

# Climate change and the adaptive adjustments of traditional extractive communities in the Médio Juruá territory, Central Amazon

*A mudança climática e os ajustes adaptativos de  
comunidades tradicionais extrativistas no território do  
Médio Juruá, Amazônia Central*

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## ABSTRACT

In the Médio Juruá territory, local governance is strongly led by extractive communities. However, climate change has made the adaptations of riverine socio-ecological systems insufficient in the face of transformations in the region's physical-climatic rhythms. With this in mind, this study aimed to analyse climate change in terms of temperature and fluvial disasters, its socio-environmental implications and the adaptive adjustments adopted by extractivist communities in Médio Juruá. We combined analysis of physical climate data and semi-structured interviews with social actors from traditional riverside communities in the region. We found that climate change is already impacting the region. Extractive communities are feeling the impacts of increased excessive heat, rainfall, and extreme fluvial events, which are altering the dynamics of work and life in these communities. Communities are responding with a series of autonomous, adaptive adjustments, while government strategies are limited to emergency support. Traditional extractive communities need robust adaptation policies and programs that can increase the resilience of their socio-ecological systems.

**Keywords:** Resilience. Adaptation. Extreme events. Heat increase. River environmental disasters.

## RESUMO

*O território do Médio Juruá possui uma alta governança promovida pelas comunidades extrativistas. Entretanto, a mudança climática tem tornado as adaptações dos sistemas socioecológicos ribeirinhos insuficientes diante das transformações dos ritmos físicos climáticos da região. Nesse sentido, o presente trabalho teve como objetivo analisar alterações climáticas de temperatura e dos desastres fluviais, suas implicações socioambientais e os ajustes adaptativos às comunidades extrativistas do Médio Juruá. Para tanto, a pesquisa contou com análise estatística dos dados físicos climáticos e entrevistas semiestruturadas com atores sociais de comunidades tradicionais ribeirinhas da região. Os dados demonstram que a mudança climática já gera impactos na região. As comunidades extrativistas sentem o aumento do calor excessivo, precipitação e de eventos extremos fluviais que já alteram a dinâmica de trabalho e da vida nas comunidades. As comunidades já respondem com uma série de ajustes adaptativos autônomos, enquanto as estratégias governamentais só são vinculadas a apoio emergencial. As comunidades tradicionais extrativistas necessitam de políticas e programas de adaptações robustos que possam aumentar a resiliência de seus sistemas socioecológicos.*

**Palavras-chave:** Resiliência. Adaptação. Eventos extremos. Aumento do calor. Desastres ambientais fluviais.

## 1 INTRODUCTION

The socioecological systems composed of traditional riverine and extractivist communities<sup>1</sup> in the Amazon are based on a series of strategies historically adapted to the physical environment of the tropics and to the isolation caused by the precariousness of transportation routes (Moran, 1974). This high adaptive capacity is due to the plasticity of human responses to the environment, both socioculturally and physiologically (Filizola *et al.*, 2006; Laraia, 1996; Moran, 1994).

The historical adaptability of human societies to environmental conditions occurs mainly through regulatory or adaptive adjustments (Moran, 1994), which may be social, behavioural or cultural, and are important to the relationship between humans and their environment. In the Amazon floodplains, this historical adaptation capacity is well represented in the dwellings of riverine communities. The houses are built on stilts (*palafitas*) to match the height of the floods or float on the water (*flutuantes*) to withstand the seasonality of the rivers. The cultural strategy of shelter is among the most common regulatory mechanisms.

Climate change has brought critical conditions to communities located in the floodplains and uplands through the intensification of extreme climatic events (Artaxo, 2020; IPCC, 2014). This new hydroclimatological context creates insecurity for socioecological systems, especially for communities whose livelihoods are highly dependent on the environment, thereby exposing them to greater risk.

Extreme events represent abrupt variations in local climatological conditions that exceed normal thresholds and can expose human societies to increased vulnerability (Marchezini *et al.*, 2023). In the Amazon, extreme climatic events are mainly associated with floods, droughts, and heavy rainfall, leading to disasters due to their impacts on human settlements (Guimarães *et al.*, 2021; Vasconcelos *et al.*, 2020).

Adaptive capacity is understood as the potential to shift toward a more desirable state in the face of risks and impacts of climate change (Eakin *et al.*, 2014). Adaptation, in turn, is defined as the process of making the necessary adjustments to anticipate and prevent the impacts of climate change (IPCC, 2007).

According to IPCC (2007), there are several categories of adaptation, with emphasis on autonomous, anticipatory, and planned adaptation. Autonomous adaptation refers to the immediate response to the occurrence of extreme events. Anticipatory adaptation occurs when governments and society adopt measures before such events take place. Planned adaptation, meanwhile, results from political decisions, such as climate change adaptation plans (May; Vinha, 2012).

Another strategic approach to climate adaptation centres on collective action, emphasising social organisation, social capital, and social justice (Engle, 2011). However, adaptation actions and measures are still not treated as priorities by governments, hindering the implementation of adaptive strategies and amplifying vulnerabilities (Dos Santos *et al.*, 2024; Teixeira *et al.*, 2021).

The Médio Juruá territory, located in the western Brazilian Amazon, is recognised regionally for its strong social organisation, well-structured environmental governance, and a socioeconomic system based on sociobiodiversity productive chains (Guimarães *et al.*, 2023). Nevertheless, the occurrence of extreme climatic events in the region has been causing significant social losses and altering the lifestyles of extractivist populations. In this context, the present study aimed to analyse temperature-related climate changes and fluvial environmental disasters, their socio-environmental implications, and the adaptive adjustments of traditional riverine and extractivist communities in the Médio Juruá.

