UNIVERSIDADE FEDERAL DE ALAGOAS – UFAL
INSTITUTO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos/PPG-DIBICT
Nível Mestrado

MARIANA DE OLIVEIRA ESTEVO

O IMPACTO DAS MUDANÇAS CLIMÁTICAS SOBRE COMUNIDADES LOCAIS NA AMAZÔNIA: A PERCEPÇÃO DOS RIBEIRINHOS DO RIO JURUÁ

Dissertação apresentada ao Programa de Pós-Graduação em Diversidade Biológica e Conservação nos Trópicos do Instituto de Ciências Biológicas e da Saúde, Universidade Federal de Alagoas, como requisito para obtenção do grau de Mestre em CIÊNCIAS BIOLÓGICAS na área da Biodiversidade.

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Orientador: Dr. João Vitor Campos-Silva

Co-orientador: Dr. André Braga Junqueira

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SUMÁRIO

1. APRESENTAÇÃO

As mudanças climáticas têm causado grandes impactos aos ecossistemas terrestres e oceânicos, representando um dos maiores desafios atuais à nossa civilização. De acordo com os relatórios do IPCC, o aquecimento global que vem sido detectado desde 1950 é fortemente influenciado pelas ações humanas, principalmente pela queima de combustíveis fósseis e pelo desmatamento, causando além do aquecimento da atmosfera, a elevação do nível dos oceanos e diversos outros impactos em sistemas biofísicos e socioecológicos (IPCC 2014; Marengo e Souza Jr, 2018).

Atualmente a região amazônica vem sofrendo com a ocorrência de eventos extremos cada vez mais frequentes, caracterizados por inundações catastróficas e secas extremas que impactam de forma substancial as comunidades biológicas e humanas (Lewis et al. 2011; Marengo et al. 2011 a,b; Zeri et al. 2014; Nobre et al. 2016; Wongchuig Correa et al. 2017; Garcia et al. 2018). Essa situação é agravada pela ocorrência de incêndios florestais e pela variabilidade climática oriunda dos fenômenos climáticos El Niño e La Niña (Marengo et al. 2008; da Silva Abel et al. 2021). Além disso, o desmatamento e o aumento da liberação de gases do efeito estufa afetam drasticamente o clima regional, podendo levar o sistema para um limiar crítico (*tipping point*), onde uma mudança pequena pode alterar substancialmente o estado de todo o sistema, o que teria um efeito dramático nos sistemas socioecológicos que compõem a Amazônia (Lovejoy and Nobre, 2018; Marengo e Souza Jr, 2018).

Uma vasta porção da Amazônia é formada por mosaicos de ambientes alagáveis inseridos em uma matriz de florestas de terra firme as quais estão sempre acima do nível máximo das águas dos rios. As áreas alagáveis das várzeas e dos igapós estão sujeitas à dinâmica hídrica dos rios regida pelo pulso anual de inundação (Marengo et al. 2011; Hawes et al. 2012; Zulkafli et al. 2016; Bredin et al. 2020; da Silva Abel et al. 2021). As comunidades biológicas e humanas inseridas nesses ambientes necessitam de adaptações exclusivas para se manterem nesse ambiente dinâmico. Assim, o pulso de inundação sincroniza uma série de processos ecológicos que regem toda a dinâmica socioecológica do sistema, interferindo na disponibilidade de nutrientes e habitats para diferentes espécies (Schöngart and Junk 2007; Junk et al. 2018).

Alguns impactos das mudanças climáticas já foram detectados ao longo do Rio Juruá (variações atípicas na temperatura média anual, mudanças no regime de chuvas e nos níveis de enchentes dos rios – grandes inundações, pequenas inundações e secas extremas) (da Silva Abel et al. 2021) e essas mudanças têm vários impactos diretos e indiretos nas atividades de subsistência locais. O Rio Juruá, um dos principais afluentes do rio Solimões, abriga importantes sistemas socioecológicos (Campos-Silva e Peres, 2016), que podem ser severamente impactados pelos avanços das mudanças climáticas e da maior incidência dos eventos extremos. Essas mudanças têm o potencial de gerar efeitos drásticos em diversas atividades produtivas, incluindo a pesca, a agricultura e a extração de produtos florestais, comprometendo substancialmente a segurança alimentar e econômica das comunidades rurais.

Uma ferramenta aliada na avaliação dos efeitos das mudanças climáticas e do aumento dos eventos climáticos extremos sobre as atividades desenvolvidas pelas comunidades locais é o Conhecimento Ecológico Local (LEK), que representa o conjunto de conhecimento, práticas e crenças dos povos indígenas e comunidades locais desenvolvido a longo prazo através da interação com o meio ambiente (Brook e McLachlan 2008; Joa et al. 2018; Reyes-García e Benyei 2019; Tengö et al. 2021).

Alguns estudos já avaliaram o impacto das mudanças climáticas através do conhecimento ecológico local na Amazônia através da forma como o conhecimento local percebe esses impactos (Brondízio and Moran 2008; Camacho Guerreiro et al. 2016; Oviedo et al. 2016; Ruiz-Mallén et al. 2017; Funatsu et al. 2019), porém poucos estudos avaliaram de forma ampla os efeitos das mudanças climáticas sobre as principais atividades desenvolvidas pelas comunidades humanas que dependem dos recursos naturais para sua subsistência e reprodução social. Nesse sentido, investigar e incorporar a perspectiva local dessas comunidades através do conhecimento ecológico local na compreensão desse fenômeno é fundamental (Reyes-García et al. 2015). O potencial do conhecimento ecológico local para o entendimento das mudanças climáticas e seus efeitos tem sido cada vez mais reconhecido e demonstrado, visto que baseia-se no conhecimento empírico que as comunidades locais desenvolvem como o meio ambiente a longo prazo, capaz de detectar mudanças sutis e de propor estratégias que auxiliem na mitigação de seus efeitos (Brook e

McLachlan 2008; Joa et al. 2018; Reyes-García e Benyei 2019; Tengö et al. 2021).

Com o objetivo de investigar como as comunidades ribeirinhas do Rio Juruá percebem os impactos das mudanças climáticas sobre o uso dos recursos naturais que estruturam seus modos de vida, formulei algumas questões de pesquisa: *Quais são os principais impactos das mudanças climáticas de acordo com a percepção das comunidades locais? Quais são as atividades de subsistência mais afetadas pelas mudanças percebidas no clima, particularmente por eventos climáticos extremos (grandes inundações, pequenas inundações e secas extremas)? Como os impactos percebidos dos eventos climáticos extremos variam de acordo com as atividades de subsistência, o ambiente onde esta atividade é desenvolvida (várzea e terra-firme) e a idade do entrevistado?*

Para responder a essas questões, utilizei informações obtidas a partir de entrevistas com moradores de 24 comunidades rurais espalhadas por aproximadamente 600 km do rio Juruá. Realizei o levantamento dos impactos percebidos pelos comunitários das mudanças climáticas em vários componentes biofísicos e socioecológicos, incluindo mudanças na temperatura, precipitação, na flutuação do nível da água dos rios, na frequência e intensidade de eventos climáticos extremos (grandes inundações, pequenas cheias e secas extremas), na biodiversidade e no uso e manejo de recursos naturais. Por meio do conhecimento ecológico local, também identifiquei quais atividades de subsistência são afetadas por diferentes mudanças relacionadas ao clima e os mecanismos que levam a esses impactos. Posteriormente, avaliei os impactos de eventos climáticos extremos nas atividades de subsistência locais e investiguei os efeitos que o ambiente onde a atividade é desenvolvida (várzea e terra-firme) e a idade podem exercer sobre as percepções dos membros da comunidade em relação aos eventos extremos. Os resultados obtidos ajudam a ampliar o conhecimento sobre os impactos das mudanças climáticas, em particular a maior incidência de eventos climáticos extremos, sobre comunidades locais na Amazônia.

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2. REVISÃO DE LITERATURA

Breve histórico sobre as mudanças climáticas globais e na Amazônia

As mudanças climáticas têm causado grandes impactos aos ecossistemas terrestres e oceânicos, representando um dos maiores desafios atuais à nossa civilização. A criação do Painel Intergovernamental de Mudanças Climáticas (IPCC) em 1988 consolidou a hipótese acerca da grande influência das ações humanas sobre as mudanças climáticas. De acordo com os relatórios do IPCC, o aquecimento global que vem sido detectado desde 1950 é fortemente influenciado pelas ações humanas, principalmente pela queima de combustíveis fósseis e pelo desmatamento, causando além do aquecimento da atmosfera, a elevação do nível dos oceanos e diversos outros impactos em sistemas biofísicos e socioecológicos (IPCC 2014; Marengo e Souza Jr, 2018).

