



**PG·ECO·INPA**  
PÓS-GRADUAÇÃO EM ECOLOGIA



MINISTÉRIO DA  
CIÊNCIA, TECNOLOGIA  
E INOVAÇÃO



**INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA – INPA**

**PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA**

**TRAJETÓRIAS ESPAÇO-TEMPORAIS DE PALMEIRAS EM RESPOSTA À  
FRAGMENTAÇÃO FLORESTAL NA AMAZÔNIA CENTRAL**

**SPATIO-TEMPORAL TRAJECTORIES OF PALMS IN RESPONSE TO  
FOREST FRAGMENTATION IN CENTRAL AMAZON**

**MILLA DE FREITAS OLIVEIRA**

Manaus, Amazonas

Março, 2024

**TRAJETÓRIAS ESPAÇO-TEMPORAIS DE PALMEIRAS EM RESPOSTA À  
FRAGMENTAÇÃO FLORESTAL NA AMAZÔNIA CENTRAL**

MILLA DE FREITAS OLIVEIRA

Orientador: DR. JOSÉ LUÍS CAMPANA CAMARGO

Coorientador: DR. ALDICIR OSNI SCARIOT

Dissertação de mestrado apresentada no Programa de Pós-Graduação em Ecologia (PPGECO) do Instituto Nacional de Pesquisas da Amazônia (INPA), como parte dos requisitos para obtenção do título de mestre em Biologia (Ecologia).

Manaus, Amazonas

Março, 2024

## FICHA CATALOGRÁFICA:

### Catálogo na Publicação (CIP-Brasil)



O48t Oliveira, Milla

Trajelórias espaço-temporais de palmeiras em resposta à fragmentação florestal na Amazônia Central / Milla de Freitas Oliveira; orientador José Luís Campana Camargo; coorientador Aldicir Osni Scariot. - Manaus: [s.l.], 2024.

6,80 MB

55p. : il. color.

Dissertação (Mestrado - Programa de Pós-Graduação em Ecologia) - Coordenação do Programa de Pós-Graduação, INPA, 2024.

1. Fragmentos Florestais. 2. Dinâmica florestal. 3. Arecaceae. I. Camargo, José Luís Campana. II. Scariot, Aldicir Osni. III. Título

CDD 577.309 13

**Sinopse:** O estudo investiga efeitos temporais e espaciais causados pela fragmentação florestal na estrutura e composição da assembleia de palmeiras na Amazônia Central. Abundância, densidade e composição de espécies de palmeira nos estádios ontogenéticos adulto, jovem e plântula foram avaliadas em fragmentos florestais de diferentes tamanhos em contraste com florestas contínuas adjacentes.

**Palavras-chave:** 1. Arecaceae; 2. dinâmica florestal; 3. ecologia de comunidades; 4. floresta tropical; 5. fragmentos florestais.

## ATA DA DEFESA:



### PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA

#### ATA DA DEFESA PÚBLICA DA DISSERTAÇÃO DE MESTRADO DO PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA DO INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA.

Aos 13 dias do mês de Março do ano de 2024, às 08:h00min, via videoconferência, reuniu-se a Comissão Examinadora de Defesa Pública, composta pelos seguintes membros: a Dr<sup>a</sup>. **Thaise Emílio Lopes de Sousa**, da Universidade Estadual Paulista – UNESP, a Dra. **Rita de Cássia Quitete Portela**, da Universidade Federal do Rio de Janeiro – UFRJ e a Dr<sup>a</sup>. **Simone Benedet Fontoura**, do Instituto Federal do Amazonas – IFAM, sendo os suplentes o Dr. Marcel Caritá Vaz, da Wilkes University e o Dr. Rodrigo Ferreira Fadini, da Universidade Federal do Oeste do Pará – UFOPA, sob a presidência do orientador, a fim de proceder a arguição pública da **DISSERTAÇÃO DE MESTRADO de MILLA DE FREITAS OLIVEIRA**, intitulada: **"TRAJETÓRIA ESPAÇO-TEMPORAL DE PALMEIRAS SOB FRAGMENTAÇÃO FLORESTAL NA AMAZÔNIA CENTRAL"**, orientada pelo Dr. José Luis Campana Camargo, do Instituto Nacional de Pesquisas da Amazônia – INPA e coorientada pelo Dr. Aldicir Osni Scariot, da Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA.

Após a exposição, o(a) discente foi arguido oralmente pelos membros da Comissão Examinadora, tendo recebido o conceito final:

- |   |  |
|---|--|
| <input checked="" type="checkbox"/> APROVADO (A)    | <input type="checkbox"/> REPROVADO (A) |
| <input checked="" type="checkbox"/> POR UNANIMIDADE | <input type="checkbox"/> POR MAIORIA   |

Nada mais havendo, a presente ata foi lida, lavrada e assinada pelos membros da Comissão Examinadora.

DR<sup>a</sup>. THAISE EMÍLIO LOPES DE SOUSA

  
\_\_\_\_\_

DR<sup>a</sup>. RITA DE CÁSSIA QUITETE PORTELA

  
\_\_\_\_\_

DR<sup>a</sup>. SIMONE BENEDET FONTOURA

  
\_\_\_\_\_

DR. MARCEL CARITÁ VAZ

\_\_\_\_\_

DR. RODRIGO FERREIRA FADINI

\_\_\_\_\_

  
\_\_\_\_\_  
(Coordenação PPG-ECO/INPA)

*Dedico esta dissertação a Deus, aos meus familiares e a todas as pessoas que têm amor pela natureza e trabalham para sua conservação.*

## AGRADECIMENTOS

Primeiramente agradeço a Deus, que tem me guiado e cuidado desde o momento de inscrição para a prova até o presente, e sempre colocando pessoas incríveis em meu caminho. A meus pais, Iris e Milton e minha irmã, Maisa, que não pouparam esforços para que eu seguisse meus sonhos e estiveram sempre ao meu lado. Igualmente a meus familiares, de sangue ou não, por cada pensamento, oração ou abraço que me deu força para continuar.

Ao meu querido orientador, José Luís Camargo (Zé), que me apresentou as palmeiras e oportunizou trabalhar com meu grande desejo, a fragmentação florestal. Nosso vínculo foi além de uma orientação, sendo também minha família e conselheiro, acreditou em mim quando eu mesmo não mais o fazia. E ao meu coorientador Aldicir Scariot, que cedeu os dados de sua tese de doutorado para que fosse possível realizar a parte temporal de meu estudo e pelo auxílio no recenseamento das palmeiras.

A todos meus amigos e colegas que tive o prazer de caminhar durante esses anos de pós-graduação, mesmo que de forma mais restrita devido à pandemia, e aos que de longe sempre estiveram perto. De maneira especial ao Paulo Neto, colega desde o primeiro dia de aula, parceiro de campo, dividimos o orientador e até a casa, amigo desde um açaí à surtos normais da pós. E ao Dr. Paulo Bobrowiec, professor e salvador nas análises estatísticas dos meus dados, obrigada por todo suporte e prestatividade.

A todos integrantes do Projeto Dinâmica Biológica de Fragmentos Florestais (PDBFF), em especial ao especialista e mateiro Ocírio (Juruna), por todo conhecimento sobre a floresta Amazônica, histórias, comidas e acima de tudo amizade, que deixaram os campos mais leves e memoráveis. Aos professores e demais funcionários do Instituto

Nacional de Pesquisas da Amazônia (INPA), em especial os professores do PPG-ECO por todo auxílio e conhecimento transmitido.

Agradeço ao Programa de Apoio à Pesquisa de Campo Thomas Lovejoy pelo financiamento da pesquisa, à Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM) e ao PDBFF pela bolsa de estudos concedida durante o período de vigência do mestrado e à prorrogação devido à pandemia, respectivamente.

Enfim, a todas as pessoas que por meio de um olhar ou uma longa conversa, durante toda a trajetória ou apenas um segundo dela, fizeram a diferença na minha caminhada até aqui. Por medo de esquecer nomes prefiro não os citar, mas a todos vocês meu muito obrigada, conseguimos!

“Não fui eu que lhe ordenei? Seja forte e corajoso! Não se apavore, nem se desanime, pois o Senhor, o seu Deus, estará com você por onde você andar”. (Josué 1:9)



## **Resumo**

A fragmentação florestal é uma das maiores ameaças à biodiversidade global. Uma nova configuração espacial da paisagem pode expor áreas isoladas a alterações abióticas e bióticas que provocam mudanças na estrutura e composição da vegetação nativa remanescente. Porém, essas alterações podem levar algum tempo para serem percebidas, principalmente em processos que dependem de organismos com ciclo de vida longo. Somente estudos de longo prazo que considerem diferentes estádios ontogenéticos das plantas poderão fornecer evidências de como e por quanto tempo o processo de fragmentação florestal pode afetar a vegetação. Porém, apesar de essenciais, tais estudos ainda precisam estar disponíveis. Aqui tivemos a oportunidade de compilar dados coletados 15 e 42 anos após a formação dos fragmentos florestais para analisar a trajetória espaço-temporal das palmeiras, considerando plântulas, juvenis e adultos. As parcelas permanentes estavam em fragmentos florestais de diferentes tamanhos e florestas contínuas adjacentes na Amazônia Central. Como visto 15 anos após o isolamento, registramos novamente um declínio acentuado entre a população imatura de palmeiras em fragmentos florestais. No entanto, as palmeiras adultas, antes não afetadas pela fragmentação florestal, aumentaram significativamente em ambos os ambientes ao longo do tempo. Contudo, tais mudanças não alteraram o número de espécies nem a composição da assembleia de palmeiras quando analisamos o efeito da fragmentação florestal e do tamanho dos fragmentos florestais. Concluímos que houve baixa resiliência entre as palmeiras na recuperação populacional após mudanças causadas pela fragmentação florestal, e não houve evidências claras de que mesmo com um número mais significativo de palmeiras reprodutivas, ocorreu um maior sucesso no estabelecimento de novos indivíduos. Este fenômeno pode ter sido ainda mais agravado sinergicamente pelas mudanças recorrentes nos novos padrões climáticos testemunhados na região.

**Palavras-chave:** Arecaceae; dinâmica florestal; ecologia de comunidades; floresta tropical; fragmentos florestais.

## **Abstract**

Forest fragmentation is one of the biggest threats to global biodiversity. A new spatial configuration of the landscape can expose isolated areas to abiotic and biotic alterations that cause changes in the structure and composition of the remaining native vegetation. However, these changes may take some time to be noticed, especially in processes that depend on organisms with a long life cycle. Only long-term studies that consider different ontogenetic stages of plants can provide evidence of how and for how long the process of forest fragmentation can affect vegetation. However, despite being essential, such studies still need to be available. Here, we had the opportunity to compile data collected 15 and 42 years after the formation of forest fragments to analyze the spatial-temporal trajectory of palms, considering seedlings, juveniles, and adults. The permanent plots were in forest fragments of different sizes and adjacent continuous forests in the Central Amazon. As seen 15 years after isolation, we again recorded a sharp decline among the immature palm population in forest fragments. However, adult palms, previously unaffected by forest fragmentation, increased significantly in both environments over time. However, such changes did not alter the number of species or the composition of the palm assemblage when we analyzed the effect of forest fragmentation and different sizes of forest fragments. We conclude that there was low resilience among palm trees in population recovery after changes caused by forest fragmentation, and there was no clear evidence that even with a more significant number of reproductive palms, there was a success in establishing new individuals. This phenomenon can be further synergistically aggravated by the recurring changes in new climate patterns witnessed in the region.

**Keywords:** Areaceae; forest dynamics; community ecology; tropical forest; forest fragments.

## Sumário

<b>Introdução geral.....</b>	<b>13</b>
<b>Capítulo Único.....</b>	<b>21</b>
<b>Summary.....</b>	<b>22</b>
<b>Introduction.....</b>	<b>23</b>
<b>Material and Methods.....</b>	<b>26</b>
Study area.....	26
Taxonomic group.....	28
Data Assembly.....	28
Ontogenetic Stages.....	29
Statistical analysis.....	30
<b>Results.....</b>	<b>32</b>
Overview data.....	32
Effect of forest fragmentation.....	32
Effect of forest fragment size.....	35
Species response to fragmentation and forest fragment size.....	36
<b>Discussion.....</b>	<b>38</b>
Effect of forest fragmentation and forest fragment size.....	38
Species response to fragmentation and forest fragment size.....	42
<b>References.....</b>	<b>43</b>
<b>Supplementary Information.....</b>	<b>55</b>
<b>Conclusão geral.....</b>	<b>71</b>
<b>Referências bibliográficas.....</b>	<b>73</b>

## Introdução geral

A fragmentação de florestas tropicais e a consequente perda de habitat é uma das maiores ameaças à biodiversidade global (Pires et al., 2006) e tem sido acelerada devido ao corte ilegal de madeira, grilagem de terras, avanço das fronteiras agrícolas, grandes obras de infraestrutura e urbanização (Thomazini & Thomazini, 2000). O fato dessas forças motrizes serem de cunho antropogênico aumenta a chance dessas áreas serem ainda mais fragmentadas com o tempo (Wade et al., 2003), o que torna inevitável a ocorrência intensiva de um processo de fragmentação florestal, onde outrora extensas florestas contínuas e intactas, virem um crescente mosaico de ‘verdes’ desagregados (Murcia, 1995; Scariot, 1996; Pires et al., 2006).

Quando ocorre a subdivisão de uma área florestal, remanescentes florestais tornam-se isolados e uma maior quantidade de área fica exposta aos efeitos de borda (Fischer et al., 2021). Ambientes de borda florestal ou similares eram típicos de ecótonos ou regiões limítrofes, mas agora tornam-se comuns (Scariot, 1996). As bordas florestais se caracterizam por apresentar mudanças abruptas abióticas ou bióticas em relação ao interior da floresta (Murcia, 1995). Essa nova configuração faz com que os fragmentos florestais recebam maior quantidade de radiação solar e incidência de ventos, além do aumento na temperatura média e uma queda na umidade relativa do ar (Jose et al., 1996). Mas, as mudanças podem superar as condições microclimáticas *por se*, pois os fragmentos florestais podem ter seus processos de sucessão ecológica alterados (Echeverría et al., 2007), retornando a ser colonizados predominantemente por espécies pioneiras (Gauí et al., 2019). Mudanças em processos ecológicos importantes, como polinização, dispersão de sementes e herbivoria podem também ser intensivamente alterados (Murcia, 1995; Scariot, 1999; Laurance et al., 2006; Rodrigues & Nascimento, 2006; Laurance & Vasconcelos, 2009). Dessa forma, é notável que a maior perda florestal,

tanto em estrutura como em composição pode ocorrer nas bordas de fragmentos florestais, o que pode culminar em um *looping* de redução do seu tamanho original e ainda o aumento do isolamento (Taubert et al., 2018; Hansen et al., 2020; Fischer et al., 2021).

Quanto menor e mais isoladas são essas manchas florestais na paisagem, mais intensas são as forças externas sobre eles (Haddad et al., 2015). A relação espécie-área manifesta uma relação positiva entre o tamanho da área e o número de espécies encontrada nela, como relatado para ilhas oceânicas (Preston, 1962; Macarthur & Wilson, 1967). Contudo, diferentemente de ilhas, o meio onde os fragmentos florestais estão inseridos podem não ser totalmente inóspitos. As matrizes do entorno podem ser mais ou menos favoráveis à vegetação natural, principalmente quando composta por uma formação florestal secundária. Quanto maior a semelhança entre a vegetação da matriz e a vegetação do fragmento florestal, maior tende a ser a permeabilidade desse sistema (Assis et al., 2019). Assim, a influência da matriz abrange desde o controle da dinâmica da paisagem e o efeito de borda, como o fluxo genético, migrações, dispersão e os *stepping stones*, que atuam como corredores ecológicos (Antonini et al., 2003; Ewers & Didham, 2006; Laurance & Vasconcelos, 2009).

Há uma correlação direta e positiva entre o tamanho de um fragmento florestal e o número de espécies e indivíduos registradas nele (Laurance & Vasconcelos, 2009). Quanto maior o fragmento florestal, maior também tende a ser sua heterogeneidade ambiental, o que permite atender os requisitos para a persistência e reprodução de uma maior quantidade de espécies, inclusive muitas espécies raras. Espécies raras são a grande maioria das espécies encontradas em florestas tropicais (Laurance et al., 2011), que em áreas menores tenderiam a desaparecer com a restrição da quantidade e qualidade ambiental (Haddad et al., 2015). A capacidade de comportar grandes populações, não só de plantas, mas também de animais como de pequenos mamíferos, como as cutias, que

são responsáveis pela dispersão de sementes de palmeiras (Donatti, 2004), também garante o sucesso e permanência de espécies de plantas nos fragmentos florestais. Deste modo, a presença de certos animais reflete diretamente na ocorrência de determinadas espécies (Borges, 2007; Andreazzi et al., 2009).

As mudanças ambientais causadas pela fragmentação florestal podem fazer com que o ambiente deixe de ser favorável para algumas espécies, ocasionando uma redução em sua abundância e distribuição. Em contrapartida, outras espécies, que anteriormente se encontravam com sua distribuição reduzida, agora podem ter sua abundância ampliada (Filgueiras et al., 2021). Outra possível mudança na vegetação causada pela fragmentação florestal é a substituição de espécies. Um ambiente perturbado propicia a entrada de espécies invasoras que tenderão a competir com espécies nativas e colonizar a área (Wirth et al., 2008; Laurance & Vasconcelos, 2009). O estudo de Fauset e colaboradores (2012) constatou mudanças na composição de plantas de clima úmido para mais tolerantes à seca nas florestas tropicais de Gana, devido a duas décadas de estiagem.

Em uma comunidade fragmentada, as características intrínsecas à cada espécie como sua plasticidade, resiliência e ciclo de vida, devem determinar quando e como ela responderá às novas condições ambientais (Pimm, 1991; Scariot, 1996; Svenning, 1998). Contudo, a fragmentação florestal também influencia na capacidade das plantas de detectar mudanças no ambiente, diminuindo a eficácia na adaptação e resiliência (Cheptou et al., 2017). Como um efeito de redes ecológicas, as mudanças nas principais funções dos ecossistemas, declínio da biomassa e alteração dos ciclos de nutrientes (Haddad et al., 2015; Ordway & Asner, 2020) afetam outros componentes que interligados podem desestabilizar todo o ambiente, a começar pela fase de vida mais vulnerável, comum em todos os organismos, o estágio ontogenético imaturo.

Plantas no início do desenvolvimento são as primeiras a perecer em situações desfavoráveis, seguido do estágio juvenil e por último os adultos, que podem levar anos para apresentar mudanças efetivas (Ferraz, 2004). Brum e colaboradores (2008), ao estudar a influência da fragmentação florestal sobre sementes de *Oenocarpus bacaba* Mart. na Amazônia Central, observou que a perturbação causada pela fragmentação florestal influenciou diferentemente em cada fase da vida da palmeira. Plântulas foram afetadas negativamente, apresentando queda na abundância relativa, enquanto indivíduos já estabelecidos foram favorecidos. Com isso é notável que com o tempo haja uma redução da população de algumas espécies e conseqüentemente a diminuição de adultos viáveis, o que a longo prazo pode acarretar até mesmo em uma extinção local da espécie (Montúfar et al., 2011).

O estudo de comunidades, apesar de consistir em uma visão ampla, deve também levar em consideração como a população de cada espécie responde aos efeitos de uma nova conformação florestal. Seguindo apenas às condições impostas pelas espécies mais comuns ou filogeneticamente semelhantes pode acarretar conclusões errôneas (Irwin et al., 2010). Piovesan e colaboradores (2022), estudando cipós do gênero *Machaerium*, relataram que duas entre oito espécies não foram favorecidas em ambientes de floresta fragmentada e outras quatro espécies apresentaram um comportamento neutro em relação à degradação ambiental causada pela fragmentação florestal. Muitos dos relatos indicam que cipós são sempre beneficiados após distúrbio florestal, mas muitas vezes tais conclusões não são baseadas em espécies devidamente identificadas. Assim como os cipós, algumas espécies de palmeiras não devem responder de forma uniforme às alterações no ambiente, além disso, estudar diferentes estágios ontogenéticos pode ajudar a inferir as futuras trajetórias e permanência de espécies nas comunidades (Lueder et al., 2022).



