences. The floristic, structural, and environmental information examined provides answers that will help fill the gaps in our understanding of the effects of chronic anthropic disturbance (CAD) on plant community dynamics in semi-arid environments. Our results attest to the magnitude of vegetation variability displayed within a small range of climatic variation and CAD intensities. Along with other factors, CAD idiosyncrasies determine the heterogeneity of present scenarios in the Caatinga. Most importantly, our results provide evidence for the capacity of low precipitation to intensify the effects of CAD on the SDTF vegetation of the Cariri Velhas region, which may potentially drive plant communities into alternative stable states. By focusing on the regenerating stratum, we were able to make predictions about how human impacts, in synergy with low precipitation, may be reflected in the structuring of future plant communities in this region.

4.1. Responses to anthropic disturbances in community structuring

Our results demonstrated the large variation in vegetation attributes along the examined gradients (Table 1), particularly of abundance of individuals and ${}^{0}D$ (species richness), both of which had higher values in areas with the lowest CPI (Fig. 3a, f). GLMs showed the existence of direct and indirect effects of CPI and HAI, the two human disturbance indices, on vegetation attributes (Appendix B). Such relationships provide evidence for the role of CAD in the Caatinga which, like other SDTFs, shows a dynamic response to different disturbance types (Álvarez-Yépiz et al., 2008; Arroyo-Rodríguez et al., 2017; Romero-Duque et al., 2007), derived from the heterogeneity of ecosystem properties, particularly the climatic regime.

SDTFs have been historically transformed into human-modified landscapes (Castillo et al., 2005; Ellis, 2015), with chronic anthropogenic disturbance being the fundamental driver of these changes, particularly due to their intensity and frequency, effectively retarding ecosystem recovery (Ellis et al., 2010; Singh, 1998). Feces biomass, a component of CPI, is related to the direct effects of grazing on plant communities. Large, domesticated herbivores may exert a top-down control that may potentially drive plant communities along two pathways. On the one hand, the action of these herbivores may result in higher community diversity due to the consumption of dominant species and the resulting release of space that becomes available to colonization by other species (Belsky, 1987; Olff and Ritchie, 1998; Osborne et al., 2018). However, herbivores may also reduce the size of the flora in a given environment if they affect mainly rare species or the most sensitive taxa to disturbance (Ford et al., 2018; Hobbs and Huenneke, 1992; Rutherford et al., 2014). This latter situation is common in low productivity environments (Marinho et al., 2016; Travers et al., 2018), as is the case of the Cariri Velhas.

Domestic herbivore pressure in the Caatinga began in the 16th century with the European colonization. The recognition of the foraging potential of native vegetation set the basis for the rapid expansion of cattle ranching in Brazil’s semi-arid region (Hemming, 1978). At present, goats (*Capra hircus*) are the most abundant domesticated herbivores in the Caatinga (IBGE, 2017), and their generalist diet virtually spares no plant organ or individual of any age, size, and growth form. Goats browsing is considered the main agent of the alteration of plant community dynamics in the Caatinga, with effects ranging from plant cover reduction to the simplification of community taxonomic and functional diversity (Marinho et al., 2016; Sfair et al., 2018). Ultimately, these factors may potentially drive the socio-ecological systems of the Caatinga to their collapse.

The consequences of grazing are not limited to the damage to individual plants; domesticated herbivores can also cause community-level changes, including litter stock and species composition (Almeida et al., 2020). Litter stock plays a key role in micro-habitat formation by reducing evapotranspiration while increasing organic matter and nutrient contents, and soil water retention, all of which are fundamental factors for seed germination and seedling establishment (Mejía-Domínguez et al., 2012), particularly in semi-arid ecosystems (Bradford et al., 2015; Sobrinho et al., 2016). In addition, soil bulk density, also included in CPI, increases because of the constant trampling of herds (van der Sande et al., 2023). Overgrazing decreases macropore volume and connectivity, reducing soil water infiltration and storage (Minasny and McBratney, 2018). The edaphic stress due to lower water availability negatively affects the establishment of new individuals (Marinho et al., 2016), leading to a low-diversity community, and contributing to the number of dead adults, a variable that was positively related to CPI in this study.

The analysis of the Human Activity Index (HAI), whose metrics comprise various activities of the local human populations (Martorell and Peters, 2005), showed that the areas closest to the largest human settlements and undergoing a more intensive land use are related to an increasing number of dead individuals and a decreasing community height (HD10; Appendix B). These results suggest that the historical pressures to which plant communities have been subjected have caused a reduction in plant stature and a species composition characterized by taxa resistant to the joint action of CPI and HAI.

Throughout their evolution, humans have established complex interactions with biodiversity, which are fundamental for understanding biodiversity patterns worldwide (Ellis, 2015). In our study area, the extraction of plants from nature for fodder, fuel, construction materials, and even for veterinary purposes is common (Cunha et al., 2022; Pedrosa et al., 2022). This activity has different consequences depending on plant life history and the plant part extracted (Ticktin, 2004). For example, the removal of trees for timber generally selects bigger individuals and implies their total or partial cutting, interfering with ecological processes at different levels. This suggests the occurrence of short-term changes in the vertical and horizontal structural patterns in the community, with more individuals concentrating in the smallest size classes, a reduction in species richness, and an increase in plant mortality in the most impacted areas. These effects potentially impact both the adult and regenerating strata, since moving through the forest to access adult plants damages young ones, affecting their growth and survival (Schulz et al., 2016). A number of other negative processes may take place later, including the reduction in plant reproductive potential and the concomitant limitation in seed availability (Chaturvedi et al., 2017; Driscoll and Freudenberger, 2000; Luna-Nieves et al., 2019). In addition to alterations in soil cover, changes in carbon stocks and the physical and chemical composition of soil may occur due to the burning of plant remains (leaves and small branches left after wood removal), a common practice in human-modified landscapes (Fraga and Salcedo, 2004; Schulz et al., 2016; Specht et al., 2015). All these processes directly affect both adult vegetation dynamics and the regeneration process (Burgos and Maass, 2004).

4.2. The synergism between climate and anthropic disturbances on community assembly

Precipitation is an effective environmental filter with positive effects on species diversity in both the adult and the regenerating strata (Fig. 5), and on vegetation development (mean community height and diameter). Our results show that sites with low precipitation and higher temperature represent more stressful scenarios, with particularly strong effects on tree death (as indicated by the proportion of dead standing individuals). Admittedly, the high number of dead trees recorded in our study may also be the outcome of the prolonged drought that affected the region between 2011 and 2017. Extreme droughts have been shown to have profound effects on the structure and composition of semi-arid ecosystems (Allen et al., 2010; Chaturvedi et al., 2017; Powers et al., 2020; Pérez-Navarro et al., 2021). Moreover, the combination of a low water regime, high temperatures, and strong chronic anthropogenic disturbances induces physiological stress in plants through changes in the soil, vegetation cover and microclimate, especially in drought-sensitive species. This is the case of plants with shallow root systems (Anderegg et al., 2019; Suresh et al., 2010), exemplified in the Cariri Velhas by *Croton blanchetianus* and *Mimosa ophthalmocentra*, the two species that concentrated the largest numbers of dead individuals and possess this morphological characteristic.

The hydrological regime is largely responsible for regulating the growth and the spatial distribution of plant species, as well as for determining species richness in different ecosystems (Pinheiro et al., 2017; Silva and Souza, 2018). Most climatic projections forecast for the Caatinga increased temperatures and intense droughts in the coming decades (IPCC, 2014); these climatic scenarios will likely bring about community structure modifications and altered species distributions, mainly through increased tree mortality due to a higher frequency and duration of extreme droughts (Suresh et al., 2010; Powers et al., 2020). Our results point to the overarching role of MAP and MAT in driving the different responses of plant communities to CAD (Appendix B).

We provide evidence of a broad separation between two distinctly different environments according to floristic composition, associated with differences in the precipitation regime, both for the adult and the regenerating strata (Fig. 5). The most humid areas sustained higher species richness, as well as many species typical of more humid environments within the Caatinga (Ramos et al., 2020). In tropical regions, the distribution of plant species is associated with climatic gradients (Boucher-Lalonde et al., 2013; Currie et al., 2004); while water stress-intolerant species occur preferably in wetter areas and hence display more restricted ranges, species more tolerant to extreme conditions are more widely distributed along these climatic gradients (Esquivel-Muelbert et al., 2017).

Despite the preeminent role of climatic variables as drivers of species distributions in arid and semiarid ecosystems (Currie et al., 2004; Moro et al., 2015), CAD can also act as an environmental filter by selecting species with certain functional characteristics in response to disturbances. For example, increased livestock pressure affects community diversity because it favors species with physical defenses and secondary compounds that deter herbivory (Olff and Ritchie, 1998) and higher resistance to hydric stress. Similarly, human pressure (selective logging, for example) favors species of low wood density and small stature, as these are not highly valued wood sources (Pedrosa et al., 2022). In our study, *Cenostigma pyramidale, Aspidosperma pyrifolium, Croton blanchetianus, Jatropha mollissima, Mimosa ophthalmocentra, Tacinga palmadora* and *Croton heliotropiifolius* accounted for 74.5% of total abundance in the adult stratum, and for 83.2% in the regenerating stratum. Interestingly, all these species are successful resprouters, an important ecological strategy in the recovery of disturbed SDTF (Kennard et al., 2002; Vieira and Scariot, 2006).

Our results show that areas with low rainfall and severe anthropogenic disturbance are associated with lower species richness and greater dominance, a likely result of uneven competitive and colonizing abilities of species under such unfavorable conditions, confirming the negative synergy between disturbance, low rainfall, and low productivity (Gibb et al., 2015; Rito et al., 2017a). Among those species exerting a strong dominance in these stressing environments are *Croton heliotropiifolius* and *C. blanchetianus*, both of which are amply distributed along the studied gradients. These rather shrubby species seldom attain tree stature and thus have small diameters; their high resprouting ability after selective logging or herbivore pressure contributes to cross-site diameter homogeneity.

In the most anthropized areas, *Aspidosperma pyrifolium* dominates the regenerating stratum. Several characteristics seem to confer adaptive advantages to this species, making it very drought-resistant and ensuring its persistence in these stressful environments: high lignin and phenolic compound leaf contents (Almeida et al., 2005), which makes it unpalatable to domestic herbivores, a robust root system, and thick epicuticular wax on its leaves (Medeiros et al., 2017). Also, this species exhibits some degree of dwarfism when impacted, a phenomenon commonly observed in plants from arid ecosystems (Díaz et al., 2007; Ren et al., 2017).

The low environmental heterogeneity resulting from disturbances leads to biotic homogenization, affecting diversity by filtering the most sensitive species to environmental changes (Rito et al., 2017b; Ramos et al., 2020). Our results for the adult stratum showed that

Anadenanthera colubrina, *Bauhinia cheilantha*, *Cochlospermum vitifolium*, *Commiphora leptophloeos*, *Myracrodruon urundeuva*, *Pseudobombax marginatum* and *Schinopsis brasiliensis* are restricted to the most humid and less impacted environments. By contrast, populations of disturbance-tolerant species, such as *Aspidosperma pyrifolium*, *Cenostigma pyramidale*, *Croton blanchetianus*, *C. heliotropiifolius*, and *Jatropha mollissima* are more successful. In addition to being generalists in disturbed environments of the Caatinga, these species benefit from the edaphic conditions prevailing in them, such as high base saturation (Tabarelli et al., 2012; Ramos et al., 2020).