Dentre os principais efeitos decorrentes das mudanças climáticas, destacam-se as alterações na composição e distribuição das espécies, aumento das taxas de extinção, redução de serviços ecossistêmicos e comprometimento da segurança alimentar, hídrica e econômica de populações humanas (Thomas et al. 2004; Schmidhuber and Tubiello, 2007; Rockström et al. 2014). Os impactos das mudanças climáticas, no entanto, variam substancialmente entre diferentes regiões e populações. Estima-se que os países mais pobres são os que mais sofrerão com a fome em decorrência das mudanças climáticas (Schmidhuber and Tubiello, 2007). Povos indígenas e comunidades locais tendem a ser particularmente vulneráveis a essas mudanças, dada a sua histórica marginalização, o seu relativo baixo nível de acesso a recursos e estratégias de adaptação, e a sua estreita dependência de recursos naturais (Bradshaw et al. 2009).

A floresta amazônica tem um papel importante na chuva local e regional, contribuindo para o ciclo hidrológico e transporte de umidade dentro e fora da região, além de se configurar como uma reserva de estoque de carbono, cuja liberação, por desmatamento ou degradação, poderia elevar ainda mais a temperatura global (Malhi et al. 2009; Arraut et al. 2012; Abril et al. 2014; Boisier et al. 2015; Sorribas et al. 2016). Na Amazônia, as mudanças climáticas já têm causado alterações como o aumento da temperatura média anual e o aumento da incidência (principalmente a partir da década de 1950) de eventos extremos, como grandes inundações e secas, representando uma ameaça com consequências importantes de curto e longo prazo (Lewis et al. 2011; Marengo et al. 2011a,b; Zeri et al. 2014; Nobre et al. 2016; Wongchuig Correa et al. 2017; Garcia et al. 2018). A intensidade desses eventos extremos e de seus impactos é agravada pela ocorrência de incêndios florestais e pela variabilidade climática oriunda dos fenômenos climáticos El Niño e La Niña (Marengo et al. 2008; da Silva Abel et al. 2021).

A Amazônia pode ser compreendida como um grande sistema sociocológico, onde comunidades humanas e os sistemas ecológicos mantém relação de dependência mútua (Berkes and Folke, 1998). A maior incidência desses eventos climáticos extremos pode alterar o equilíbrio desses sistemas, impactando importantes processos ecológicos e comprometendo atividades que garantem a subsistência dessas populações humanas (Cochrane and Barber 2009; Sorribas et al. 2016). Dessa forma, a investigação dos efeitos das mudanças climáticas nas populações locais em suas atividades e modos de vida, e a identificação das atividades de subsistência mais vulneráveis frente a incidência das mudanças climáticas e dos eventos extremos pode fornecer subsídios importantes para o desenvolvimento de iniciativas e políticas públicas voltadas para essas populações e para a sua resiliência frente às mudanças climáticas.

Contribuição do Conhecimento Ecológico Local em pesquisas sobre mudanças climáticas

Uma das formas de compreender os efeitos das mudanças climáticas nas comunidades locais é por meio do Conhecimento Ecológico Local, cujo potencial para o entendimento das mudanças climáticas e para o desenvolvimento de estratégias adaptativas tem cada vez mais sido reconhecido (Brook e McLachlan 2008; Joa et al. 2018; Reyes-García e Benyei 2019). Por meio de sua histórica e estreita relação com o meio ambiente, comunidades locais desenvolveram, ao longo de gerações, um conjunto de conhecimentos e práticas voltadas para o uso e manejo de recursos naturais, que também as permite identificar efeitos das mudanças climáticas em diversos elementos da natureza (Hou et al. 2012; Rodriguez et al. 2017; Lemahieu et al. 2018; e Yager et al. 2019). O conhecimento ecológico local pode ser particularmente importante para o entendimento de mudanças climáticas em países ou regiões onde os dados climáticos são escassos, incompletos ou inexistentes

Estudos enfocados no conhecimento ecológico local sobre as mudanças climáticas têm sido realizados em diversas regiões e com diversas populações indígenas e comunidades locais ao redor do mundo. Alguns exemplos recentes incluem os estudos com agricultores na Índia (Shukla et al. 2015, Panda 2016 e Pandey et al. 2018), com comunidades locais no Nepal (Uprety et al. 2017), com agricultores tradicionais de terraços de arroz no norte das Filipinas (Soriano et al. 2017), com comunidades pesqueiras em Madagascar (Lemahieu et al. 2018) e com pantaneiros no Pantanal Mato Grossense (Da Silva et al. 2014). Na Amazônia, estudos dessa natureza ainda são escassos. Alguns estudos investigaram as percepções de comunidades locais na Amazônia sobre risco e vulnerabilidade em relação às mudanças no regime hidrológico, nas práticas agrícolas, mudanças associadas a incêndios acidentais e a eventos climáticos extremos como grandes secas e inundações (e.g. Brondízio e Moran 2008;; Camacho Guerreiro et al. 2016; Fernández-Llamazares et al. 2017; Ruiz-Mallén et al. 2017; Funatsu et al. 2019).

No entanto, a maneira como as mudanças climáticas impactam e são percebidas por comunidades pode variar substancialmente dependendo, por exemplo, do grau de exposição dos ambientes que ocupam e manejam, dos tipos de recursos que utilizam, das atividades de subsistência desenvolvidas e de suas características socioeconômicas e culturais (Deressa et al. 2010; Sampson Yamba et al. 2019). Para a melhor compreensão dos impactos das mudanças climáticas a partir do conhecimento ecológico local, portanto, é necessário considerar essas especificidades contextuais e características individuais e coletivas das comunidades locais, como por exemplo o tipo de ambiente em que a comunidade está inserida, quais os meios de subsistência desenvolvidos e como esses podem ser diferentemente impactados, assim como a idade e experiência individual dos comunitários (de Oliveira Braga et al. 2018). Isso é particularmente relevante na Amazônia, dada a sua alta diversidade de ambientes, de recursos e de atividades de subsistência desenvolvidas pelas comunidades locais.

Caracterização da área de estudo

O estudo foi realizado na região do Médio Juruá, em duas unidades de conservação: a Reserva Extrativista do Médio Juruá (RESEX Médio Juruá) e a Reserva de Desenvolvimento Sustentável do Uacari (RDS Uacari), ambas localizadas no município de Carauari, estado do Amazonas (Souza, 2010). O rio Juruá tem mais de 3.000km de extensão, desde sua nascente no Peru até onde deságua no rio Solimões, sendo o rio mais sinuoso da Amazônia e um dos maiores do mundo (Souza, 2010; Hurd et al. 2016). Para as comunidades locais, o rio é o principal cenário de desenvolvimento da dinâmica social do território, que possibilita a integração, comunicação, abastecimento e escoamento da produção das comunidades locais com outras comunidades e com a capital amazonense (Souza, 2010).

As duas unidades de conservação onde estão localizadas as comunidades estudadas neste trabalho cobrem um total de 11.331,67 km² (Souza, 2010). Os residentes dessas reservas vivem em comunidades localizadas ao longo do rio Juruá e de seus afluentes, tanto em áreas de terra-firme quanto em áreas de várzea. A RESEX Médio Juruá, criada em 1997, possui aproximadamente 1.921 residentes, distribuídos em 338 famílias e 24 comunidades. A RDS Uacari, criada em 2005, possui aproximadamente 1300 residentes, distribuídos em 234 famílias e 33 comunidades (ICMBio, 2012; SEMA, 2019). A distância do rio coberta pela área de estudo foi de 500km.

A paisagem local é composta por um mosaico de ambientes alagados de várzea inserido em uma matriz de florestas de terra-firme que estão sempre acima do nível máximo das águas do rio e estão sazonalmente sujeitos ao pulso de inundação anual (Hawes et al. 2012; da Silva Abel et al. 2021). A dinâmica hídrica é regida pelo pulso de inundação anual, que marca as estações de cheia e de seca, sincronizando uma série de processos ecológicos que regem toda a dinâmica socioecológica do sistema, interferindo na disponibilidade de nutrientes e habitats para diferentes espécies (Junk et al. 1989).

As comunidades ribeirinhas do rio Juruá exploram diversos recursos naturais por meio de diversas atividades de subsistência, como por exemplo a extração de recursos vegetais (produtos florestais madeireiros e não madeireiros), agricultura e pesca, para subsistência e geração de renda (Newton et al. 2011; Icmbio 2012). Essas atividades demonstram a forte relação interdependente que as comunidades locais mantêm com o meio ambiente onde vivem. Gerações de famílias são mantidas e se reproduzem social e culturalmente por meio do contato estreito com o meio ambiente local.

Essas comunidades desenvolvem diversas atividades de subsistência, incluindo agricultura (focada no cultivo de mandioca), quintais e outros sistemas agroflorestais onde são manejados diversas espécies anuais (e.g., melancia, milho, jerimum, feijão) e perenes (e.g., cupuaçu, goiaba, manga, jambo, banana, laranja, etc.), extração de recursos florestais (borracha - *Hevea brasiliensis*, açaí - *Euterpe oleracea*, ucuúba - *Virola surinamensis*, andiroba - *Carapa guianensis* e muru-muru - *Astrocaryum murumuru*) (Newton et al. 2011), pesca tendo como principal atividade o manejo comunitário do pirarucu (pirarucu - *Arapaima gigas*) (Campos-Silva et al. 2016; Campos-Silva et al. 2019); caça (queixada - *Tayassu pecari*, cotia - *Dasyprocta*, paca - *Cuniculus paca* e tatu - *Dasypodidae*) (Abrahams et al. 2017); manejo comunitário de quelônios (Campos-Silva et al. 2018). Entre as principais atividades geradoras de renda, destacam-se o cultivo da mandioca para venda de farinha refinada, a venda de sementes de ucuúba, andiroba e muru-muru para extração de óleo em cooperativas, extração da borracha, pesca e manejo do pirarucu (Sarti et al. 2015; Endo et al. 2016).