Contudo, cada ambiente reage a perturbações de uma forma e é passível de influências únicas e específicas, podendo essa resposta ocorrer de forma imediata ou não. Assim, mesmo que os processos ecológicos possam ser modificados pouco tempo após a fragmentação florestal, os seus efeitos na composição, estrutura e dinâmica da vegetação podem levar anos para serem identificados (Antonini et al., 2003; Ewers & Didham, 2006). Por isso a existência de trabalhos a longo prazo é tão importante, a rápida perda e degradação do habitat atrelado à demora na resposta das espécies vegetais, torna substancial o acompanhamento dessas áreas a fim de conhecer e interpretar as tendências e quais condições serão impostas às comunidades (Rodrigues & Nascimento, 2006).

Numerosos estudos analisam os efeitos da fragmentação florestal sobre a biodiversidade. Contudo, a maioria se concentra em retratos pontuais da paisagem, sem de fato considerá-lo como um processo dinâmico ao longo do tempo (Ma et al., 2023). Escassos são os estudos a longo prazo que permitem o acompanhamento das áreas fragmentadas com possível comparação a florestas contínuas intactas adjacentes e diferentes tamanhos de fragmentos florestais, o que pode ajudar a detectar padrões não estudados. Além da necessidade de estudos que contemplem diferentes aspectos como número e composição de espécies e diferentes estádio ontogenéticos para uma compreensão mais aprofundada da relação ambiente e biodiversidade (Lueder et al., 2022).

A família Arecaceae apresenta uma distribuição Pantropical (Henderson et al., 1995), além de uma alta diversidade e grandes populações. As florestas tropicais, pelas próprias características ambientais, como o clima quente e úmido e o elevado índice pluviométrico são detentoras de mais de 90% da diversidade de palmeiras (Couvreur et al., 2011). No Brasil são encontradas 389 espécies de palmeiras (Flora do Brasil, 2023),

especificamente, para o bioma amazônico, há o registro de *ca.* 150 espécies registradas até o momento (Flora do Brasil, 2023), sendo muitas endêmicas.

As palmeiras apresentam grande relevância para as populações locais, sendo utilizadas intensivamente na produção de alimentos, remédios e em construções (Kahn & Castro, 1985; Kahn et al., 1988). Essa importância se estende também para as relações ecológicas, pois os frutos e sementes de palmeiras servem de alimento em épocas desfavoráveis para muitas espécies frugívoras (Bodmer & Ward, 2006; Balslev et al., 2008) e podem intervir no processo de sucessão ecológica (Peters et al., 2004) ou na mudança funcional (Dantas et al., 2022). Mesmo com tal relevância e a garantia de manejos de uma cadeia produtiva para algumas espécies exploradas comercialmente como o açaí (*Euterpe oleracea* Mart.) e o babaçu (*Attalea speciosa* Mart.; Jardim & Anderson, 1987), a maioria das espécies podem estar sucumbindo pela perda de seus habitats devido ao cenário crescente de desmatamento e aumento do número de pequenos fragmentos florestais (Montibeller et al., 2020; Fischer et al., 2021).

Além da importância para a fauna e para o homem, as palmeiras são boas indicadoras de alterações ambientais, tanto causadas pela fragmentação florestal ou por mudanças climáticas em geral. Mas devido às poucas inclusões em monitoramentos florestais, ainda não são bem representadas em estudos que levam em conta a composição e a dinâmica de comunidade (Rocha & Silva, 2005; Montúfar et al., 2011). Dentro deste cenário de exclusão das palmeiras em monitoramentos florestais de longo prazo, há algumas exceções, como a rede de parcelas permanentes estabelecidas no Projeto Dinâmica Biológica de Fragmentos Florestais (PDBFF – INPA) que desde *ca.* quatro décadas teve como missão conhecer a diversidade do grupo e avaliar os efeitos causados pela fragmentação florestal. Agora, com o passar do tempo, surgiu uma ótima

oportunidade para ampliar o conhecimento sobre o efeito causado pela fragmentação florestal ao longo do tempo.

O resultado desta oportunidade é apresentado nas próximas páginas em um capítulo único, em formato de artigo e escrito em inglês, onde exploramos a relação entre os efeitos espaciais e temporais, decorrente da fragmentação florestal, nos estádios ontogenéticos adulto, jovem e plântula das assembleias de palmeiras típicas da Amazônia Central. Para atingirmos este objetivo, contamos com a colaboração do Dr. Aldicir Scariot que em 1994, 15 anos após a criação do PDBFF, realizou o primeiro levantamento demográfico da família Arecaceae nos fragmentos florestais como parte das atividades de doutorado defendido pela Universidade da Califórnia (UCSB). O intuito principal na época era compreender como o processo de fragmentação florestal afetou a assembleia de palmeiras.

O estudo representou uma iniciativa pioneira por realizar um extenso censo demográfico das palmeiras da região e acima disto, com a qualidade advinda da identificação taxonômica de cada uma das espécies. Assim, contávamos com um quadro bastante completo da flora de palmeiras das florestas de terra firme fragmentadas e contínuas da ARIE PDBFF.

Vale lembrar que o processo de conhecimento taxonômico das palmeiras havia começado um pouco antes com um inventário das palmeiras em uma área de floresta contínua de 10 ha localizada na reserva KM 41 composto unicamente por floresta contínua. Este estudo também pioneiro foi liderado pelo Dr. Andrew Henderson do Jardim Botânico de Nova Iorque e equipe. Assim, o conhecimento taxonômico das palmeiras desde o início contou com a qualidade de um especialista no grupo que passou seu conhecimento para seus colaboradores diretos. Entre eles, Aldicir Scariot, Manoel

Pacheco e Ocírio “Juruna” Souza que além de localizar e marcar cada indivíduo adulto de palmeiras na área de estudo, aprenderam a identificar as espécies registradas na ocasião. Juruna não só aprendeu, mas se tornou um especialista que durante todos esses anos, também contribuiu intensamente com inúmeros pesquisadores e alunos que trabalharam com palmeiras em diversos sítios, principalmente na Amazônia.

Não foi diferente neste estudo, contamos com o apoio imprescindível do Juruna e desta vez, para termos além de uma visão espacial, realizamos um novo censo das palmeiras, nas mesmas áreas de estudo selecionadas por Scariot, mas desta vez 42 anos após o processo de fragmentação florestal original e 28 anos após o primeiro censo. Assim, pudemos entender, neste estudo que compõe as próximas páginas, as trajetórias da assembleia de palmeiras e de cada uma das espécies que a compõe.

Assim, nosso estudo apresenta avanços inéditos acerca de trajetórias espaço-temporal ao nível de assembleia e populações de palmeiras nos três estádios ontogenéticos, adulto, juvenil e plântula em fragmentos florestais de 1, 10 e 100 ha, comparados às florestas contínuas adjacentes. Contribuindo tanto para o entendimento do comportamento das florestas presente em fragmentos florestais ao longo do tempo e em diferentes tamanhos, quanto para a ecologia e dinâmica de uma das mais importantes famílias de plantas da Amazônia. Além, é claro, de fornecer informações úteis aos tomadores de decisões, quanto às melhores ações a serem seguidas com o intuito de mitigar os efeitos da fragmentação e preservar o meio ambiente, mesmo em um cenário presente e futuro de cada vez mais florestas tropicais fragmentadas.

## Capítulo Único

---

Oliveira, M. F.; Melo Neto, P. R.; Pereira, O. S.; Bobrowiec, P. E. D.; Scariot, A. O.; Henderson, A. J.; Mazer, S. J. & Camargo, J. L. C. (2024). **Spatio-temporal trajectories of palms in response to forest fragmentation in Central Amazon** – Manuscrito formatado para *Journal of Ecology*.

1         **Spatio-temporal trajectories of palms in response to forest fragmentation in**  
2   **Central Amazon**

3

4         **Summary**

5             1. The demographic composition and abundances of 36 species of palms in 11  
6         genera distributed among forest fragments of different sizes were examined 15 and 42  
7         years after forest fragmentation in the Central Amazon.

8             2. After 15 years of forest fragmentation, only the immature ontogenetic stages  
9         (seedlings and juveniles) showed an abundance decrease in forest fragments compared to  
10        continuous forest.

11            3. Even 42 years after forest fragmentation, the forest fragments contained fewer  
12         adults, juveniles, and seedlings compared to their abundance in continuous forests.  
13         However, over time, there was an increase in the number of adults. On the other hand, the  
14         abundance of juveniles and seedlings remained in decline even in continuous forests.

15            4. Larger forest fragments supported a higher abundance of palms than the 1 and  
16         10-ha fragments at all stages, resembling a continuous forest.

17            5. Synthesis. Forest fragmentation alters the distribution and abundance in each  
18         stage in a species-specific manner but not the species composition of palm assemblages.  
19         Time since forest fragmentation and fragment size contribute to the magnitude of  
20         demographic changes in palm populations.

## 21            **Introduction**

22            The fragmentation of tropical forests and the consequent loss of habitat is one of  
23 the greatest threats to global biodiversity (Pires et al., 2006). Subdivided forests are  
24 comprised of isolated forested remnants that exhibit potentially strong edge effects  
25 (Fischer et al., 2021). Forest edges are characterized by abrupt abiotic and biotic changes  
26 compared to the forest interior (Murcia, 1995). This new configuration of forest fragments  
27 changes the fragments' physical, chemical, and biological characteristics, increasing  
28 temperature and reducing humidity (Camargo & Kapos, 1995; Jose et al., 1996). These  
29 local environmental changes modify the forest structure and the species composition,  
30 where increased tree mortality leads to more simplified vegetation. However, changes  
31 extend beyond these microclimatic conditions, as forest fragments can also exhibit  
32 changes in ecological processes, including succession (Murcia, 1995; Scariot, 1999;  
33 Laurance et al., 2006; Rodrigues & Nascimento, 2006; Echeverría et al., 2007; Laurance  
34 & Vasconcelos, 2009).

35            The smaller and more isolated these forest fragments are in the landscape, the  
36 more intense the external forces on them are (Haddad et al., 2015). Environmental  
37 heterogeneity increases with fragment size, such that larger fragments may generally  
38 support more species than small fragments, including many rare species (Laurance et al.,  
39 2011), which in smaller areas would tend to disappear (Haddad et al., 2015). Therefore,  
40 a direct and positive correlation exists between forest fragment size and species diversity  
41 (Hill & Curran, 2003).

42            In a fragmented community, the intrinsic characteristics of each species, such as  
43 plasticity, resilience, growth form, and life cycle, will determine when and how it will  
44 respond to local environmental conditions (Pimm, 1991; Scariot, 1996; Svenning, 1998).

45 However, because of the effects of forest fragmentation on environmental stressors (e.g.,  
46 increased insolation, temperature, and wind) and effective population size, forest  
47 fragmentation might negatively affect the ability of plants to detect and respond  
48 adaptively to environmental change (Cheptou et al., 2017). Forest fragmentation may  
49 have cascading effects on the composition and function of ecological networks (Haddad  
50 et al., 2015; Ordway & Asner, 2020), the disruption of which can be highly destabilizing  
51 to their component populations, starting with the most vulnerable ontogenetic life stage.  
52 In plants, seedlings are generally the first life stage to perish in unfavorable situations,  
53 followed by the juvenile stage and, finally, the adult stage, which can take years to show  
54 effective changes (Ferraz, 2004), this transitional dynamic is called extinction debt  
55 (Jackson & Sax, 2010). However, in the future, the changes could lead to more simplified  
56 communities if the number of plant species decreases.

57 Despite the generalizations above, the environment and taxon react to  
58 disturbances differently and at their own pace. Thus, even though ecological processes  
59 can be modified shortly after forest fragmentation, their effects on vegetation  
60 composition, structure, and dynamics can take years (Antonini et al., 2003; Ewers &  
61 Didham, 2006).

62 Even considering the increase in the number of studies on the effects of forest  
63 fragmentation on biodiversity, most of them focus on a specific landscape scenario  
64 without looking at the dynamic process over time (Ma et al., 2023). Moreover, few long-  
65 term studies have been designed to monitor forest fragments of different sizes while also  
66 monitoring adjacent continuous intact forests. In addition, studies need to consider the  
67 responses to fragmentation of a range of community attributes, such as species  
68 composition and the relative abundances of different functional traits (Liu et al., 2019).



69 Examining the responses of different ontogenetic stages in ecologically important plant  
70 taxa will contribute to a more in-depth understanding of the relationship between  
71 environmental conditions and biodiversity (Lueder et al., 2022), highlighting the  
72 importance of monitoring and carrying on long-term studies to interpret the trends and  
73 what conditions will be imposed on the communities. Building knowledge and  
74 information may contribute to their conservation and management (Rodrigues &  
75 Nascimento, 2006; Fischer et al., 2021).

76 In the current study, we focus on the effects of forest fragmentation on a  
77 geographically widespread and taxonomically diverse angiosperm family of great  
78 ecological importance: the Arecaceae (palms). Palms have a pantropical distribution  
79 (Henderson et al., 1995), high species diversity, and are representative of tropical forests,  
80 often characterized by large populations. Palms play a fundamental role in both human  
81 and ecological relations, as they provide food in unfavorable times for many frugivorous  
82 species (Bodmer & Ward, 2006; Balslev et al., 2008) and affect the processes of  
83 ecological succession (Peters et al., 2004) and functional change (Dantas et al., 2022).  
84 Furthermore, palms are good indicators for evaluating environmental changes (Walther  
85 et al., 2007). However, because most species were worthless for the timber industry and  
86 did not reach the minimum diameter at the breast height (10 cm, in general) to be included  
87 in forest inventories, they are often excluded from inventories and monitoring (Rocha &  
88 Silva, 2005). Consequently, they are still poorly represented in studies of community  
89 composition and dynamics (Montúfar et al., 2011).

90 This study aimed to investigate the spatiotemporal effects of forest fragmentation  
91 on palm assemblages using the world's most significant and oldest experimental study of  
92 habitat fragmentation, the Biological Dynamics of Forest Fragment Project (BDFFP)

93 (Laurance et al., 2011). We leveraged historical data on the composition of BDFFP palms  
94 obtained by Scariot (1996) 15 years after forest fragmentation, and we collected new data  
95 in the same sites 42 years after the initial fragmentation, which allowed us to measure the  
96 trajectories of palm populations in the different age groups (seedlings, juveniles, and  
97 adults).

98 Thus, we asked: (1) Comparing the responses obtained 15 and 42 years after forest  
99 fragmentation, how do the consequences of forest fragmentation influence the  
100 ontogenetic stage structure and composition of palm assemblage? Moreover, (2) How  
101 does forest fragment size influence the ontogenetic stage structure and composition of  
102 palm assemblages? Furthermore, (3) Which species present a disadvantage, advantage,  
103 or neutrality in the face of forest fragmentation?

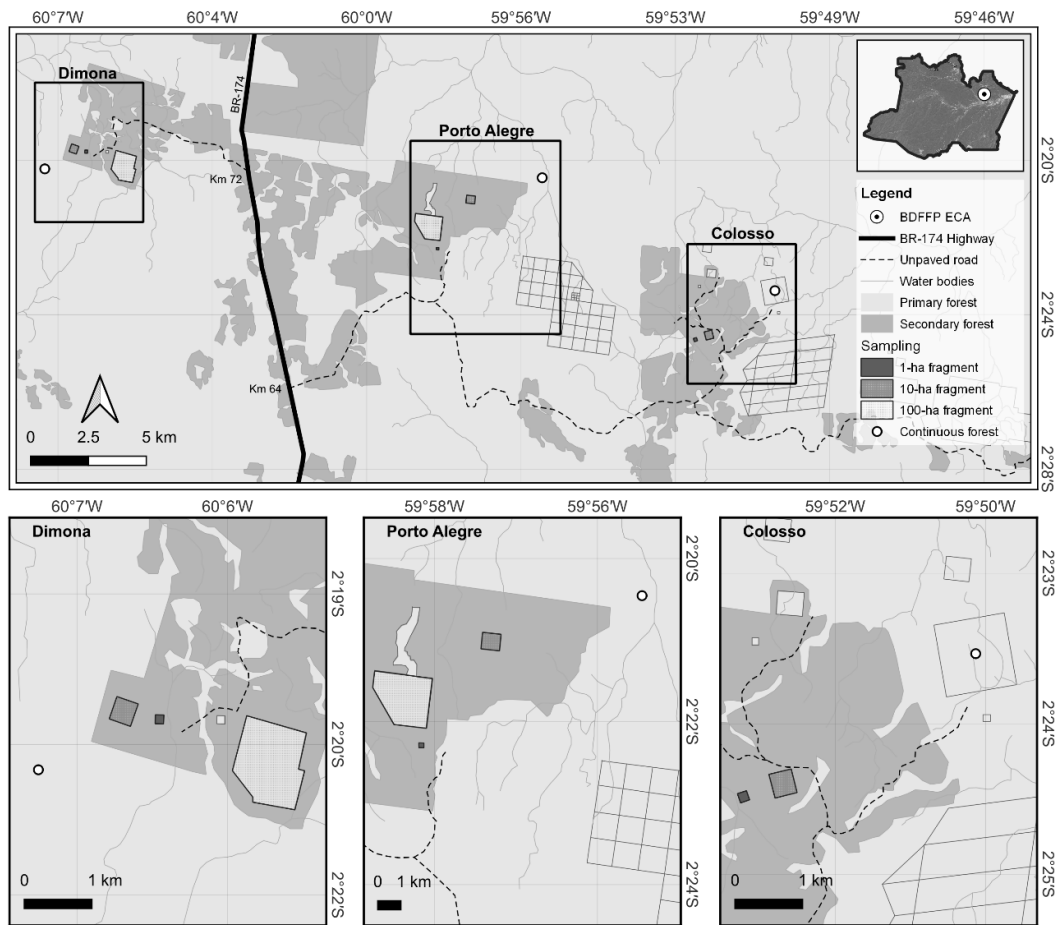
104 We hypothesized that even 42 years after forest fragmentation, it would be  
105 possible to detect a change in the composition of palm assemblages throughout their life  
106 stage structures. We also predicted that the number of species and the population density  
107 of palms would be lower in isolated areas, mainly in smaller forest fragments. Thus, a  
108 decline of most palm populations and a possible local extinction of some species may  
109 occur, especially in smaller forest fragments.

## 110 **Material and Methods**

### 111 *Study area*

112 The study was carried out in the Area of Relevant Ecological Interest Biological  
113 Dynamics of Forest Fragments Project (ARIE BDFFP; Fig. 1), which has reserves located  
114 in extensive continuous forests and reserves that were experimentally isolated between  
115 1980 and 1984. The isolated forest fragments are squared reserves between 100 and 350

116 m from the nearest continuous forest. Initially, each forest fragment was surrounded by  
 117 pastures, but they are currently embedded in a matrix of regenerating secondary forests.  
 118 The adjacent intact forests were maintained as control areas. ARIE BDFFP is  
 119 located *ca.* 100 km north of Manaus; it has clay soil in plateaus and sandy soil in the  
 120 valleys (Quesada et al., 2011), with a hot and humid climate (Fisch et al., 1996), and an  
 121 average annual rainfall of 2,300 mm (Carvalho, 2012). Vegetation is classified as a dense  
 122 rainforest with a closed canopy at an average height of 35 m and emerging trees reaching  
 123 up to 50 m. Stemless palms dominate the typically more open understory, and some  
 124 species of arboreal palms can reach up to 20 m in height (Scariot, 1996).