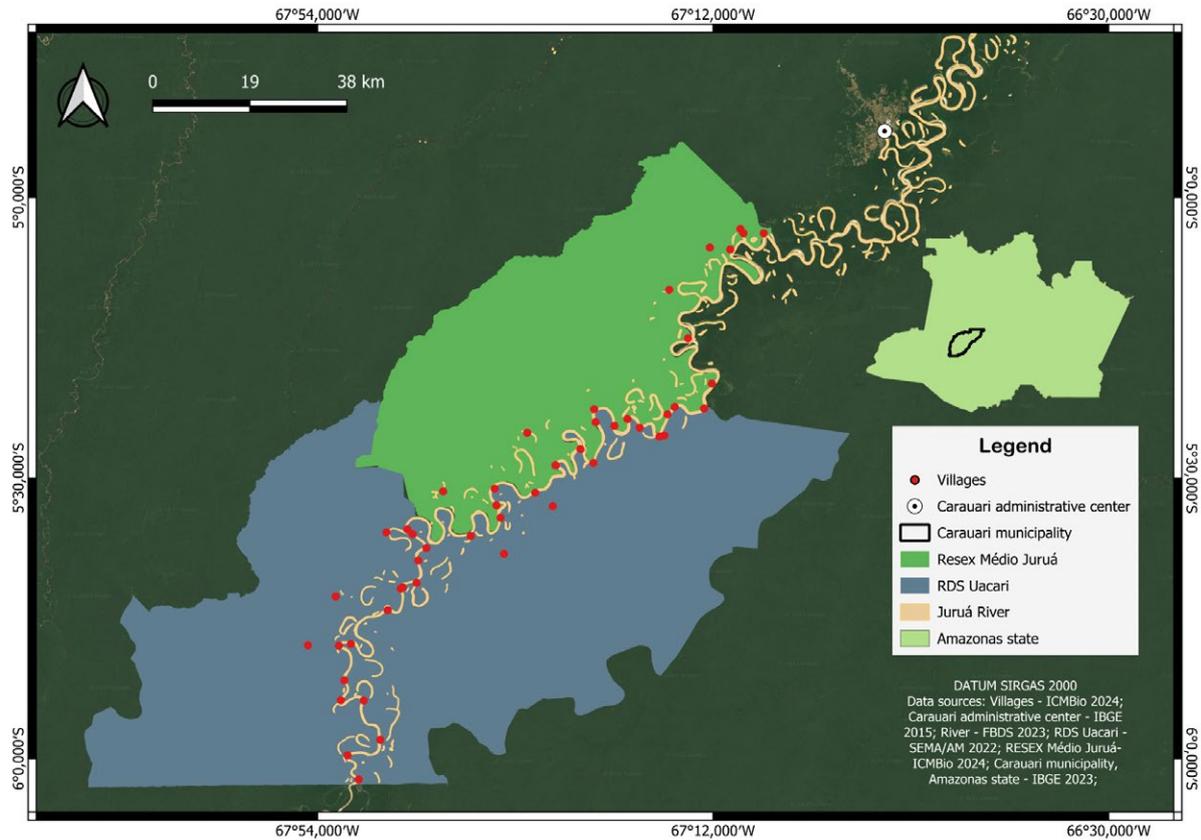
This research is based on the premise that hydroclimatic dynamics can be understood through the concepts of holorrhythms and rhythmanalysis. Holorrhythms encompass the totality of all rhythms within the climatic realm: social, biological, and physical (Sette, 2000). Rhythmanalysis refers to the theory that seeks to understand the polyrhythms of bodies and space, systematically integrating diverse disciplines (Tarifa, 2002). Therefore, research grounded in these epistemologies confers a higher level of complexity to the analyses than a disciplinary lens would do, observing phenomena through a systematic, interdisciplinary lens.

## 2 METHODOLOGY

### 2.1 STUDY AREA

The Médio Juruá territory, the locus of this study, is characterised by the presence of two sustainable use conservation units: the Médio Juruá Extractive Reserve, federally managed, and the Uacari Sustainable Development Reserve<sup>2</sup>, under Amazonas state management (Figure 1). Together, the two sustainable use protected areas cover more than 920,000 hectares. In this region, there are over 1,200 families from traditional riverine and extractivist communities who make their living from family

agriculture, co-management of pirarucu (*Arapaima gigas*), rubber tapping (*Hevea brasiliensis*), and the harvesting of açai (*Euterpe precatoria*) and oilseeds such as andiroba (*Carapa guianensis*) and murumuru (*Astrocaryum murumuru*).



**Figure 1 – Map of the Médio Juruá territory.**

*Source: authors*

The Juruá River region lies within fault structures associated with neotectonic reactivations (Passos; Soares, 2017). The Juruá River is known for its meanders, which make it extremely sinuous and further increase the distances between villages located along its margins. This sinuosity is related to lithological and topographic characteristics and can be influenced by changes in the climatic seasonality (Passos; Campos-Silva, 2019).

Rivers in the Amazon have four well-defined seasons: the rising water period, the flood, the receding water period, and the dry season (Witkoski, 2010). These seasons represent the river's natural cycle of flooding and receding throughout the year. The dynamics of the hydrological cycle in the Amazon reshape both space and landscape through alternating drought and flood periods, a phenomenon known as seasonality (Abreu; Oliveira, 2012).

The hydrological system in the region is also influenced by the Intertropical Convergence Zone (ITCZ), the inflow of moisture from the Atlantic Ocean carried by trade winds, and the exchanges of heat and humidity between the vegetation and the atmosphere within the region itself (Marengo *et al.*, 2001; Tucci, 2002).