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3. MANUSCRITO

Climate change impacts on local communities: the perception of the riverine communities of the Juruá River, Brazilian Amazon

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Abstract

Since the 1950s remarkable climate-related changes have been observed in the Amazon, including an increase in mean annual temperature and changes in river dynamics, particularly an increase of the incidence of large river floods and droughts. These changes can substantially impact social-ecological systems affecting a wide set of livelihoods strongly relying on natural resources. Here, we investigated the effects of climate change on the livelihood activities of riverine communities in western Amazonia. We conducted semi-structured interviews with local residents (n=359) from 24 rural communities of the Juruá River, a major white-water tributary of the Amazon River. Local residents perceive a vast set of changes and many of them are associated with strong impacts on local livelihoods. Beyond the manifold impacts identified in our analysis, our findings reinforce the imperative importance to include local communities in decision making of public policies to prevent and mitigate climate change impacts in Amazonian communities.

Key-words: Climate change; Local Ecological Knowledge; Local perception; Socioecological systems.

Impactos das mudanças climáticas sobre comunidades locais: a percepção das comunidades ribeirinhas do Rio Juruá, Amazônia Brasileira

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Resumo

Desde a década de 1950, mudanças notáveis relacionadas ao clima têm sido observadas na Amazônia, incluindo um aumento na temperatura média anual e mudanças na dinâmica dos rios, particularmente um aumento na incidência de grandes enchentes e secas. Essas mudanças podem impactar substancialmente os sistemas sócio-ecológicos, afetando um amplo conjunto de meios de subsistência que dependem fortemente dos recursos naturais. Aqui, nós investigamos os efeitos das mudanças climáticas nas atividades de subsistência de comunidades ribeirinhas no oeste da Amazônia. Conduzimos entrevistas semiestruturadas com residentes locais (n = 359) de 24 comunidades rurais do rio Juruá, um importante afluente de águas brancas do rio Amazonas. Os residentes locais percebem um vasto conjunto de mudanças e muitas delas estão associadas a fortes impactos nos meios de subsistência locais. Além dos múltiplos impactos identificados em nossa análise, nossas descobertas reforçam a importância imperiosa de incluir as comunidades locais na tomada de decisões de políticas públicas para prevenir e mitigar os impactos das mudanças climáticas nas comunidades amazônicas.

Palavras-chave: Mudanças climáticas; Conhecimento Ecológico Local; Percepção local; Sistemas socioecológicos.

Introduction

Climate change represents one of the greatest challenges to our civilization due to its pronounced impacts and in the last decades, remarkable environmental changes have been observed in the Amazon, including an increase in the mean annual temperature and changes in river dynamics – particularly an increase in large river floods and droughts (Thomas et al. 2004; Schmidhuber and Tubiello, 2007; Rockström et al. 2014; Marengo e Souza 2018). Although seasonal climatic variability and extreme events have historically occurred in the Amazon, the frequency and intensity of these events has increased, representing a potential threat for the ecological stability of the region (Lewis et al. 2011; Marengo et al. 2011a,b; Zeri et al. 2014; Nobre et al. 2016; Wongchuig Correa et al. 2017; Garcia et al. 2018) and for the livelihood of Indigenous peoples and local communities living in it (Nobre and Nobre 2020a; Menezes et al. 2018). Moreover, the increased frequency and intensity of extreme events is aggravated by the occurrence of forest fires and the climatic variability arising from the phenomena of El Niño and La Niña (Marengo et al. 2008; da Silva Abel et al. 2021).

A vast portion of the Amazon is formed by mosaics of flooded environments inserted in a matrix of non-flooded upland forests. Flooded areas are subject to a predictable annual flood pulse (Marengo et al. 2011b; Hawes et al. 2012; Zulkafli et al. 2016; Bredin et al. 2020; da Silva Abel et al. 2021) that shapes the life of biological and human communities who have developed exclusive adaptation strategies to maintain themselves in this dynamic environment (Schöngart and Junk 2007; Junk et al. 2018). Given their long history of human habitation, flooded environments are examples of social-ecological systems, where ecological systems and human communities maintain a relation of mutual dependence (Berkes and Folke, 1998). Amazonian flooded social-ecological systems are particularly vulnerable to climate change, and particularly to the increased incidence of extreme weather events (Cochrane and Barber 2009; Sorribas et al. 2016). These changes could compromise not only ecological stability but also the subsistence, income and wellbeing of local communities that depend on these areas.

An effective strategy to understand how climate change, in general, and the increase of the extreme weather events, in particular, impact local communities is to assess local understandings of change. Through their long-term direct relation with the environment, local communities have developed detailed ecological knowledge that they apply in the use and management of the local resources, and based on which they also identify (and react to) changes (Hou et al. 2012; Rodriguez et al. 2017; Lemahieu et al. 2018; Yager et al. 2019). Researchers have highlighted the potential of such knowledge system, referred to as Local Ecological Knowledge (LEK), to identify and analyze climate change impacts (e.g., Reyes-García et al. 2019 a,b). For example, previous research in the Amazon has relied on LEK to capture local perceptions of risk, vulnerability and adaptation to climate-driven changes in the hydrological regime, agricultural practices, wild fires, and extreme weather events (Brondízio and Moran 2008; Camacho Guerreiro et al. 2016; Oviedo et al. 2016; Fernández-Llamazares et al. 2017; Ruiz-Mallén et al. 2017; Funatsu et al. 2019).

Despite these advances, there are still many knowledge gaps regarding how climate change, and particularly extreme weather events, impact livelihood activities. Different livelihood activities can be differently impacted by climate change, depending on how and where activities are developed, and on the extent to which the resources on which these activities are based are being affected. For example, floodplains and upland environments have very different degrees of exposure to climate change, so livelihood activities conducted in these environments might be differently affected by extreme river floods and droughts (Barros and Albernaz 2014). Hence, to thoroughly understand how climate change is affecting local communities in Amazonia, it is necessary to take into account both the diversity of livelihood activities, and of the environments where these activities are practiced.

Here, we investigate how riverine communities in western Amazonia perceive the impacts of climate change on different livelihood activities. In particular, our research addresses the following research questions: i) Which are the main changes in elements of the climatic system perceived by local communities? ii) What are the livelihood activities perceived to be most impacted by changes in elements of the climatic system, particularly by extreme climatic events?; iii) How does the perceived impacts of extreme weather events vary across livelihood activities and environments?

Material and Methods

Study area and socioecological context

The study was carried out along the middle section of the Juruá River an important white-water tributary of the Amazon River. The Juruá River comprises more than 3000km in length, from its source in Peru until it flows into the Solimões River in Brazil, being the most meandering river in the Amazon and one of the largest rivers in the world (Souza, 2010; Souza and Oliveira, 2016). Through its journey, the river carries a large amount of nutrient-rich Andean alluvial sediments that are deposited during the annual flooding in the floodplains (Hawes et al. 2012; da Silva Abel et al. 2021). (Figure 1).

Figure 1. 1) Location of the protected areas RDS Uacari and RESEX Médio Juruá in the Juruá River in the state of Amazonas in Brazil. Solid green and blue lines indicate the boundaries of RDS Uacari and RESEX Médio Juruá respectively; yellow triangles and pink dots represent the sampled rural communities where qualitative and quantitative data collection occurred respectively; 2) main livelihood activities carried out by the riverine communities along the Juruá Rive: a) andiroba (Carapa guianensis) extraction, photo credit Mamirauá Institute; (b) fruits from the açaí palm (Euterpe oleracea), photo credit Andreza Andrade/Bem Diverso; (c) co-management of arapaima (Arapaima gigas), credit photo O Globo; (d) manioc flour production, photo credit Mariana O. Estevo; (e) rubber (Hevea brasiliensis) extraction, credit photo Rogerio Assis/ISA and (f) homegarden / agroforestry system, photo credit Valter Ziantoni/Pretaterra.

Currently, the main livelihood activities practiced by riverine communities along the middle Juruá River include the extraction of forest products (timber and non-timber), agriculture, and fishing (Newton et al. 2011; ICMBio 2012). Communities in the Juruá river conduct several livelihood activities, including upland and floodplain agriculture (focused on manioc production), homegardens and agroforestry systems, carpentry (Newton et al. 2011), fishing (Campos-Silva et al. 2016; Campos-Silva et al. 2018), hunting (Abrahams et al. 2017) and extraction of non-timber forest resources such as rubber (Hevea brasiliensis), açaí (Euterpe precatoria), andiroba (Carapa guianensis), muru-muru (Astrocaryum murumuru), and ucuúba (Virola surinamensis). Manioc is the main source of carbohydrate for local communities and one of the main sources of cash income through the sale of flour (Newton et al. 2011; Abrahams et al. 2018). Fishing and hunting are crucial for protein intake (Sarti et al. 2015; Endo et al. 2016) (See further details regarding the socioecological context within Supplemental material).