125

Geographic Coordinate System • Datum SIRGAS 2000 • Main scale 1:190.000 • Data source: DNIT, IBGE, Natural Earth Data, and BDFFP • Prepared by Caroline Vasconcelos (2023)

126 **Fig 1.** ARIE BDFFP in north of Manaus, Central Amazon. In detail, the three study sites, Dimona,  
127 Porto Alegre, and Colosso. Each site has forested fragment reserves of 1, 10, and 100 ha, marked  
128 by polygons closed by solid lines, except Colosso, which has no 100-ha reserve.

### 129 *Taxonomic group*

130 Palms (Arecaceae) are one of the world's most abundant and diverse taxonomic  
131 groups, comprising species representing a variety of life histories, reproductive  
132 characteristics, and habitat preferences (Muscarella et al., 2020). However, the highest  
133 species concentration is typically found in areas with a hot and humid climate (Kahn &  
134 Castro, 1985; Balslev et al., 2011). In terra firme-type forests in the Central Amazon, the  
135 understory is characterized by high diversity and abundance of palms (Montúfar et al.,  
136 2011). Specifically, palms are part of the sub-canopy of plateaus and steep slopes or  
137 compose the canopy of valleys where the forest structure may be lower in height and  
138 more open. In 1989, Henderson and a working team recorded 11 genera and 30 species  
139 of palms in a permanent plot of 10 ha in a continuous forest of the BDFFP (unpublished  
140 study). Scariot (1996), after a spatially broader palm inventory in the BDFFP, recorded  
141 11 genera and 36 species of palms.

### 142 *Data Assembly*

143 In 1993-94, Scariot randomly established but restricted to topographically flatter  
144 areas, ten 20 x 20 m permanent plots, in forest fragments of 1, 10, and 100 ha in the  
145 Dimona, Porto Alegre, and Colosso sampling sites, and adjacent continuous forest. At  
146 each site, there was one representation of each size of forest fragment and continuous  
147 forest, except at the Colosso site, where no 100-ha reserve was established, totaling 11  
148 reserves studied (see Fig. 1). In each plot, all palm seedlings, juveniles, and adults were  
149 located, recorded, and identified to the species level.

150           During the inventory conducted in 2021-22, we also mapped and marked all adult  
151 palms using a metal identification tag. For more details on the sampling design, see  
152 Scariot (1999). Therefore, the first inventory was carried out 15 years after the initial  
153 isolation of forest fragments, and the second inventory was conducted ca. 28 years later  
154 (i.e., 42 years after forest fragmentation). To avoid pseudo-replications in the statistical  
155 analyses, the ten plots sampled in each fragment and adjacent continuous forest were  
156 summarized into a single data set.

157           Several taxonomic updates were published during the time between the two  
158 inventories. Accordingly, several names of palm species found in time zero (T0-1994)  
159 were updated, as well as the emergence of new infra-specific varieties, such as *Bactris*  
160 *hirta* var. *hirta* Mart. and *Bactris hirta* var. *pectinata* (Mart.) Govaerts. However, the  
161 emergence of varieties was not considered in the analysis because there was no way to  
162 reassemble this information in the first survey. Likewise, species identified only at the  
163 genus level in the first and second inventory may not correspond to the same  
164 morphotypes. In these cases, we also consider only the genus for statistical analyses.

#### 165           *Ontogenetic Stages*

166           We classified arborescent palms or those with stemless (underground stems)  
167 following the same criteria adopted by Scariot (1996). Adult individuals were those  
168 showing any evidence of current or previous reproduction, such as the presence of  
169 reproductive scars and leaves composed of fully formed leaflets. Juvenile individuals,  
170 with or without aerial stems, were identified by the presence of leaflets but without  
171 evidence of current or previous reproduction. Seedlings were identified as plants lacking  
172 an aerial stem or had yet to produce fully mature leaves typical of any focal species.

173           It is important to note that for some palm species, the classification into  
174 ontogenetic stages, especially for seedlings, may need to be revised, requiring a more  
175 robust approach. For example, *Bactris hirta* Mart. and its two variations, *Bactris hirta*  
176 var. *pectinata* (Mart.) Govaerts and *Bactris hirta* var. *hirta* Mart. are indistinguishable  
177 when immature. Therefore, in the current study, these taxa were assigned to the species  
178 *Bactris hirta* when examining its seedling life stage.

### 179           *Statistical analysis*

180           We used a BACI (before-after-control-impact) design to assess the effect of forest  
181 fragmentation and forest fragment size (1, 10, 100 ha) on the number of palm species,  
182 total abundance, and species composition for each ontogenetic stage (adult, juvenile,  
183 seedling). The fixed predictor variables were 'time' (T0 = 1994 and T1 = 2022), 'site'  
184 (continuous forest and fragment or fragment size), and the interaction between them. To  
185 evaluate species composition, we used Generalized Linear Models (GLM) to analyze  
186 multivariate abundance data from *manyglm* function with a negative binomial distribution  
187 (Warton et al., 2012) in the *mvabund* package (Wang et al., 2012). The *p*-value was  
188 calculated from 999 bootstraps using the *ANOVA.manyglm* function. To visualize the  
189 spatial and temporal composition of palm assemblages from different ontogenies in the  
190 continuous forest and forest fragments, we employed the first two ordination axes of the  
191 principal coordinate analysis (PCoA) built from the *vegan* package (Oksanen et al., 2022)  
192 and also, we used the Bray-Curtis dissimilarity matrix. We corrected negative eigenvalues  
193 using the Cailliez method (Legendre & Legendre, 2012).

194           The effects of forest fragmentation and forest fragment size on the abundance and  
195 number of palm species were evaluated for each ontogenetic stage using generalized  
196 linear mixed models (GLMM) with the Poisson distribution of the *glmmTMB* package,

197 which fit well to the data count with many zeros (Brooks et al., 2017). The fixed predictor  
198 variables were 'time' (T0 = 1994 and T1 = 2022), 'site' (control and fragment or fragment  
199 size), and the interaction between them, and the random variable was the sampling  
200 location (fragment). The effect of interacting variables was evaluated using likelihood-  
201 ratio tests. For models with significant interaction of the predictor variables, we assessed  
202 pairwise comparison between the 'time' × 'fragment' and 'time' × 'fragment size' using the  
203 *lsmeans* function from the *emmeans* package (Lenth, 2021) followed by Tukey (HSD)  
204 tests.

205 We selected common species with better relative distribution (in % of the  
206 coverage area for all study sites) and high relative abundance at both study times in each  
207 ontogenetic stage to evaluate the effect of forest fragmentation and fragment size. The  
208 selection resulted in nine species for the adult stage (91% coverage of the studied area  
209 and 85% of total abundance), 11 species for juveniles (86% coverage of the studied area  
210 and 82% of total abundance), and 14 species for seedlings (86% coverage of the studied  
211 area and 95% of total abundance). The list of species in each ontogenetic stage can be  
212 seen in the supplementary material (Supplementary Table 1). Continuous forest and forest  
213 fragments and fragment size were compared for each species using GLMMs as previously  
214 described.

215 We also used this analysis to evaluate the trajectory of the most common species  
216 in each ontogenetic stage regarding the effect of forest fragmentation. For each period  
217 inventoried (1994 - T0 and 2022 - T1), we made a spatial comparison between the  
218 continuous forest (CF) and forest fragments (FF), and for the interaction between the  
219 periods (1994 × 2022), a temporal comparison for both the continuous forest (CF) and  
220 the forest fragments (FF). Each species presented a neutral, negative, or positive trajectory  
221 in response. A neutral trajectory indicates that the species did not present significant

222 changes in its abundance for the comparisons; the negative trajectory indicates that the  
223 species presented significant changes, decreasing its abundance in forest fragments and/or  
224 over time; the positive trajectory indicates that the species presented significant changes,  
225 increasing its abundance in forest fragments and/or over time. All statistical operations  
226 were performed using the computer program R 4.2.3 (R Core Team, 2023).

## 227 **Results**

228 *Overview data:* In 1994 (T0), 23,225 palms were recorded, of which 1,274 were  
229 adults, 4,584 juveniles, and 17,367 seedlings, distributed among 11 genera, 33 spp., and  
230 three morphotypes. *Ca.* 28 years after the first survey and 42 years after the creation of  
231 forest fragments, we recorded 14,426 palms. Of this total, 3,542 were adults, 1,670 were  
232 juveniles, and 9,214 were seedlings (see more details in Supplementary Table 2). The  
233 palms were classified into 11 genera and 34 spp., and other three morphotypes were  
234 recorded during the inventory.

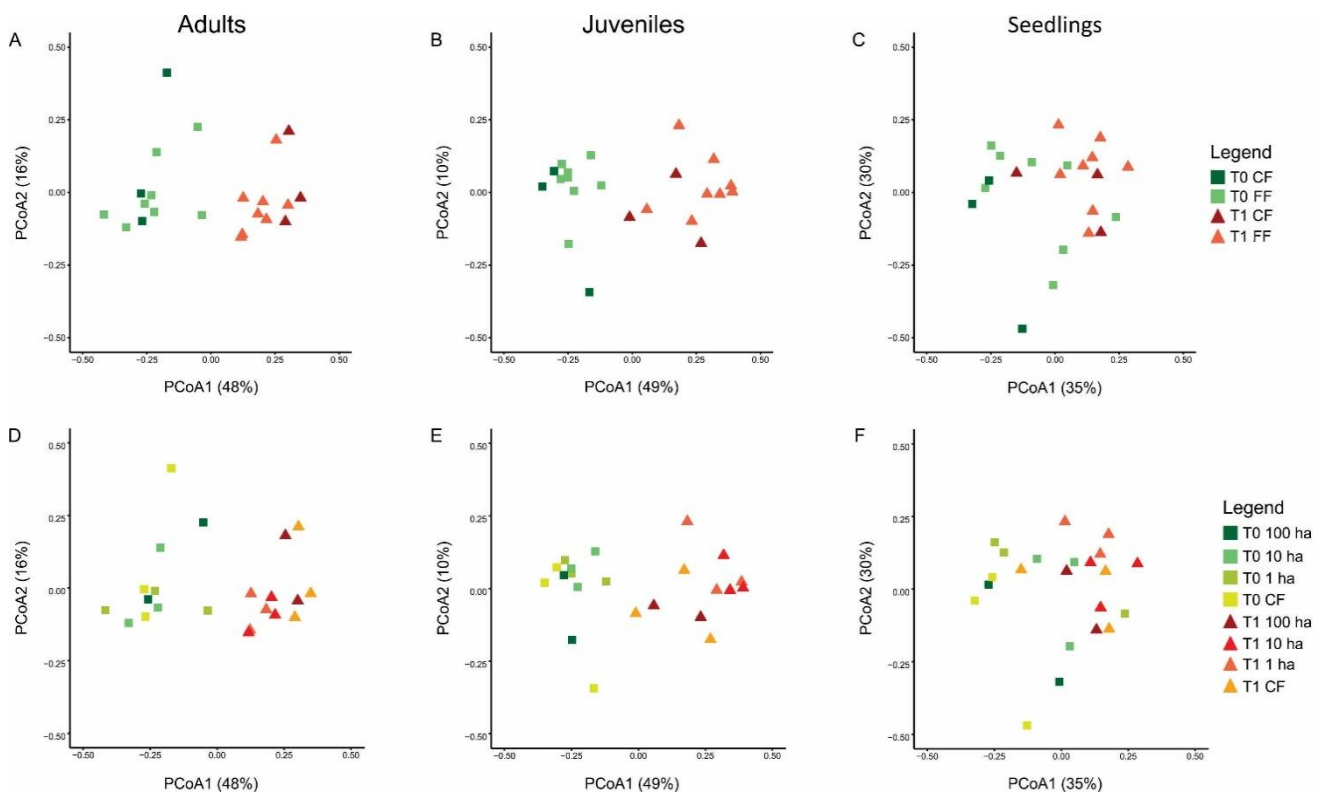
235 *Effect of forest fragmentation:* Species composition has changed over time, both  
236 in continuous forests and forest fragments, but there was interaction of time and site  
237 (Table 1). The PCoA ordinations showed an evident temporal separation of assemblages  
238 for adults and juveniles but not so strong for seedlings (Figure 2 A-C). Time influenced  
239 the number of species for adults and juveniles, but no effect of site or interaction was  
240 recorded (Table 1). Over time, more species showed an increase in the number of adults  
241 and a decrease in the number of species with juveniles in T1.

242 The time and site interaction affected abundance for all ontogenetic stages (Table  
243 1). Adult abundance was highest in continuous forests in T1, followed by forest fragments  
244 in T1, continuous forests in T0, and forest fragments in T0 (Table S3; Figure 3A). On the  
245 other hand, the effect of forest fragmentation on juveniles and seedlings was opposite to



246 that on adults; there was a higher abundance in the continuous forest in T0, followed by  
 247 forest fragments in T0, continuous forest in T1, and forest fragments in T1 (Table S3;  
 248 Figure 3C and 3E). This pattern indicates that the effect of forest fragmentation was  
 249 evident in both periods, with greater abundance in continuous forests compared to forest  
 250 fragments. Over time, the abundance of the palm assemblage was severely reduced by  
 251 62%. However, the reduction was not homogeneous between ontogenetic classes since  
 252 there was a 53% and 36% decrease for seedlings and juveniles, respectively. At the same  
 253 time, there was an important increase of 278% among adults.

254

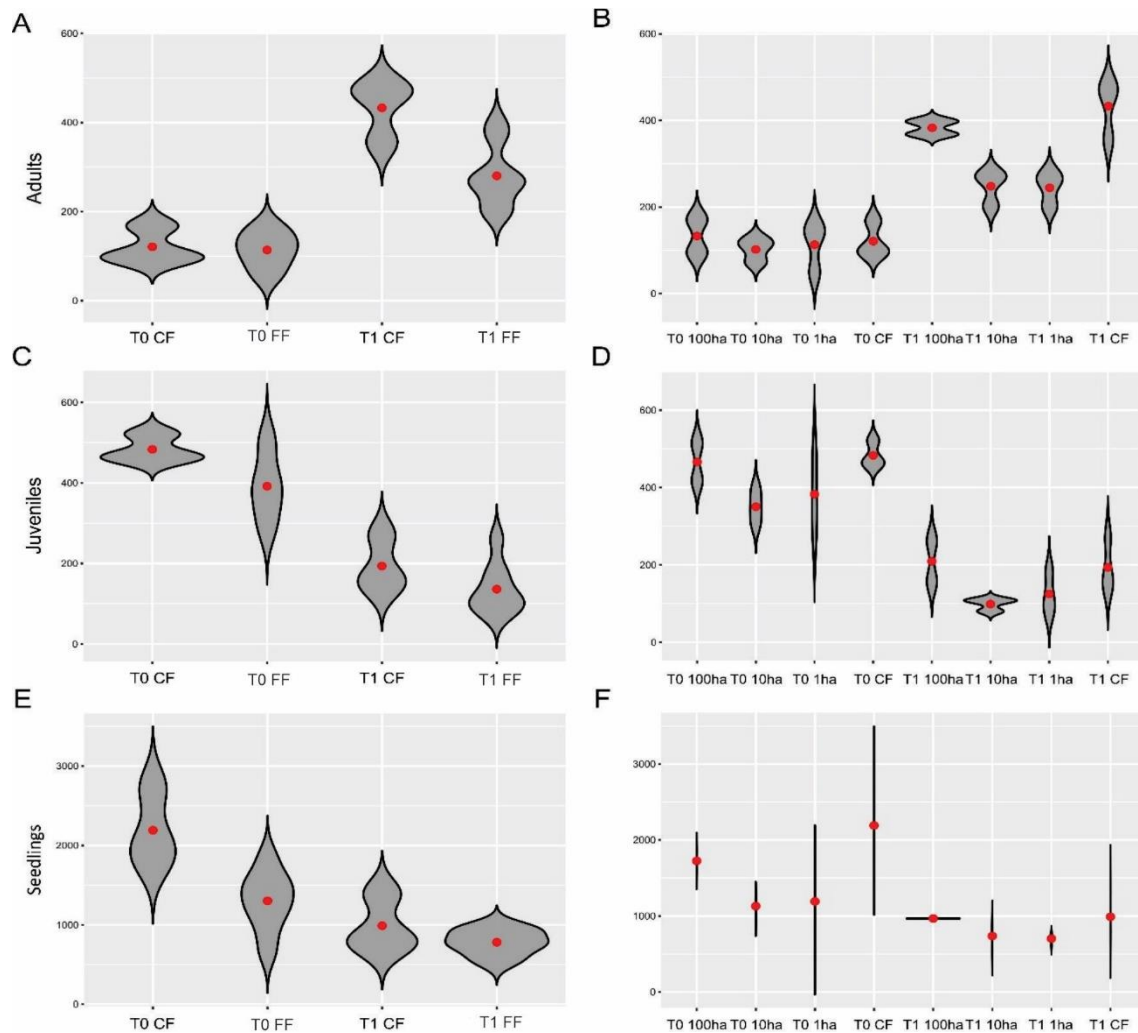


255 **Fig 2.** The first two axes of principal coordinate analysis (PCoA) to assess the effect of forest  
 256 fragmentation (A, B, C) and the effect of forest fragment size (D, E, F) on changing the abundance  
 257 and composition of adult individuals (A and D), juveniles (B and E), and seedlings (C and F) of  
 258 species from the Arecaceae family surveyed in 1994 and 2022 in areas of continuous forest and  
 259 forest fragments of 1, 10 and 100-ha in the study sites of the Biological Dynamics of Forest  
 260 Fragments Project (BDFFP), Central Amazon, Brazil.

261 **Table 1.** GLMM and *mvabund* analyze to evaluate the influence of location, time, and location  $\times$  time interaction on the number of species, abundance, and  
 262 species composition in the three ontogenetic stages (adult, juvenile and seedling) of species of the Arecaceae family in continuous forests and fragments forests  
 263 of 100, 10, and 1 ha in two sampling periods (1994 and 2022) in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP), Central Amazon,  
 264 Brazil. Significant results ( $P < 0.05$ ) are highlighted in bold.

Response variables	Forest Fragmentation						Fragment Size					
	Location		Time		Location $\times$ Time		Location		Time		Location $\times$ Time	
	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>
# of spp.: adults	0.69	0.41	7.35	<b>0.01</b>	0.04	0.85	1.33	0.72	7.35	<b>0.01</b>	0.33	0.96
Abundance: adults	128.56	<b>&lt;0.0001</b>	1111.53	<b>&lt;0.0001</b>	283.26	<b>0.0001</b>	207.22	<b>&lt;0.0001</b>	1111.53	<b>&lt;0.0001</b>	37.17	<b>&lt;0.0001</b>
# of spp.: juveniles	1.55	0.21	8.46	<b>0.004</b>	0.38	0.54	2.99	0.39	8.46	<b>0.004</b>	2.25	0.52
Abundance: juveniles	83.98	<b>&lt;0.0001</b>	1411.72	<b>&lt;0.0001</b>	552.82	<b>0.02</b>	198.61	<b>&lt;0.0001</b>	1411.72	<b>&lt;0.0001</b>	35.82	<b>&lt;0.0001</b>
# of spp.: seedlings	0.39	0.53	0.08	0.78	0.01	0.94	16.86	0.64	0.08	0.78	0.27	0.97
Abundance: seedlings	1010.5	<b>&lt;0.0001</b>	2341.6	<b>&lt;0.0001</b>	109.50	<b>&lt;0.0001</b>	1551	<b>&lt;0.0001</b>	2341.6	<b>&lt;0.0001</b>	124.68	<b>&lt;0.0001</b>
Species composition	<i>Wald</i>	<i>P</i>	<i>Wald</i>	<i>P</i>	<i>Wald</i>	<i>P</i>	<i>Wald</i>	<i>P</i>	<i>Wald</i>	<i>P</i>	<i>Wald</i>	<i>P</i>
Adult spp.	7.37	<b>0.01</b>	15.49	<b>0.01</b>	4.85	0.15	7.37	<b>0.01</b>	15.49	<b>0.01</b>	4.85	0.1
Juvenile spp.	8.21	<b>0.01</b>	17.32	<b>0.01</b>	4.39	0.24	14.37	<b>0.01</b>	17.32	<b>0.01</b>	7.32	0.24
Seedling spp.	10.01	<b>0.01</b>	14.63	<b>0.01</b>	3.89	0.75	18.32	<b>0.01</b>	14.63	<b>0.01</b>	6.79	0.88

265



266

267 **Fig 3.** Effect of forest fragmentation (A, C, E) and size of the forest fragment (B, D, F) on the  
 268 abundance of palms found in the adult, juvenile, and seedling ontogenetic stages in areas of  
 269 continuous forest (CF) and forest fragments (FF) of 1, 10, and 100 ha in the two sampling periods  
 270 (T0-1994 and T1-2022) in the reserves of the Biological Dynamics of Forest Fragments Project  
 271 (BDFFP), Central Amazon, Brazil.