## 2.2 DATA COLLECTION

This research was conducted through the collection of primary data via semi-structured interviews, aiming to better understand climate change in the Médio Juruá region through the perceptions of local people. It also included secondary data from documents in the archives of Inmet (National Institute of Meteorology), Civil Defence, ICMBio (Chico Mendes Institute for Biodiversity Conservation, a federal environmental agency in Brazil), Idam (Institute for Sustainable Development of Agriculture and Forestry of the Amazonas State), and Sema (Amazonas State Secretariat for the Environment). To complement the information collected, a bibliographic review was carried out on the studied themes using databases such as Google Scholar, the Capes Journals Portal, SciELO, and Web of Science, with the following keywords: climate change, impacts of extreme events, adaptive adjustments, Médio Juruá, and traditional populations. Thus, data collection consisted of a combination of secondary and primary data.

To identify extreme hydrological events in the Carauari region, we accessed and processed public temperature data from Inmet. We used data from the hydroclimatological station of Eirunepé/ Amazonas (Code 82610), located upstream on the Juruá River. The Eirunepé station was selected for the historical temperature series analysis because it contains more recent and complete data and is located closer to the municipality of Carauari. The Carauari station has records up to 1990, which would compromise the analysis of more recent data.

Regarding environmental disasters in the municipality of Carauari, we obtained records from the Integrated Disaster Information System (S2iD), the platform of the National System for Protection and Civil Defence, which aims to improve and bring transparency to risk and disaster management in Brazil through the digitalisation of processes regarding such disaster events and the publication of systematised information (Brasil, 2025).

Through statistical analysis (Mann-Kendall test) of these physical data, normality thresholds were established, and events that exceeded those thresholds were identified as extreme temperature events in the region. Primary data for this research were obtained through individual semi-structured interviews in traditional riverine communities of the municipality of Carauari.

The number of interviewees was based on the number of households in the selected villages. It is important to note that this qualitative component of the research prioritised the representation of community leaders. In total, 72 family leaders from different communities in the Médio Juruá territory were interviewed—47 men and 25 women. Unfortunately, greater gender parity could not be achieved, as men are still the majority in leadership positions in the territory.

The interview group included fishers, extractivists, family farmers, pirarucu (*Arapaima gigas*) managers, and riverine residents who held leadership positions within their villages or local organisations. The extractivist and riverine communities of the Médio Juruá are composed of migrants from northeastern Brazil who arrived during the rubber boom<sup>2</sup> and intermingled with Indigenous peoples from ethnic groups such as the Kulina and Kanamari, originary peoples in the Médio Juruá region. Most interviewees identify as Catholic, due to the work carried out in the territory by the Basic Education Movement (MEB), an initiative linked to the Catholic Church that supported traditional populations in their process of social organisation (Guimarães *et al.*, 2023).

Throughout history, these traditional populations have played a fundamental role in conserving natural environments by maintaining sustainable land and resource use practices, particularly in the Médio Juruá region, known for its struggles and resistance to the rubber exploitation system. Therefore, understanding adaptive adjustments in response to climate change reinforces the importance of effectively protecting these territories to safeguard traditional knowledge and the ways of life of the communities that rely on them.

Semi-structured interviews followed a script of 37 open- and closed-ended questions addressing climate perception, adaptation, and vulnerability. The goal was to assess whether the intensity or scarcity of factors such as heat and rainfall affect community dynamics and livelihoods, as well as to evaluate the effectiveness of both governmental adaptive strategies and those developed by the communities themselves in different situations, such as rising temperatures, rainfall, extreme floods, and extreme droughts. Interviews were conducted with one adult resident per household who had lived in the community for more than eight years.

Participants were selected using the snowball sampling method, and data collection continued until responses reached saturation, that is, when no new information emerged (Baldin; Munhoz, 2011). This technique allowed participants to suggest other individuals who could contribute to the study, thereby maximising heterogeneity in data collection.

The analysis and interpretation of information were carried out through content analysis, using manual coding of variables to ensure greater objectivity and to go beyond the surface level of the text (Rocha; Deusdará, 2005). To ensure the interpretations were unbiased, data validation was conducted through external peer review. It is worth noting that in this research, interviewees were treated as research participants, and several excerpts of their statements appear in the text to give voice to their perceptions of extreme events, such as increased temperatures, heavy rains, extreme floods, and droughts, as well as the adaptive adjustments observed in riverine socioecological systems.

Since this research involved human participants, all methodological procedures were submitted to the Ethics and Research Committee of the Federal University of Amazonas (CEP/Ufam), CAAE No. 54763221.0.0000.5020, and to the Brazilian Biodiversity Authorisation and Information System (Sisbio), No. 80629-1.

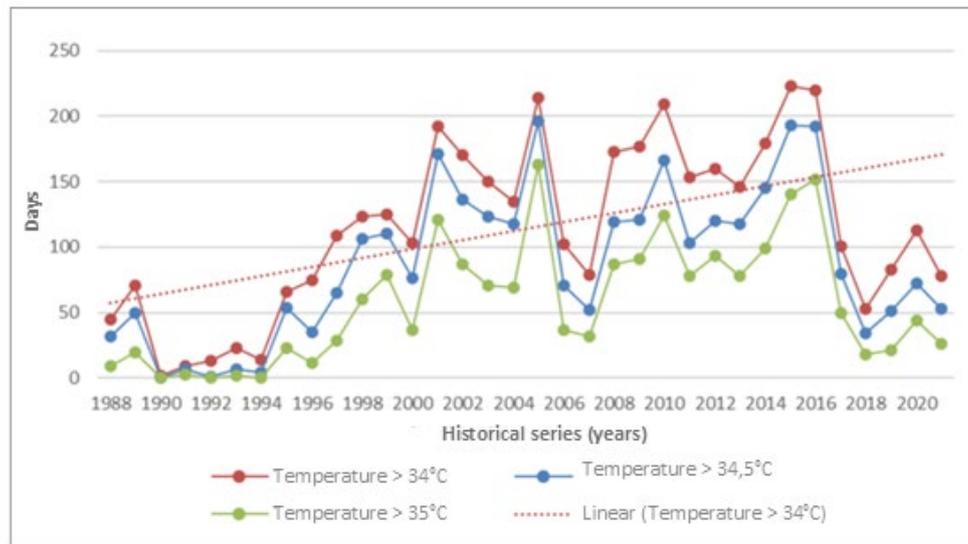
Integrating data analysis with information on the social impacts of climate transformations in the Amazon region is essential for understanding climate change across this vast territory (Vasconcelos, 2020). This methodological effort is crucial for environmental science studies because it enables correlating different disciplines to elucidate phenomena and their consequences (Moran, 2011).