Site selection

We conducted research within two sustainable-use protected areas, the Extractive Reserve of Médio Juruá (hereafter RESEX) and the Uacari Sustainable Development Reserve (hereafter RDS), both located in the municipality of Carauari, Amazonas state (Souza, 2010). These two protected areas cover a total of 11,331.67 km². Local populations in the area are spread in small communities located on the margins of the Juruá or its tributaries. The RESEX was created in 1997 and currently has 1921 residents distributed in 338 families and 24 communities. The RDS was created in 2005 and currently houses approximately 1300 people, distributed in 234 families and 33 communities (ICMBio 2012; SEMA 2019).

Research communities were selected taking into account the existing variation in their location in the landscape. Five communities were located in floodplains and three in non-flooded uplands. Communities were also selected considering predominance of different livelihood activities. Although all communities sampled carry out the same main livelihood activities (i.e., fishing, homegardens / agroforestry systems, extractivism, hunting and carpentry), due to landscape characteristics and cultural background, some activities are more prominent in certain communities than in others.

Data collection

We collected different sets of data to achieve different objectives. To obtain information on local perceptions of climate change impacts and how different livelihood activities are affected by them, in March 2020 (i.e., before the COVID-19 pandemic hit the area), we collected qualitative data through 42 semi-structured interviews in eight communities. For the semi-structured interviews, we selected people locally recognized as knowledgeable about the environment, environmental changes and local livelihoods (i.e., people notoriously holding LEK). We selected informants using the snowball method and considering a balanced number of women and men of different ages.

During semi-structured interviews, we asked participants about any change that they had noticed in the environment since their early adulthood. Initially we asked about all perceived changes, regardless of whether they were climate-related or not. After the interviewee stopped mentioning environmental changes, we asked about perceived changes in specific elements of the climatic, the biophysical and the socio-economic systems, including changes in rainfall, temperature, river dynamics, wind, wild plants, crops, livestock, wild animals, fish and human health. To better understand whether the change was only or mainly attributed to climate change, for each change reported, we also asked about the cause (driver) of change.

In each community, after finishing the semi-structured interviews, we conducted a focus group discussion (FGD). FGD were intended to provide collective validation of observations of environmental changes collected during semi-structured interviews and to record additional observations of change. Participants in FGD numbered between 4 and 14, adding up to a total of 85 participants in eight FGD (see details in Table S2. in Supplemental material). Most FGD participants had not participated in semi-structured interviews. Participants were diverse in terms of sex, age, and livelihood activities performed in the community.

To evaluate the impact of extreme weather events on different livelihood activities, from March to April of 2018, we conducted individual surveys with 317 randomly selected residents from 21 communities (see details in Table S1. in Supplemental material). We focused on the perceived impacts of three extreme events related with changes in the river dynamics: large river floods, small river floods and large river droughts. We started interviews asking participants about their main livelihood activity and the environment where this activity was conducted (upland or floodplains). Then, we asked if the activity had been negatively impacted by the last occurrence of each of the extreme events selected. Specifically, we asked: “Did you suffer any production loss in the last large river flood/small river flood/large river drought that you remember?”

Data analysis

We used descriptive statistics from data obtained in semi-structured interviews to quantify the most frequently mentioned climatic changes, the most impacted livelihood activities, and the most important climatic drivers leading to reported changes. As we aim to investigate the perceived climate changes and their impacts to different livelihoods activities, in the analysis we focus on perceived changes on elements of the climatic system (e.g., a change in rainfall) or directly driven by a change in an element of the climatic system (e.g., a change in crop growth driven by a change in rainfall). Hence, we excluded all changes that, according to informants’ perceptions, were driven by non-climatic factors.

Observations of change reported during semi-structured interviews and FGD were classified using a hierarchical system devised to categorize observations of climate change impacts made by local communities (Reyes-García et al. 2015). Thus, observations were categorized in Local Indicators of Climate Change Impacts (LICCI) based on the different systems in which they are observed (climatic, physical, biological and human), and subsequently in subsystems and elements impacted. We used information provided by informants to classify each LICCI as having a positive, neutral or negative impact in one or more livelihood activities. Impacts considered as positive by some informants and as negative by others were classified as neutral. The livelihood activities considered were andiroba seed harvesting, açaí extraction, fishing, hunting, manioc cultivation, muru-muru seed harvesting, homegardens / agroforestry systems, rubber extraction, turtle management, and ucuúba seed harvesting. Finally, we classified the changes in elements of the climatic system mentioned in semi-structured interviews in one of the following categories: “large river drought”, “large river flood”, “small river flood”, “change in frequency of flooding”, “change in rainfall,” and “change in temperature”. The non-climatic changes in elements of the climatic system were not included in analysis. For each reported change, we coded its association with impacts in livelihood activities if this association was explicitly made by one or more of the respondents during the interviews. For example, the change ´the large floods are killing the andiroba trees in the floodplains´ was associated with the livelihood activity ´andiroba harvesting´, and the change ´the heavier rains during summer can help manioc and fruits to grow more´ was associated with the livelihood activities ´manioc cultivation´ and ´homegardens/agroforestry systems´.

To investigate how the perceived impacts of large river floods, small river floods and large river droughts vary according to livelihood activities and environment, we used survey data to perform Generalized Linear Models (GLMs) using binomial error structures. The response variable in the GLMs was the presence or absence of reported production losses in the last episode of each extreme weather event, while the predictors were the main livelihood activity of the interviewee and the environment where the livelihood is practiced (floodplains or uplands). Models were fitted using the lmer function from the lme4 package and each model combination was examined using the MuMIn package (Barton, 2009). We selected the most parsimonious model with the lowest Akaike Information Criterion, correcting for small sample sizes (AICc). Δ AICc is calculated as the difference between each model’s AICc and the lowest AICc, with a Δ AICc < 2 interpreted as substantial support that the model belongs to the set of best models (Burnham and Anderson, 2004). After model selection, we calculated a model average, which considers the beta average of all variables included in parsimonious models. As the variables were standardized (z-scores), we compared the relative effect size of all variables. All assumptions were examined prior to analyses, including linear relations, correlations between explanatory factors, homoscedasticity and distribution of residuals (Zuur et al.

2010). All analyses were performed within the R platform and the dataset can be found at Supplemental material.

We acknowledge some important methodological limitations of our work. We recognize that LEK is holistic in nature, a characteristic that is not properly reflected in the classification used in this work. We also recognize that some of the livelihood activities analyzed here are less important in some sampled communities that in others, for which informants might not have referred to them during interviews. Finally, we also acknowledge that reliance on memory to report on past events can bias respondents' responses, as extreme weather events that have recently occurred tend to be more often mentioned by respondents.

Results

Local perceptions of environmental change

During semi-structured interviews and FGD, respondents mentioned 477 observations of change (hereafter ´citations´), which were classified into 53 Local Indicators of Climate Change Impacts (LICCI). 183 of the citations (38.5%, classified into 15 LICCI) referred to changes in elements of the climatic system, including changes in mean temperature, changes in mean rainfall, and changes in the amount of rainfall in a given season. Changes in elements of the physical system were cited 126 times (26.5%, classified into 11 LICCI), including changes in the water level of the river / stream / lake in a given season, changes in the intensity of sedimentation of the river or lakes, and changes in the speed of seasonal fluctuation in the water level of the river. Changes in elements of the human system were cited 89 times (18.5%, classified into 11 LICCI), including changes in crop mortality, changes in crop productivity, and changes in the incidence of human diseases (e.g., flu, allergies). Changes in elements of the biological system were cited 79 times (16.5%, classified into 16 LICCI), including changes in the mortality of species of wild plants or fungi, changes in the abundance of freshwater fish, and changes in vegetation dynamics (see details in Table S2. and in Table S3. in Supplemental material).

Perceived impacts on livelihood activities

Of the 477 observations of change reported, 202 (42.3%) referred to changes with a direct impact on livelihood activities, from which 112 (55.5%) citations (classified into 15 LICCIs) referred to changes in elements of the biological system, while the remaining 90 (44.5%) (classified into 7 LICCI) referred to changes in elements of the human system (see details in Table S4. in Supplemental material). Most perceived changes impacting livelihood activities refer to changes in wild plant or fungi species mortality (64 citations, 31.6%). Other changes included changes in crop mortality rates (37 citations, 18.3%); changes in crop productivity / yield (33 citations, 16.3%); changes in the productivity of wild plant or fungi species (9 citations, 4.5%); changes in the abundance of freshwater fish (6 citations, 3%); changes in wild plant or fungi species fruiting time (6 citations, 3%); changes in length of crop harvesting time (6 citations, 3%), and changes in the frequency or occurrence of weed species stated as invasive (6 citations, 3%).