272 *Effect of forest fragment size:* As found for forest fragmentation, time and site  
 273 interaction on the effect of forest fragment size was restricted to abundance at all  
 274 ontogenetic stages (Table 1). The decline in the palm abundance was more pronounced in  
 275 the 1 and 10 ha forest fragments (Table 1; Figure 3 B, D, F). By contrast, the palm

276 abundance in the 100 ha forest fragments was similar to that of adjacent continuous  
277 forests, particularly for juveniles and seedlings (Table S5; Figure 3 B, D, F).

278 *Species response to fragmentation and forest fragment size:* The effect of forest  
279 fragmentation and fragment size on the abundance of the most common palm species,  
280 based on local and time interaction, revealed that the isolation of forest fragments affected  
281 each ontogenetic stage in a species-specific way (Supplementary Table 6). For only the  
282 effect of forest fragmentation, we observed that in the adult and juvenile ontogenetic  
283 phases, only three of the most common species showed significance for local and  
284 temporal interaction. At the same time, for seedlings, this number increased for five  
285 species (Supplementary Table 6). Of the species that did not show the influence of local  
286 and time interaction, time *per se* has influenced more species than site. Five adult, seven  
287 juvenile, and eight seedling species presented distinct temporal abundance. While  
288 considering solely site, five adult, four juvenile, and seven seedling species were  
289 influenced by forest fragmentation.

290 For the effect of forest fragment size, the interaction between site and time  
291 influenced more species than forest fragmentation *per se*. Among adults, six species were  
292 influenced by the interaction, while five and nine species among juveniles and seedlings  
293 were influenced, respectively. The unique influence of site or time has been found for  
294 almost the same species at all ontogenetic stages (Supplementary Table 6).

295 Considering all ontogenetic stages in both inventories, the response to forest  
296 fragmentation of the most common species was neutral (17 spp. in 1994 and 15 spp. in  
297 2022) or negative (14 spp. in 1994 and 17 spp. in 2022; Table 2). In 1994, most negative  
298 effects were found for seedlings (for 9 spp.). In 2022, the negative effects of forest  
299 fragmentation were found mainly among adult species (7 spp.) and seedlings (6 spp.).

300 *Geonoma aspidiifolia* and *Astrocaryum sociale* were the most negatively affected species,  
 301 with a reduction in abundance in all ontogenetic stages (except for *A. sociale* for the adult  
 302 stage) in both inventories. Only *Geonoma deversa*, *Oenocarpus minor*, and *Syagrus*  
 303 *inajai* increased abundance at some ontogenetic stage in both inventories.

304 In the temporal comparison between inventories, most species in the seedling and  
 305 juvenile stages decreased abundance in the continuous forest (17 spp.) and the forest  
 306 fragments (20 spp.; Table 2). On the other hand, practically all adults had an increased  
 307 abundance in forest fragments and continuous forests. *Bactris gastoniana* was the species  
 308 with the most positive trajectory over time, with an increased abundance of adults and  
 309 seedlings in the forest fragments and continuous forest in the second inventory.

310 **Table 2.** Summarized results of the GLMM analysis for the effect of forest fragmentation after  
 311 two inventories (1994 and 2022) and considering the interaction with time (1994×2022) for  
 312 common palm species in each ontogenetic stage: Adult (A), Juvenile (J) and Seedling (S) in areas  
 313 of Continuous Forest (CF) and Forest Fragments (FF) of the Biological Dynamics of Forest  
 314 Fragments Project (BDFFP) in Central Amazon, Brazil. The result for each year is the spatial  
 315 comparison between CF and FF, while the interaction between inventories represents the temporal  
 316 comparison for CF and FF. Zero (0) indicates a neutral effect after forest fragmentation and no  
 317 temporal effect; the negative sign (-) indicates that the species showed a significant reduction in  
 318 its abundance due to forest fragmentation and/or over time; the positive sign (+) indicates that the  
 319 species presented a significant positive change, increasing its abundance and, consequently being  
 320 favored by the isolation of forest fragments and/or over time. Blank results indicate that the  
 321 species were not considered for analyzing that specific ontogenetic stage because they were rare,  
 322 not very abundant, or distributed in clusters.

	1994 (T0)			2022 (T1)			1994 × 2022					
	CF × FF			CF × FF			CF		FF			
Palm species	A	J	S	A	J	S	A	J	S	A	J	S

<i>Astrocaryum gynacanthum</i>	0	0	-	0	0	-	+	0	-	+	0	-
<i>Astrocaryum sociale</i>	0	-	-	-	-	-	+	-	0	+	-	-
<i>Attalea attaleoides</i>	0	0	0	-	0	0	+	-	-	+	-	-
<i>Bactris acanthocarpa</i> var. <i>exscapa</i>	0	0	-	-	-	0	+	-	-	+	-	-
<i>Bactris acanthocarpa</i> var. <i>intermedia</i>	0			-			+			0		
<i>Bactris gastoniana</i>	0	0	-	-	0	0	+	0	0	+	0	+
<i>Bactris hirta</i>	0	-		-	-		+	-		+	-	
<i>Bactris simplicifrons</i>			0			0			-			-
<i>Euterpe precatoria</i>			0			-			0			0
<i>Geonoma aspidiifolia</i>	-	-	-	-	-	-	0	-	-	0	-	-
<i>Geonoma deversa</i>	0	+	0	0	0	0	+	0	-	+	-	-
<i>Iriartella setigera</i>			-			-			-			-
<i>Oenocarpus bacaba</i>		0	-		0	-		+	-		0	-
<i>Oenocarpus bataua</i>			-			0			-			-
<i>Oenocarpus minor</i>		-	-		0	+		-	-		-	-
<i>Syagrus inajai</i>		+	+		0	+		0	-		-	-

323

## 324 Discussion

325 *Effect of forest fragmentation and forest fragment size:* We generally found a  
326 reduction in the number of individuals in palm assemblages after forest fragmentation,  
327 which is associated with the reduction in the forest fragment size. Palms have long life  
328 cycles (Henderson, 2002); 15 years since forest fragmentation seemed insufficient to  
329 significantly affect the adult ontogenetic stages, but juvenile and seedling stages were  
330 negatively affected, mostly in smaller forest fragments. Thus, adult palms may have  
331 needed more time to respond to these changes (Scariot, 1996), generating a phenomenon  
332 called extinction debt (Jackson & Sax, 2010). Still, juveniles and especially seedlings, the  
333 most vulnerable life stages (Scariot, 1996), already have shown a drastic increase in  
334 mortality, possibly due to increases in solar radiation (Saunders et al., 1991), litterfall,  
335 trampling (Echeverría et al., 2007), and decreases in water availability near the edges  
336 (Camargo & Kapos 1995).

337 The second survey finds that forest fragmentation is still a vector of persistent  
338 modification, as in addition to the continued reduction in abundance in the initial

339 ontogenetic stages, the effects also reached adult palms. However, even though the  
340 abundance of seedlings found was greater than that of juveniles, the latter were not  
341 superior to adults, contradicting the staggered pattern typically found in native forests, a  
342 strategy that guarantees a viable reproductive population (Giroldo & Scariot, 2015) and  
343 which was found in the first inventory.

344         The higher values of abundance found in continuous forests and the stability of  
345 palm assemblies evidenced in censuses such as the study by Olivares et al. (2017) in the  
346 western Amazon indicate that the decrease in palm abundance resulted from the isolation  
347 of the areas. The trend we observed in our study may have been due to demographic  
348 stochasticity, which is important mainly in smaller populations (Aguilar et al., 2008), and  
349 environment stochasticity as the loss of specific microhabitats and reduction of available  
350 habitats (Saunders et al., 1991). These indicators are more accentuated in smaller forest  
351 fragments than larger ones (Saunders et al., 1991; Haddad et al., 2015).

352         However, temporally, unlike the early stages, which saw a decrease in their  
353 abundance, the adults showed an increase in their number of individuals. Thus, increased  
354 adult population density may be a result of adult persistence as well as recruitment from  
355 other life stages, favored by increased formation of extensive gaps due to forest isolation  
356 (Svenning, 1998; Rodrigues & Nascimento, 2006), El Niño events and other climatic  
357 anomalies throughout the time frame of this study (Slik, 2004; Hansen et al., 2020), as in  
358 the significant droughts of 1998 and 2005 (Slik, 2004; Phillips et al., 2009). We cannot  
359 specify the age of each registered adult, but indeed, there was an accumulation of adults  
360 from different cohorts and lower mortality. However, reduced densities in the seedling  
361 and juvenile life stages indicated that although adults may be reproducing, the  
362 establishment of new individuals is persistently hindered (Baez & Balslev, 2007).

363           The disturbance from the isolation of forest fragments can affect palm  
364 assemblages directly and indirectly (Arroyo-Rodríguez et al., 2007), in an immediate way  
365 or not. As a cascade effect, forest fragmentation reduces habitat quality as foraging area  
366 and food availability to seed dispersers (Scariot, 1999; Galetti et al., 2006), consequently  
367 reducing opportunities for seed germination and decreasing seedling establishment.  
368 Furthermore, increased tree or debris fall (Montúfar et al., 2011) may increase seedling  
369 mortality (Rodrigues et al., 2014). Decreased seedling abundance reduces opportunities  
370 for the transition to the juvenile stage, which may lead to a following decline in adult  
371 abundance (Santos et al., 2016). The consequence is the loss of population viability and  
372 local ultimate extinction (Arroyo- Rodríguez et al., 2007), reducing palm diversity locally  
373 (Benitez-Malvido & Martinez-Ramos, 2003). We did not find such an extreme phase, but  
374 a sharp population decline could lead to this process over a few more decades (Turner et  
375 al., 1996; Jackson & Sax, 2010; Lueder et al., 2022).

376           The differences in palm abundances between the first and second inventory in  
377 continuous forests indicate that factors other than forest fragmentation may influence  
378 palm assemblages. Although the study's intent was not to evaluate the impacts of climate  
379 change, the changes in palm assembly in intact forests may be of concern with the  
380 increased frequency of droughts and flood periods in Central Amazon (Blach-Overgaard  
381 et al., 2009; Flores et al., 2024). Melo Neto et al. (2014; article in preparation), in a 10-  
382 ha plot of intact forest in the same Conservation Unit as our study, found, in a 30-year  
383 interval, that the total density of palms increased by 79%, leveraged by increased density  
384 in 83% of the presence of palm species, they also recorded three new species for the plot.  
385 These changes can represent the natural dynamics of the assembly or be associated with  
386 stochastic events and more complex phenomena that are difficult to detect and may be  
387 related to broader climate changes (Laurance et al., 2014).



388           Despite the temporal change in the number of species and both the effect of time  
389 and local for the composition, the non-relationship between time and location may be  
390 explained because the adjacent continuous forests or the secondary forested matrix acting  
391 as a source of propagules for the fragments (Laurance & Vasconcelos, 2009; Ferreira et  
392 al., 2017). In addition to the particularities of the landscape and metapopulation dynamics,  
393 some species can remain in fragmented areas simply because part of their population is  
394 resistant to environmental changes and has specific longevity (Melo Neto et al., 2024;  
395 article in preparation), causing a delay in extinction (Jackson & Sax, 2010). However,  
396 these surviving individuals may be 'living dead' or 'ghosts' as they are ineffective in  
397 maintaining their populations (Saunders et al., 1991; Scariot, 1996). Alternatively, even  
398 being effectively reproductive, many of their descendants did not resist the environmental  
399 changes in the fragmented areas, as demonstrated by the decrease in the number of  
400 seedlings recorded in this study. This result, however, differs from the findings of  
401 Bernacci et al. (2006), who found significant changes in the composition and the numbers  
402 of trees between a large reserve (>10,000 ha) and small forest fragments, although the  
403 number of species did not vary.

404           Smaller forest fragments, in turn, when isolated and have their abiotic and biotic  
405 characteristics altered, especially considering that the edge effect can penetrate the entire  
406 forest fragment (Baez & Balslev, 2007; Nunes et al., 2022), lose the original  
407 microclimatic conditions and forest structure. With so many environmental changes, local  
408 species may disappear, allowing new colonization based on the new conditions, changing  
409 the natural environmental balance of the place (Scariot, 1998). As observed, this  
410 replacement of species composition may not necessarily change the number of species in  
411 the new environment.

412           *Species response to fragmentation and forest fragment size:* The response time of  
413 each species after environmental disturbance is not related only to its intrinsic  
414 characteristics but also to the time it takes until the new environmental conditions start to  
415 act. The time frame for palms to show the effects of the new environment differs across  
416 species and ontogenetic stages (Scariot, 1999). The adult life stage may take longer to  
417 respond depending on its biological characteristics, such as its life expectancy and  
418 resistance to disturbances (Scariot, 1999). As in any environment, most (common) species  
419 present similar conditions. However, *Geonoma aspidiifolia* was the only species with  
420 adult individuals already affected 15 years after the isolated areas. Species with aerial  
421 stems tend to be damaged more easily, in addition to being more exposed to winds and  
422 lightning or other unfavorable weather conditions, such as high temperatures and low air  
423 humidity. Conversely, underground stems give the individual more resistance, as in  
424 *Astrocaryum sociale* and *Attalea attaleoides*, which showed the adverse effects only 42  
425 years after forest fragmentation.

426           The juveniles and seedlings were the life stages most negatively impacted since  
427 the first inventory. The increased abundance of juveniles of *Geonoma deversa* and  
428 *Syagrus inajai* and seedlings of *S. inajai* 15 years after forest fragmentation was not  
429 observed in the second inventory; the juvenile stage of both species was neutral to forest  
430 fragmentation. These species are typical of open and anthropized environments  
431 (Henderson et al., 1995; Briceño et al., 2021) and adapted to water storage (Briceño et  
432 al., 2021).

433           Over time, the permeability of the matrix may change, which may or may not  
434 contribute to mitigating the consequences of forest fragmentation (Laurance et al., 2002),  
435 such as dispersal or fire. Initially, in our study, with the isolation of the areas, the matrix  
436 was composed of pastures, which over the years became secondary forest. The greater

437 the similarity between the matrix and the vegetation that makes up the forest fragments,  
438 the more significant the contribution of this filter to the patterns found in the forest  
439 fragments and possible resilience (Pires et al., 2006). A secondary forest can act as a  
440 refuge and reservoir of biodiversity. From the moment seedlings and juvenile palms are  
441 recruited, for example, they may return to the environmental conditions of mature forests  
442 (Norden et al., 2009). It is essential to note that the studied fragmented forests were  
443 inserted into a largely forested landscape, unlike the fragments in the eastern Amazon or  
444 the Brazilian Atlantic Forest. Therefore, the conclusions obtained by our study may be  
445 even more severe for other regions.

446 Although Arecaceae is pantropical and generalist family, the species are limited  
447 by different conditions, such as topography (Raupp & Cintra, 2011), soil (Figueiredo et  
448 al., 2017), hydrology (Schiatti et al., 2013), altitude and even due to the composition of  
449 species in the surrounding area (Scariot, 1996; Balslev et al., 2011; Olivares et al., 2017).  
450 Thus, only large areas can enjoy these broad attributes, including the most significant part  
451 of palm species. Therefore, only extensive, and protected areas can best contemplate the  
452 conservation of what is one of the most important and abundant botanical families in the  
453 Amazon (Cintra et al., 2005; Kahn & Granville, 2012; Lueder et al., 2022).

454

#### 455 **References**

- 456 Aguilar, R.; Quesada, M.; Ashworth, L.; Herrerias-Diego, Y. & Lobo, J. (2008). Genetic  
457 consequences of habitat fragmentation in plant populations: susceptible signals in  
458 plant traits and methodological approaches. *Molecular Ecology*, 17(24), 5177–5188.  
459 doi:10.1111/j.1365-294x.2008.03971.x.
- 460 Antonini, Y.; Accacio, G. M.; Brant, A.; Cabral, B. C.; Fontenelle, J. C. R.; Nascimento,  
461 M. T.; et al. (2003). Insetos. In: Rambaldi, D. M.; Oliveira, D. A. S. (org.).

462 *Fragmentação de Ecossistemas: causas, efeitos sobre a biodiversidade e*  
463 *recomendações de políticas públicas*. Brasília: Ministério do Meio Ambiente. p. 239-  
464 273.

465 Arroyo-Rodríguez, V.; Aguirre, A.; Benítez-Malvido, J. & Mandujano, S. (2007). Impact  
466 of rain forest fragmentation on the population size of a structurally important palm  
467 species: *Astrocaryum mexicanum* at Los Tuxtlas, Mexico. *Biological Conservation*,  
468 138(1-2), 198–206. doi:10.1016/j.biocon.2007.04.016.

469 Baez, S. & Balslev, H. (2007). Edge effects on palm diversity in rain forest fragments in  
470 western Ecuador. *Biodivers Conserv* 16, 2201–2211. doi: 10.1007/s10531-007-9159-  
471 5.

472 Balslev, H.; Grandez, C.; Zambrana, N. Y. P.; Moller, A. L. & Hansen, S. L. (2008).  
473 Palmas (Arecaceae) útiles en los alrededores de Iquitos, Amazonía Peruana. *Revista*  
474 *Peruana de Biología*, v. 15, n. 3, p. 121-132. Universidad Nacional Mayor de San  
475 Marcos, Vicerectorado de Investigacion. doi:10.15381/rpb.v15i3.3343.

476 Balslev, H.; Kahn, F.; Millan, B.; Svenning, J.-C.; Kristiansen, T.; Borchsenius, F. et al.  
477 (2011). Species Diversity and Growth Forms in Tropical American Palm  
478 Communities. *The Botanical Review*, 77(4), 381–425 doi:10.1007/s12229-011-9084-  
479 x.

480 Benitez-Malvido, J. & Martinez-Ramos, M. (2003). Impact of Forest Fragmentation on  
481 Understory Plant Species Richness in Amazonia. *Conservation Biology*, 17(2), 389–  
482 400. doi:10.1046/j.1523-1739.2003.01120.x.

483 Bernacci, L. C.; Franco, G. A. D. C.; Arbocz, G. F.; Catharino, E. L. M.; Durigan, G. &  
484 Metzger, J. P. (2006). O efeito da fragmentação florestal na composição e riqueza de

485 árvores na região da Reserva Morro Grande (Planalto de Ibiúna, SP). *Revista do*  
486 *Instituto Florestal*, 18(1), 121-166.

487 Blach-Overgaard, A.; Svenning, J-C. & Balslev, H. (2009). Sensibilidade às mudanças  
488 climáticas da palmeira africana, *Hyphaene petersiana* Klotzsch ex Mart. (Arecaceae)  
489 – uma espécie-chave no sudeste da África. *Série de Conferências IOP: Ciências da*  
490 *Terra e do Meio Ambiente*, 8, 012014. doi:10.1088/1755-1315/8/1/012014.

491 Bodmer, R. & Ward, D. (2006). Frugivory in large mammalian herbivores. *Large*  
492 *Herbivore Ecology, Ecosystem Dynamics and Conservation*. p. 232-26. Cambridge  
493 University Press.