For this study, temperature data from the Eirunepé station covering the period from 1988 to 2021 were considered. The 90th percentile was calculated to identify extreme temperature events in the region over the historical series.

## 3 RESULTS AND DISCUSSION

### 3.1 CHANGES IN TEMPERATURE AND SOCIO-ENVIRONMENTAL IMPLICATIONS

The temperature considered extreme for the Eirunepé station was any temperature above 34°C, which showed statistical significance with the following values:  $S = 217$ ;  $Z = 3.2021$ ;  $p = 0.001364$ . Figure 2 shows the relationship between the number of days per year and each temperature level for the analysed period.



**Figure 2** – Number of days per year with maximum temperature over the 90th percentile (34°C) in the municipality of Eirunepé/AM

Source of data: INMET. Figure made by the authors

During the period analysed, an average of 114 days with maximum temperatures above 34°C were identified, reaching as many as 223 days above 34°C in 2015. Similarly, the average was 87 days with maximum temperatures above 34.5°C, and 57 days with temperatures above 35°C. This high number of hot days indicates a sustained increase in heat in the Juruá River region, with a statistically significant upward trend over the period analysed. These days with temperatures above 34°C are considered extreme temperature events for that region.

Extreme temperature events were identified in the years 2015, 2016, and 2005, respectively. In 2015 and 2016, El Niño events were particularly strong in the Pacific Ocean, and their effects were felt in the Juruá River region near Eirunepé, in the Amazon (Ggweather, 2021). According to the study, the year 2005 can be considered atypical because the extremes in temperature were not influenced by El Niño; instead, the phenomenon can be explained by temperature variations in the Tropical North Atlantic.

Applying the Mann–Kendall test to the 34-year historical series showed that the trend is statistically significant and exponential. Temperature in the Amazon has risen by an average of 0.65°C over the last century (Marengo; Souza Jr., 2018). This temperature increase in the region is linked to global warming, which has been intensified by rising emissions of greenhouse gases in the Earth’s atmosphere (Fearnside, 2018).

The year 2017 is considered the hottest since the mid-20th century in the Amazon region (Marengo; Souza Jr., 2018). Climate change projections for the Amazon indicate a temperature increase of up to 4°C and a 40% reduction in rainfall (IPCC, 2014). Thus, global warming will bring enormous implications for the hydrological regulation provided by the Amazon through evapotranspiration, which helps promote rainfall across South America (Marengo; Souza Jr., 2018).

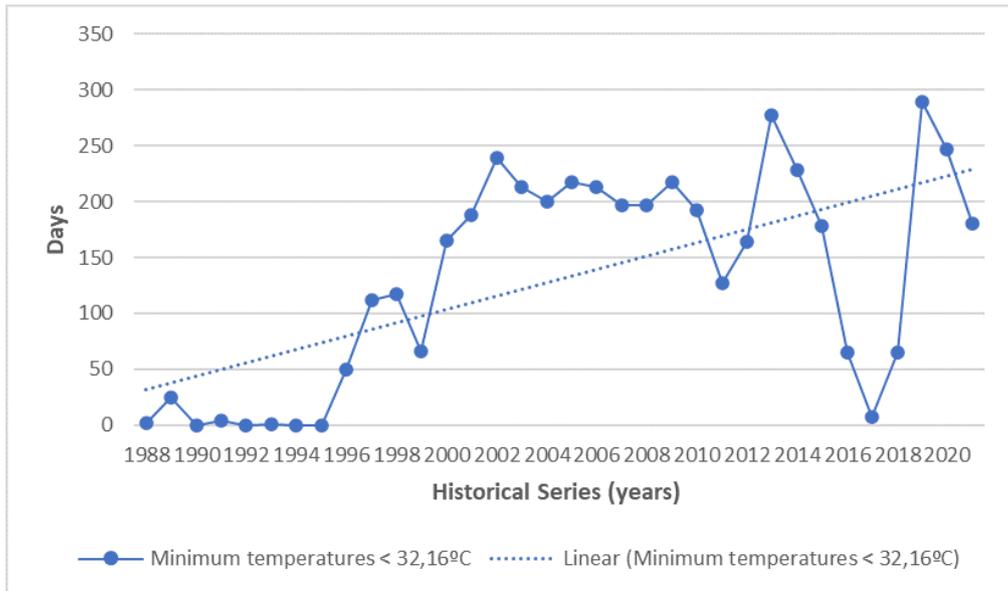
Future scenarios for the Amazon foresee an incremental increase in regional temperatures (IPCC, 2014). This process will trigger transformations in Amazonian ecosystems, particularly affecting species and populations in terms of phenology, biotic interactions, extinction rates, and species distribution (Marengo; Souza Jr., 2018).