The livelihood activities perceived to be most impacted by changes in elements of the climatic system according to the amount of impact observations of climate change associated with them were homegardens / agroforestry systems (48 citations, 24%, mostly impacted through observations classified as changes in crop mortality rates and changes in crop productivity / yield) and manioc cultivation (41 citations, 20%; mostly impacted through observations classified as changes in crop mortality rates and changes in crop productivity / yield). Andiroba harvesting was also frequently cited as impacted by changes in elements of the climatic system (28 citations, 14%; mostly impacted through observations classified as changes in wild plant or fungi species mortality) (see details in Table S4. in Supplemental material) (Figure 2.a).

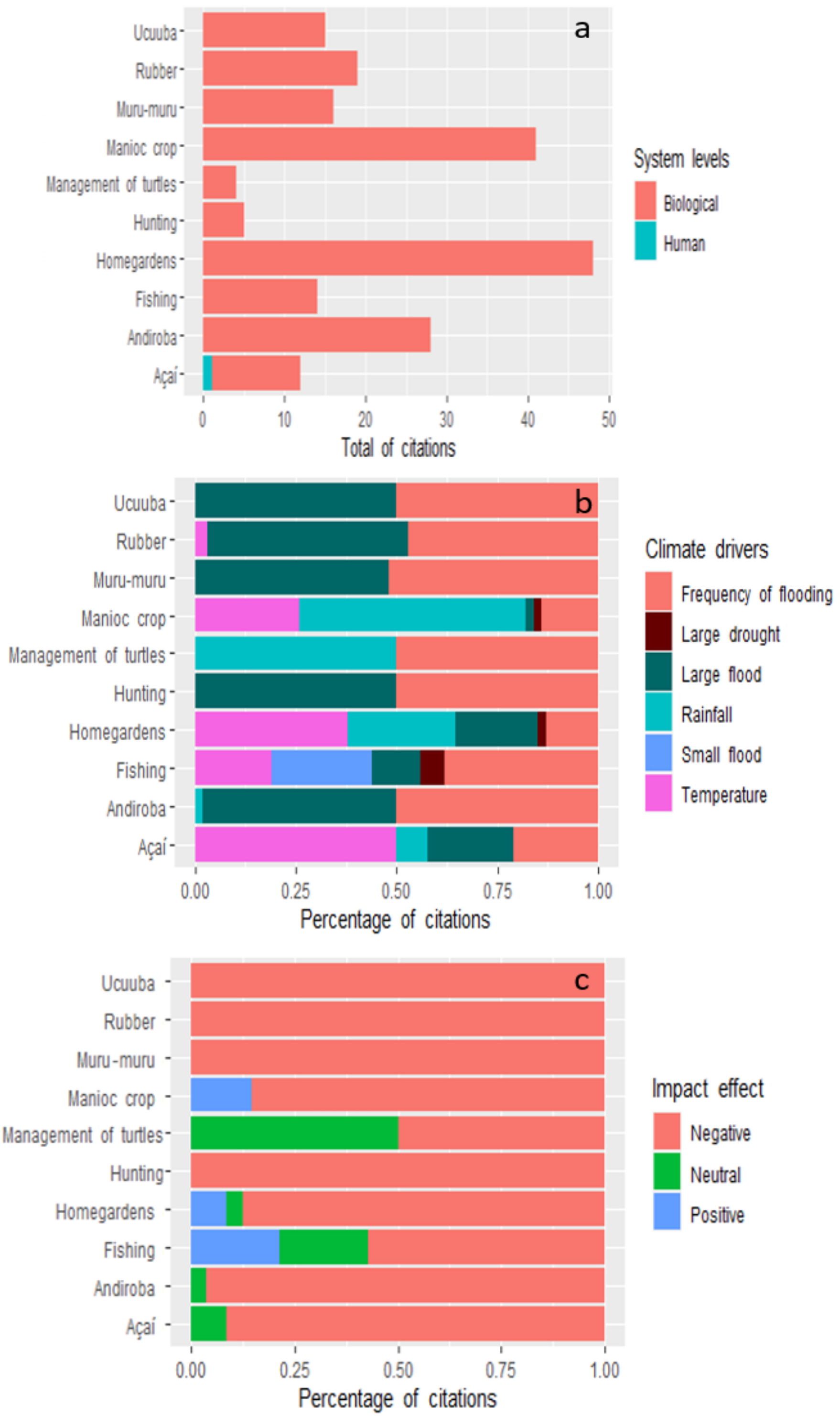

Figure 2. a) Number of Observations of environmental change associated with different livelihood activities, grouped by system levels (biological and human); b) Percentage of citations of changes in elements of the climatic system impacting different livelihood activities according to the perceptions of local residents along the middle Juruá river; and c) Negative, neutral, and positive effects of the impacts of changes in elements of the climatic system on different livelihood activities along the middle Juruá river. Bars indicate the percentage of citations associated with each livelihood activity that have negative, positive or neutral impacts.

For the 202 observations of change directly associated with livelihood activities, specific changes in elements of the climatic system were mentioned 170 times. Of these, 50 (29.5%) referred to changes in the frequency of river flooding, 34 (20%) to changes in temperature, and 32 (19%) to changes in the rainfall regime. Another 54 of the mentioned changes in elements of the climatic system referred to changes in extreme events, of which 48 (28%) referred to large river floods, 4 (2.5%) to small river floods, and 2 (1%) to large river droughts.

The analysis shows that different livelihood activities are perceived to be impacted by different changes in elements of the climatic system. Manioc cultivation is more impacted by changes in the rainfall regime (26 citations, 57%), while homegardens / agroforestry systems and açaí extraction are perceived as being more affected by changes in temperature (20 citations, 37.5%; and 7 citations, 50%). Changes in large floods and changes in the frequency of flooding are the most frequently cited changes in elements of the climatic system impacting ucuúba harvesting (14 citations each change, 50%) and hunting (5 citations each change, 50%). Changes in the frequency of flooding is the most cited change in elements of the climatic system impacting muru-muru and (15 citations, 52%) andiroba harvesting (24 citations, 50%) and fishing (6 citations, 37.5%). Rubber extraction is most impacted by large floods (18 citations, 50%), whereas the management of turtles is equally impacted by changes in temperature (1 citation, 50%) and by changes in the frequency of flooding (1 citation, 50%) (Figure 2.b)

Most of the 202 observations of change impacting livelihood activities were perceived as having negative effects on livelihood activities (180 citations, 89% were perceived as having a negative effect vs. 13 citations, 6.5%, perceived as having a positive effect and 9 citations, 4.5%, perceived as having a neutral effect). Negative impacts are seen in all livelihood activities, although the described impacts are different for each activity. All perceived impacts on hunting (5 citations), muru-muru harvesting (16 citations), rubber (19 citations) and ucuúba harvesting (15 citations) were negative. Other activities such as andiroba harvesting (28 citations; 96.5% negative, 3.5% neutral), açaí harvesting (12 citations; 91.5% negative, 8.5% neutral) and turtles' management (4 citations; 50% negative, 50% neutral) were mostly associated with negative impacts, but informants also perceived some neutral impacts (Figure 2.c).

Only three livelihood activities were perceived to be positively impacted by the reported changes in elements of the climatic system. Fishing is, proportionally, the livelihood activity receiving most positive impacts from changes in elements of the climatic system (14 citations; 21.5% positive, 57% negative, 21.5% neutral). As informants explained, changes in large flood events and changes in the frequency of flooding increases fish abundance, and higher temperatures prevent fish from dying during the cold season. Similarly, manioc cultivation (41 citations; 14.5% positive, 85.5% negative) is perceived to benefit from changes in the rainfall regime, as increased rainfall in the summer helps plant growth. Finally, homegardens / agroforestry systems (48 citations; 8.5% positive, 87.5% negative, 4% neutral) are perceived to benefit from changes in the rainfall regime, as the increase in rain abundance during the summer helps plants growth (Figure 2.c).

Extreme weather impact on livelihood activities

Using survey data to analyze the perceived impacts of extreme events on different livelihood activities, we found that river floods and droughts have significant, but differentiated impacts in the livelihood activities conducted in the area. Thus, the GLM show a positive and statistically significant association between large floods and muru-muru palm and andiroba production loss, but a negative and statistically significant association between large floods and açaí, ucuúba and fishing production loss (Figure 3.a). Small flood events show a negative association with ucuúba harvesting and fishing (Figure 3.b), whereas large droughts show a positive association with ucuúba production losses, but a negative association with muru-muru palm harvesting production losses (Figure 3.c).