Our results also provide evidence for novel changes in community composition patterns. For example, *Croton blanchetianu*s is a common Caatinga species with high densities reported in numerous studies, especially in impacted areas. To our surprise, we found that this species is also noticeable for a large number of dead individuals in the study sites, suggesting a potential deviation from the compositional pattern repeatedly reported for the Caatinga (Andrade et al., 2005; Araujo et al., 2010; Barbosa et al., 2007; Cabral et al., 2013; Ribeiro et al., 2015; Rodal et al., 2008), and opens the floor to speculations as to which species will occupy this prominent place in the future. Based on our results, we point to *Cenostigma pyramidale* and *Aspidosperma pyrifolium* as potential future dominants in these Caatinga communities, provided the persistence of current trends in future decades.

Finally, drier and more impacted areas frequently host communities characterized by lower densities of individuals. For the Cariri Velhas, it is worth noting that three species alone accounted for over 50% of all individuals in the regenerating stratum, which delineates a worrisome scenario regarding this ecosystem's resilience (Poorter et al., 2021). These areas have lower primary productivity, lower plant species diversity, and a larger proportion of exposed soil (Tomasella et al., 2018). The increased soil exposure in areas with reduced vegetation cover renders these environments more susceptible to severe erosion and may be indicative of incipient desertification (Marinho et al., 2016).

5. Conclusions

This study offers new insights into key aspects of community assembly along climatic gradients in plant communities of a tropical semi-arid region affected by a diverse array of chronic anthropogenic disturbances. Communities in areas receiving little rain and subjected to high chronic anthropogenic disturbance emerge as the most vulnerable ones. This situation is mainly due to grazing by domesticated herbivores, whose effects range from reduced vegetation cover and litter stock, to increased soil compaction, ultimately altering the course of natural regeneration and affecting ecosystem resilience. Only species tolerant to large herbivore grazing and human pressure are likely to persist in this environment in the future, potentially leading to the creation of communities with homogeneous species composition in both their adult and regenerating strata, with a concomitant reduction in regional diversity.

Considering that climate change projections forecast reduced rainfall regimes in semiarid regions, future research should focus on areas with low precipitation and high levels of anthropogenic disturbance as research models of climate change scenarios. The combination of low vegetation cover, low rainfall, and high anthropogenic disturbance makes these environments prone to desertification, and therefore restoration and rehabilitation efforts in these regions are urgently needed.

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Table 1. Statistical summary of per-plot attributes of the adult and regenerating communities in 21 Caatinga sites distributed along environmental and human disturbance gradients in the semi-arid region of Brazil. ${}^{0}D$, ${}^{1}D$ and ${}^{2}D$ are Hill numbers of order $q = 0$, 1, and 2, respectively, representing diversity measures (effective number of species). NM, not measured

Community variables	**Adult stratum**		**Regenerating stratum**	
	Mean (± SD)	Range	Mean (± SD)	Range
Abundance (ind./plot)	214.3 ± 68.7	89–332	78.5 ± 56.1	10–264
Dead individuals (ind./plot)	61.2 ± 51.9	3–226	NM	NM
Mean height (m[a] or cm[b])	3.5 ± 1.3	1.8–7.0	51.6 ± 8.6	37.9–72.3
TOP 10% height (m[a] or cm[b])	6.7 ± 2.6	3.0–12.7	89.2 ± 7.2	7 5–98.7
Diameter at ground level (cm)	9.0 ± 1.9	6.8–15.4	1.3 ± 0.4	0.7–1.9
Basal area (m^2)	105.0 ± 54.7	0.42–3.2	1.7 ± 0.8	54.0–309.4
${}^{0}D$	14.64 ± 6.6	5–35	9.0 ± 4.2	3.0–18.6
${}^{1}D$	6.9 ± 2.4	3.1–12.0	5.2 ± 2.3	1.9–11.4
${}^{2}D$	5.0 ± 1.5	2.3–7.6	3.9 ± 1.6	1.37–8.4
Family richness	7.2 ± 2.5	4–13	5.2 ± 2.6	1–33
Evenness factor	0.4 ± 0.1	0.20–0.6	0.5 ± 0.2	0.1–0.8

[a] for the adult stratum; [b] for the regenerating stratum.

Table 2. Relationships between the scores in the first two NMDS axes (NMDS1 and NMDS2) and predictor variables. R^2 = linear regression fit. Environmental factors: MAP, mean annual precipitation; MAT, mean annual temperature; MAE, mean annual evapotranspiration; AI, aridity index; LS, litter stock. Human factors: HAI, human activity index; CPI, Cattle Pressure Index. Significant *P*-values are highlighted in bold typeface.

Predictor variables	Adult stratum				Regenerating stratum			
	NMDS1	NMDS2	R^2	*P*	NMDS1	NMDS2	R^2	*P*
Environmental predictor variables								
MAP	0.507	0.862	0.018	0.841	0.500	0.866	0.131	0.282
MAT	0.972	0.237	0.263	0.069	0.936	0.353	0.130	0.276
MAE	-0.980	0.199	0.111	0.364	0.554	0.833	0.084	0.454
AI	0.976	0.216	0.254	0.077	0.466	0.885	0.117	0.336
LS	—	—	—	—	0.579	0.815	0.550	**0.003**
Chronic anthropogenic disturbance variables								
CPI	-0.686	-0.727	0.303	**0.049**	-0.912	0.409	0.545	**0.001**
HAI	-0.834	-0.550	0.110	0.349	-0.518	0.855	0.114	0.325

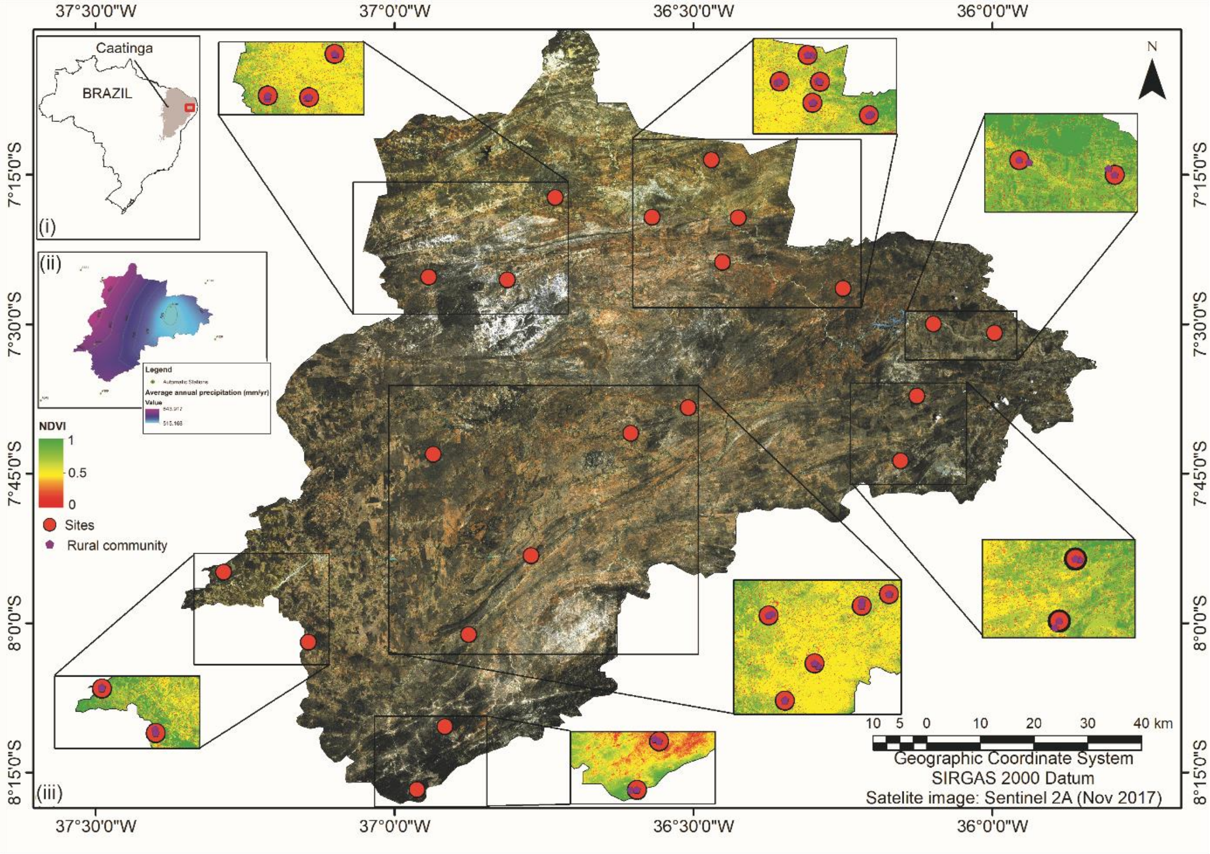

Fig. 1. Map of the Cariri Velhas region, Paraíba state, northeastern Brazil. i. location of the study region in the Caatinga realm. ii. regional distribution of the average annual precipitation. iii: detailed map of the study region; the red circles show the locations of the 21 study sites; insets next to them show the distribution of NDVI used to assess vegetation development in their vicinity, and the presence of rural communities within their buffers.