Results from the Eirunepé station indicate an increase in the region’s nighttime minimum temperature, the period in which minimum temperatures occur. In 2019, a record of days with minimum temperatures

above 22.16°C (the 90th percentile) was reached, totalling 289 days (Figure 3). This exponential temperature increase has direct implications for the livelihoods of riverine populations and has been increasingly perceived by community members:

Over the past 15 years, the heat has been getting worse. And every year it just gets worse. Sometimes you take a bath and go to sleep, and until that little bit of coolness comes in the early morning, you don't sleep, as you keep soaked in sweat. (JC, Rubber tapper, 2021).

**Figure 3** – Number of days per year with minimum temperatures above the 90th percentile (22,16°C) in the



municipality of Eirunepé/AM.

Source of data: INMET. Figure made by the authors

Hotter nights have made it difficult for agro-extractivist producers in the region to rest, as those living in the forest do not have access to electricity or resources to relieve the heat, such as fans or air conditioners. Mr Joaquim's perception reflects the long-term experience of a rubber tapper who has lived for over 90 years along the Juruá River, relying on natural resources. Living in the forest, he clearly perceives the region's climate changes and is concerned about the transformations they bring.

These trends of rising minimum temperatures have also been observed in the Manaus region, where results do not indicate variability in the average temperature but do show a clear trend (Vasconcelos, 2020). This trend has been affecting agricultural work in the region:

You go to the cassava field, and it's already hot. Then there's this unbearable heat, you just can't stand it. In the past, you could work the whole day in the field. Sometimes you'd stop for a drink of water, sit by the trunk of a tree, and cool off for two or five minutes... Now, you come back from the field at 10 a.m. already exhausted. (JC, Rubber tapper, 2021).

Thus, rising temperatures have become a crucial factor changing the daily work routines of agro-extractivist populations in the Juruá River region of Carauari. The heat has made it increasingly difficult for farmers to remain in their planting areas, particularly cassava fields, due to high exposure to sunlight. Climate change tends to increase population vulnerability and lead to more illnesses (Sette, Ribeiro et

al., 2011). This vulnerability is even greater for populations living in the forest who depend on income from managing natural resources.

Studies indicate that climate change will directly affect working conditions worldwide in the near future. Labour-intensive activities, such as agriculture, are expected to experience a drastic reduction in the number of workers, potentially leading to greater food insecurity and a decrease in food produced by family farming (Souza *et al.*, 2020).

The absence of hydroclimatological stations in the municipality of Carauari with a long historical record is a limiting factor for more precise climate studies in the region. However, the data obtained from the Eirunepé station, located along the same Juruá River, combined with local residents' perceptions already demonstrate that the socioenvironmental impacts of climate change have arrived in the region.

### 3.2 SEASONAL VARIABILITY AND EXTREME FLUVIAL EVENTS IN CARAUARI

Human adaptation strategies in the riverine regions of Carauari are increasingly insufficient in the face of the intensity and timing of extreme climatic events, which are becoming progressively more frequent. Extreme climate events in the Amazon have been attributed to El Niño and La Niña phenomena, which increase or decrease rainfall and cause changes in river discharge and water levels (Zeng *et al.*, 2008).

According to the Brazilian Disaster Classification (Cobrade), extreme flood events are classified as *inundações* (floods) and extreme drought events as *estiagens* (droughts). Both are hydrological disasters, also known as fluvial environmental disasters (Guimarães *et al.*, 2023). It is important to note that events do not need to exceed normality thresholds in order to be classified as disasters; in this framework, impacts to humans are central to determining disaster status. Thus, in the Amazon, where traditional riverine communities live along riverbanks, these events generate enormous socioeconomic losses and place their livelihoods in socioenvironmental vulnerability.

Floods, like the 2021 one, affect everything. Economically, people can't collect fruits [andiroba and murumuru]. Socially, homes go underwater, material belongings, production... So it affects every aspect of community life: social, economic, and cultural, especially for families. (MS, Farmer, 2022).

By analysing environmental disaster occurrences in the municipality of Carauari using records from the Integrated Disaster Information System (S2iD), we focused on the typology of these disasters and their relationship with extreme events in the region from 2005 to 2025.

When considering disasters linked to the Juruá River's seasonality, it becomes clear that they are the most frequently declared by public authorities over the years. This is due to the importance of river resources for municipalities in the interior of Amazonas, such as Carauari, where access to food and transportation relies on rivers, which are also tightly connected to cultural identity and belonging to place. Overall, "in Amazonas, 89.79% of disasters recorded since 2005 are related to riverine events (droughts, floods, and fluvial erosion), totalling 386 events" (Guimarães *et al.*, 2021).

In Carauari, five drought-related disasters and six flood-related disasters were officially declared. Drought disasters occurred in 2005 and 2010, while flood declarations are associated with events in 2012, 2013, 2015, 2017, 2019, and 2021. Because of the strong relationship between communities and rivers, these disasters are most perceptible to the population and, consequently, are most often reported by municipal governments.

The events of 2013 and 2014 were influenced by La Niña and/or an increase in sea-surface temperature in the South Atlantic (Marengo; Espinoza, 2016). Another factor is related to the 2015 floods in the Juruá

region: rainfall amounts were more than twice the volume recorded in normal years (Espinoza *et al.*, 2014). As for droughts, the 2005/2006 events were linked to anomalous warming of the Tropical North Atlantic (Marengo *et al.*, 2018), while the 2010/2011 period had the highest warming ever recorded in the Tropical Atlantic, combined with an El Niño event (Liberato, 2014).