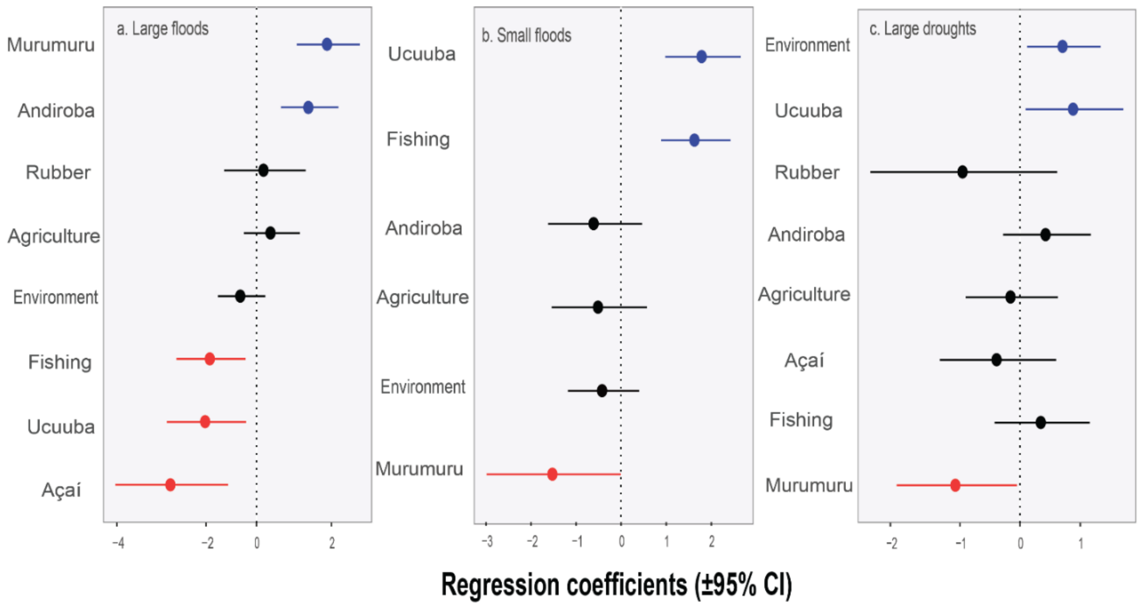

Figure 3. Estimates for regression slopes (± 95% confidence intervals, CIs) showing the magnitude and direction of the effects of a) large floods, b) small floods, and c) large droughts on production losses for different livelihood activities, according to the perceptions of local residents along the middle Juruá River (n=317). Solid circles indicate the mean estimates and horizontal lines indicate confidence intervals. For significant variables, CIs do not cross the horizontal dotted line at zero. Red and blue symbols represent, respectively, significant positive and negative association between the predictor and response variable (production loss).

We also found that the environment where the livelihood activity is conducted (uplands vs. floodplains) is an important factor in explaining local perception of the impact of large droughts. The livelihood activity that had a significant relationship with the variable environment was agriculture. Respondents conducting agriculture in floodplains areas were more likely to report negative impacts of large river droughts in agricultural production losses than their peers conducting agriculture in the uplands. We did not find significant effects of environment on the perception of the impacts of large or small river floods (see details in Table S5. in Supplemental material).

Discussion

The myriad of perceived changes

In recent decades, different climate change impacts have already been noticed in the Amazon, such effects often being exacerbated by environmental degradation caused by other drivers of change (Silveira et al. 2020; Silva et al. 2021; Lovejoy and Nobre 2018). We show that some of the known changes in elements of the climatic system affecting the area, such as warmer temperatures and less predictable rains, are also perceived by local communities along the Juruá. But our findings also show that local residents perceive a vast set of changes in elements of the climatic system that go beyond changes in weather patterns. Thus, local communities along the Juruá river also recognize many changes occurring in elements of the physical, the human and the biological systems. This finding highlights the importance of local knowledge systems to identify not only changes in elements of the climatic system, but also their cascading impacts in multiple elements of social-ecological systems (Oviedo et al. 2016). Our results also highlight how climate-driven impacts in elements of the biophysical system substantially affect local livelihoods, a finding that has also been reported for other communities particularly dependent on nature (Macchi et al. 2008; Salick and Ross 2009, Funatsu et al. 2019). Moreover, we show that while a handful of these impacts are perceived as positive, most of them are perceived as negative, calling the attention to the vulnerability of these communities to ongoing and future climate change impacts (Macchi et al. 2008; Salick and Ross 2009).

Local residents reported important changes in the dynamics of the river, and particularly the occurrence of larger, more frequent and more unpredictable floods than in the past. According to local residents, large floods deposit a substantial amount of sediments along the river margins, leading to the mortality of several trees on floodplains, including some that are economically important (e.g., andiroba). Local residents also reported a higher incidence of extreme river droughts during the dry season, during which the river water level gets very low and hampers their mobility and the transportation of products. Within the reported changes in elements of the climatic system, temperature increase was the change most often cited, which was also perceived as having multiple cascading impacts such as increasing the water temperature of rivers and streams, which is perceived to negatively affect fish. Previous research in other Amazonian regions has found similar changes, including an increase of the incidence of the extreme weather events, an increase of temperature, and changes in the wind and rainfall, which have become more unpredictable (Brondízio and Moran, 2008; Oviedo et al. 2016).

Regarding climate-driven impacts on elements of the human system, local residents associated changes in elements of the climatic system with an increased incidence of diseases, including malaria, dengue and filaria. This finding is in line with previous studies showing that the increase in temperature and large floods frequency can lead to increases in vector-borne diseases (Iwamura et al. 2020; Ryan et al. 2019, Oviedo et al. 2016). This is reason for concern, considering the relatively precarious access to formal healthcare in most rural Amazonia (Garnelo et al. 2020). Informants also reported that higher temperatures also increase their headaches while conducting agricultural work. In this context, small farmers are forced to reduce their work journey to avoid high temperature within day periods.

Impacts on livelihoods

Previous research has already shown that climate change has strong impacts in small-scale agriculture (Mendelsohn, 2008; Labeyrie et al. 2021). These impacts are likely to be stronger for subsistence and smallholder farmers in the tropics, due to their limited capacity to adapt to change due to fragile socioeconomic and political conditions (Morton, 2007). Subsistence farmers of the riverine communities of the Juruá river perceive that their agricultural and agroforestry systems are impacted by changes in elements of the climatic system. For example, research participants mentioned that some crop species are producing less under higher temperatures, that the soil is drier during the summer, and that crop losses are becoming more frequent on the floodplains due to the greater incidence of large floods. Interestingly, farmers also mention that some changes on elements of the climatic system can lead to positive impacts. For example, the increase in rainfall during the summer is perceived as favoring crop growth. However, most of the perceived impacts in plant cultivation are negative, which is a large concern considering the importance of agriculture for food security and income generation for the communities along the middle Juruá and elsewhere in Amazonia (Abrahams et al. 2018; Newton et al. 2011).

Changes in elements of the climatic system can strongly affect the distribution of palm and tree species that are culturally and economically important for local communities in the Amazon (Evangelista-Vale et al. 2021). Along the middle Juruá, local residents reported increased mortality and reduced productivity of açaí, ucuúba and muru-muru due to greater incidence of large river floods. However, the perceived impact of large floods on these species is not homogeneous. While some activities such as muru-muru palm and andiroba harvesting are negatively impacted by large floods, others such as açaí and ucuúba harvesting show a more complex pattern. On the one side, açaí and ucuúba production is negatively impacted by climate change, on the other side, large floods improves access to some individuals of these species, thus temporarily increasing the ability to harvest them. The extraction of rubber is also perceived to be negatively impacted by higher temperatures, higher incidence of large floods, and changes in the frequency of flooding, changes that either jeopardize the production of rubber or that can lead to the death of rubber trees.

Changes in frequency and size of river floods can also impact fish, turtles and game species abundance, size, and reproduction cycles. Large floods are perceived to increase fish availability and capture in subsequent years. During large floods, aquatic species, especially fish, have a larger area to reproduce and to obtain food resources, contributing to their development and growth (Castello et al. 2015; Hurd et al. 2016; De Mérona and Gascuel, 1993). On the contrary, small floods cause a negative impact in fishing because the restriction on flooded habitats harms the reproduction and growth of fish species. Hunting is perceived to be negatively impacted by the increased incidence of large floods since game species are restricted to smaller areas and more vulnerable for predators. Finally, the community-based management of freshwater turtles is also perceived to be negatively impacted by large floods, which can flood the turtles' nests, and by small floods, which can jeopardize the reproduction of turtles.

Overall, the combined effects of changes in different elements of the climatic system can compromise local communities' income generation, food security, and food sovereignty. In addition, these impacts can compromise the social dynamics of such communities and may induce local migrations (Brondízio and Moran 2008, Oviedo et al. 2016).

Impacts of extreme events

We found that a substantial amount of the reported changes is driven by extreme events related to river water level fluctuation (large river floods, small river floods and large river droughts). Indeed, water fluctuation represented 34.7% of the reported changes impacting livelihood activities. These findings highlight that these extreme events are very important and have many impacts on local livelihoods, according to local perceptions.

Extreme events impact differently different livelihoods. For example, in our models, fishing has a negative association with production losses, which implies that people do not associate large river floods with loss of production in fishing. Indeed, during interviews, informants mentioned that fish species benefit from large floods, which increase the food availability and habitat surface to reproduce. The finding is important because it highlights the complexity of the consequences of climate change impacts, which can be multidirectional. Consequently, initiatives in the area aiming to build adaptation capacity/resilience in relation to extreme events should take into account these multidirectional impacts. In particular, a focus on activities that are most negatively impacted, including muru-muru palm and andiroba during large floods, ucuúba harvesting and fishing during small floods ucuúba harvesting during large droughts, would be recommended.