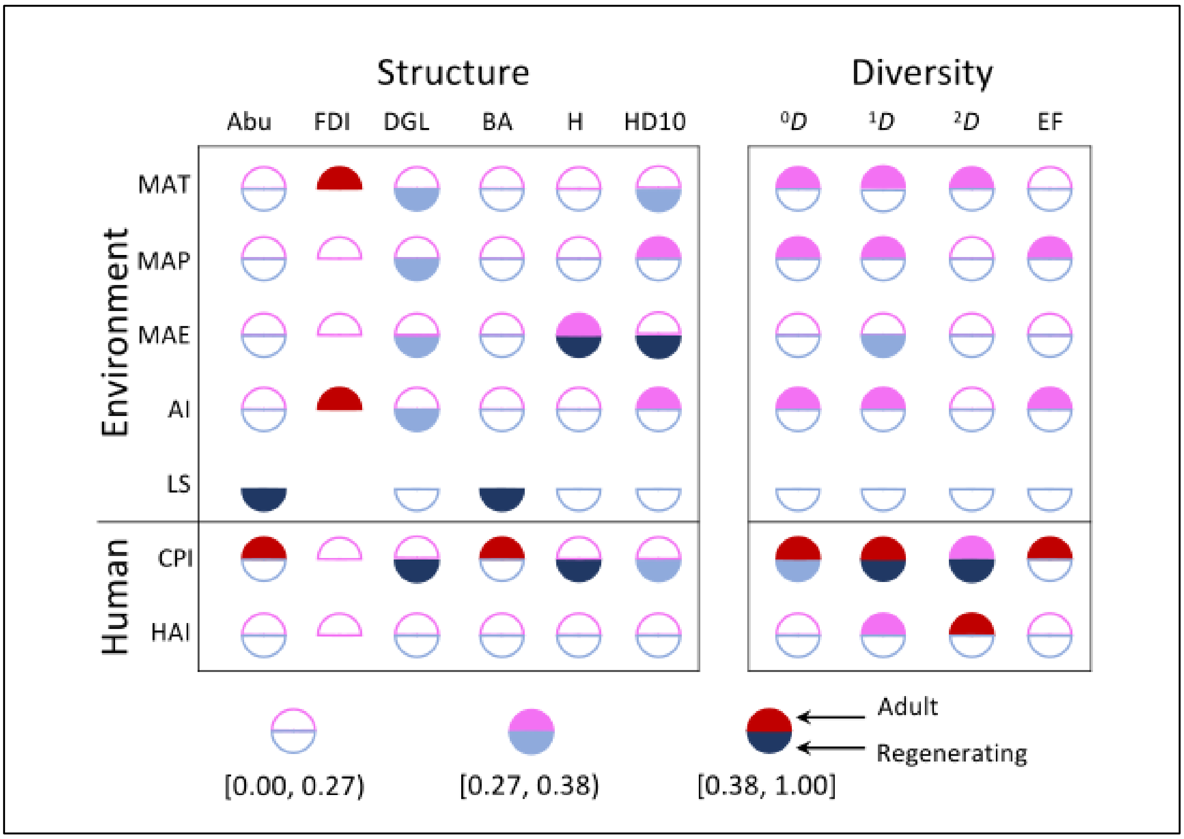

Fig. 2. Graphic representation of the assessment of factor (predictive variable) importance in the generalized linear models constructed to analyze their role in explaining the variation of response variables for the adult and the regenerating strata in Caatinga forest of NE Brazil along climatic and disturbance gradients. Environmental predictive variables: MAT, mean annual temperature; MAP, mean annual precipitation; MAE, mean annual evapotranspiration; AI, aridity index; LS, litter stock; human disturbance variables: CPI, Cattle Pressure Index; HAI, human activity index. Community structure response variables: Abu, abundance; FDI, fraction of death individuals; DGL, diameter at ground level; BA, basal area; H, mean tree heigh; HD10, mean height of the tallest (uppermost decile) trees; community diversity response variables: ^0D, ^1D, ^2D, true diversity (Hill numbers) of orders q = 0, 1, and 2; EF, evenness factor). The upper halves of the circles correspond to the adult stratum (shades of red) and the lower halves to the regenerating stratum (shades of blue). Increasing color intensity reflects increasing importance, according to thresholds defined in Burnham and Anderson (2002). Empty circles: [0.00, 0.27); light colored circles: [0.27, 0.38); dark-colored circles: [0.38, 1.00]. Only dark colors represent truly important variables.

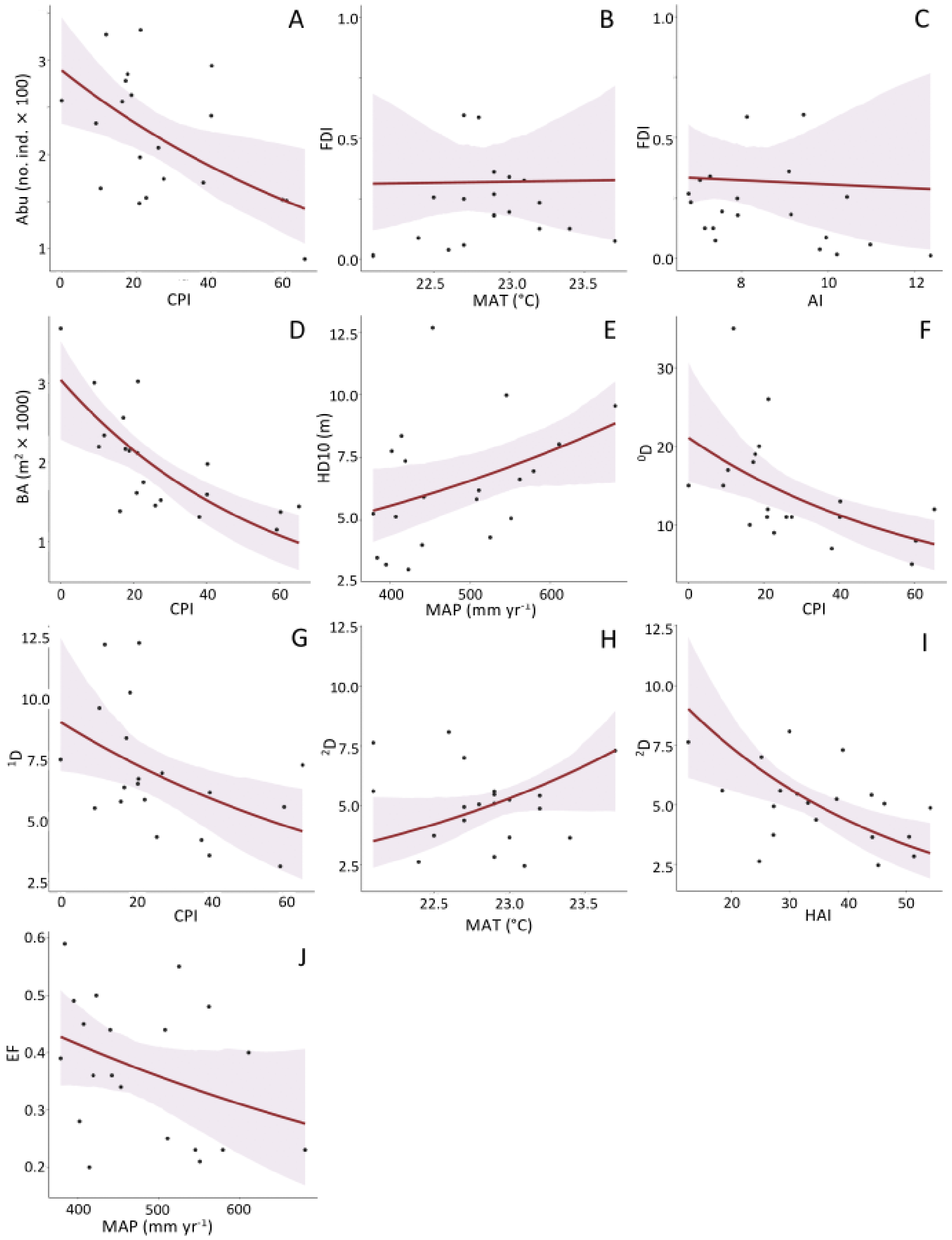

Fig. 3. Model predictions from the best-supported generalized linear models explaining the variation of community structural and diversity response variables as a function of environmental and human disturbance variables for the adult stratum in the Caatinga forest, NE Brazil. Solid red lines represent model predictions and red shading represents the 95% confidence envelope. Black dots represent the data used in fitting the models. Response variables: Abu, stem abundance in the plot (A); FDI, fraction of standing dead trees (B, C); BA,

basal area (D); HD10, mean height of the tallest (uppermost decile) trees in the community (E); 0D, 1D and 2D, true diversity measure through Hill numbers of orders q = 0, 1 and 2, respectively (F-I); EF, evenness factor (J). Environmental predictive variables: AI, aridity index; MAP, mean annual precipitation; MAT, mean annual temperature. Human disturbance predictor variables: HAI, human activity index; CPI Cattle Pressure Index. Response variables examined in the study for which no model is shown were best fit by the null model (no factor effect). Note that for some response variables the best-supported model included more than one predictive variable, in which case one graph is shown for each variable separately.

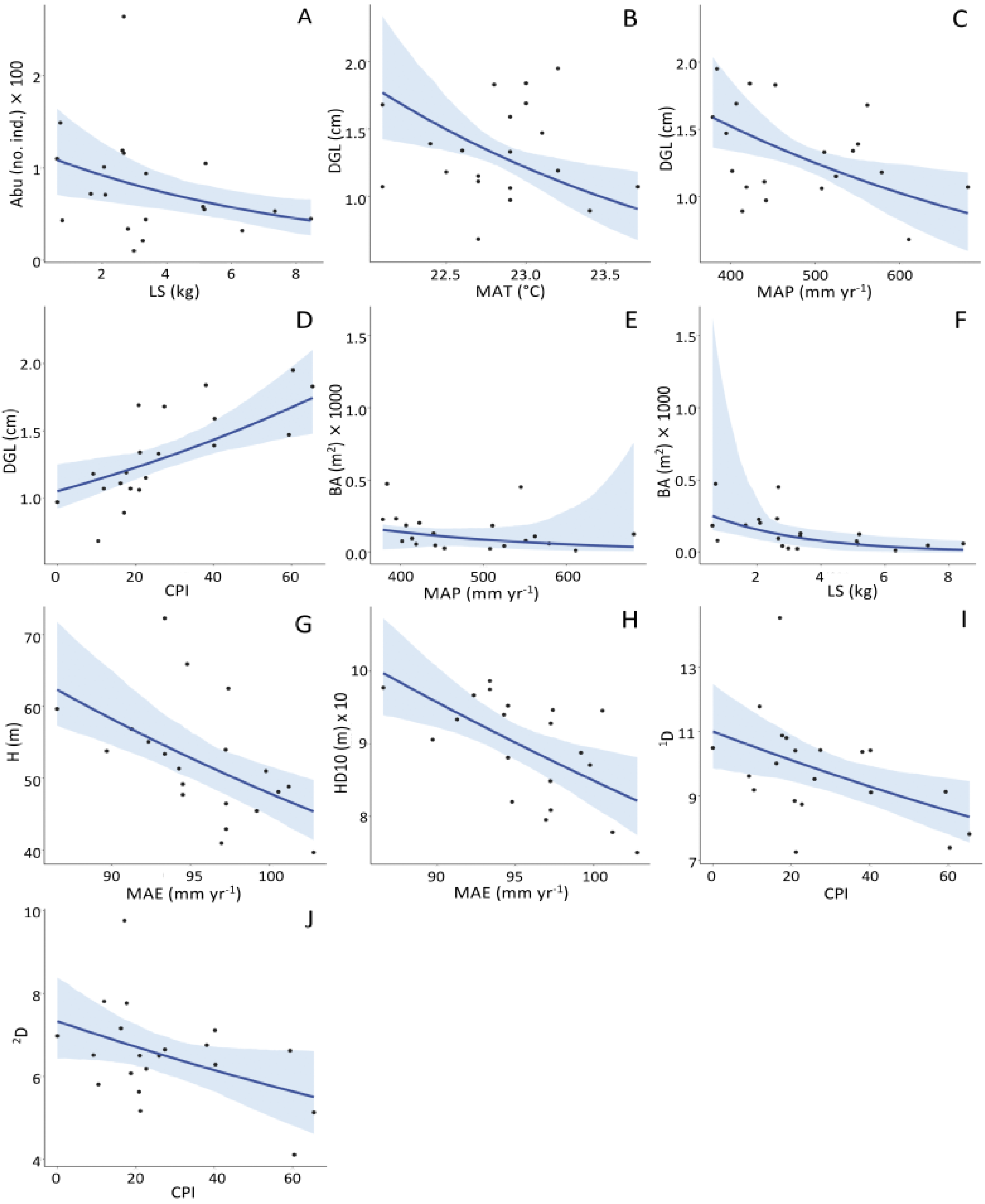

Fig. 4. Model predictions from the best-supported generalized linear models explaining the variation of community structural and diversity response variables as a function of environmental and human disturbance variables for the regenerating stratum in the Caatinga forest, NE Brazil. Solid blue lines represent model predictions for each response variable and

blue shading represents the 95% confidence envelope. Black dots represent the data used for fitting the models. Response variables: Abu, stem abundance in the plot (A); DGL, mean diameter at ground level (B-D); BA, basal area (E, F); H, mean plant height in this stratum (G); HD10, mean height of the tallest (uppermost decile) trees in this stratum (H); ^{1}D and ^{2}D, true diversity measure through Hill numbers of orders q = 1 and 2, respectively (I, J). Environmental predictive variables: LS, litter stock; MAE, mean annual evapotranspiration; MAP, mean annual precipitation; MAT, mean annual temperature. Human disturbance predictor variable: CPI Cattle Pressure Index. Response variables examined in the study for which no model is shown were best fit by the null model (no factor effect). Note that for some response variables the best-supported model included more than one predictive variable, in which case one graph is shown for each variable separately.