A similar study was conducted by Pereira and Szlafsztein (2016) on natural disaster risks and the main human, material, environmental, social, and economic data in the Purus River basin. The goal was to catalogue past disasters to anticipate future events. Their results showed:

The 21 municipalities with more than 40% of their territory in the Purus River basin recorded 104 disasters between 1971 and 2012. The most recurrent (70%) were disasters associated with increased precipitation, such as floods, flash floods, fluvial and linear erosion, waterlogging, landslides, windstorms, and thunderstorms. [...] The municipalities of Boca do Acre (AM) and Rio Branco (AC) were the most susceptible to precipitation-related disasters (8 and 16 records). Except for the southwestern Acre municipalities of Senador Guiomard, Capixaba, Bujari, and Acrelândia, the remaining municipalities were classified as low or moderate threat. (p. 77-78)

12 out of 17 years with extreme hydrological variations in the Purus basin can be explained by changes in meteorological and hydrological parameters in the Amazon region. (p. 87)

Among the damages caused during low-rainfall periods are increases in natural and human-induced fires for field clearing, resulting in crop and livestock loss and worsening air quality. Environmental damages also include:

Impacts on fauna and water resources. Water scarcity dries up many channels, causing mortality among aquatic and terrestrial species. Such extreme events also reduce the availability of water for human consumption and compromise much of the river transportation system, isolating many localities due to difficulties in travel, distribution, and access to supplies, fuel, and medicine. Limited water availability often leads not only to respiratory illnesses but also to waterborne diseases due to animal die-offs and high sediment concentrations. (p. 84-85)

Thus, the increasing frequency and intensity of extreme hydrological events in the Juruá River region have produced major socioeconomic impacts on riverine communities, qualifying these events as environmental disasters, as their effects go beyond the adaptive capacities that socioecological systems have developed over decades. In this context, socioecological systems have been developing a series of adaptive adjustments in response to climate change.

### 3.3 ADAPTATIONS TO CLIMATE CHANGE IN THE MÉDIO JURUÁ TERRITORY

When addressing the transformations in climatic rhythms in the Médio Juruá, the first cultural adjustment in human adaptability identified by research participants was a response to intense heat. All interviewees emphasised changes in working hours in the region's agriculture. According to most accounts, work previously occurred from 7:00 a.m. to 11:30 a.m. and from 2:00 p.m. to 5:00 p.m., totalling 7 hours and 30 minutes of labour. However, due to rising temperatures in the region, the schedule shifted to 6:30 a.m. to 9:30 a.m. and 3:30 p.m. to 5:00 p.m., totalling 5 hours of work. This reduction in working hours in family agriculture activities is reshaping labour relations in the region and decreasing production in these socioecological systems, generating impacts on income generation and food security.

The heat... I also want to talk about the sun. In the past, when we went to plant in the fields, you could work comfortably until around 11 or 11:30 in the open fluvial beaches. We used to plant a lot on fluvial beaches. We would leave at 6:30 or 7:00. You could plant until 11 with no problem, then go back home for lunch. Now, by 9 in the morning, the sun has the same intensity it used to have at 11 or 11:30, and anyone who insists on being stubborn and working under that harsh sun is having serious health problems. In São Raimundo, a man went out on a sunny day like that, and before even reaching the community, he died holding onto the handle of his boat's motor. The sun is so unbearable that when you're out in it, you can feel it harming you. And that sun is tied to the heat, and the heat is absurd. It's so intense that if you insist on working, you suffocate, you feel your heart beating abnormally, you feel yourself overheating, and your body works so hard to regulate its temperature that you end up feeling sick [...] (MC, Rubber tapper, 2022).

Back then, with my mother, we would always leave around 7:30 or 8:00 and return around 11 or 11:30 for lunch. Today, you have to leave no later than 6:30 in the morning to go to the fields and be back by 9:30 at the latest because of the heat. (MS, Farmer, 2022).

Today, people have to leave for the fields at 6 a.m. at the latest, and by 9:30, they can't handle it anymore. (FS, Oilseed collector, 2021).

This reduction in working time was also documented by Vasconcelos (2020) when studying the impacts of climate change in the Rio Negro region. In that context, farmers likewise reduced their exposure to the sun during agricultural activities.

Throughout the 21st century, rising temperatures are expected to reduce labour activity, especially in occupations that require direct exposure to sunlight, such as agriculture (Souza *et al.*, 2020). High solar exposure tends to generate socioeconomic impacts, but above all, it affects workers' health and decreases productivity. Therefore, other adaptations, such as adjusting clothing for sun exposure and reducing work time with longer rest cycles, are recommended to mitigate the effects of climate change on the capacity of outdoor workers (Souza *et al.*, 2020).

Other adaptive adjustments to support human adaptation within these socioecological systems in the face of climate change were also identified by research participants (Table 1).

**Table 1 – Adaptive adjustments by type of climatic event: rise in temperature, rainfall, extreme flood, extreme drought**

Category	Event	Adjustments
Work	Rise in temperature	Reduced time working in the fields Planting other crops Returning to activities that do not take place in exposed areas
	Intense rainfall	Suspension of work on rainy or stormy days
	Extreme floods	Planting less in floodplain areas and more on upland; avoiding the planting of species susceptible to water stress; interruption of agro-extractivist activities; early harvesting of cassava; collective efforts ( <i>mutirões</i> ) for flour production
	Extreme droughts	Construction of wooden walkways ( <i>trapiches</i> ) to facilitate movement during work activities