We only found a relation between the environment where the activity is conducted (uplands vs. floodplains) and production losses perception during the large droughts. Respondents that conduct their activities in the upland forest are more likely to perceive negative effects of extreme droughts. Within the extreme drought, upland environments can become dryer, increasing the mortality of plants (Aleixo et al. 2019) and strongly affecting the livelihoods such as homegardens / agroforestry systems and manioc cultivation.

Conclusion

Based on local perceptions of change by local communities, this study shows multidimensional impacts of climate change on local livelihood activities. Results suggest that local knowledge systems are a valuable source of knowledge to assess the diverse and cascading effects of climate change on social-ecological systems. Given this knowledge, the inclusion of local knowledge holders in global climate change policies formulation, from local to global levels, is urgent not only due to social justice since historically these communities have been relegated to decision-making space (Reyes-García et al. 2021), but also because they are holders of unique and valuable knowledge that should be taken into consideration in public policies to prevent and mitigate climate change impacts in Amazonian communities.

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Supplemental material

Methods

Study area and socioecological context

The middle Juruá is inserted in the Amazonian floristic region, with predominance of dense Ombrophilous forest. The climate is humid equatorial, with yearly rainfall ranging from 1800 to 2200mm and average temperatures around 29 °C. The relative humidity in the area generally remains above 90% (Hawes and Peres 2016; da Silva Abel et al. 2021). The seasonality pattern is intensely marked by the hydric dynamics of the river, alternating periods of high (´floods´) and low (´drought´) river water levels. The rainy season starts in November, reaching its peak between January and April. The wet and the dry seasons coincide with periods of high (January-June) and low river water levels (August-November), respectively (Souza, 2010; Alvares et al. 2013). River fluctuation also determines the availability and use of natural resources, thus directly affecting the livelihood activities of riverine populations (Souza, 2010).

The Juruá region is composed by flooded environments and non-flooded upland forests (Hawes et al. 2012; da Silva Abel et al. 2021). The Juruá region was occupied almost exclusively by indigenous groups until the middle of the 19th century, when it started to witness the arrival of traders and explorers from other areas. The first and second rubber cycles (during the late 19th century and the middle of the 20th century) led to a large influx of migrants from northeastern Brazil who came to work as rubber tappers for large landowners (Souza 2010). After the Second World War, with the decline of the Amazon rubber economy, many rubber tappers migrated to urban areas in search of work. Those who remained in the rural areas of the Juruá intensified the extraction of timber resources, agriculture and fisheries for subsistence (ICMBio, 2012).

Table S1. Communities sampled in the Middle Juruá during qualitative and quantitative data collections.

Communities sampled in the qualitative data collection				
Community	Environments	Protected area	Estimated population size	Sampled population
Toari	Floodplain	RDS	40	4
Xibauazinho	Floodplain	RDS	52	5
Mandioca	Floodplain	RDS	18	3
Nova União	Floodplain	RESEX	74	7
Santo Antônio do Brito	Floodplain	RDS	85	4
São Raimundo	Upland	RESEX	148	6
Vila Ramalho (Xué)	Upland	RDS	91	6
Pupuaí	Upland	RESEX	187	7
Communities sampled in the quantitative dataset				
Community	**Environments**	**Protected area**	**Estimated population size**	**Sampled population**
Bauana	Upland	RDS	122	9
Boa Vista	Floodplain	RESEX	46	9
Bom Fim	Floodplain	RDS	8	3
Bom Jesus	Upland	RDS	178	6
Fortuna	Floodplain	RESEX	53	5
Imperatriz	Floodplain	RESEX	117	5
Liberdade	Floodplain	RESEX	13	7
Manarian	Floodplain	RESEX	31	6
Morada Nova	Floodplain	RESEX	40	51
Morro Alto	Floodplain	RDS	73	20
Nova Esperança	Floodplain	RESEX	238	5
Nova União	Floodplain	RESEX	74	50
Novo Horizonte	Floodplain	RESEX	62	1
Ouro Preto	Upland	RDS	91	14
Roque	Floodplain	RESEX	495	4
São Raimundo	Upland	RESEX	148	36
Santo Antônio do Brito	Floodplain	RDS	85	24
Tabuleiro	Floodplain	RESEX	147	3
Vila Ramalho (Xué)	Upland	RDS	91	4
Xibauá	Floodplain	RDS	39	26
Xibauazinho	Floodplain	RDS	52	29

Table S2. LICCIs grouped at System level and number of citations per LICCI.

Climatic system	**183**
Air masses	**27**
Change in the frequency of storms (not further specified)	7
Changes in the frequency of lightning and thundering	1
Changes in wind strength or speed	17
Changes in wind temperature	2
Precipitation	**62**
Changes in mean rainfall (not further specified)	13
Changes in the amount of rainfall in a given season	36
Changes in the frequency of dry spells	5
Changes in the intensity / strength of heavy rainfall events	1
Changes in the predictability of rainfall	7
Temperature	**94**
Change in the intensity / strength of cold waves	14
Changes in mean temperature (not further specified)	47
Changes in the length / duration of cold waves	27
Changes in the mean temperature in a given season	4
Changes in the temperature during the night	1
Changes in the timing of cold waves	1
Physical system	**126**
Freshwater physical systems (continental waters)	**119**
Changes in predictability or variation of seasonal fluctuation in river / stream / lake water level	7
Changes in river / stream / lake water level in a given season	59
Changes in temperature of lake water	5
Changes in temperature of river / stream water	4
Changes in the frequency of occurrence of seasonal fluctuation in river / stream / lake water level	1
Changes in the intensity of river or pond bank erosion	2
Changes in the intensity of river or pond sedimentation	20
Changes in the speed of seasonal fluctuation in river / stream / lake water level	11
Changes in the timing of seasonal fluctuation in river / stream / lake water level	10
Terrestrial physical systems (Soil & Land)	**7**
Changes in soil moisture / humidity	6
Changes in soil temperature	1
Human system	**89**
Cultivated plant spp (crops, orchards)	**67**
Changes in crop flowering time	2
Changes in crop harvesting time	1
Changes in crop mortality rates	28

Changes in crop productivity / yield	22
Changes in length of crop harvesting time	3
Changes in the frequency of crop diseases (virus, fungi, bacteria, nematodes, etc)	5
Changes in the frequency or occurrence of weed species stated as invasive	6
Human health	**20**
Change in the incidence of human vector borne diseases (malaria, dengue, etc)	6
Changes in the incidence of human diseases (flu, allergies, etc)	11
Changes in the incidence of human health injuries (eg., ice-related accidents, weather inclemency, walking longer distances to water)	3
Livestock	**2**
Changes in livestock/raised animals mortality	2
Biological system	**79**
Freshwater Biological system	**18**
Changes in the abundance of freshwater fish	6
Changes in the behaviour of freshwater animals	1
Changes in the mortality of freshwater animal and plant species	2
Changes in the number of eggs, pups or offspring of freshwater species	1
Changes in the size of freshwater animal and plant species	3
Changes in the timing of mating or reproduction of freshwater animal species	5
Land cover change & land degradation	**2**
Changes in wildfire frequency	2
Terrestrial Wild Fauna	**5**
Changes in the abundance of terrestrial fauna (mammals, birds, reptiles, insects, etc)	5
Terrestrial Wild Flora	**54**
Change in the productivity of wild plant or fungi species (without further specification)	9
Change in the variation of productivity of wild plant or fungi species	3
Changes in the occurrence of diseases/pests in wild flora	1
Changes in the type of vegetation	4
Changes in the variation or predictability of wild plant / fungi species phenology	1
Changes in wild plant or fungi species fruiting time	4
Changes in wild plant or fungi species mortality	31
Changes in wild plant species flowering time	1
Total	**477**

Table S3. Observations of change (citations) by the system (i.e., climatic, physical, human and biological) and the element (e.g., temperature, precipitation, air masses) where they are observed.

Type of change	Citations	Percentage
Climatic system	**183**	**38.5%**
Temperature	94	51.5%
Precipitation	62	34%
Air masses	27	14.5%
Physical system	**126**	**26.5%**
Freshwater physical systems (continental waters)	119	94.5%
Terrestrial physical systems (Soil & Land)	7	5.5%
Human system	**89**	**18.5%**
Cultivated plant spp (crops, orchards)	67	75%
Human health	20	22.5%
Livestock	2	2.5%
Biological system	**79**	**16.5%**
Terrestrial Wild Flora	54	68.5%
Freshwater Biological system	18	22.5%
Terrestrial Wild Fauna	5	6.5%
Land cover change & land degradation	2	2.5%
Total citations	**477**	**100%**

Table S4. Observations of change (citations) grouped into the local indicators of climate changes categories (LICCIs) in their respective system (Climatic, Physical, Human and Biological) and the livelihood activity to which it refers. Numbers show the frequency of citations associated with each livelihood activity.