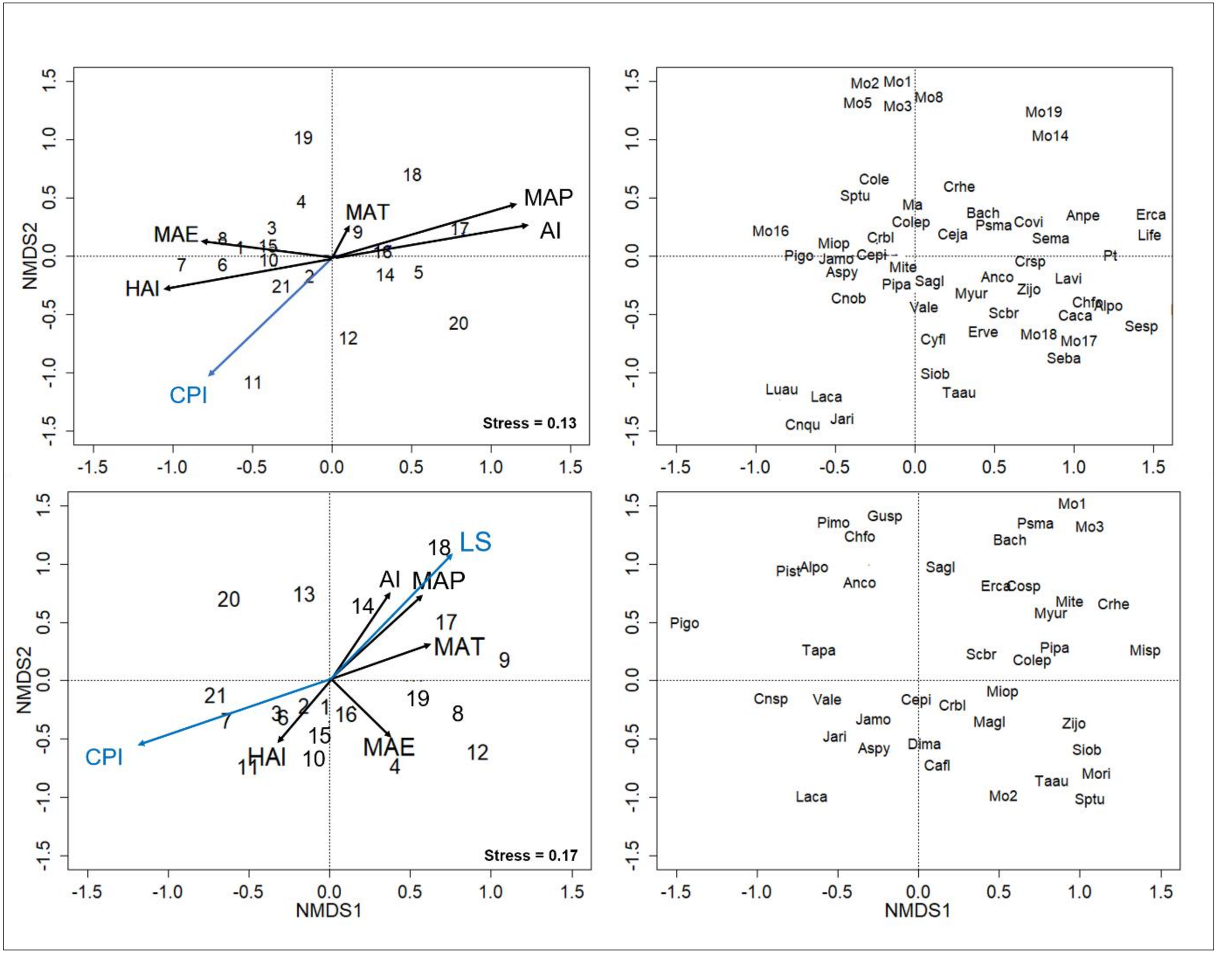

Fig. 5. Non-metric multi-dimensional scaling (NMDS) ordination to analyze the variation of species composition in Caatinga sites across the Cariri Velhas region. Shown are the first two NMDS axes based on species composition for the adult (upper panels) and the regenerating (lower panels) strata, with predictor variable vectors and sites (left panels), and species (right panels) shown on the ordination space. Environmental predictive variables: LS, litter stock; MAE, mean annual evapotranspiration; MAP, mean annual precipitation; MAT, mean annual temperature. Human disturbance predictor variable: CPI, Cattle Pressure Index. Significant predictors ($P < 0.05$) are shown as blue vectors. Species abbrevations: Anpe, *Anadenanthera peregrina*; Alpo, *Albizia polycephala*; Anco, *Anadenanthera colubrina*; Aspy, *Aspidosperma pyrifolium*; Bach, *Bauhinia cheilantha*; Caca, *Capiscum caatingae*; Cegl, *Ceiba glaziovii*; Cepi, *Cenostigma pyramidale*; Ceja, *Cereus jamacaru*; Chfo, *Chloroleucon foliolosum*; Cnob, *Cnidoscolus obtusifolius*; Cnqu, *Cnidoscolus quercifolius*; Covi, *Cochlospermum vitifolium*; Cole, *Combretum leprosum*; Colep, *Commiphora leptophloeos*; Crsp, *Crombretum* sp.; Crbl, *Croton blanchetianus*; Crhe, *Croton heliotropiifolius*; Crsp, *Croton* sp.; Cyfl, *Cynophalla flexuosa*; Erve, *Erythrina velutina*; Erca, *Erythroxylum caatingae*; Gula, *Guapira laxa*; Gusp,

Guappira sp.; Jamo, *Jatropha mollissima*; Jari, *Jatropha ribifolia*; Lavi, *Lachesiodendron viridiflorum*; Laca, *Lantana camara*; Life, *Libidibia ferrea*; Luau, *Lutzemburgia auriculata*; Maca, *Manihot carthagenensis*; Miop, *Mimosa ophthalmocentra*; Misp, *Mimosa* sp. 2; Mite, *Mimosa tenuiflora*; Mori, *Monteverdia rigida*; Myur, *Myracrodruon urundeuva*; Pigo, *Pilosocereus gounellei*; Pipa, *Pilosocereus pachycladus*; Pist, *Piptadenia stipulacea*; Pimo, *Pityrocarpa moniliformis*; Psma, *Pseudobombax marginatum*; Pssp, *Psidium* sp.; Ptnu, *Ptilochaeta nudipes*; Sagl, *Sapium glandulosum*; Scbr, *Schinopsis brasiliensis*; Sema, *Sebastiana macrocarpa*, Seba, *Senegalia bahiensis*; Sesp, *Senegalia* sp.; Sesp, *Senna spectabilis*; Siob, *Sideroxylon obtusifolium*; Sptu, *Spondias tuberosa*; Taau, *Tabebuia aurea*; Tapa, *Tacinga palmadora*; Vale, *Varronia leucocephala*; Zijo, *Ziziphus joazeiro*; Mo1 to M19, unidentified morphospecies (see Appendix C for full species names and authorities).

Appendix A. Statistical descriptors of predictor variables analyzed in this study. MAP, mean total annual precipitation; MAT, mean annual temperature; LS, litter stock; CATTLE, cattle droppings biomass; EQUINE, horse and donkey droppings biomass; GOAT, goat and sheep droppings biomass; COMP, soil compaction; PH, proximity to rural property; PUC, proximity to urban center; HD housing density; LUSE, land use; TRAN, trail density. See text for a detailed description of these variables.

Predictor variable	**Mean (SD)**	**Min**	**Max**
Environmental indicators			
MAP	491.48 (95.29)	379.0	690.0
MAT	22.94 (0.61)	22.1	25.0
LS	3.54 (2.15)	0.61	8.45
Cattle pressure indicators			
CATTLE	2514.33 (5287.76)	0.00	22896.00
EQUINE	643.24 (1348.63)	0.00	4873.00
GOAT	752.33 (1173.18)	0.00	3343.00
COMP	1.56 (0.14)	1.16	1.81
Human activity indicators			
PH	519.90 (385.04)	1.00	1552.00
PUC	51.22 (197.95)	3.10	915.00
HD	2.93 (2.83)	0.40	13.30
LUSE	4.38 (2.16)	1.00	9.00
TRAN	1.07 (1.14)	0.00	3.52

Appendix B. Best supported models (i.e., ΔAICc ≤ 2) constructed to assess the effects of environmental and human factors on community attributes of the adult and regenerating strata in the Caatinga forest, NE Brazil. Environmental factors: MAP, mean annual precipitation; MAT, mean annual temperature; MAE, mean annual evapotranspiration; AI, aridity index; LS, litter stock. Human factors: HAI, human activity index; CPI, Cattle Pressure Index. Response variables: Abu, abundance (no. of individuals) per site; FDI, fraction of standing death individuals (adult stratum only); DGL, diameter at ground level; BA, basal area; H, mean height for all trees recorded at the site; HD10, mean height of the tallest trees (uppermost decile) at the site; ^0D, ^1D, and ^2D, community true diversity measures (Hill numbers) for $q = 0$, $q = 1$, and $q = 2$, respectively; EF, evenness factor, calculated as $^2D/^0D$. The total number of models fitted for each response variable is shown on the second column. The label 'Null' indicates that the best supported model did not include any explanatory variable, thus it was the null model.