494 Briceño, A.; Jáuregui, D. & Stauffer, F. (2021). Root anatomy of Venezuelan species of  
495 *Geonoma* (Arecaceae: Arecoideae: Geonomateae). *Rodriguésia*. 72.  
496 doi:10.1590/2175-7860202172006.

497 Brooks, M. E.; Kristensen, K.; Van Benthem, K. J.; Magnusson, A.; Berg, C. W.; Nielsen,  
498 A.; Skaug, H. J., Maechler, M. & Bolker, B. M. (2017). glmmTMB balances speed  
499 and flexibility among packages for zero-inflated generalized linear mixed modeling.  
500 <https://cran.r-project.org/web/packages/glmmTMB/index.html>.

501 Camargo, J. L. C. & Kapos, V. (1995). Complex edge effects on soil moisture and  
502 microclimate in Central Amazonian Forest. *Journal of Tropical Ecology*. 11, 205–  
503 221.

504 Carvalho, J. S. (2012). Caracterização hidrogeológica da região a norte da cidade de  
505 Manaus, com base em informações geofísicas (resistividade elétrica), geológicas e  
506 geomorfológicas. Tese (Doutorado) - Curso de Clima e Ambiente, Instituto Nacional  
507 de Pesquisas da Amazônia (INPA), Manaus, 157 f.

508 Cheptou, P. O.; Hargreaves, A. L.; Bonte, D., & Jacquemyn, H. (2017). Adaptation to  
509 fragmentation: evolutionary dynamics driven by human influences. *Philosophical*  
510 *Transactions of the Royal Society B: Biological Sciences*, 372(1712).  
511 doi:10.1098/rstb.2016.0037

512 Cintra, R.; Ximenes, A. C.; Gondim, F. R. & Kropf, M. S. (2005). Heterogeneidade  
513 espacial florestal e riqueza, abundância e composição comunitária de palmeiras na  
514 floresta de Terra Firme, Amazônia Central. *Revista Brasileira de Botânica*, 28(1),  
515 75–84. doi:10.1590/s0100-84042005000100007.

516 Dantas, A.; Dantas, T. & Ribeiro Neto, J. (2022). Pioneer palm tree as an ecosystem  
517 engineer: Effects on ant community structure. *Austral Ecology*. 00. 1-16.  
518 doi:10.1111/aec.13239.

519 Echeverría, C.; Newton, A. C.; Lara, A.; Benayas, J. M. R. & Coomes, D. A. (2007).  
520 Impacts of forest fragmentation on species composition and forest structure in the  
521 temperate landscape of southern Chile. *Global Ecology and Biogeography*, 16(4),  
522 426–439. doi:10.1111/j.1466-8238.2007.00311.x.

523 Ewers, R. M. & Didham, R. K. (2006). Confounding factors in the detection of species  
524 responses to habitat fragmentation. *Biological Reviews*, 81(01), 117.  
525 doi:10.1017/s1464793105006949.

526 Ferraz, D. K. (2004). Ecologia de populações de *Lytocaryum hoehnei* (Burret) Toledo  
527 (Arecaceae) na Reserva Florestal do Morro Grande, Cotia, SP. Tese (Doutorado) -  
528 Universidade Estadual de Campinas, Campinas, 118 p.

529 Ferreira, P. I.; Paludo, G. F.; Chaves, C. L.; Bortoluzzi, R. L. C. & Mantovani, A. (2017).  
530 Potencial de fragmentos florestais inseridos dentro de floresta de exóticas para a

531 restauração da floresta com araucárias. *Ciência Florestal*, v. 27, n. 3, p. 1049-1060.  
532 Universidad Federal de Santa Maria. doi:10.5902/1980509828680.

533 Figueiredo, F. O. G.; Zuquim, G.; Tuomisto, H.; Moulatlet, G. M.; Balslev, H. & Costa,  
534 F. R. C. (2017). Beyond climate control on species range: The importance of soil data  
535 to predict distribution of Amazonian plant species. *Journal of Biogeography*, 45(1),  
536 190–200. doi:10.1111/jbi.13104.

537 Fisch, G.; Marengo, J. A. & Nobre, C. A. (1996). Clima da Amazônia. Climanálise-  
538 Boletim de Monitoramento e Análise Climática-Edição Comemorativa, v. 10.

539 Fischer, R.; Taubert, F.; Müller, M. S.; Groeneveld, J.; Lehmann, S.; Wiegand, T. & Huth,  
540 A. (2021). Accelerated forest fragmentation leads to critical increase in tropical forest  
541 edge area. *Science advances*, 7(37), doi: 10.1126/sciadv.abg7012.

542 Flores, B. M.; Montoya, E.; Sakschewski, B. et al. (2024). Critical transitions in the  
543 Amazon forest system. *Nature* 626. doi: 10.1038/s41586-023-06970-0.

544 Galetti, M.; Donatti, I. C.; Pires, S. A.; Guimarães, P. & Jordano, P. (2006). Seed survival  
545 and dispersal of an endemic Atlantic forest palm: the combined effects of defaunation  
546 and forest fragmentation. *Jornal Botânico da Sociedade Linneana*, 151(1), 141–149.  
547 doi:10.1111/j.1095-8339.2006.00529.x.

548 Giroldo, A. B. & Scariot, A. (2015). Land use and management affects the demography  
549 and conservation of an intensively harvested Cerrado fruit tree species. *Biological*  
550 *Conservation*, 191, 150–158. doi:10.1016/j.biocon.2015.06.020.

551 Haddad, N. M.; Brudvig, L. A.; Clobert, J.; Davies, K. F.; Gonzalez, A. et al. (2015).  
552 Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science*  
553 *Advances*, 1(2). doi:10.1126/sciadv.1500052.

- 554 Hansen, M. C.; Wang, L.; Song, X.-P.; Tyukavina, A.; Turubanova, S.; Potapov, P. V. &  
555 Stehman, S. V. (2020). The fate of tropical forest fragments. *Science Advances*, 6(11),  
556 eaax8574. doi:10.1126/sciadv.aax8574.
- 557 Henderson, A. (2002). *Evolution and ecology of palms*. New York Botanical Garden Press  
558 Bronx, NY.
- 559 Henderson, A.; Galeano, G. & Bernal, R. (1995). *Field Guide to the Palms of the*  
560 *Americas*. Princeton: University Press, Princeton.
- 561 Hill, J. L. & Curran, P. J. (2003). Area, shape and isolation of tropical forest fragments:  
562 effects on tree species diversity and implications for conservation. *Journal of*  
563 *Biogeography*, 30(9), 1391–1403. doi:10.1046/j.1365-2699.2003.00930.x.
- 564 Jackson, S. T. & Sax, D. F. (2010). Balancing biodiversity in a changing environment:  
565 extinction debt, immigration credit and species turnover. *Trends in Ecology &*  
566 *Evolution*, 25(3), 153–160. doi:10.1016/j.tree.2009.10.001.
- 567 Jose, S.; Gillespie, A. R.; George, S. J. & Kumar, B. M. (1996). Vegetation responses  
568 along edge-to-interior gradients in a high altitude tropical forest in peninsular India.  
569 *Forest Ecology and Management*, 87(1-3), 51–62. doi:10.1016/s0378-  
570 1127(96)03836-4.
- 571 Kahn, F. & Castro, A. (1985). The Palm Community in a Forest of Central Amazonia,  
572 Brazil. *Biotropica*, v. 17, n. 3, p. 210-216.
- 573 Kahn, F. & Granville, J. J. (2012). *Palms in forest ecosystems of Amazonia* (Vol. 95).  
574 Springer Science & Business Media.



575 Laurance, W. F. & Vasconcelos, H. L. (2009). Consequências ecológicas da fragmentação  
576 florestal na Amazônia. *Oecologia Brasiliensis*, v. 13, n. 03, p. 434-451.  
577 doi:10.4257/oeco.2009.1303.03.

578 Laurance, W. F.; Camargo, J. L. C.; Luizão, R. C. C.; Laurance, S. G.; Pimm, S. L.; Bruna,  
579 E. M. et al. (2011). The fate of Amazonian forest fragments: A 32-year investigation.  
580 *Biological Conservation*, 144(1), 56–67. doi:10.1016/j.biocon.2010.09.021.

581 Laurance, W. F.; Lovejoy, T. E.; Vasconcelos, H. L.; Bruna, E. M.; Didham, R. K.;  
582 Stouffer, P. C. et al. (2002). Ecosystem Decay of Amazonian Forest Fragments: a 22-  
583 year Investigation. *Conservation Biology*, 16(3), 605–618. doi:10.1046/j.1523-  
584 1739.2002.01025.x.

585 Laurance, W. F.; Nascimento, H. E. M.; Laurance, S. G.; Andrade, A. C.; Fearnside, P.  
586 M.; Ribeiro, J. E. L. & Capretz, R. L. (2006). Rain forest fragmentation and the  
587 proliferation of successional trees. *Ecology*, 87(2), 469–482. doi:10.1890/05-0064.

588 Laurance, W.; Andrade, A.; Magrach, A.; Camargo, J. L.; Campbell, M.; Fearnside, P.;  
589 Edwards, W.; Valsko, J.; Lovejoy, T. & Laurance, S. (2014). Apparent environmental  
590 synergism drives the dynamics of Amazonian forest fragments. *Ecology*. 95. 3018-  
591 3026. doi:10.1890/14-0330.1.

592 Legendre, P. & Legendre L. (2012). *Ecology Numérica*. 3ª ed. Elsevier.

593 Lenth, R.V. (2021). emmeans: Estimated Marginal Means, aka Least-Squares Means. R  
594 Package Version 1.6. 0]. Comprehensive R Archive Network (CRAN).

595 Liu, J.; Coomes, D. A.; Gibson, L.; Hu, G.; Liu, J.; Luo, Y.; Wu, C. & Yu, M. (2019).  
596 Forest fragmentation in China and its effect on biodiversity. *Biological Reviews*,  
597 94(5), 1636–1657. doi:10.1111/brv.12519.

598 Lueder, S.; Narasimhan, K.; Olivo, J.; Cabrera, D.; Jurado, J. G.; Greenstein, L. &  
599 Karubian, J. (2022). Functional traits, species diversity and species composition of a  
600 neotropical palm community vary in relation to Forest age. *Frontiers in Ecology and*  
601 *Evolution*, 10, 678125.

602 Ma, J.; Li, J.; Wu, W. & Liu, J. (2023). Global forest fragmentation change from 2000 to  
603 2020. *Nature Communications*, 14(1), 3752. doi: 10.1038/s41467-023-39221-x.

604 Melo Neto, P. R. et al. (2024). Dynamics of the palm assembly and its relationship with  
605 topography in terra firme forest in the Central Amazon [Article in preparation].

606 Montúfar, R.; Anthelme, F.; Pintaud, J.-C. & Balslev, H. (2011). Disturbance and  
607 Resilience in Tropical American Palm Populations and Communities. *The Botanical*  
608 *Review*, 77(4), 426–461. doi:10.1007/s12229-011-9085-9.

609 Murcia, C. (1995). Edge effects in fragmented forests: implications for conservation:  
610 implications for conservation. *Trends in Ecology & Evolution*, v. 10, n. 2, p. 58-62.

611 Muscarella, R.; Emilio, T.; Phillips, O. L.; Lewis, S. L.; Slik, F.; Baker, W. J. et al. (2020).  
612 The global abundance of tree palms. *Global Ecology and Biogeography*, p. 1-20.

613 Norden, N.; Chazdon, R. L.; Chao, A.; Jiang, Y.-H. & Vilchez-Alvarado, B. (2009).  
614 Resilience of tropical rain forests: tree community reassembly in secondary forests.  
615 *Ecology Letters*, 12(5), 385–394. doi:10.1111/j.1461-0248.2009.01292.x.

616 Nunes, M. H.; Camargo, J. L. C.; Vincent, G.; Calders K.; Oliveira, R. S.; Huete, A.;  
617 Moura, Y. M.; Nelson, B.; Smith, M. N.; Stark, S. C. & Maeda, E. E. (2022). Forest  
618 fragmentation impacts the seasonality of Amazonian evergreen canopies. *Nat*  
619 *Commun* 13, 917. doi:10.1038/s41467-022-28490-7.

620 Oksanen, J.; Simpson, G.; Blanchet, F.; Kindt, R.; Legendre, P.; Minchin, P.; O'Hara, R.;  
621 Solymos, P.; Stevens, M.; Szoecs, E.; Wagner, H.; Barbour, M.; Bedward, M.; Bolker,  
622 B.; Borcard, D.; Carvalho, G.; Chirico, M.; Caceres, M.; Durand, S.; Evangelista, H.;  
623 FitzJohn, R.; Friendly, M.; Furneaux, B.; Hannigan, G.; Hill, M.; Lahti, L.; McGlinn,  
624 D.; Ouellette, M. et al. (2022). *\_vegan: Community Ecology Package\_*. R package  
625 version 2.6-4, <<https://CRAN.R-project.org/package=vegan>>.

626 Olivares, I.; Svenning, J.-C.; van Bodegom, P. M.; Valencia, R. & Balslev, H. (2017).  
627 Stability in a changing world - palm community dynamics in the hyperdiverse  
628 western Amazon over 17 years. *Global Change Biology*, 23(3), 1232–1239.  
629 doi:10.1111/gcb.13494.

630 Ordway, E. M. & Asner, G. P. (2020). Carbon declines along tropical forest edges  
631 correspond to heterogeneous effects on canopy structure and function. *Proceedings*  
632 *of the National Academy of Sciences*, 117(14), 7863-7870. doi:  
633 10.1073/pnas.1914420117.

634 Peters, H. A.; Pauw, A.; Silman, M. R. & Terborgh, J. W. (2004). Falling palm fronds  
635 structure Amazonian rainforest sapling communities. *Proceedings of the Royal*  
636 *Society B: Biological Sciences*, 271(Suppl\_5), S367–S369.  
637 doi:10.1098/rsbl.2004.0197.

638 Phillips, O. L.; Aragao, L. E. O. C.; Lewis, S. L.; Fisher, J. B.; Lloyd, J. et al. (2009).  
639 Drought Sensitivity of the Amazon Rainforest. *Science* 323, 1344 -1347.  
640 doi:10.1126/science.1164033.

641 Pimm, S. L. (1991). *The balance of nature?: ecological issues in the conservation of*  
642 *species and communities*. University of Chicago Press.

- 643 Pires, A. S.; Fernandez, F. A. & Barros, C. S. (2006). Vivendo em um mundo em pedaços:  
644 efeitos da fragmentação florestal sobre comunidades e populações animais. *Biologia*  
645 *da Conservação: Essências*. São Carlos, São Paulo, Brazil, 231-260.
- 646 Quesada, C. A.; Lloyd, J.; Anderson, L. O.; Fyllas, N. M.; Schwarz, M. & Czimczik, C.  
647 I. (2011). Soils of Amazonia with particular reference to the RAINFOR sites.  
648 *Biogeosciences* 8, 1415–1440. doi:.5194/bg-8-1415-2011.
- 649 R Core Team. (2023). R: A language and environment for statistical computing. R  
650 Foundation for Statistical Computing, Vienna, Austria. URL [https://www.R-](https://www.R-project.org/)  
651 [project.org/](https://www.R-project.org/).
- 652 Raupp, S. V. & Cintra, R. (2011). Influence of a topographic gradient on the occurrence,  
653 abundance and composition of nine species of palms (Arecaceae) in the Central  
654 Amazon. *Neotropical Biology and Conservation*. Pensoft Publishers.  
655 doi:10.4013/nbc.2011.62.07.
- 656 Rocha, A. E. S. & Silva, M. F. F. (2005). Aspectos fitossociológicos, florísticos e  
657 etnobotânicos das palmeiras (Arecaceae) de floresta secundária no município de  
658 Bragança, PA, Brasil. *Acta Botanica Brasilica*, 19(3), 657–667. doi:10.1590/s0102-  
659 33062005000300028.
- 660 Rodrigues, L.; Cintra, R.; Castilho, C.; Pereira, O. S. & Pimentel, T. (2014). Influences  
661 of forest structure and landscape features on spatial variation in species composition  
662 in a palm community in central Amazonia. *Journal of Tropical Ecology*, 30(6), 565-  
663 578. doi:10.1017/S0266467414000431.
- 664 Rodrigues, P. J. F. P. & Nascimento, M. T. (2006). Fragmentação florestal: breves  
665 considerações teóricas sobre efeitos de borda. *Rodriguésia*, 57, 67-74.

666 Santos, L.; Gonçalves S. A.; Teixeira, F.; Santos, C.; Silva, D.; Rodrigues, L. & Lopes, C.  
667 (2016). Análise das populações de *Astrocaryum* G. Mey. (Arecaceae) em fragmentos  
668 florestais de Alta Floresta - MT. *Scientific Electronic Archives: Especial Edition*. 9.  
669 429-431.

670 Saunders, D. A.; Hobbs, R. J. & Margules, C. R. (1991). Biological consequences of  
671 ecosystem fragmentation: a review. *Conservation biology*, v. 5, n. 10, p. 18-32.

672 Scariot, A. (1996). The Effects of Rain Forest Fragmentation on the Palm Community in  
673 Central Amazonia. Tese (Doutorado) - Curso de Philosophy in Biology, University  
674 of California, Santa Barbara, 209 f.

675 Scariot, A. (1998). Consequências da fragmentação da floresta na comunidade de  
676 palmeiras na Amazônia Central. *Série Técnica IPEF*, 12(32), 71-86.

677 Scariot, A. (1999). Forest fragmentation effects on palm diversity in central Amazonia.  
678 *Journal of Ecology*, v. 87, n. 1, p. 66-76.

679 Schietti, J.; Emilio, T.; Rennó, C. D.; Drucker, D. P.; Costa, F. R. C.; Nogueira, A. et al.  
680 (2013). Vertical distance from drainage drives floristic composition changes in an  
681 Amazonian rainforest. *Plant Ecology & Diversity*, 7(1-2), 241–253.  
682 doi:10.1080/17550874.2013.783642.

683 Slik, J. W. F. (2004). El Niño droughts and their effects on tree species composition and  
684 diversity in tropical rain forests. *Oecologia*, 141,114–120. doi:10.1007/s00442-004-  
685 1635-y.

686 Svenning, J. C. (1998). The effect of land-use on the local distribution of palm species in  
687 an Andean rain forest fragment in northwestern Ecuador. *Biodiversity &*  
688 *Conservation*, 7(12), 1529–1537. doi:10.1023/a:1008831600795.

- 689 Turner, I. M.; Chua, K. S.; Ong, J. S. Y.; Soong, B. C. & Tan, H. T. W. (1996). A Century  
690 of Plant Species Loss from an Isolated Fragment of Lowland Tropical Rain Forest.  
691 *Conservation Biology*, 10(4), 1229–1244. doi:10.1046/j.1523-  
692 1739.1996.10041229.x.
- 693 Walther, G.-R.; Gritti, E. S.; Berger, S.; Hickler, T.; Tang, Z. & Sykes, M. T. (2007). Palms  
694 tracking climate change. *Global Ecology and Biogeography*, 16(6), 801–809.  
695 doi:10.1111/j.1466-8238.2007.00328.x.
- 696 Wang Y.; Neuman U.; Wright S. & Warton D. I. (2012). mvabund: an R package for  
697 model-based analysis of multivariate abundance data. *Methods in Ecology and*  
698 *Evolution*.
- 699 Warton, D. I.; Wright, S. T. & Wang, Y. (2012). Distance-based multivariate analyses  
700 confound location and dispersion effects. *Methods in Ecology and Evolution*, 3(1),  
701 89–101. doi:10.1111/j.2041-210x.2011.00127.x.

## SUPPLEMENTARY INFORMATION

**Supplementary Table 1.** List of palm species (Arecaceae) separated in adult, juvenile, and seedling ontogenetic stages to evaluate the influence of location, time, and location  $\times$  time interaction in areas of continuous forest and forest fragments of 100, 10, and 1 ha of the Biological Dynamics Project of Forest Fragments (BDFFP), Central Amazon, Brazil. Common species in both sampling periods (1994-2022) presented better distribution and a high relative abundance in the inventoried areas.