Citations regarding livelihood activites grouped in LICCIs	Citations	Andiroba	Açaí	Fishing	Hunting	Manioc	Muru-muru	Homegardens	Rubber	Turtles	Ucuuba
Biological system	112										
Change in the productivity of wild plant or fungi species (without further specification)	9	1	5	0	0	0	1	0	1	0	1
Change in the variation of productivity of wild plant or fungi species	2	0	2	0	0	0	0	0	0	0	0
Changes in the abundance of freshwater fish	6	0	0	6	0	0	0	0	0	0	0
Changes in the abundance of terrestrial fauna (mammals, birds, reptiles, insects, etc)	5	0	0	0	5	0	0	0	0	0	0
Changes in the behaviour of freshwater animals	1	0	0	1	0	0	0	0	0	0	0
Changes in the mortality of freshwater animal and plant species	2	0	0	1	0	0	0	0	0	1	0
Changes in the number of eggs, pups or offspring of freshwater species	1	0	0	0	0	0	0	0	0	1	0
Changes in the occurrence of diseases/pests in wild flora	1	0	0	0	0	0	0	0	1	0	0
Changes in the size of freshwater animal and plant species	3	0	0	3	0	0	0	0	0	0	0
Changes in the timing of mating or reproduction of freshwater animal species	5	0	0	3	0	0	0	0	0	2	0
Changes in the type of vegetation	4	1	0	0	0	0	1	0	1	0	1
Changes in the variation or predictability of wild plant / fungi species phenology	2	1	0	0	0	0	1	0	0	0	0
Changes in wild plant or fungi species fruiting time	6	3	1	0	0	0	1	0	0	0	1
Changes in wild plant or fungi species mortality	64	21	3	0	0	0	12	0	16	0	12
Changes in wild plant species flowering time	1	1	0	0	0	0	0	0	0	0	0
Human system	90										
Changes in crop flowering time	2	0	0	0	0	0	0	2	0	0	0
Changes in crop harvesting time	1	0	0	0	0	1	0	0	0	0	0
Changes in crop mortality rates	37	0	0	0	0	14	0	23	0	0	0
Changes in crop productivity / yield	33	0	1	0	0	15	0	17	0	0	0
Changes in length of crop harvesting time	6	0	0	0	0	3	0	3	0	0	0
Changes in the frequency of crop diseases (virus, fungi, bacteria, nematodes, etc)	5	0	0	0	0	2	0	3	0	0	0
Changes in the frequency or occurrence of weed species stated as invasive	6	0	0	0	0	6	0	0	0	0	0
Total citations	202	28	12	14	5	41	16	48	19	4	15

Table S5. Model selection table to Generalized Linear Models (GLMs) using binomial error structures considering all potential predictors.

Model selection table to extreme weather events of Large floods

Model	(Intrc)	acai	andrb	farnh	muru	pesca	serng	TF	ucuub	df	logLik	AICc	delta	weight
1	-0,3309	-2,308	1,377		1,871	-1,25			-1,356	6	-175,291	362,8	0	0,196
2	-0,2266	-2,322	1,339		1,842	-1,286		-0,3843	-1,439	7	-174,572	363,5	0,65	0,142
3	-0,4829	-2,156	1,529	0,3958	2,023	-1,098			-1,204	7	-174,743	363,8	0,99	0,12
4	-0,3846	-2,159	1,501	0,4299	2,005	-1,124		-0,4096	-1,279	8	-173,934	364,3	1,48	0,094
5	-0,3589	-2,28	1,405		1,899	-1,222	0,2254		-1,327	7	-175,209	364,8	1,92	0,075

Model selection table to extreme weather events of Small floods

Model	(Intrc)	acai	andrb	farnh	muru	pesca	TF	ucuub	df	logLik	AICc	delta	weight	
1	-1,786				-1,413	1,737		1,911	4	-142,062	292,2	0	0,156	
2	-1,674		-0,5232		-1,525	1,625		1,799	5	-141,513	293,2	0,97	0,096	
3	-1,702				-1,439	1,726	-0,3779	1,851	5	-141,599	293,4	1,14	0,089	
4	-1,705			-0,3994	-1,494	1,656		1,83	5	-141,751	293,7	1,44	0,076	
5	-1,521		-0,6758	-0,5827	-1,677	1,473		1,647	6	-140,877	294	1,77	0,065	
6	-1,571		-0,5689		-1,565	1,602	-0,4163	1,722	6	-140,953	294,2	1,92	0,06	

Model selection table to extreme weather events of Large droughts

Model	(Intrc)	acai	andrb	farnh	muru	pesca	serng	TF	ucuub	df	logLik	AICc	delta	weight
1	-1,302				-1,07			0,6945	0,8781	4	-171,313	350,8	0	0,056
2	-1,266				-1,118		-0,9492	0,7366	0,8388	5	-170,424	351	0,29	0,049
3	-1,407		0,4303		-0,9753			0,7336	0,9808	5	-170,613	351,4	0,66	0,04
4	-1,361		0,3774		-1,031		-0,8702	0,7674	0,9322	6	-169,89	352	1,29	0,029
5	-1,365				-1,011	0,3296		0,7086	0,9399	5	-170,957	352,1	1,35	0,029
6	-1,526		0,5432		-0,8648	0,4779		0,7635	1,098	6	-169,929	352,1	1,37	0,028
7	-1,265	-0,3368			-1,109			0,7011	0,8407	5	-171,062	352,3	1,56	0,026
8	-1,22	-0,3984			-1,167		-1,001	0,7476	0,7925	6	-170,074	352,4	1,66	0,025
9	-1,32				-1,066	0,2759	-0,8998	0,746	0,8926	6	-170,177	352,6	1,87	0,022
10	-1,28			-0,1358	-1,095			0,7055	0,8549	5	-171,251	352,7	1,94	0,021

4. CONCLUSÕES

Impactos nos modos de vida dos ribeirinhos do Rio Juruá

Os eventos climáticos extremos relacionados à flutuação do nível da água do rio (grandes enchentes, pequenas cheias e grandes secas) são percebidos pelas comunidades do médio rio Juruá como importantes causadores de mudanças nos sistemas socioecológicos e nas atividades de subsistência. Embora essas mudanças possam gerar alguns impactos positivos, a maioria dos impactos de eventos climáticos extremos tem um enorme potencial de comprometer os meios de subsistência locais. O conhecimento ecológico local (LEK) tem enorme potencial para elucidar os impactos potenciais de eventos climáticos extremos nas atividades de subsistência.

Além de demonstrar, a partir do conhecimento local, que diferentes atividades de subsistência podem ser afetadas de diferentes maneiras por eventos extremos, esse trabalho também mostra que a percepção desses impactos varia conforme o tipo de ambiente em que essas atividades são desenvolvidas. Áreas de várzea amazônicas são particularmente vulneráveis aos impactos das mudanças climáticas, especialmente aos eventos de grandes cheias e secas extremas, e portanto as comunidades que habitam esses ambientes estão mais expostas a esses eventos do que as comunidades que habitam as áreas de terra-firme (Barros e Albernaz 2014). Embora a diferença no ambiente não tenha sido uma variável determinante para grandes enchentes e pequenas cheias dos rios ao avaliar a quantificação dos impactos de eventos extremos nas atividades de subsistência, as atividades mais fortemente desenvolvidas em áreas de várzea, como pesca e extrativismo, são impactadas de forma diferente por eventos climáticos extremos. Enquanto a pesca pode se beneficiar de grandes enchentes de rios, o extrativismo pode ser prejudicado por esse mesmo evento extremo, assim como o evento de grande seca pode prejudicar a pesca nesses ambientes. As atividades mais desenvolvidas nas áreas de terra-firme, como quintais / sistemas agroflorestais e o cultivo da mandioca, são mais suscetíveis às mudanças no regime de chuvas e na temperatura, não tanto pela incidência de eventos climáticos extremos.

Direções futuras

A floresta amazônica é fundamental para garantir serviços de ecossistemas locais, regionais e globais (Levis et al. 2020). É imperativo garantir políticas públicas mais fortes que abordem os impactos potenciais que essas comunidades estão enfrentando, aumentando a sua capacidade de adaptação e resiliência. Portanto, o governo brasileiro deve mudar sua direção para garantir políticas e incentivos que possam fortalecer a capacidade das comunidades locais de cooperação e adaptação às mudanças globais (Lapola et al. 2018). Por fim, esse estudo reforça a importância do conhecimento ecológico local para avaliar os múltiplos impactos das mudanças climáticas nos sistemas socioecológicos. A inclusão dessas comunidades tradicionais na formulação de políticas globais de mudanças climática é urgente não só pela justiça social, já que historicamente essas comunidades foram relegadas ao espaço de tomada de decisão (Reyes-García et al. 2015), como também porque são detentoras de conhecimentos valiosos que podem fornecer subsídios para políticas públicas mais eficazes para prevenir e mitigar impactos das mudanças climáticas em comunidades locais na Amazônia.

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