Response variable	**Total no. of models**	**Model**	**ΔAICc**
Adult stratum			
Abu	48	5.37 – 0.19·CPI	0
FDI	49	-0.76 + 0.02·MAT – 0.06·AI + 0.98·MAT·AI	0
DGL	48	2.17 (Null)	0
BA	46	9.85 – 0.31·CPI	0
H	47	1.20 (Null)	0
		1.19 + 0.09·MAP	0.962
		1.19 – 0.09·MAE	0.974
		1.19 + 0.09·AI	1.027
		1.19 – 0.09·CPI	1.352
		1.20 – 0.08·HAI	1.410
HD10	44	1.85 + 0.14·MAP	0
		1.85 + 0.14·AI	0.072
		1.86 (Null)	0.382
		1.86 – 0.12·MAE	0.825

^{0}D	48	2.62 – 0.28·CPI	0
		2.61 + 0.15·MAP – 0.22·CPI	0.180
		2.61 – 0.22·CPI + 0.14·AI	0.231
		2.48 + 0.21·MAT + 0.29·MAP – 0.17·MAT·MAP	0.845
		2.48 + 0.22·MAT + 0.30·AI – 0.17·MAT·AI	0.903
		2.62 – 0.21·CPI – 0.13·HAI	1.288
		2.62 – 0.27·CPI – 0.10·MAE	1.576
		2.62 + 0.26·MAT + 0.43·AI	1.774
		2.62 + 0.25·MAT + 0.42·MAP	1.905
^{1}D	45	1.91 – 0.19·CPI	0
		1.92 – 0.17·HAI	0.486
		1.90 + 0.19·MAT – 0.34·HAI	0.702
		1.92 + 0.16·MAP	0.703
		1.92 + 0.16·AI	0.815
		1.91 + 0.21·MAT + 0.33·AI	1.065
		1.91 + 0.11·MAP – 0.15·CPI	1.142
		1.91 + 0.20·MAT + 0.31·MAP	1.172
		1.91 – 0.14·CPI – 0.12·HAI	1.185
		1.91 – 0.15·CPI + 0.11·AI	1.188
		1.91 – 0.19·CPI – 0.09·MAE	1.660
		1.82 + 0.20·MAT + 0.25·AI – 0.10·MAT·AI	1.963
		1.83 + 0.19·MAT + 0.24·MAP – 0.10·MAT·MAP	1.982
^{2}D	47	1.59 + 0.18·MAT – 0.30·HAI	0
		1.61 – 0.14·HAI	0.592
		1.61 – 0.14·CPI	1.750
EF	48	-1.00 – 0.12·MAP	0
		-1.00 + 0.11·CPI	0.018
		-1.00 – 0.12·AI	0.089
		-0.99 (Null)	0.092

		-1.00 – 0.09·MAP + 0.08·CPI	1.631
		-1.00 + 0.08·CPI – 0.09·AI	1.673
		-1.00 – 0.13·MAT – 0.23·AI	1.874
		-1.00 – 0.13·MAT – 0.22·MAP	1.881
		-0.99 + 0.07·HAI	1.966
		-0.99 + 0.07·MAE	1.971
Regenerating stratum			
Abu	75	4.35 – 0.26·LS	0
		4.38 (Null)	0.069
DGL	74	0.26 – 0.17·MAT – 0.17·MAP + 0.14·CPI	0
		0.26 – 0.17·MAT + 0.14·CPI – 0.17·AI	0.050
		0.27 + 0.18·CPI	0.164
		0.26 – 0.11·MAP + 0.16·CPI – 0.11·MAE	0.372
		0.26 + 0.16·CPI – 0.11·AI – 0.11·MAE	0.531
		0.26 + 0.15·CPI – 0.08·LS	1.190
		0.26 + 0.19·CPI – 0.06·MAE	1.209
		0.26 + 0.15·CPI + 0.10·HAI – 0.11·MAE	1.436
BA	75	4.58 – 0.39·MAP – 0.73·LS	0
		4.58 – 0.73·LS – 0.40·AI	0.033
		4.83 – 0.58·LS	0.061
		4.63 – 0.67·LS – 0.04·AI + 0.41·LS·AI	0.147
		4.63 – 0.04·MAP – 0.68·LS + 0.40·MAP·LS	0.182
		4.69 – 0.04·MAT – 0.65·LS – 0.52·MAT·LS	0.640
		4.71 – 0.61·LS – 0.23·MAE – 0.55·LS·MAE	1.045
		4.72 + 0.16·CPI – 0.23·MAE + 0.54·CPI·MAE	1.412
		4.79 + 0.20·HAI – 0.50·LS	1.647
		4.72 + 0.22·MAT – 0.68·LS	1.962
H	74	3.95 – 0.08·MAE	0

		3.95 + 0.05·CPI – 0.09·MAE	0.089
		3.95 + 0.05·HAI – 0.11·MAE	1.356
HD10	75	4.49 – 0.05·MAE	0
		4.49 – 0.02·CPI – 0.05·MAE	0.508
		4.49 + 0.02·LS – 0.05·MAE	1.197
		4.49 – 0.05·MAT	1.573
^{0}D	75	3.49 (Null)	0
		3.49 – 0.06·CPI	0.872
^{1}D	75	2.29 – 0.08·CPI	0
		2.28 – 0.08·CPI + 0.05·MAE	0.946
		2.29 (Null)	1.758
		2.28 + 0.04·MAT – 0.08·CPI	1.971
^{2}D	75	1.87 – 0.08·CPI	0
		1.88 (Null)	1.332
EF	75	-0.73 (Null)	0
		-0.73 + 0.08·CPI	1.804

Appendix C. List of species and families, along with number of individuals, recorded in the adult and the regenerating strata in 21 Caatinga forest sites, semiarid Cariri Velhas region, Paraiba state, Brazil.

Families/Species	**Adult stratum**	**Regenerating stratum**
Anacardiaceae		
Myracrodruon urundeuva Allemão	38	4
Schinopsis brasiliensis Engl.	25	6
Spondias tuberosa Arruda	3	0
Apocynaceae		
Aspidosperma pyrifolium Mart.	856	362
Bignoniaceae		
Tabebuia aurea (Silva Manso) Benth. & Hook.f. ex S.Moore	6	1
Bixaceae		
Cochlospermum vitifolium (Willd.) Spreng.	18	0
Boraginaceae		
Varronia leucocephala (Moric.) J.S.Mill.	6	7
Burseraceae		
Commiphora leptophloeos (Mart.) J.B.Gillett	92	34
Cactaceae		
Cereus jamacaru DC.	8	0
Pilosocereus gounellei (F.A.C.Weber) Byles & Rowley	83	11
Pilosocereus pachycladus F.Ritter	32	8
Tacinga palmadora (Britton & Rose) N.P.Taylor & Stuppy	263	384
Capparaceae		
Cynophalla flexuosa (L.) J.Presl	15	10
Celastraceae		
Maytenus rigida Mart.	1	**1**
Combretaceae		
Combretum leprosum Mart.	2	7

Families/Species	Adult stratum	Regenerating stratum
Combretum sp.	16	0
Erythroxylaceae		
Erythroxylum caatingae Plowman	5	**2**
Euphorbiaceae		
Cnidoscolus quercifolius Pohl	2	0
Cnidoscolus obtusifolius Pohl ex Baill	26	1
Croton blanchetianus Baill.	536	107
Croton heliotropiifolius Kunth	114	5
Croton sp.	1	0
Jatropha mollissima (Pohl) Baill.	373	144
Jatropha ribifolia (Pohl) Baill.	9	40
Manihot carthagenensis (Jacq.) Müll.Arg.	57	6
Sapium glandulosum (L.) Morong	23	3
Sebastiania macrocarpa Müll.Arg.	6	0
Fabaceae		
Albizia polycephala (Benth.) Killip ex Record	55	3
Anadenanthera peregrina (L.) Speg.	10	0
Anadenanthera colubrina (Vell.) Brenan	50	27
Bauhinia cheilantha (Bong.) Steud	85	22
Cenostigma pyramidale (Tul.) E.Gagnon & G.P.Lewis	1031	250
Chloroleucon foliolosum (Benth.) G.P.Lewis	18	16
Erythrina velutina Willd.	4	0
Lachesiodendron viridiflorum (Kunth) P.G.Ribeiro, L.P.Queiroz	2	0
Libidibia ferrea (Mart. ex Tul.) L.P.Queiroz	8	0
Luetzelburgia auriculata (Allemão) Ducke	2	0
Mimosa ophthalmocentra Mart. ex Benth.	293	124
Mimosa sp.	1	4

Families/Species	**Adult stratum**	**Regenerating stratum**
Mimosa tenuiflora (Willd.) Poir.	7	1
Piptadenia retusa P.G.Ribeiro, Seigler & Ebinger	76	1
Pityrocarpa moniliformis (Benth.) Luckow & R.W.Jobson	63	10
Senegalia bahiensis Benth.	8	0
Senegalia sp.	3	0
Senna spectabilis (DC.) H.S.Irwin & Barneby	2	0
Malpighiaceae		
Ptilochaeta nudipes Griseb	1	0
Malvaceae		
Ceiba glaziovii (Kuntze) K.Schum.	1	0
Pseudobombax marginatum (A.St.-Hil., Juss. & Cambess.)	23	6
Myrtaceae		
Psidium sp.	2	0
Nyctaginaceae		
Guapira laxa (Netto) Furlan	2	0
Guapira sp.	3	2
Rhamnaceae		
Ziziphus joazeiro Mart.	4	5
Sapotaceae		
Sideroxylon obtusifolium (Roem. & Schult.) T.D.Penn.	3	8
Solanaceae		
Capiscum caatingae Barboza & Agra	20	3
Verbenaceae		
Lantana camara L.	25	7
Not identified		
Morphospecies I	25	1
Morphospecies II	1	1

Families/Species	Adult stratum	Regenerating stratum
Morphospecies III	7	1
Morphospecies IV	1	0
Morphospecies V	1	0
Morphospecies VI	12	0
Morphospecies VII	1	0
Morphospecies VIII	1	0
Morphospecies VX	14	0
Morphospecies X	2	0
Morphospecies XI	1	0
Morphospecies XII	2	0
Morphospecies XIII	1	0
Morphospecies XIV	4	0
Morphospecies XV	1	0
Morphospecies XVI	3	0
Morphospecies XVII	3	0
Morphospecies XVIII	2	0
Morphospecies XIX	1	13

6. CAPÍTULO V: CONSIDERAÇÕES FINAIS

6.1 Principais conclusões

A Caatinga compreende a maior região semiárida do mundo, possui uma elevada heterogeneidade ambiental, com diversas formações geológicas, uma variedade de tipos de solo, de relevo, alta variabilidade espacial e temporal pluviométrica. Além disso, o histórico de uso por populações humanas que ocorre a milhares de anos, culminou em sistemas socioecológicos complexos e dinâmicos. Esse histórico de uso resultou em variados tipos e intensidades de distúrbios antrópicos, tornando o ambiente ainda mais complexo. Embora algumas informações já tenham sido identificadas, pouco se sabe sobre como todos esses fatores interagem, juntamente com os sistemas sociais e os danos ao ecossistema. Dessa forma, acreditamos que muitas lacunas ainda existem, e são necessários ainda muitos esforços de pesquisa. É necessário compreender os diferentes efeitos de forma combinada e isolada, bem como avaliar as particularidades de cada sub-região da Caatinga e os cenários representados em cada projeto de pesquisa. Nosso estudo foi realizado em uma área submetida a múltiplos distúrbios antrópicos crônicos e totalmente desprovida de qualquer tipo de proteção ambiental. Outro ponto importante é que nossa região de estudo possui a menor precipitação pluviométrica do semiárido brasileiro e compreende um núcleo de desertificação, fazendo com que essa porção específica da Caatinga necessite urgentemente de mais estudos.

A integração de conhecimento ecológico de populações humanas sobre a utilização de espécies vegetais, aos aspectos da ecologia de comunidades vegetais, empregada nessa tese foi fundamental para traçar novas ideias sobre os fatores que afetam o uso e a seleção de espécies de plantas por populações humanas da Caatinga. Assim, a abordagem a partir das características funcionais nos permitiu traçar um perfil funcional das espécies de planta para cada serviço ecossistêmico de interesse dos humanos que vivem nessa região.