<b>Adult</b>	<b>Juvenile</b>	<b>Seedling</b>
<i>Astrocaryum gynacanthum</i> Mart.	<i>Astrocaryum gynacanthum</i> Mart.	<i>Astrocaryum gynacanthum</i> Mart.
<i>Astrocaryum sociale</i> Barb.Rodr.	<i>Astrocaryum sociale</i> Barb.Rodr.	<i>Astrocaryum sociale</i> Barb.Rodr.
<i>Attalea attaleoides</i> (Barb.Rodr.) Wess.Boer	<i>Attalea attaleoides</i> (Barb.Rodr.) Wess.Boer	<i>Attalea attaleoides</i> (Barb.Rodr.) Wess.Boer
<i>Bactris acanthocarpa</i> var. <i>exscapa</i> Barb.Rodr.	<i>Bactris acanthocarpa</i> var. <i>exscapa</i> Barb.Rodr.	<i>Bactris acanthocarpa</i> var. <i>exscapa</i> Barb.Rodr.
<i>Bactris acanthocarpa</i> var. <i>intermedia</i> A.J.Hend.	<i>Bactris gastoniana</i> Barb.Rodr.	<i>Bactris gastoniana</i> Barb.Rodr.
<i>Bactris gastoniana</i> Barb.Rodr.	<i>Bactris hirta</i> Mart.	<i>Bactris simplicifrons</i> Mart.
<i>Bactris hirta</i> Mart.	<i>Geonoma aspidiifolia</i> Spruce	<i>Euterpe precatoria</i> Mart.
<i>Geonoma aspidiifolia</i> Spruce	<i>Geonoma deversa</i> (Poit.) Kunth	<i>Geonoma aspidiifolia</i> Spruce
<i>Geonoma deversa</i> (Poit.) Kunth	<i>Oenocarpus bacaba</i> Mart.	<i>Geonoma deversa</i> (Poit.) Kunth
	<i>Oenocarpus minor</i> Mart.	<i>Iriartella setigera</i> (Mart.) H. Wendl.
	<i>Syagrus inajai</i> (Spruce) Becc.	<i>Oenocarpus bacaba</i> Mart.
		<i>Oenocarpus bataua</i> Mart.
		<i>Oenocarpus minor</i> Mart.
		<i>Syagrus inajai</i> (Spruce) Becc.

**Supplementary Table 2.** Number of individuals per species of the Arecaceae family at each ontogenetic stage (adult, juvenile and seedling) in areas of continuous forest (CF) and forest fragments of 100, 10, and 1 ha distributed per sampling period (T0 = 1994; T1 = 2022) in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP), Central Amazon, Brazil.

Adults	T0 (1994)				Total	T1 (2022)				Total
	CF	100 ha	10 ha	1 ha		CF	100 ha	10 ha	1 ha	
<i>Astrocaryum gynacanthum</i>	14	17	8	29	68	57	32	42	49	180
<i>Astrocaryum sociale</i>	105	110	120	110	445	480	275	293	231	1279
<i>Attalea attaleoides</i>	33	6	31	51	121	225	102	175	194	696
<i>Attalea maripa</i>	0	0	0	1	1	0	0	0	0	0
<i>Bactris acanthocarpa</i> var. <i>exscapa</i>	29	17	28	20	94	75	56	31	32	194
<i>Bactris acanthocarpa</i> var. <i>intermedia</i>	18	15	21	13	67	45	26	9	13	93
<i>Bactris aubletiana</i>	0	0	0	0	0	9	23	5	7	44
<i>Bactris balanophora</i>	0	0	0	1	1	0	6	0	0	6
<i>Bactris constanciae</i>	4	10	0	1	15	2	13	1	4	20
<i>Bactris elegans</i>	2	5	12	1	20	11	17	19	9	56
<i>Bactris gastoniana</i>	7	5	8	6	26	80	59	41	18	198
<i>Bactris hirta</i>	13	3	4	6	26	53	19	5	9	86
<i>Bactris killipii</i>	0	0	0	0	0	1	1	2	0	4
<i>Bactris oligocarpa</i>	5	8	8	8	29	5	3	4	1	13
<i>Bactris simplicifrons</i>	2	1	5	6	14	8	4	4	9	25
<i>Bactris</i> spp.	1	0	1	1	3	2	0	2	3	7
<i>Bactris tomentosa</i>	4	6	1	5	16	6	9	1	11	27
<i>Desmoncus mitis</i>	0	0	0	0	0	1	0	0	0	1
<i>Desmoncus polyacanthos</i>	0	4	0	1	5	11	14	5	10	40
<i>Euterpe precatoria</i>	2	0	0	1	3	35	7	12	7	61
<i>Geonoma aspidifolia</i>	75	33	14	17	139	88	35	12	30	165
<i>Geonoma deversa</i>	9	15	20	20	64	48	22	36	30	136
<i>Geonoma maxima</i> subsp. <i>maxima</i>	2	0	1	2	5	2	0	0	1	3
<i>Geonoma maxima</i> subsp. <i>spixiana</i>	1	0	0	1	2	0	1	0	1	2
<i>Geonoma</i> spp.	0	0	0	0	0	1	1	0	0	2
<i>Geonoma stricta</i> subsp. <i>stricta</i>	4	0	8	0	12	7	0	11	2	20
<i>Iriartella setigera</i>	7	0	3	0	10	2	3	3	1	9
<i>Lepidocaryum tenue</i>	0	0	0	23	23	0	0	7	29	36
<i>Oenocarpus bacaba</i>	2	0	2	1	5	12	7	8	16	43
<i>Oenocarpus minor</i>	20	8	7	0	35	11	14	3	7	35
<i>Socratea exorrhiza</i>	0	0	1	1	2	1	1	2	2	6
<i>Syagrus inajai</i>	4	3	3	13	23	21	16	11	7	55
Total	363	266	306	339	1274	1299	766	744	733	3542
<b>Juveniles</b>										
<i>Astrocaryum acaule</i>	0	0	1	0	1	0	0	0	0	0
<i>Astrocaryum aculeatum</i>	0	0	0	0	0	0	0	1	0	1
<i>Astrocaryum gynacanthum</i>	45	43	41	41	170	40	39	38	30	147



<i>Astrocaryum sociale</i>	469	297	321	332	1419	145	100	77	93	415
<i>Attalea attaleoides</i>	249	105	240	284	878	66	29	40	58	193
<i>Bactris acanthocarpa</i> var. <i>excapa</i>	84	61	46	63	254	15	6	6	2	29
<i>Bactris acanthocarpa</i> var. <i>intermedia</i>	71	71	58	53	253	1	0	1	0	2
<i>Bactris aubletiana</i>	0	0	0	0	0	2	10	1	5	18
<i>Bactris balanophora</i>	2	1	0	1	4	0	3	0	0	3
<i>Bactris constanciae</i>	12	15	2	1	30	0	1	0	0	1
<i>Bactris elegans</i>	10	16	11	10	47	2	6	1	3	12
<i>Bactris gastoniana</i>	47	51	43	21	162	32	34	20	31	117
<i>Bactris hirta</i>	103	30	21	33	187	64	13	6	5	88
<i>Bactris killipii</i>	2	0	1	0	3	0	0	1	0	1
<i>Bactris maraja</i> var. <i>maraja</i>	0	0	6	1	7	0	0	0	0	0
<i>Bactris oligocarpa</i>	18	17	9	8	52	3	4	2	1	10
<i>Bactris simplicifrons</i>	18	15	13	17	63	7	8	0	8	23
<i>Bactris</i> spp.	6	2	3	1	12	2	0	0	0	2
<i>Bactris tomentosa</i>	17	19	1	10	47	1	3	0	1	5
<i>Desmoncus polyacanthos</i>	10	11	27	24	72	2	3	5	2	12
<i>Euterpe precatorea</i>	11	7	26	14	58	21	9	11	1	42
<i>Geonoma aspidiifolia</i>	126	36	29	43	234	50	17	12	13	92
<i>Geonoma deversa</i>	14	37	36	38	125	22	11	15	11	59
<i>Geonoma maxima</i> subsp. <i>maxima</i>	4	0	3	0	7	1	1	1	1	4
<i>Geonoma maxima</i> subsp. <i>spixiana</i>	7	0	1	1	9	0	1	0	0	1
<i>Geonoma</i> spp.	0	0	1	0	1	0	0	0	0	0
<i>Geonoma stricta</i> subsp. <i>stricta</i>	7	0	17	5	29	1	0	0	0	1
<i>Iriartella setigera</i>	39	6	7	0	52	1	5	0	0	6
<i>Lepidocaryum tenue</i>	0	0	10	68	78	0	0	11	67	78
<i>Oenocarpus bacaba</i>	19	18	28	22	87	47	55	19	24	145
<i>Oenocarpus bataua</i>	1	0	0	1	2	28	37	16	3	84
<i>Oenocarpus minor</i>	44	29	22	19	114	10	7	4	5	26
<i>Socratea exorrhiza</i>	1	1	5	4	11	1	0	6	1	8
<i>Syagrus inajai</i>	14	45	23	34	116	17	17	2	9	45
Total	1450	933	1052	1149	4584	581	419	296	374	1670

#### Seedlings

<i>Astrocaryum aculeatum</i>	0	0	0	0	0	0	0	12	7	19
<i>Astrocaryum gynacanthum</i>	318	191	233	230	972	147	87	131	58	423
<i>Astrocaryum sociale</i>	718	429	434	363	1944	630	390	346	223	1589
<i>Attalea attaleoides</i>	208	121	174	209	712	133	114	173	127	547
<i>Attalea maripa</i>	4	0	0	0	4	0	1	0	0	1
<i>Bactris acanthocarpa</i> var. <i>excapa</i>	204	85	53	70	412	18	12	14	9	53
<i>Bactris acanthocarpa</i> var. <i>intermedia</i>	88	38	48	31	205	2	0	1	0	3
<i>Bactris aubletiana</i>	0	0	0	0	0	3	12	9	3	27
<i>Bactris balanophora</i>	0	0	0	0	0	0	17	0	0	17
<i>Bactris constanciae</i>	5	6	1	0	12	0	4	0	0	4
<i>Bactris elegans</i>	4	4	12	2	22	1	8	6	0	15
<i>Bactris gastoniana</i>	35	31	12	10	88	41	38	37	17	133
<i>Bactris hirta</i>	0	0	0	0	0	110	25	26	31	192
<i>Bactris killipii</i>	9	2	2	0	13	2	1	0	1	4
<i>Bactris maraja</i> var. <i>maraja</i>	0	0	2	0	2	0	0	0	0	0

<i>Bactris oligocarpa</i>	24	31	14	8	77	4	2	1	0	7
<i>Bactris simplicifrons</i>	66	60	42	42	210	29	25	34	26	114
<i>Bactris</i> spp.	2	5	3	3	13	2	0	0	1	3
<i>Bactris tomentosa</i>	20	11	1	6	38	11	17	2	6	36
<i>Desmoncus polyacanthos</i>	5	3	16	3	27	3	2	8	12	25
<i>Euterpe precatoria</i>	191	166	195	66	618	193	91	248	52	584
<i>Geonoma aspidiifolia</i>	523	143	67	56	789	168	65	41	16	290
<i>Geonoma deversa</i>	134	99	163	57	453	66	38	78	30	212
<i>Geonoma maxima</i> subsp. <i>chelidonura</i>	15	5	0	5	25	0	0	0	1	1
<i>Geonoma maxima</i> subsp. <i>maxima</i>	114	23	21	24	182	59	19	7	15	100
<i>Geonoma maxima</i> subsp. <i>spixiana</i>	5	2	0	3	10	6	0	1	3	10
<i>Geonoma</i> spp.	0	0	0	0	0	2	3	1	0	6
<i>Geonoma stricta</i> subsp. <i>stricta</i>	13	0	12	4	29	1	0	8	1	10
<i>Iriartella setigera</i>	284	44	21	5	354	27	27	4	2	60
<i>Lepidocaryum tenue</i>	0	0	10	77	87	0	0	13	16	29
<i>Oenocarpus bacaba</i>	1857	1096	1161	1840	5954	985	522	635	1098	3240
<i>Oenocarpus bataua</i>	1114	276	185	116	1691	157	168	105	66	496
<i>Oenocarpus minor</i>	439	361	285	64	1149	60	109	93	103	365
<i>Socratea exorrhiza</i>	8	11	20	13	52	6	12	24	9	51
<i>Syagrus inajai</i>	167	208	202	267	844	102	125	149	172	548
Total	6574	3451	3389	3574	16988	2968	1934	2207	2105	9214

**Supplementary Table 3.** Pairwise multiple comparisons of GLMM models of the effect of forest fragmentation on the number of species and abundance of the three ontogenetic stages (adult, juvenile and seedling) of species from the Arecaceae family in areas of continuous forest (CF) and forest fragments (FF) in the sampling time periods: T0 = 1994 and T1 = 2022 in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP) in the Central Amazon, Brazil. Significant results ( $p < 0.05$ ) are highlighted in bold.

Comparisons	Abundance	
	<i>z</i>	<i>P</i>
<b>Adults</b>		
T0 CF × T0 FF	1.17	0.65
T1 CF × T1 FF	12.77	<b>&lt;0.0001</b>
T0 CF × T1 CF	-21.48	<b>&lt;0.0001</b>
T0 FF × T1 FF	-22.94	<b>&lt;0.0001</b>
<b>Juveniles</b>		
T0 CF × T0 FF	6.71	<b>&lt;0.0001</b>
T1 CF × T1 FF	6.92	<b>&lt;0.0001</b>
T0 CF × T1 CF	18.63	<b>&lt;0.0001</b>
T0 FF × T1 FF	30.05	<b>&lt;0.0001</b>
<b>Seedlings</b>		
T0 CF × T0 FF	32.67	<b>&lt;0.0001</b>
T1 CF × T1 FF	10.39	<b>&lt;0.0001</b>
T0 CF × T1 CF	35.96	<b>&lt;0.0001</b>
T0 FF × T1 FF	31.94	<b>&lt;0.0001</b>

**Supplementary Table 4.** Average number of species and abundance ( $\pm$  Standard Deviation) for the three ontogenetic stages (adult, juvenile and seedling) of the Areaceae family in areas of continuous forest (CF) and forest fragments of 100, 10, and 1 ha distributed per period of sampling (T0 = 1994; T1 = 2022) in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP), Central Amazon, Brazil.

Response variables	T0 (1994)				T1 (2022)			
	CF	100 ha	10 ha	1 ha	CF	100 ha	10 ha	1 ha
Number of adults spp.	17 $\pm$ 2.65	15.5 $\pm$ 0.71	14.3 $\pm$ 5.03	15.7 $\pm$ 3.51	21.7 $\pm$ 3.51	22.5 $\pm$ 4.95	19.3 $\pm$ 3.06	19.3 $\pm$ 3.06
Abundance of adults	121 $\pm$ 40.73	133 $\pm$ 53.74	102 $\pm$ 27.5	113 $\pm$ 56.15	433 $\pm$ 66.84	383 $\pm$ 21.21	248 $\pm$ 39.95	244.3 $\pm$ 39.11
Number of juveniles spp.	22.7 $\pm$ 0.58	21 $\pm$ 0	21.7 $\pm$ 4.04	20.3 $\pm$ 2.31	18.7 $\pm$ 1.53	19.5 $\pm$ 0.71	13.7 $\pm$ 0.58	13.7 $\pm$ 5.13
Abundance of juveniles	483.3 $\pm$ 34.02	466.5 $\pm$ 68.59	350.7 $\pm$ 46	383 $\pm$ 107.59	193.7 $\pm$ 68.86	209.5 $\pm$ 74.25	98.7 $\pm$ 16.2	124.7 $\pm$ 55.77
Number of seedlings spp.	23 $\pm$ 2.65	24 $\pm$ 1.41	21.7 $\pm$ 2.08	20.3 $\pm$ 0.58	22.7 $\pm$ 2.52	23.5 $\pm$ 0.71	19.7 $\pm$ 3.51	21 $\pm$ 1.73
Abundance of seedlings	2,191.3 $\pm$ 487.05	1,725.5 $\pm$ 191.63	1,129.7 $\pm$ 150.19	1,191.3 $\pm$ 467.61	989.3 $\pm$ 354.95	967 $\pm$ 1.41	735.7 $\pm$ 194.28	701.7 $\pm$ 78.93
Total number of spp.	26.3 $\pm$ 0.58	25.5 $\pm$ 0.71	25.3 $\pm$ 2.89	23.7 $\pm$ 2.52	26 $\pm$ 2.6	25.5 $\pm$ 2.12	23.3 $\pm$ 4.51	23 $\pm$ 1.73
Total abundance	2,875 $\pm$ 561.63	2,360.5 $\pm$ 51.62	1,593.67 $\pm$ 216.01	1,699.33 $\pm$ 353.90	1,616 $\pm$ 464.90	1,559.5 $\pm$ 51.62	1,082.33 $\pm$ 222.33	1,070.67 $\pm$ 168.14

**Supplementary Table 5.** Multiple pairwise comparisons of GLMM models for the effect of forest fragment size on the number of species and abundance in the three ontogenetic stages (adult, juvenile and seedling) of species from the Arecaceae family in areas of continuous forest (CF) and forest fragments of 100, 10, and 1 ha in two sampling periods (T0 = 1994; T1 = 2022) in the areas of the Biological Dynamics of Forest Fragments Project (BDFFP) in the Central Amazon, Brazil. Significant results ( $p < 0.05$ ) are highlighted in bold.

Comparisons	Abundance	
	<i>z</i>	<i>P</i>
<b>Adults</b>		
T0 1ha × T0 CF	-0.91	0.99
T0 10ha × T0 CF	-2.20	0.35
T0 100ha × T0 CF	0.89	0.99
T0 10ha × T0 1ha	-1.30	0.90
T0 100ha × T0 1ha	1.71	0.68
T0 100ha × T0 10ha	2.88	0.08
T1 1ha × T1 CF	-12.39	<b>&lt;0.0001</b>
T1 10ha × T1 CF	-12.12	<b>&lt;0.0001</b>
T1 100ha × T1 CF	-3.09	<b>0.04</b>
T1 10ha × T1 1ha	0.29	0.99
T1 100ha × T1 1ha	8.10	<b>&lt;0.0001</b>
T1 100ha × T1 10ha	7.85	<b>&lt;0.0001</b>
T0 CF × T1 CF	-21.48	<b>&lt;0.0001</b>
T0 1ha × T1 1ha	-11.74	<b>&lt;0.0001</b>
T0 10ha × T1 10ha	-13.08	<b>&lt;0.0001</b>
T0 100ha × T1 100ha	-14.86	<b>&lt;0.0001</b>
<b>Juveniles</b>		
T0 1ha × T0 CF	-5.89	<b>&lt;0.0001</b>
T0 10ha × T0 CF	-7.92	<b>&lt;0.0001</b>
T0 100ha × T0 CF	-0.57	0.99
T0 10ha × T0 1ha	-2.07	0.44
T0 100ha × T0 1ha	4.62	<b>0.0001</b>
T0 100ha × T0 10ha	6.45	<b>&lt;0.0001</b>
T1 1ha × T1 CF	-6.65	<b>&lt;0.0001</b>
T1 10ha × T1 CF	-9.45	<b>&lt;0.0001</b>
T1 100ha × T1 CF	1.38	0.86
T1 10ha × T1 1ha	-3.01	0.05
T1 100ha × T1 1ha	7.39	<b>&lt;0.0001</b>
T1 100ha × T1 10ha	9.98	<b>&lt;0.0001</b>
T0 CF × T1 CF	18.63	<b>&lt;0.0001</b>
T0 1ha × T1 1ha	18.86	<b>&lt;0.0001</b>
T0 10ha × T1 10ha	19.28	<b>&lt;0.0001</b>
T0 100ha × T1 100ha	13.61	<b>&lt;0.0001</b>

Seedlings		
T0 1ha × T0 CF	-29.33	<0.0001
T0 10ha × T0 CF	-31.33	<0.0001
T0 100ha × T0 CF	-8.58	<0.0001
T0 10ha × T0 1ha	-2.22	0.34
T0 100ha × T0 1ha	17.31	<0.0001
T0 100ha × T0 10ha	19.24	<0.0001
T1 1ha × T1 CF	-12.06	<0.0001
T1 10ha × T1 CF	-10.54	<0.0001
T1 100ha × T1 CF	1.01	0.97
T1 10ha × T1 1ha	1.55	0.78
T1 100ha × T1 1ha	11.70	<0.0001
T1 100ha × T1 10ha	10.33	<0.0001
T0 CF × T1 CF	35.96	<0.0001
T0 1ha × T1 1ha	19.27	<0.0001
T0 10ha × T1 10ha	15.68	<0.0001
T0 100ha × T1 100ha	20.39	<0.0001

**Supplementary Table 6.** GLMM models and likelihood ratio tests to evaluate the influence of location, time and location  $\times$  time interaction on the abundance of common species of the three ontogenetic stages (adult, juvenile and seedling) of the Arecaceae family in continuous forest areas and forest fragments of 100, 10, and 1 ha in two sampling periods (1994 and 2022) in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP), Central Amazon, Brazil. Related to the effect of forest fragmentation, data from different sizes of forest fragments are grouped into a single variable. Related to the effect of forest fragment size, each forest fragment size is an independent variable. Significant results ( $P < 0.05$ ) are highlighted in bold.