Category	Event	Adjustments
Housing	Rise in temperature	To present concepts and information related to scientific production; to integrate with the information discussed by the participants in the first activity.
	Extreme floods	Raising house floors; relocating homes to higher areas; staying temporarily on houseboats ( <i>chalanas</i> ); building elevated platforms ( <i>marombas</i> ) to lift appliances and furniture
Food	Rise in temperature	Greater purchase of industrialised foods
	Intense rainfall	Avoiding the planting of species susceptible to water stress
	Extreme floods	Lake preservation; increased fishing during certain periods
	Extreme droughts	Protecting lakes for community consumption; increased acquisition of industrialised foods
Nature	Rise in temperature	Planting trees near houses to provide shade
	Extreme floods	Avoiding latex extraction from rubber trees affected by water stress, and adding new rubber trees along tapping trails
Education	Rise in temperature	Holding classes outside the classrooms Changes in school schedules
	Extreme floods	Suspension of classes; difficulty reaching school
	Extreme droughts	Parents accompanying children to school
Health	Rise in temperature	Less time exposed to the sun Carrying out activities during periods of lower solar incidence
	Extreme floods	Greater care with water due to waterborne diseases; increased malaria prevention
Leisure	Rise in temperature	Changing the time of soccer matches
	Extreme floods	Holding canoe-racing tournaments
Religion	Extreme floods	Changing the dates of festivals and religious celebrations
Migation	Extreme floods	Temporary relocation to another community
Mobility	Extreme droughts	Avoiding long-distance travel during the dry season

Source: Authors

Adaptive adjustments were identified across the categories of housing, labour, food, nature, education, health, and leisure. In a study conducted by Teklay *et al.* (2025) in Ethiopia, similar shifts were observed, such as changes in crop types and the adoption of genetically improved varieties, adaptations that were only possible through effective technical assistance and rural extension services. Thus, one possible pathway to avoiding the replacement of traditional crops is the development and consolidation of varieties that are better adapted to the new climatic conditions of the region. However, this would only be achievable with technological development and a more consistent presence of agricultural extension.

As in the labour category, solar exposure was also relevant in relation to health issues, as interviewees mentioned reduced solar exposure as an adaptation to avoid health problems. This preventative approach also appears in the leisure category, as the timing of soccer matches was shifted to avoid the hottest hours of the day.

In relation to heavy rainfall, adjustments were identified in agricultural labour: on days with intense precipitation, work in forests, fields, and rivers becomes impossible, hindering the activities of agroextractivist workers. This directly impacts household income due to the loss of workdays. Food practices are also affected, as some species are highly sensitive to either excess or scarcity of water, leading, for example, to the abandonment of banana cultivation (*Musa* sp.).

Regarding extreme floods, interviewees reported a series of long-standing adaptations developed to maintain livelihoods in riverine socioecological systems. In the labour category, most adjustments were linked to cassava production, one of the most impacted crops during floods in the region. The flooding of swidden fields causes major economic losses for family farmers, who see their investments of time and labour wiped out by extreme flooding.

In the housing category, two types of adjustments were identified: preventive and emergency. Relocating homes and raising house floors are considered preventive measures (Guimarães *et al.*, 2019). Emergency adjustments include building *marombas* (elevated wooden platforms inside the houses) and temporarily living in *chalanas* (houseboats). These adaptations entail high costs, and many residents cannot afford structural changes to their homes, meaning climate change further intensifies the socioeconomic vulnerability of these communities.

Related to the food category, it is worth noting that communities in the region have adopted fishing agreements to protect certain lakes for their own consumption and to establish managed fisheries for species such as pirarucu and tambaqui. Even though not directly driven by climate change, this can be understood as a strategy that leverages food security and community resilience in the face of climatic extremes. Such agreements serve as fisheries governance tools and are essential for maintaining food security year-round, generating commercial fishing income, and protecting fish stocks. Food scarcity caused by extreme events has also been documented elsewhere, as in the study by Chowdhury *et al.* (2025) in northwestern Bangladesh, where farmers reported similar impacts, highlighting that regions of the Global South share considerable similarities in how climate change affects socially and economically vulnerable populations dependent on natural resources.

Due to the high mortality of rubber trees during floods, interviewees noted that rubber tappers avoid latex extraction from affected trees so they can recover from attacks by xylophagous insects.

In the education category, during extreme floods such as the 2021 event, classes were suspended because schools were underwater and because the physical space of schools was very hard to access due to the amount of mud in the paths. The need to suspend classes due to extreme floods was similarly documented in other studies in the Amazonian region (Vasconcelos, 2020). In health, adjustments involved preventive measures against waterborne diseases, including drinking filtered water and maintaining constant surveillance for malaria symptoms.

Another important point is temporary migration, which occurs between Médio Juruá communities and even to the municipal centre of Carauari during floods. In some cases, this migration becomes permanent, as reported:

We are going to face many delicate situations if the effects of climate change continue. One is the rural exodus. If you conduct a survey, there are more than 20 families who moved to town because of last year's flood [2021]. (MC, Rubber tapper, 2022).

This migration concerns conservation unit management bodies and community organisations, as it may lead to a large rural exodus, a practice that has been reduced in recent decades thanks to improved living conditions in the communities. Poorer families face greater difficulty developing adaptation strategies; thus, for many, remaining in their socioecological systems, even under extreme climatic impacts, is often the only path (Bedran-Martins, 2016).

In relation to droughts, fewer adjustments were identified compared to floods, but communities have begun to develop strategies to deal with extreme droughts. One challenge that emerges is accessing lakes during the dry season, even more so during events of extreme droughts. Construction of *trapiches* (wooden docks) is a strategy to overcome this challenge, as they connect villages or places of fish processing to the lakes, enabling land transportation of the produce. The construction of *trapiches* and elevated walkways is done through collective efforts, and it is important for both the outflow of fish and the facilitation of people's movement within the villages.

Lake protection is a year-round activity, but in extreme droughts, these lakes become crucial for community food security, as many households rely almost exclusively on fishing for animal protein. Another adjustment is the increased purchase of industrialised foods due to the reduced availability of local protein sources.