Em geral, observamos que os agropastores apontam uma série de importantes características, positivas e negativas, que distingue as necessidades desejadas para cada serviço ecossistêmico. Por exemplo, para o uso forrageiro, os agropastores descrevem características associadas a textura, sabor, cheiro como fundamentais para uso e seleção das espécies pelos herbívoros domésticos. Nossas análises confirmaram que as características funcionais das plantas correspondem a fatores fundamentais na tomada de decisão para seleção de espécies vegetais. A densidade de madeira por exemplo, é uma característica fundamental para seleção de espécies nas categorias combustível e construção, conferindo maior resistência e durabilidade a madeira. Destacamos ainda que as relações de manejo das plantas podem ter vários impactos econômicos, sociais e ambientais. Por exemplo, a pressão de uso sobre alguns grupos de plantas pode levar a perda de espécies e funções específicas alterando a prestação de serviços ecossistêmicos. Portanto, compreender a complexidade do uso e seleção de espécies pelos agropastores têm um papel significativo na conservação da biodiversidade.

Em relação as comunidades vegetais, entendemos que as condições climáticas da Caatinga podem trazer informações substanciais e previsões para cenários futuros perante as mudanças climática. Utilizamos esses gradientes ambientais para analisar de forma isolada e interativa os efeitos das variáveis bióticas e abióticas sobre a estruturação das comunidades de plantas, e quais efeitos podem reverberar na dinâmica do sistema ecológico e social. A interdependência com a disponibilidade de água, torna os sistemas vegetais de ambientes semiáridos bastante vulneráveis as mudanças climáticas. Há grande preocupação com a resiliência destes sistemas, sobretudo aos efeitos sinergéticos com o crescimento exponencial das atividades antrópicas, visto que os estudos sobre as interações entre essas variáveis são bastante incipientes e ainda obscuros.

Nossos resultados revelam que nas áreas com menor regime hídrico, os impactos antrópicos têm um forte efeito sob a diversidade das comunidades, levando a uma baixa riqueza de espécies, em função da homogeneização biótica, e dificuldade no restabelecimento e recrutamento de indivíduos. Esse cenário pode ocasionar uma desestabilização nos sistemas socioecológicos, uma vez que as populações locais dependem de maneira direta de alguns serviços ecossistêmicos que estão sendo perdidos. Por fim, nos apêndices da presente tese apresentamos o registro de ocorrência de uma espécie endêmica do semiárido brasileiro, cuja ocorrência era desconhecida para o estado da Paraíba, esse achado reforça a ideia de que muitas lacunas ainda existem, e são necessários grandes esforços de pesquisa para conhecermos e compreendermos a biodiversidade da Caatinga.

6.2 Contribuições teóricas e /ou metodológicas da tese

As evidências encontradas neste estudo apresentam contribuições metodológicas para estudos em Ecologia vegetal e Etnobiologia, sobretudo para ambientes áridos e semiáridos. Do ponto de vista teórico, fornecemos novas informações sobre as interações entre seres humanos e os vegetais, e seus respectivos efeitos para a montagem de comunidades vegetais. Acreditamos que o conhecimento ecológico local é uma ferramenta essencial para tomada de decisões que buscam alcançar a sustentabilidade de um sistema. A integração entre o conhecimento ecológico local e a ecologia de comunidades vegetais nos permitiu traçar um perfil funcional das espécies de plantas utilizadas e dessa forma, identificar as características funcionais mais desejadas, e aquelas que são indesejadas pelos agropastores da região. Demonstramos ainda, os estratos adultos e regenerantes de comunidades vegetais da Caatinga, elucidando os aspectos da estrutura, composição e diversidade de espécies, frente a distintos distúrbios antrópicos crônicos e condições climáticas em uma área de Caatinga desprovida de qualquer tipo de proteção ambiental. Esse contexto revelou resultados críticos para os processos de resiliência e manutenção dos serviços ecossistêmicos desse ambiente.

Com relação as contribuições metodológicas, apresentamos aqui uma estrutura interdisciplinar que nos permitiu analisar as relações entre atividades humanas, serviços ecossistêmicos, características funcionais e as prioridades dos agropastores envolvidos. Do ponto de vista do entendimento da montagem de comunidades vegetais, mensuramos variáveis climáticas, um conjunto variado de métricas de distúrbios antrópicos, e associamos ao acúmulo de serrapilheira para compreender a estrutura, e diversidade de espécies das comunidades vegetais.

6.3 Principais limitações do estudo

Com a pandemia do COVID-19 e consequentemente interrupções das expedições a campo, houve atraso no desenvolvimento de algumas partes da pesquisa, como o levantamento dos dados etnobotânicos. Dentro desse contexto, não foi possível a inclusão do número de comunidades locais propostas inicialmente, bem como o retorno a campo para coleta de material vegetal para mensuração de traços funcionais e informações etnobotânicas relacionadas as características funcionais das espécies. Tais problemáticas interferiram diretamente na finalização dos trabalhos elaborados. Além disso, enfrentamos algumas dificuldades para coletar e depositar material botânico no herbário. Embora com a chegada das vacinas houvesse uma diminuição das taxas de transmissão do vírus, existia uma certa resistência das pessoas em participarem das pesquisas. Dentro desse contexto, a pesquisa teve que ser redirecionada, o número de comunidades rurais foi reduzido e a inserção de características funcionais foi compactada.

6.4 Propostas de investigações futuras

Os produtos apresentados na tese sugerem a necessidade de mais trabalhos que investiguem de maneira mais detalhada os efeitos dos distúrbios antrópicos crônicos, especialmente devido a heterogeneidade ambiental da Caatinga. Acreditamos que os efeitos dos distúrbios responderam de maneiras distintas de acordo com a interação com outras variáveis.

Através das investigações etnobotânicas apontamos a necessidade de mais estudos que integrem conhecimento ecológico local a outros campos da Ciência, especialmente a ecologia, conservação e gestão de recursos. Além disso, no decorrer do desenvolvimento desta tese, diversos questionamentos surgiram e podem ser possíveis propostas para investigações futuras. Destacamos a necessidade de compreender a influência dos gradientes climáticos na seleção de espécies, bem como, entender de que maneira os critérios de seleção de espécies foram moldados ao longo do tempo. Dessa forma, entenderemos quais as espécies e ou serviços são prioritários no cenário atual.

6.5 Orçamento

O presente trabalho foi realizado com apoio do Conselho Nacional de Desenvolvimento Científico e Tecnológico CNPq) (nº 42 490/2018-6) e Pró-Reitoria de Pós-Graduação e Pesquisa -UEPB (2.05.03.00-8-375 / 2017-1). Além disso, a Agência de fomento Fundação de Apoio à Pesquisa do Estado da Paraíba (FAPESq) forneceu bolsa de estudos a Maiara Bezerra Ramos. A Universidade Estadual da Paraíba também ofereceu apoio através da liberação de transporte para as expedições à campo. As despesas para as coletas dos dados incluem: material de campo, incluindo material permanente e material de consumo, alimentação e hospedagens. Com esse investimento foram realizadas: reconhecimento e marcação das áreas de interesse, levantamento florístico e fitossociológico das comunidades vegetais, coleta de variáveis ambientais, mensuração de métricas de distúrbios antrópicos crônicos, coleta de material botânico, 120 entrevistas com agropastores, moradores da região do Cariri, no estado da Paraíba, Brasil.

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ANEXOS

ANEXO I

CENTRO DE ENSINO
SUPERIOR E
DESENVOLVIMENTO

COMPROVANTE DE ENVIO DO PROJETO

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: EFEITO DOS IMPACTOS ANTRÓPICOS NA MONTAGEM DE COMUNIDADES VEGETAIS NO ECOSSISTEMA DA CAATINGA

Pesquisador: Maiara Bezerra Ramos

Versão: 2

CAAE: 07564918.2.0000.5175

Instituição Proponente: Universidade Estadual da Paraíba - UEPB

DADOS DO COMPROVANTE

Número do Comprovante: 010713/2019

Patrocionador Principal: Universidade Estadual da Paraíba - UEPB

Informamos que o projeto EFEITO DOS IMPACTOS ANTRÓPICOS NA MONTAGEM DE COMUNIDADES VEGETAIS NO ECOSSISTEMA DA CAATINGA que tem como pesquisador responsável Maiara Bezerra Ramos, foi recebido para análise ética no CEP Centro de Ensino Superior e Desenvolvimento-CESED/PB em 11/02/2019 às 16:56.

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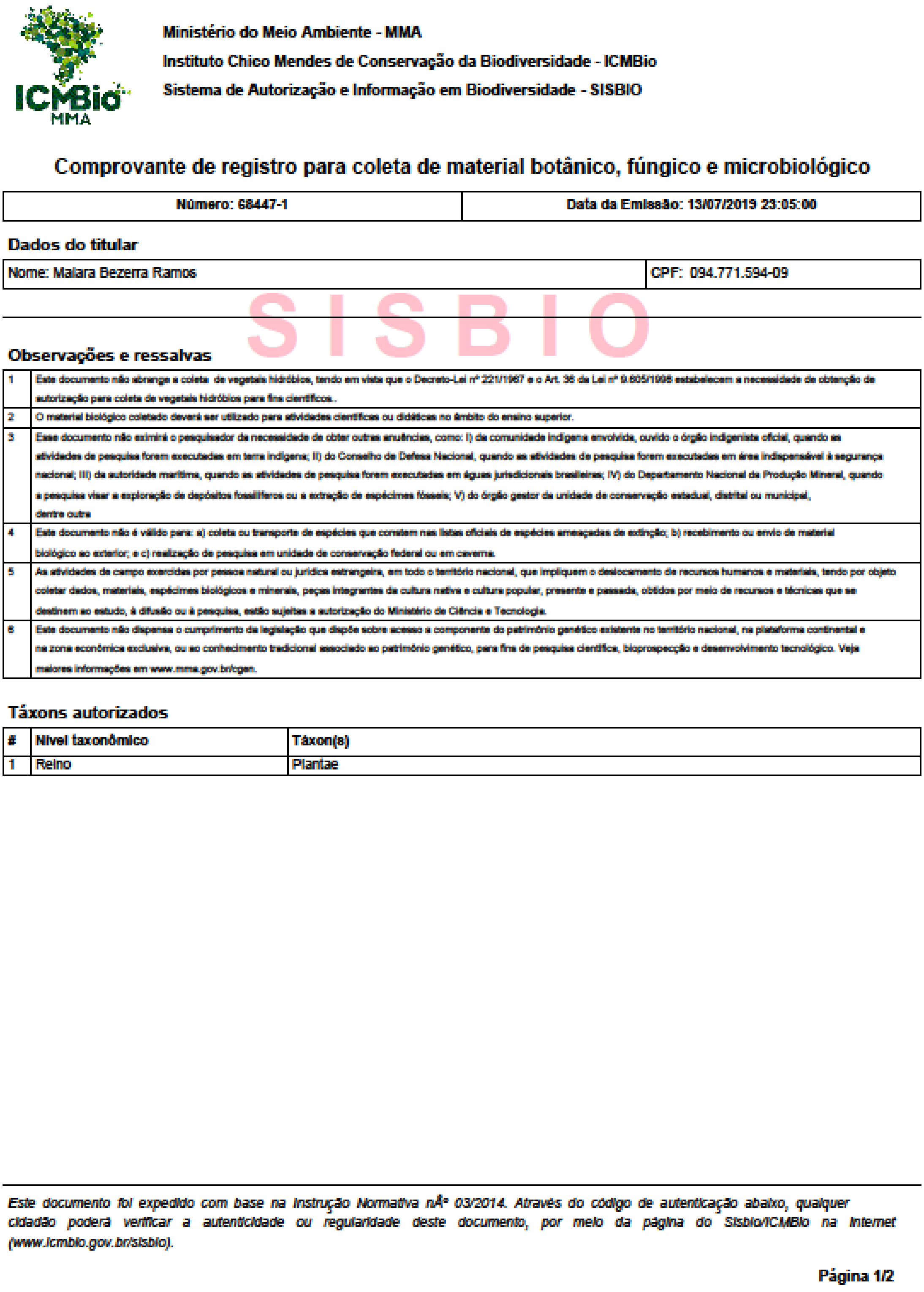
ANEXO II