Response variables	Fragmentation						Fragment size					
	Location		Time		Location $\times$ Time		Location		Time		Location $\times$ Time	
	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>	<i>LRT</i>	<i>P</i>
<b>Adults</b>												
<i>Astrocaryum gynacanthum</i>	0.43	0.51	52.46	<b>&lt;0.0001</b>	3.09	0.08	6.66	0.08	52.46	<b>&lt;0.0001</b>	10.67	<b>0.01</b>
<i>Astrocaryum sociale</i>	34.72	<b>&lt;0.0001</b>	420.88	<b>&lt;0.0001</b>	29.82	<b>&lt;0.0001</b>	97.59	<b>&lt;0.0001</b>	420.88	<b>&lt;0.0001</b>	31.17	<b>&lt;0.0001</b>
<i>Attalea attaleoides</i>	5.92	<b>0.02</b>	447.30	<b>&lt;0.0001</b>	1.25	0.26	15.08	<b>0.002</b>	447.3	<b>&lt;0.0001</b>	16.51	<b>0.001</b>
<i>Bactris acanthocarpa</i> var. <i>exscapa</i>	10.21	<b>0.001</b>	35.46	<b>&lt;0.0001</b>	1.70	0.19	33.56	<b>&lt;0.0001</b>	35.46	<b>&lt;0.0001</b>	10.52	<b>0.02</b>
<i>Bactris acanthocarpa</i> var. <i>intermedia</i>	12.69	<b>0.0004</b>	4.24	<b>0.04</b>	7.72	<b>0.01</b>	22.12	<b>&lt;0.0001</b>	4.24	<b>0.04</b>	15.64	<b>0.003</b>
<i>Bactris gastoniana</i>	17.43	<b>&lt;0.0001</b>	149.69	<b>&lt;0.0001</b>	1.84	0.18	44.58	<b>&lt;0.0001</b>	149.69	<b>&lt;0.0001</b>	6.44	0.09
<i>Bactris hirta</i>	48.68	<b>&lt;0.0001</b>	33.89	<b>&lt;0.0001</b>	1.10	0.29	61.96	<b>&lt;0.0001</b>	33.89	<b>&lt;0.0001</b>	5.80	0.12
<i>Geonoma aspidiifolia</i>	107.31	<b>&lt;0.0001</b>	2.23	0.14	0.01	0.91	131.57	<b>&lt;0.0001</b>	2.23	0.14	2.67	0.45
<i>Geonoma deversa</i>	0.53	0.47	26.51	<b>&lt;0.0001</b>	10.47	<b>&lt;0.0001</b>	1.57	0.67	26.51	<b>&lt;0.0001</b>	10.77	<b>0.01</b>
<b>Juveniles</b>												
<i>Astrocaryum gynacanthum</i>	0.02	0.90	1.67	0.20	0.02	0.88	12.05	<b>0.01</b>	1.67	0.20	0.64	0.89
<i>Astrocaryum sociale</i>	31.03	<b>&lt;0.0001</b>	581.02	<b>&lt;0.0001</b>	0.51	0.47	81.70	<b>&lt;0.0001</b>	581.02	<b>&lt;0.0001</b>	4.46	0.22
<i>Attalea attaleoides</i>	1.27	0.26	474.33	<b>&lt;0.0001</b>	2.54	0.11	20.24	<b>0.0002</b>	474.33	<b>&lt;0.0001</b>	5.96	0.11
<i>Bactris acanthocarpa</i> var. <i>exscapa</i>	6.53	<b>0.01</b>	205.27	<b>&lt;0.0001</b>	3.81	0.05	29.02	<b>&lt;0.0001</b>	205.27	<b>&lt;0.0001</b>	7.38	0.06
<i>Bactris gastoniana</i>	0.51	0.47	7.29	<b>0.01</b>	0.09	0.76	21.42	<b>&lt;0.0001</b>	7.29	<b>0.01</b>	9.53	<b>0.02</b>
<i>Bactris hirta</i>	133.26	<b>&lt;0.0001</b>	36.45	<b>&lt;0.0001</b>	8.04	<b>0.005</b>	146.94	<b>&lt;0.0001</b>	36.45	<b>&lt;0.0001</b>	11.56	<b>0.01</b>

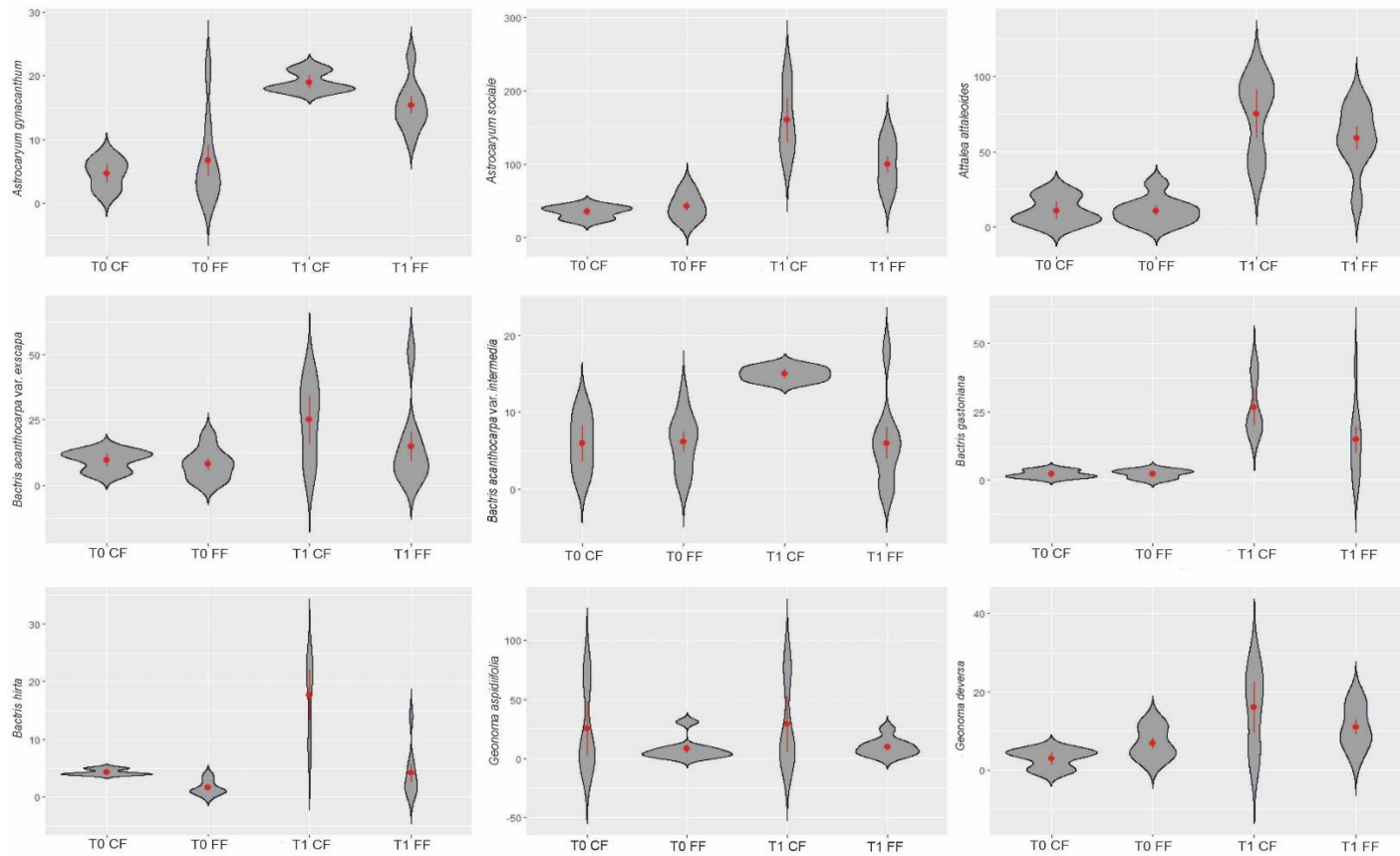
<i>Geonoma aspidiifolia</i>	114.46	<0.0001	63.97	<0.0001	0.01	0.93	118.93	<0.0001	63.97	<0.0001	1.12	0.77
<i>Geonoma deversa</i>	3.93	<b>0.05</b>	24.21	<0.0001	16.30	<0.0001	4.24	0.24	24.21	<0.0001	17.10	<b>0.001</b>
<i>Oenocarpus bacaba</i>	0.15	0.70	14.65	<b>0.0001</b>	3.06	0.08	30.50	<0.0001	14.65	<b>0.0001</b>	19.08	<b>0.0003</b>
<i>Oenocarpus minor</i>	10.79	<b>0.001</b>	59.70	<0.0001	0.0002	0.99	16.20	<b>0.001</b>	59.70	<0.0001	0.28	0.96
<i>Syagrus inajai</i>	4.94	<b>0.03</b>	32.41	<0.0001	12.63	<b>0.0004</b>	37.28	<0.0001	32.41	<0.0001	17.20	<b>0.001</b>
<hr/>												
Seedlings	<hr/>											
<i>Astrocaryum gynacanthum</i>	24.45	<b>0.001</b>	222.01	<0.0001	0.55	0.46	45.87	<0.0001	222.01	<0.0001	21.13	<0.0001
<i>Astrocaryum sociale</i>	186.22	<0.0001	35.73	<0.0001	2.73	0.10	427.02	<0.0001	35.73	<0.0001	15.60	<b>0.001</b>
<i>Attalea attaleoides</i>	0.10	0.75	21.69	<0.0001	3.78	0.05	1.31	0.73	21.69	<0.0001	15.37	<b>0.002</b>
<i>Bactris acanthocarpa</i> var. <i>exscapa</i>	85.62	<0.0001	314.71	<0.0001	4.64	<b>0.03</b>	117.32	<0.0001	314.71	<0.0001	7.66	0.05
<i>Bactris gastoniana</i>	5.61	<b>0.02</b>	9.23	<b>0.002</b>	1.87	0.17	46.04	<0.0001	9.23	<b>0.002</b>	7.17	0.07
<i>Bactris simplicifrons</i>	1.14	0.29	28.88	<0.0001	1.30	0.25	12.76	<b>0.005</b>	28.88	<0.0001	5.42	0.14
<i>Euterpe precatorea</i>	12.98	<b>0.0003</b>	0.96	0.33	0.63	0.43	230.74	<0.0001	0.96	0.33	29.28	<0.0001
<i>Geonoma aspidiifolia</i>	698.01	<0.0001	239.79	<0.0001	6.34	<b>0.01</b>	791.64	<0.0001	239.79	<0.0001	11.44	<0.0001
<i>Geonoma deversa</i>	4.04	<b>0.04</b>	89.36	<0.0001	0.16	0.68	80.10	<0.0001	89.36	<0.0001	1.52	0.68
<i>Iriartella setigera</i>	420.96	<0.0001	231.29	<0.0001	29.88	<0.0001	508.94	<0.0001	231.29	<0.0001	34.40	<0.0001
<i>Oenocarpus bacaba</i>	32.49	<0.0001	813.21	<0.0001	0.61	0.43	376.45	<0.0001	813.21	<0.0001	12.61	<b>0.01</b>
<i>Oenocarpus bataua</i>	943.25	<0.0001	690.10	<0.0001	184.01	<0.0001	1166	<0.0001	690.1	<0.0001	184.26	<0.0001
<i>Oenocarpus minor</i>	38.66	<0.0001	426.41	<0.0001	64.87	<0.0001	235.91	<0.0001	426.41	<0.0001	152.57	<0.0001
<i>Syagrus inajai</i>	44.32	<0.0001	63.43	<0.0001	0.29	0.59	62.16	<0.0001	63.44	<0.0001	2.10	0.55



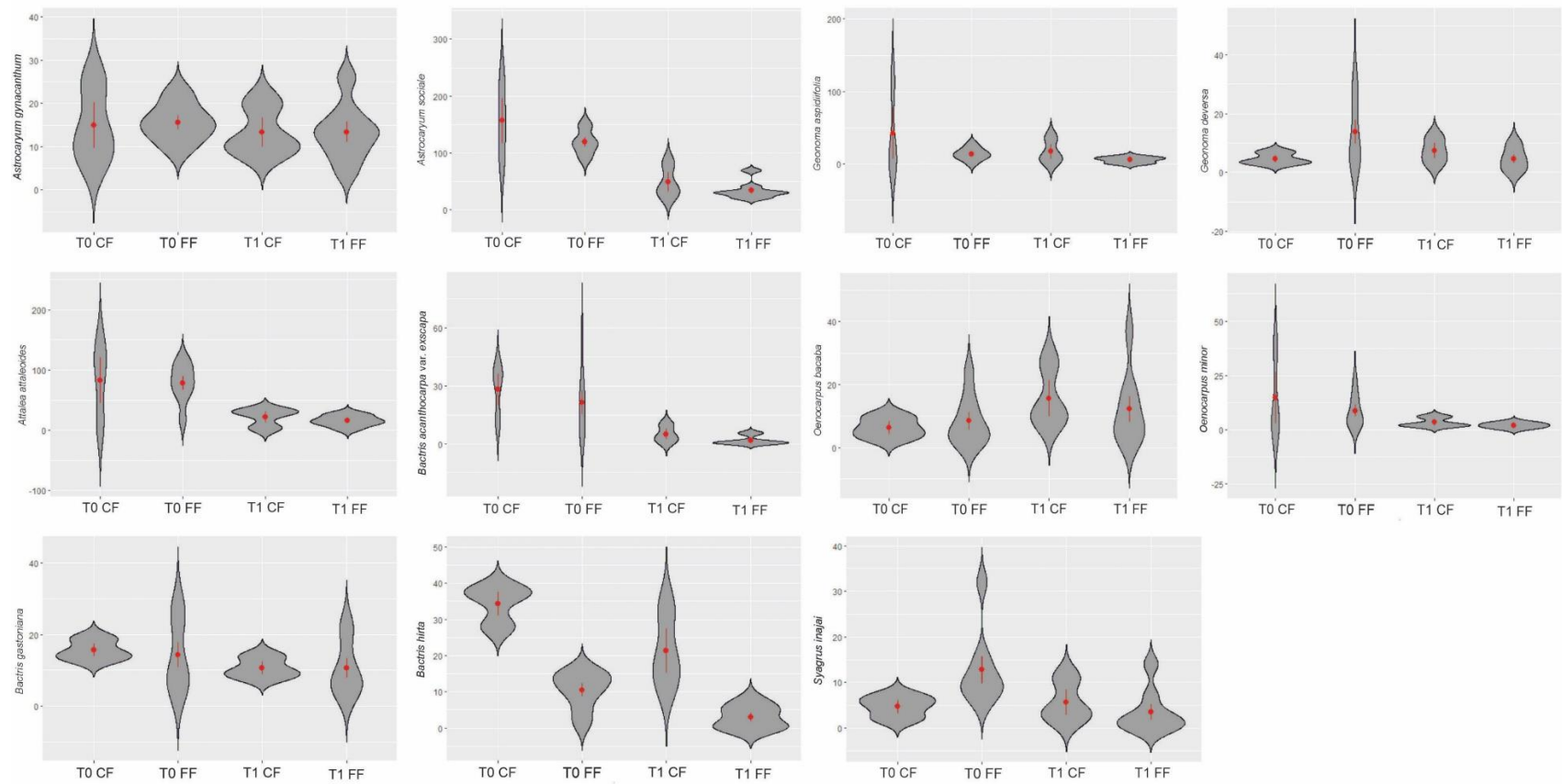
**Supplementary Table 7.** Results of pairwise multiple comparisons for the effect of forest fragmentation on the abundance of common species in each ontogenetic stage (Adults, Juveniles and Seedlings) of the Arecaceae family in Continuous Forest (CF) and Forest Fragments (FF) between two sampling periods (T0 = 1994; T1 = 2022) in the study sites of the Biological Dynamics of Forest Fragments Project (BDFFP) in Central Amazon, Brazil. Significant results ( $P < 0.05$ ) are highlighted in bold.