In relation to access to food, during the 2021 flood, public authorities and civil society responded mainly with reactive measures, such as food basket distribution and the construction of *marombas* in flooded areas to allow for movement and protect appliances and furniture. It is important to highlight the coordinated action of organisations participating in the Médio Juruá Territory Forum, which, together with multiple partners, mobilised humanitarian aid by distributing food baskets and hygiene items and providing 1,050 prepaid cards of R\$ 300 to affected families. With this collective mobilisation and support from the Fórum's regional governance structure, more than 3,000 food baskets were delivered to riverine families in the Médio Juruá Extractive Reserve, the Uacari Sustainable Development Reserve, surrounding areas, fishing agreement territories, and the Indigenous land of the Deni People.

These emergency response strategies in Médio Juruá demonstrate the territory's high level of social organisation. Strengthening this collective action is essential for consolidating programs and policies that enhance the adaptive capacity of local communities (Bulkeley, 2010).

Resilience, indicating both how people absorb impacts and when transformations in their ways of life become necessary, depends on the perception of thresholds, when communities reach their limits and seek new ways of living, dwelling, and producing in Amazonian floodplain environments (Filizola *et al.*, 2006; Guimarães *et al.*, 2019; IPCC, 2024; Vasconcelos, 2020).

However, even with these adaptation processes, extreme events create disruptions that farmers cannot manage, leading to the abandonment of crops, the loss of vulnerable species, and reduced production of key foods for household sovereignty, such as cassava and sweet potato.

It is important to emphasise that communities themselves develop these autonomous adaptations as strategies to remain within their socioecological systems. Yet they occur without government support, which makes more resource-intensive strategies, such as structural home adaptations or the purchase of industrialised foods like chicken, sausage, canned goods, and other animal proteins, difficult. These alternatives require financial resources and often lead to nutritional losses. Therefore, government measures are essential so that riverine socioecological systems can adjust to new climatic conditions brought about by climate change.

## 4 CONCLUSION

The methodology used to compare climatic data with social actors' perceptions in the Médio Juruá territory enabled understanding the region's socio-environmental impacts of climate change. Riverine populations clearly perceive the extreme increase in heat. These perceptions corroborate the physical indicators obtained in this study and demonstrate how climatic rhythms regulate life in the Médio Juruá. According to interviewees, these transformations have become more noticeable over the past two decades and are linked to environmental imbalance.

The Juruá River region shows an exponential increase over the years in the number of days with maximum and minimum temperatures above the 90th percentile, indicating a rise in extreme events in the region. Traditional communities are already modifying their ways of life to maintain their labour and social practices in the face of this new reality. One strategy identified for coping with extreme heat is changing and reducing working hours involving sun exposure, meaning farmers leave earlier and return earlier. However, this adjustment directly affects family farmers' production.

Extreme hydrological events, floods and droughts, are also producing social impacts and altering the dynamics of riverine socioecological systems in the Médio Juruá. The increased frequency of extreme floods and droughts affects production and social activities and isolates communities in the region.

Numerous adaptive adjustments were identified, particularly in the labour and food categories, where adjustments were reported for all extreme events. In the labour category, in addition to the shift in working hours, interviewees highlighted the abandonment of species vulnerable to water stress or intense heat. In the food category, the increased consumption of industrially processed foods stands out, an adjustment observed during both droughts and heat-related events.

Extreme floods were the events most frequently present across all categories of adaptive adjustments, with multiple strategies reported. This is explained by the high frequency and severity of the impacts caused by floods in the territory, as well as the central role of the river in the region's socioecological systems. However, further studies are needed to better understand the direct impacts of floods on productivity and social relationships in the region.

Research participants recognised the difficulties in implementing adaptive measures due to financial constraints, the ineffectiveness of existing measures, and the volatility of climatic rhythms in the Médio Juruá. This insecurity places the communities' livelihoods at risk, pushing them toward the limits of their socioecological systems and making it harder for them to remain in their traditional territories.

Territorial management, popular participation, and the polycentric governance already present in the Médio Juruá will be crucial for climate adaptation. However, without government involvement in the development of adaptive strategies across different public policies, ensuring the conditions for these systems to persist will be very difficult. In the face of socio-environmental disasters in the region, governmental responses have been largely emergency-based and reactive, consisting mainly of distributing food baskets and building *marombas*, especially by government entities.

Governments at various levels perform poorly in addressing climate issues, allowing impacts to unfold without structural or long-term responses. An important pathway for resilience in the Médio Juruá is the development of a climate change adaptation plan, built in a participatory and integrated manner.

The Médio Juruá reveals a central contradiction of climate change: the populations that conserve the forest the most are those who suffer the most from the consequences of this environmental crisis. Government support made available to these communities is still minimal when compared to their contribution to maintaining ecosystem services through forest conservation.

Greater effort is recommended in conducting research on climate change impacts and adaptation among traditional peoples and communities in the Amazon, given the scarcity of scientific studies addressing these themes and the need for better understanding the climatic vulnerabilities to which these populations are exposed.

## STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used ChatGPT (version GPT-5.1, OpenAI) for language editing and stylistic polishing only. All scientific content, analysis, and intellectual input were developed and verified by the authors; we take full responsibility for the accuracy and integrity of the manuscript.

## NOTES

1 | Traditional communities, including riverine peoples and extractivists, are culturally differentiated groups, which self-recognize as such and maintain specific social organization characteristics, occupying and using territories and natural resources to guarantee cultural, social, religious, ancestral and economic reproduction, based on traditional knowledge and practices (Brasil, 2007, p.1).

2 | Historical period between 1880 and 1910 in which there was a high global demand for rubber, especially to produce tires, making Amazonian rubber the main Amazonian exports, and one of the most important in Brazil.

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