Ministério do Meio Ambiente - MMA
Instituto Chico Mendes de Conservação da Biodiversidade - ICMBio
Sistema de Autorização e Informação em Biodiversidade - SISBIO

Comprovante de registro para coleta de material botânico, fúngico e microbiológico

Número: 68447-1	**Data da Emissão: 13/07/2019 23:05:00**

Dados do titular

Nome: Maiara Bezerra Ramos	CPF: 094.771.594-09

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#	Nível taxonômico	Táxon(s)
1	Reino	Plantae

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Página 1/2

APÊNDICES

APÊNDICE A: Registro de nova ocorrência de espécie da Familia Euphorbiaceae

(Manuscrito publicado no periódico Acta brasiliensis)

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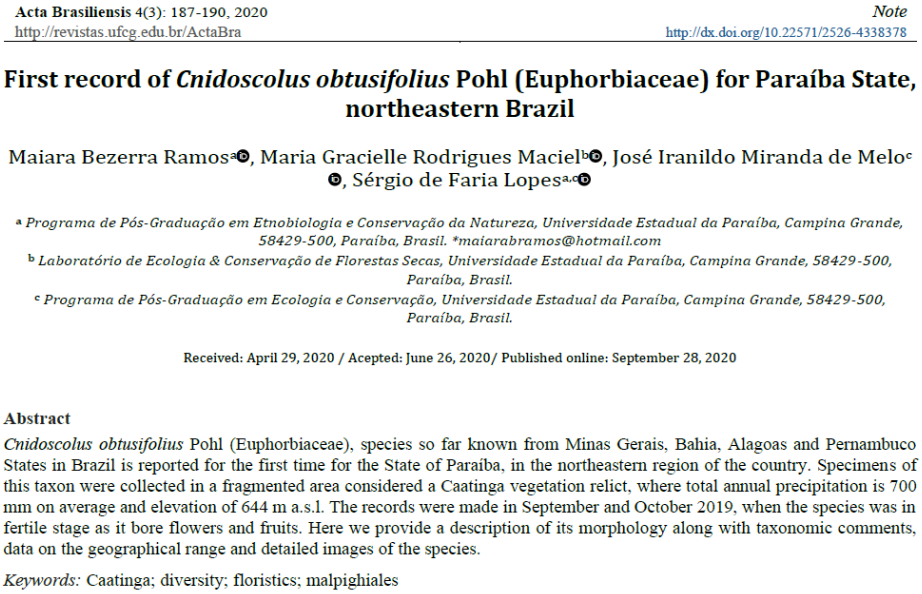

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Note

http://dx.doi.org/10.22571/2526-4338378

First record of *Cnidoscolus obtusifolius* Pohl (Euphorbiaceae) for Paraíba State, northeastern Brazil

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Abstract

Cnidoscolus obtusifolius Pohl (Euphorbiaceae), species so far known from Minas Gerais, Bahia, Alagoas and Pernambuco States in Brazil is reported for the first time for the State of Paraíba, in the northeastern region of the country. Specimens of this taxon were collected in a fragmented area considered a Caatinga vegetation relict, where total annual precipitation is 700 mm on average and elevation of 644 m a.s.l. The records were made in September and October 2019, when the species was in fertile stage as it bore flowers and fruits. Here we provide a description of its morphology along with taxonomic comments, data on the geographical range and detailed images of the species.

Keywords: Caatinga; diversity; floristics; malpighiales

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Abstract

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Keywords: Caatinga; diversity; floristics; malpighiales

Primeiro registro de *Cnidoscolus obtusifolius* Pohl (Euphorbiaceae) no estado da Paraíba, nordeste do Brasil

Resumo

Cnidoscolus obtusifolius Pohl (Euphorbiaceae) espécie até então conhecida para os Estados de Minas Gerais (Sudeste), Bahia, Alagoas e Pernambuco (Nordeste), Brasil, está sendo registrada pela primeira vez no Estado da Paraíba, nordeste do Brasil. A espécie foi coletada em uma área residual, que representa um relicto para a vegetação da Caatinga, com altitude de 644 m.s.n.m e regime pluviométrico de 700 mm anuais. Os registros foram obtidos nos meses de Setembro e Outubro de 2019, onde a espécie se encontrava florida e frutificada, a identificação foi baseada na literatura especializada. Apresentamos descrição morfológica, comentários taxonômicos, dados de distribuição geográfica e imagens detalhadas para a espécie.

Palavras-chave: Caatinga, diversidade, florística, malpighiales.

Introduction

Euphorbiaceae, a belonging family in the order Malpighiales, comprises 334 genera (Webster, 1994b) and nearly 8,000 species (Radcliffe-Smith & Esser, 2001). Representatives of this family occur in different plant formations in the Neotropics, but their distribution is mainly associated with tropical and subtropical regions, particularly in Africa and the Americas, with only a few genera and species occurring in temperate regions. The family is recognized as being one the most complex and morphologically diverse taxonomic groups within Rosidae (Cronquist & Takhtadzhian, 1981), as it exhibits all growth habits, ranging from small herbs to large size trees, in which the presence of latex is a frequent trait (Cronquist & Takhtadzhian, 1981; APG IV, 2016).

In Brazil, Euphorbiaceae is represented by 950 species distributed in 64 genera, of which four genera and 633 species are endemic in the country. Despite having a high number of species and genera, the family's diversity is still little known (Secco *et al*., 2012). This family has a wide geographical distribution, and is associated with all phytogeographic domains. Euphorbiaceae is considered an important group plants in the Brazilian semiarid (Alcofora do Filho *et al*. 2003, Andrade *et al*. 2004, Sátiro & Roque 2008, Lucena 2009). In the Caatinga domain, the family is represented by 228 species, distributed in 31 genera (Flora do Brasil 2020, under construction). However, it remains relatively little studied, since most works are centered only in the states of Pernambuco and Bahia (Secco *et al*., 2012).

Studies of the flora of Pernambuco such as those of Lucena (2009) and Lucena and Alves (2010) have contributed to the family's knowledge and distribution in the Northeast and Caatinga. Lucena and Alves (2009) added 29 occurrences to the list of Euphorbiaceae species for the Brazilian Northeast. Despite the advances provided by these studies, other work needs to be done; in order to cover the entire Northeast of Brazil to increase knowledge Euphorbiaceae diversity in the Caatinga and other northeastern ecosystems, in addition to contributing to other areas of knowledge.

Cnidoscolus Pohl is a prominent genus of Euphorbiaceae. This genus comprises 97 species exclusive of the Americas (Maya-Lastra & Steinmann, 2018), where its main diversification centers are located in Brazil, with 42 species among which 37 are endemic to the country (Flora do Brasil 2020, under construction), and Mexico, with 25 species (Maya-Lastra & Steinmann, 2019). To this date, Müller (1873) monograph remains the most comprehensive treatment on *Cnidoscolus* for Brazil, whereas Melo and Sales (2008) study has this position for the country's Northeast. With regard to the Brazilian species of this genus, 22 of them have been recorded in Caatinga vegetation, with 19 species being endemic to this floristic domain (Flora do Brasil 2020, under construction). It is worth mentioning that the genus stands out for presenting species with different therapeutic purposes and widespread in popular medicine (Moura *et al.*, 2019).

Representatives of *Cnidoscolus* are characterized by the presence of simple, alternate leaves, which are membranaceous to subcoriaceous, glabrous to velutinous-tomentose; their flowers are sessile or pedicellate, staminate ones are distal, with 10-15 free stamens organized in 2-4 whorls, while pistillate flowers are proximal; the ovary is ovoid to pyriform, glabrous to velutinous, with one ovule per locule and three styles, free or adnate at the base. The nectariferous disc is extrastaminal and annular; the presence of urticating trichomes in almost all vegetative and floral parts is particularly important as this is one of the diagnostic features of this genus (Pohl, 1827; Melo & Sales, 2008).

Among the species of this genus, *Cnidoscolus obtusifolius* Pohl was known from Minas Gerais, Bahia, Alagoas and Pernambuco States in Brazil. Now was reported for the first time for the State of Paraíba. While conducting fieldwork in the municipality of São João do Tigre, in the Brazilian semiarid, it was verified that collections of the species *Cnidoscolus obtusifolius* (Euphorbiaceae) became the first record for the state's flora, which is reported here.

Caatinga, as it is known for being the main plant formation in the Brazilian semiarid region, presents predominantly a vegetation classified as Seasonally Dry Tropical Forest, being considered the most diverse dry forest in the world (Moro *et al.*, 2015; Queiroz *et al.*, 2017). The Caatinga is marked by the influence of spatial and temporal variability of rain and landscapes, with different types of soils and a high number of endemisms (Moro *et al.* 2015; Queiroz *et al.* 2017; Silva *et al.* 2017). The results presented here were obtained in the municipality of São João do Tigre. (*município*) is located in the Cariri microrregion of Paraíba, Borborema Plateau (8°10' 27.5" S, 36° 55' 00.2" W), South extreme of Paraíba State, immersed in the Brazilian semiarid region (Mascarenhas *et al.*, 2005). This *município* is located in the portion of the Paraiban Cariri where the highest elevations are found with maxima of around

1,200 m a.s.l. (Souza *et al*., 2009). The regional climate is of the Bsh type, that is hot, semi-arid (Alvares *et al.,* 2013), with mean annual precipitation ranging around 700 mm, and mean annual temperature around 26 ºC (Mascarenhas *et al*., 2005; Moro *et al.*, 2015). With regard to geology, the study area is inserted in the domain of the crystalline, characterized in general by shallow, rocky and highly fertile soils. Specifically the Cariri region of Paraíba state, has a total area of approximately 11,225.736 km2, the region encompasses relictual reliefs that witness the pediplanation processes developed in the area; the landscape is dominated by narrow valleys and dry slopes, in addition to multiple mountain ranges, which combined with higher levels of precipitation are responsible for the occurrence of more benign temperatures in the region (Mascarenhas *et al*., 2005).

Fertile material of *Cnidoscolus obtusifolius* was collected during two expeditions conducted between September and October 2019. The vouchers were deposited at the Manuel de Arruda Câmara Herbarium (HACAM) of the Universidade Estadual da Paraíba (Paraíba State University), Campina Grande, Paraíba, Brazil. For the taxonomic identification, we used specialized literature (Müller Argoviensis, 1873; Melo & Sales, 2008), in addition to consultation of the electronic data bases of Reflora, the Herbário Virtual da Flora e dos Fungos (Virtual Flora and Fungal Virtual Herbarium), Jstor (https://plants.jstor.org/), and Tropicos (https://www.tropicos.org/).