Comparisons	T0 CF × T0 FF		T1 CF × T1 FF		T0 CF × T1 CF		T0 FF × T1 FF	
	z	P	z	P	z	P	z	P
<b>Adults – palm species</b>								
<i>Astrocaryum gynacanthum</i>	-1.14	0.66	1.48	0.45	-4.77	<b>&lt;0.0001</b>	-5.05	<b>&lt;0.0001</b>
<i>Astrocaryum sociale</i>	-1.81	0.27	7.99	<b>&lt;0.0001</b>	-14.11	<b>&lt;0.0001</b>	-13.20	<b>&lt;0.0001</b>
<i>Attalea attaleoides</i>	-0.11	1	2.71	<b>0.03</b>	-10.31	<b>&lt;0.0001</b>	-14.46	<b>&lt;0.0001</b>
<i>Bactris acanthocarpa</i> var. <i>exscapa</i>	0.74	0.88	3.46	<b>0.003</b>	-4.36	<b>0.0001</b>	-3.93	<b>0.001</b>
<i>Bactris acanthocarpa</i> var. <i>intermedia</i>	0.09	1	4.64	<b>&lt;0.0001</b>	-3.30	<b>0.01</b>	0.10	1
<i>Bactris gastoniana</i>	0.10	1	4.53	<b>&lt;0.0001</b>	-6.20	<b>&lt;0.0001</b>	-7.41	<b>&lt;0.0001</b>
<i>Bactris hirta</i>	2.50	0.06	6.55	<b>&lt;0.0001</b>	-4.55	<b>&lt;0.0001</b>	-2.85	<b>0.02</b>
<i>Geonoma aspidiifolia</i>	7.21	<b>&lt;0.0001</b>	7.70	<b>&lt;0.0001</b>	-1.02	0.74	-1.10	0.69
<i>Geonoma deversa</i>	-2.16	0.13	2.39	0.08	-4.62	<b>&lt;0.0001</b>	-2.74	<b>0.03</b>
<b>Juveniles – palm species</b>								
<i>Astrocaryum gynacanthum</i>	-0.19	1	0.02	10000	0.54	0.95	1.18	0.64
<i>Astrocaryum sociale</i>	4.63	<b>&lt;0.0001</b>	3.36	<b>0.004</b>	12.36	<b>&lt;0.0001</b>	18.25	<b>&lt;0.0001</b>
<i>Attalea attaleoides</i>	0.34	0.99	1.96	0.20	9.60	<b>&lt;0.0001</b>	16.45	<b>&lt;0.0001</b>
<i>Bactris acanthocarpa</i> var. <i>exscapa</i>	1.80	0.27	2.74	<b>0.03</b>	6.16	<b>&lt;0.0001</b>	9.00	<b>&lt;0.0001</b>
<i>Bactris gastoniana</i>	0.75	0.88	0.23	1	1.68	0.33	2.12	0.15
<i>Bactris hirta</i>	8.06	<b>&lt;0.0001</b>	8.20	<b>&lt;0.0001</b>	2.99	<b>0.02</b>	5.41	<b>&lt;0.0001</b>
<i>Geonoma aspidiifolia</i>	9.17	<b>&lt;0.0001</b>	5.85	<b>&lt;0.0001</b>	5.54	<b>&lt;0.0001</b>	5.20	<b>&lt;0.0001</b>
<i>Geonoma deversa</i>	-3.58	<b>0.002</b>	2.00	0.19	-1.33	0.55	5.81	<b>&lt;0.0001</b>

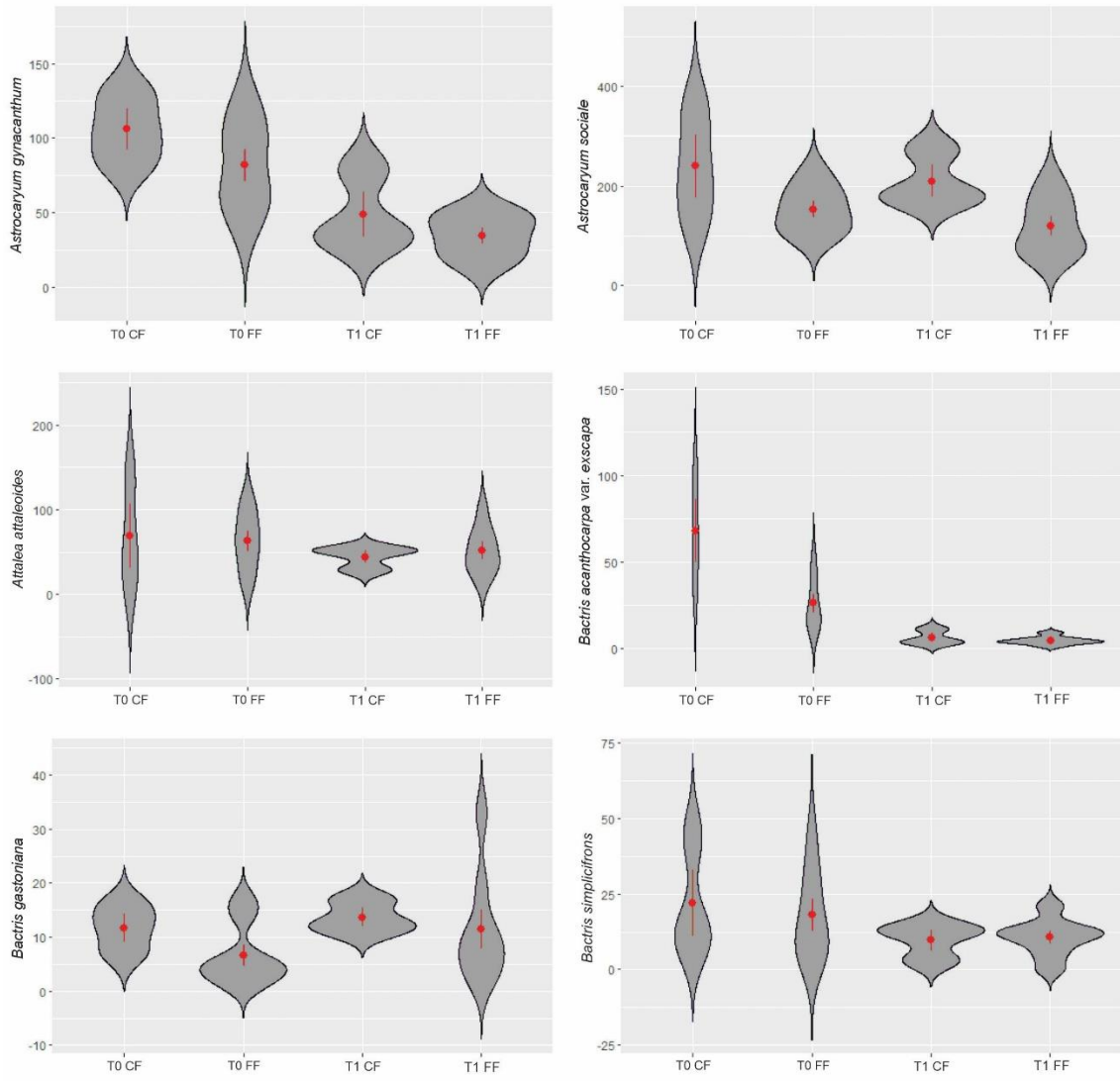
<i>Oenocarpus bacaba</i>	-1.14	0.66	1.38	0.51	-3.33	<b>0.01</b>	-2.32	0.09
<i>Oenocarpus minor</i>	3.07	<b>0.01</b>	1.45	0.47	4.25	<b>0.0001</b>	5.35	<b>&lt;0.0001</b>
<i>Syagrus inajai</i>	-3.44	<b>0.003</b>	1.65	0.35	-0.54	0.95	6.08	<b>&lt;0.0001</b>
<b>Seedlings – palm species</b>								
<i>Astrocaryum gynacanthum</i>	3.78	<b>0.001</b>	3.42	<b>0.004</b>	7.74	<b>&lt;0.0001</b>	12.02	<b>&lt;0.0001</b>
<i>Astrocaryum sociale</i>	9.21	<b>&lt;0.0001</b>	10.68	<b>&lt;0.0001</b>	2.40	0.08	5.70	<b>&lt;0.0001</b>
<i>Attalea attaleoides</i>	1.03	0.73	-1.66	0.35	4.03	<b>0.0003</b>	2.97	<b>0.02</b>
<i>Bactris acanthocarpa</i> var. <i>exscapa</i>	9.64	<b>&lt;0.0001</b>	1.06	0.72	9.89	<b>&lt;0.0001</b>	9.77	<b>&lt;0.0001</b>
<i>Bactris gastoniana</i>	2.64	<b>0.04</b>	0.96	0.77	-0.69	0.90	-3.20	<b>0.01</b>
<i>Bactris simplicifrons</i>	1.56	0.40	-0.30	0.99	3.70	<b>0.001</b>	3.86	<b>0.001</b>
<i>Euterpe precatorea</i>	2.05	0.17	3.14	<b>0.01</b>	-0.10	0.10	1.26	0.59
<i>Geonoma aspidiifolia</i>	23.09	<b>&lt;0.0001</b>	11.63	<b>&lt;0.0001</b>	12.82	<b>&lt;0.0001</b>	7.13	<b>&lt;0.0001</b>
<i>Geonoma deversa</i>	1.44	0.47	1.50	0.44	4.71	<b>&lt;0.0001</b>	7.83	<b>&lt;0.0001</b>
<i>Iriartella setigera</i>	18.11	<b>&lt;0.0001</b>	3.15	<b>0.01</b>	11.70	<b>&lt;0.0001</b>	3.57	<b>0.002</b>
<i>Oenocarpus bacaba</i>	5.11	<b>&lt;0.0001</b>	2.78	<b>0.03</b>	16.09	<b>&lt;0.0001</b>	22.77	<b>&lt;0.0001</b>
<i>Oenocarpus bataua</i>	32.42	<b>&lt;0.0001</b>	2.47	0.06	22.99	<b>&lt;0.0001</b>	7.77	<b>&lt;0.0001</b>
<i>Oenocarpus minor</i>	9.50	<b>&lt;0.0001</b>	-4.02	<b>0.0003</b>	14.47	<b>&lt;0.0001</b>	12.35	<b>&lt;0.0001</b>
<i>Syagrus inajai</i>	-4.68	<b>&lt;0.0001</b>	-4.38	<b>0.0001</b>	3.92	<b>0.001</b>	6.85	<b>&lt;0.0001</b>



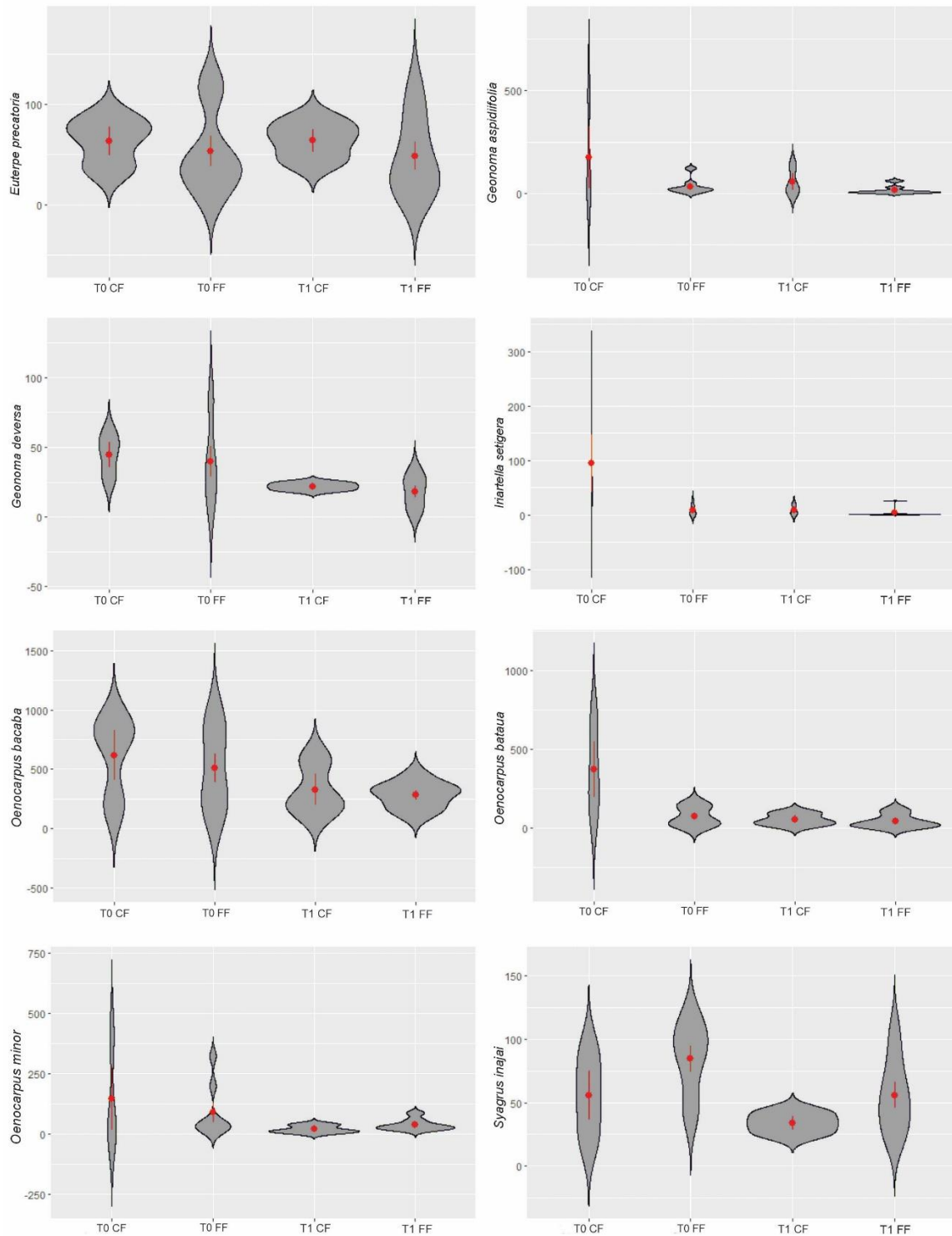
**Supplementary Figure 1.** Effect of forest fragmentation on the abundance of common palms in the adult ontogenetic stage in areas of continuous forests (CF) and forest fragments (FF) in the two sampling periods (T0-1994 and T1-2022) in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP), Central Amazon, Brazil.



**Supplementary Figure 2.** Effect of forest fragmentation on the abundance of common palms in the juvenile ontogenetic stage in areas of continuous forest (CF) and forest fragments (FF) in the two sampling periods (T0-1994 and T1-2022) in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP), Central Amazon, Brazil.



(continues on the next page)



**Supplementary Figure 3.** Effect of forest fragmentation on the abundance of common palms in the seedling ontogenetic stage in areas of continuous forests (CF) and forest fragments (FF) in the two sampling periods (T0-1994 and T1-2022) in the reserves of the Biological Dynamics of Forest Fragments Project (BDFFP), Central Amazon, Brazil.

## **Conclusão geral**

O levantamento de palmeiras nas áreas fragmentadas e nas florestas contínuas 42 anos após o isolamento das áreas e 28 após o primeiro inventário possibilitou investigar a dinâmica espacial e temporal da família Arecaceae. Constatamos que o período de 15 anos foi curto para ser observado mudanças na assembleia como um todo, porém, os estádios ontogenéticos mais sensíveis como as plântulas e jovens já apresentavam uma queda no número de indivíduos, principalmente nos fragmentos florestais menores quando comparados com a floresta contínua. Enquanto o segundo inventário confirmou nossas previsões, já que o efeito observado no primeiro levantamento foi potencializado, tanto espacial quanto temporalmente. Mas dessa vez as consequências alcançaram também o estágio adulto, mas o efeito foi inverso, tendo um aumento na quantidade de palmeiras adultas nos fragmentos florestais, mas até mesmo nas florestas contínuas.

Dessa forma, as mudanças ambientais causadas pela fragmentação florestal como a diminuição de habitat disponível, competição interespecífica e estocasticidade ambiental e demográfica, estão de fato relacionadas e são forças motrizes na diminuição expressiva no número de indivíduos e na presença de espécies exclusivas para as florestas contínuas e principalmente para os fragmentos florestais, mesmo não havendo alteração no número de espécies em geral. Mas sim uma variação temporal da composição de espécies nos três estádios ontogenéticos, o que pode revelar a ocorrência de substituição de espécies e não a sua perda.

Contudo, devemos ressaltar também a influência de eventos externos que podem ir além da dinâmica natural, já que as florestas contínuas também apresentaram alterações temporais. Isso demonstra a necessidade de soluções pragmáticas ligadas diretamente a

conservação de áreas florestais, bem como indiretas, correlacionadas às mudanças climáticas, por exemplo.

Concluimos que a fragmentação florestal atua em cada estágio ontogenético de maneira espécie-específica, mas onde a maioria das espécies apresentam respostas semelhantes, uma diminuição temporal no número de indivíduos, exceto para os adultos. Plântulas e juvenis têm uma resposta mais rápida e sendo alguns positivamente relacionados com o isolamento das áreas, enquanto adultos, com o tempo de retorno maior, não apresentam espécies favorecidas pela fragmentação florestal, o que pode ao longo de um período maior reestruturar a faixa etária dessa comunidade, já que não há uma reposição populacional viável. Dessa forma, estudos a longo prazo devem persistir e compreender monitoramentos mais longos, além dos ciclos naturais de vida das palmeiras, visto que seu processo de resposta às alterações em sua abundância e composição provenientes da fragmentação florestal pode compreender diferentes fases.



## Referências Bibliográficas

(referentes à Introdução Geral e Conclusão)

Andreazzi, C. S.; Pires, A. S. & Fernandez, F. A. S. (2009). Mamíferos e Palmeiras Neotropicais: Interações em Paisagens Fragmentadas. *Oecologia Australis*, v. 13, n. 04, p. 554-574. doi:10.4257/oeco.2009.1304.02.

Assis, L. S.; Campos, M. & Girão, V. J. (2019). Manejo de fragmentos florestais degradados. *The Nature Conservancy*, Campinas, Brazil.

Borges, M. L. O. (2007). A Comunidade de Pequenos Mamíferos e o Processo de Regeneração de Palmeiras em Fragmentos Florestais Isolados por Água na Amazônia Central. Dissertação (Mestrado) - Curso de Biologia Tropical e Recursos Naturais, Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus. 83 f.

Brum, H. D.; Nascimento, H. E. M.; Laurance, W. F.; Andrade, A. C. S.; Laurance, S. G. & Luizão, R. C. C. (2008). Rainforest fragmentation and the demography of the economically important palm *Oenocarpus bacaba* in central Amazonia. *Plant Ecology*, v. 199, n. 2, p. 209-215. doi: 10.1007/s11258-008-9425-y.

Couvreur, T. L.; Forest, F. & Baker, W. J. (2011). Origin and global diversification patterns of tropical rain forests: inferences from a complete genus-level phylogeny of palms. *BMC Biol.* 9, 44. doi:10.1186/1741-7007-9-44.

Donatti, C. I. (2004). Consequências da defaunação na dispersão e predação de sementes e no recrutamento de plântulas da palmeira brejaúva (*Astrocaryum aculeatissimum*) na Mata Atlântica. Dissertação (mestrado) – Escola Superior de Agricultura Luiz de Queiroz, Piracicaba, 89 p.

Fauset, S.; Baker, T. R.; Lewis, S. L.; Feldpausch, T. R.; Affum-Baffoe, K.; Foli, E. G. et al. (2012). Drought-induced shifts in the floristic and functional composition of

tropical forests in Ghana. *Ecology Letters*, 15(10), 1120–1129. doi:10.1111/j.1461-0248.2012.01834.x.

Flora e Funga do Brasil. (2023). Jardim Botânico do Rio de Janeiro. Disponível em: <<http://floradobrasil.jbrj.gov.br/>>.

Gauí, T. D.; Costa, F. R. C.; Souza, F. C.; Amaral, M. R. M.; Carvalho, D. C.; Reis, F. Q. & Higuchi, N. (2019). Long-term effect of selective logging on floristic composition: A 25 year experiment in the Brazilian Amazon. *Forest Ecology and Management*, 440, 258–266. doi:10.1016/j.foreco.2019.02.033.

Irwin, M. T.; Wright, P. C.; Birkinshaw, C.; Fisher, B. L.; Gardner, C. J. et al. (2010). Patterns of species change in anthropogenically disturbed forests of Madagascar. *Biological Conservation*, 143(10), 2351–2362. doi:10.1016/j.biocon.2010.01.023.

Montibeller, B.; Kmoch, A.; Virro, H.; Mander Ü. & Uemaa, E. (2020). Increasing fragmentation of forest cover in Brazil's Legal Amazon from 2001 to 2017. *Sci Rep.* 10, 5803. doi:10.1038/s41598-020-62591-x.

Piovesan, P. R. R.; Burnham, R. J.; Ferraz, I. D. K. & Camargo, J. L. C. (2022). Species density diverges after forest fragmentation in lianescent *Machaerium* Pers.(Fabaceae) in Central Amazonia. *Forest Ecology and Management*, 519, 120335. doi:10.1016/j.foreco.2022.120335.

Preston, F. W. (1962). *The canonical distribution of commonness and rarity* – I. *Ecology*, 43, 185–215.

Taubert, F.; Fischer, R.; Groeneveld, J.; Lehmann, S.; Müller, M. S.; Rödig, E.; Wiegand, T. & Huth, A. (2018). Global patterns of tropical forest fragmentation. *Nature*, 554, 519–522. doi:10.1038/nature25508.

Thomazini, M. J. & Thomazini, A. P. B. W. (2000). A fragmentação florestal e a diversidade de insetos nas florestas tropicais úmidas. Rio Branco: *Embrapa Acre*. (*Embrapa Acre. Documentos, 57*). 21p.

Wade, T. G.; Riitters, K. H.; Wickham, J. D. & Jones, K. B. (2003). Distribution and Causes of Global Forest Fragmentation. *Conservation Ecology*, 7(2). <http://www.jstor.org/stable/26271943>.

Wirth, R.; Meyer, S. T.; Leal, I. R. & Tabarelli, M. (2008). Plant Herbivore Interactions at the Forest Edge. *Progress in Botany*, 423–448. doi:10.1007/978-3-540-72954-9\_17.