Here, we present morphological description for the taxon, taxonomic and distribution notes, and illustrations (Figure 2). In the field we collected material from several individuals, and for all characteristics we analyzed three to five samples.

Cnidoscolus obtusifolius Pohl, Pl. Bras. Icon. Descr. 1: 62. 1827.

Type: BRAZIL: In deserto, Bahiensis prov., *C.F.P. von Martius 2230* (Holotype: M0233240!)

Tree, 6-8 m tall. Urticating trichomes acicular (stinging), 0.5–4 mm long, covering the branches; stinging trichomes of 2–6 mm long covering in the petioles, leaf blade, inflorescence, perianth, and fruits. Stems cylindrical, grayish to reddish, glabrous to pubescent at their distal branches. Stipules 1–3 × 1–2 cm irregularly triangular, generally deciduous, sometimes persistent after the leaves are shed, margins glandulous-papillose, pubescent to puberulent. Petiole absent or, when present, up to 1.8 cm long, cylindrical, pubescent to velutinous; petiolar glands absent. Leaf blade 3–9 × 2–5.2 cm, membranaceous to chartaceous, entire, elliptic, obovate, base obtuse to subcordate, apex acuminate to rounded, margin crenate, with urticating trichomes at each border, ciliate and undulate, adaxial face pubescent with urticating trichomes on primary veins; abaxial face sparsely velutinous with urticating trichomes on primary and secondary veins in mature (senescent) leaves only; leaf venation craspedodromous and brochidodromous, main veins 3–6. Inflorescence an imperfect dichasium 2.0 × 2.5–3 cm, or with 3 dichasia arranged in 2 levels of branching, puberulous, hispidulous-pubescent to sericeous, peduncle 0.3–0.9 (1.0 cm); bracts and bracteoles 3–4 mm, triangular, with glandulous-papillose margins at the base, pubescent. Staminate flowers sessile, located from the second level of ramification; perianth ca. 16 mm, tubular-campanulate or tubular hypocrateriform, greenish white, pubescent; tube 3–4 × 10 mm; lobes 8–9 × 7 mm, oblong-elliptic, apex rounded; stamens 18 arranged in 2-3 whorls, partially joined forming a column 2–10 mm, glabrous; filaments 3-6 mm; anthers 1 × 0.25–0.5 mm, dorsifixed, oblong; staminodes 3, filiform, ca. 5 mm; glandular disc 0.5 × 1 mm, annular, slightly lobed internally, glabrous. Pistillate flowers 3, located up to the second level of branching; pedicel ca. 2 mm; receptacle/base persistent of inconspicuous perianth; perianth ca. 13 mm, white, externally greenish, segments free, oblong to oval, pubescent and urticating, apex rounded; ovary ovoid, sub-cylindrical in cross section, pubescent to hispidulous-sericeous; styles 3–4 mm; joined at the base, four- to many-branched, 12-32 stigmatic branches; glandular disc annular striated, glabrous. Capsule 1.5–2.2 × 1.1–1.3 cm, 1.1–1.5 × 1.1–1.2, loculicidal and septicida, sub-pyriform, cylindrical in cross section, velutinous, urticating, apex acuminated, base of the styles persistent. Seeds 1.1–1.2 × 0.4–0.5 mm, oblong, concave dorsally, convex or flat ventrally, surface brown with prominent darker spots, base retuse, apex acute; caruncle 4–5 × 3 mm.

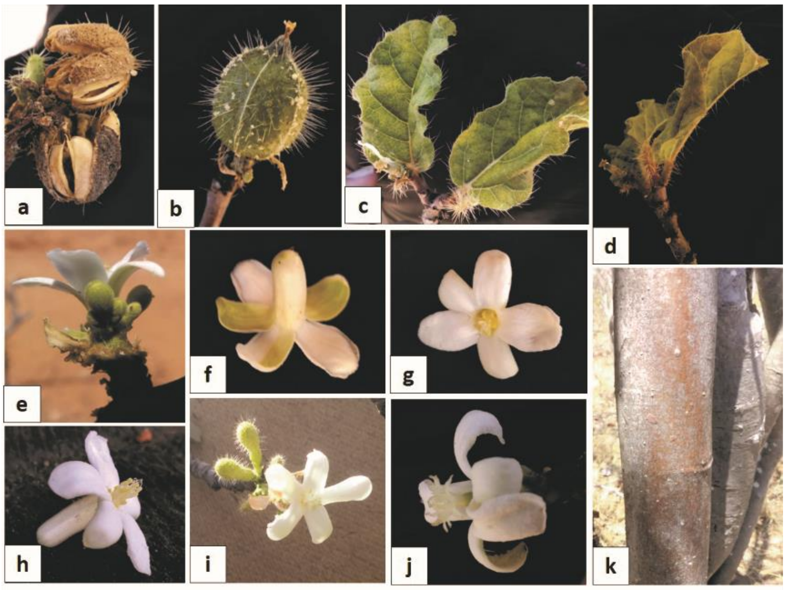

Figure 2. First record of *Cnidoscolus obtusifolius* Pohl in the estate of Paraíba, Brazil. A-B, capsule; C-D, leaves; E, inflorescence; F-I, male flower; J, female flower; K, stem.

Notes: For this genus other three species have been recorded in Paraíba: *Cnidoscolus infestus* Pax & K. Hoffm., *Cnidoscolus quercifolius* Pohl and *Cnidoscolus urens* (L.) Arthur. *Cnidoscolus obtusifolius* can be easily differentiated from these congeneric species mainly by its leaves with entire, elliptical and obovate blade, with an obtuse and sub-cordate base, its irregularly triangular, pubescent to puberulous stipules with papillose-glandulose margin, and its velutinous capsule.

Geographic range and habitat: Occurring exclusively in Brazil, this species is restricted to Seasonally Dry Tropical Forest and Seasonal Deciduous Forest being registered presence so far in the states of Minas Gerais (Southeastern Region), Alagoas, Bahia and Pernambuco (Northeastern Region) (Melo & Sales, 2008; Flora do Brasil 2020, under construction). Constituting, in this work, the first record for the State of Paraíba. Collections of this species in Paraíba were in the dry season 2019, in a fragment of Caatinga vegetation with an open physiognomy, at an elevation of 644 m a.s.l. According to World Reference Base for soil resource, soil classification prevailing soils in the study area are classified as Chromic Luvisols (IUSS Working Group WRB 2014).

The area shows signs of grazing by goats and cattle, common domestic animals and considered important drivers in the biological impoverishment of the Caatinga; which highlights the susceptibility to which *C. obtusifolius* is found. The area in which it was found is considered a fragment of shrubby Caatinga, and *C. obtusifolius* is among the five most abundant species, with random spatial distribution.

Along with *C. obtusifolius, Mimosa ophthalmocentra* Mart. ex Benth. (Fabaceae), *Cenostigma piramydale* (Tul.) Gagnon & G.P. Lewis (Fabaceae), and *Aspidosperma pyrifolium* Mart. & Zucc. (Apocynaceae) are most common species in the area.

Reproductive phenology: Found in flower and fruit in September and October for the observed specimens.

Examined material: BRAZIL. Paraíba: São João do Tigre municipality, (8° 10’ 27.5” S, 36° 55’ 00.2” W, 644 m a.s.l, 4 Oct 2019, M.B. Ramos, M.G.R. Maciel (HACAM 1978).

This new record of this specie was from in area very close to the border with Pernambuco (state where this taxon was reported before). Thus this, record underlines the importance of conducting further floristic studies in the Brazilian semiarid, since this region has a high environmental heterogeneity, which reflect the high number of endemism, species richness and variability in the plant formations and paradoxically, the knowledge about its flora is still incipient when compared to the other world plant formations.

The finding presented here refers to a Brazilian endemic species, restricted to the semiarid environment, and thus, environmental education actions about the specie and possible management plans are needed, aimed at the conservation and maintenance of high richness of Caatinga.

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APÊNDICE B: Temo de consentimento livre e esclarecido utilizado para atender

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO-TCLE

(OBS: para o caso de pessoas maiores de 18 anos e que não estejam inseridas nas hipóteses de vulnerabilidade que impossibilitam o livre discernimento com autonomia para o exercício dos atos da vida civil).

Pelo presente Termo de Consentimento Livre e Esclarecido eu, ____, em pleno exercício dos meus direitos me disponho a participar da Pesquisa **"Efeito dos impactos antrópicos na montagem de comunidades vegetais no ecossistema da Caatinga".**

Declaro ser esclarecido e estar de acordo com os seguintes pontos:

O " Qual o papel dos fatores antrópicos locais na montagem de comunidades vegetais da caatinga? " tem como objetivo identificar o conhecimento e uso que os moradores de comunidade rurais da Caatinga sobre espécies vegetais tentando elucidar quais os traços funcionais preferenciais pelas populações locais.

Aos voluntários caberá a autorização para solicitamos a sua colaboração para fornecer informações sobre as plantas da região por meio de entrevistas, como também sua autorização para apresentar os resultados deste estudo em eventos da área de ciências ambientais, além de publicar em revista científicas nacionais e internacionais. Por ocasião da publicação dos resultados, seu nome será mantido em e não haverá nenhum risco ou desconforto ao voluntário.

- Ao pesquisador caberá o desenvolvimento da pesquisa de forma confidencial; entretanto, quando necessário for, poderá revelar os resultados ao médico, indivíduo e/ou familiares, cumprindo as exigências da Resolução Nº. 466/12 do Conselho Nacional de Saúde/Ministério da Saúde.
- O voluntário poderá se recusar a participar, ou retirar seu consentimento a qualquer momento da realização do trabalho ora proposto, não havendo qualquer penalização ou prejuízo para o mesmo.
- Será garantido o sigilo dos resultados obtidos neste trabalho, assegurando assim a privacidade dos participantes em manter tais resultados sem caráter confidencial.
- Não haverá qualquer despesa ou ônus financeiro aos participantes voluntários deste projeto científico e não haverá qualquer procedimento que possa incorrer em danos físicos ou

financeiro, são voluntários e, portanto, não haveria necessidade de indenização por parte da equipe científica e/ou da Instituição responsável.

- Qualquer dúvida ou solicitação de esclarecimentos, o participante poder á contatara equipe científica no número (083) 988032622 Maiara Bezerra Ramos (aluna), Sonaly Silva da Cunha (aluna), DR. Sérgio Faria Lopes (professor)**.**
- Ao final da pesquisa, se for do meu interesse, terei livre acesso ao conteúdo da mesma, podendo discutir os dados, como pesquisador, vale salientar que este documento será impresso em duas vias e uma delas ficará em minha posse.
- Desta forma, uma vez tendo lido e entendido tais esclarecimentos e, por estar de pleno acordo com o teor do mesmo, dato e assino este termo de consentimento livre e esclarecido.

____

Assinatura do pesquisador responsável

____

Assinatura do Participante

Assinatura Dactiloscópica do participante da pesquisa

(OBS: utilizado apenas nos casos em que não seja

Possível a coleta da assinatura do participante da pesquisa).