REVISTA DELOS DESARROLLO LOCAL SOSTENIBLE

# Potential Vulnerability of Natural Populations of Camu-camu (*Myrciaria dubia*) to Anthropogenic Stressors in Southwestern Amazon

# Vulnerabilidade potencial das populações naturais de camu-camu (*Myrciaria dubia*) a perturbações antrópicas no sudoeste da Amazônia

# Vulnerabilidad potencial de las poblaciones naturales de camu-camu (*Myrciaria dubia*) a los factores de estrés antropogénicos en el suroeste de la Amazonia

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**ABSTRACT**
One economically promising Amazonian species is camu-camu (*Myrciaria dubia*) which fruits have the highest content of vitamin C recorded, with a high potential for applications on the food, supplement and cosmetic industry and which can be a cornerstone for agroforestry initiatives for

Amazonian peasants. Camu-camu has an Amazon wide distribution although most studies and collections have occurred on the Central and Western Amazon. The aim of this study is to assess the distribution and potential vulnerability of camu-camu populations in the state of Rondônia, Brazil, the southern limit of its distribution, which exhibit a drier climate. We use data recorded in herbaria and a bioprospecting expedition and data on anthopogenic stressors, estratified at the municipal level, like fire events, deforestation and dams. Camu-camu records occur preferentially in the Central and Northern part of the state, however most of the collections are around cities, major rivers and roads, showing a strong collector bias. Municipalities with camu-camu records suffered higher rates of deforestation and show higher occurrence of fire events and planned dams than municipalities without camu-camu records. Camu-camu populations in Rondônia are thriving on drier conditions and may be more adapted for future prevalent conditions for the Amazon under climate change. These adaptations may be useful for future domestication efforts. We call for an increasing effort of collecting and salvaging camu-camu populations on human dominated landscapes and to encourage participatory conservation with local farmers, for an ex-situ conservation on rural landscapes, especially under the prospect of climate change.

**Keywords:** agroforestry, *ex-situ* conservation, germplasm, fruit trees, fires, dams, deforestation, Brazil, Rondonia.

**RESUMO**

O camu-camu (*Myrciaria dubia*) é uma espécie amazônica economicamente promissora, cujos frutos possuem o maior teor de vitamina C já registrado, com alto potencial para aplicações na indústria de alimentos, suplementos e cosméticos, podendo ser a cultura principal em iniciativas agroflorestais de produtores locais. O camu-camu tem ampla distribuição na Amazônia, embora a maioria dos estudos e coletas tenham ocorrido na Amazônia Central e Ocidental. Este estudo tem como objetivo avaliar a distribuição e a vulnerabilidade das populações de camu-camu no estado de Rondônia, Brasil. Sua distribuição no limite sul apresenta áreas com um clima mais seco. Foram utilizados dados registrados em herbários e de expedições de bioprospecção, ademais, dados sobre perturbações antrópicas como incêndios, desmatamento e barragens (planejadas e existentes) estratificadas a nível municipal. Os registros de Camu-camu ocorreram preferencialmente nas regiões norte e central do estado, porém a maior parte das coletas ocorreu no entorno das cidades, grandes rios e estradas, mostrando um forte viés do coletor. Nos municípios com ocorrência de camu-camu foram observadas maiores taxas de desmatamento, incêndios e barragens, quando comparados aos municípios sem registros. As populações de camu-camu em Rondônia habitam condições mais secas e podem estar mais adaptadas às futuras condições geradas pelas mudanças climáticas na Amazônia. Estas adaptações podem ser úteis para os futuros esforços de melhoramento genético da espécie. Dessa forma, é necessário um maior esforço para manutenção da biodiversidade de populações de camu-camu em paisagens dominadas pelo homem, além de incentivar a conservação *ex situ* em áreas produtivas de agricultores locais, especialmente sob a perspectiva das mudanças climáticas globais.

**Palavras-chave:** sistema agroflorestal, conservação *ex situ*, germoplasma, fruteiras nativas, queimadas, desmatamento, barragens, Brasil, Rondônia.

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**RESUMEN**
Una especie amazónica económicamente prometedora es el camu-camu (Myrciaria dubia), cuyos frutos tienen el mayor contenido de vitamina C registrado, con un alto potencial de aplicaciones en la industria de alimentos, suplementos y cosméticos y que puede ser una piedra angular para las iniciativas agroforestales de los campesinos amazónicos. . Camu-camu tiene una amplia distribución en la Amazonía, aunque la mayoría de los estudios y colecciones se han producido en la Amazonía central y occidental. El objetivo de este estudio es evaluar la distribución y vulnerabilidad potencial de las poblaciones de camu-camu en el estado de Rondônia, Brasil, límite sur de su distribución, que exhibe un clima más seco. Utilizamos datos registrados en herbarios y una expedición de bioprospección y datos sobre factores estresantes antropógenos, estratificados a nivel municipal, como incendios, deforestación y represas. Los registros de camu-camu ocurren preferentemente en la parte central y norte del estado, sin embargo, la mayoría de las colecciones se encuentran alrededor de ciudades, ríos importantes y caminos, lo que muestra un fuerte sesgo coleccionista. Los municipios con registros de camu-camu sufrieron tasas más altas de deforestación y muestran una mayor ocurrencia de incendios y represas planificadas que los municipios sin registros de camu-camu. Las poblaciones de camu-camu en Rondônia están prosperando en condiciones más secas y pueden estar más adaptadas a las condiciones prevalecientes en el futuro en el Amazonas bajo el cambio climático. Estas adaptaciones pueden ser útiles para futuros esfuerzos de domesticación. Hacemos un llamado a un esfuerzo cada vez mayor para recolectar y rescatar poblaciones de camu-camu en paisajes dominados por el hombre y alentar la conservación participativa con los agricultores locales, para una conservación ex situ en paisajes rurales, especialmente bajo la perspectiva del cambio climático.

**Palabras clave:** agroforestería, conservación ex situ, germoplasma, árboles frutales, incendios, represas, deforestación, Brasil, Rondonia.

## 1 INTRODUCTION

Among the species with high agroforestry potential from Amazonian diversity is *Myrciaria dubia* (H.B.K.) Mc Vaugh, (Myrtaceae), the species is known in Brazil by several vernacular names: araçá-d'água, araçá-do-igapó, caçari, sarão, and marajá (Villachica, 1996; Yuyama & Valente, 2011), however, most references to *M. dubia* adopted the name that the species receives in Peru: camu-camu. It is naturally distributed over a large part of the Amazon, in the Brazilian states of Amapá, Amazonas, Pará, Rondônia, Roraima and in the Peruvian, Venezuelan and Guyana Amazon (Chagas et al., 2015; Villachica, 1996; Yuyama & Valente, 2011). It has also been cultivated outside the Amazon biome, i.e., Sao Paulo, Minas Gerais, and Tocantins (Yuyama & Valente, 2011).

The fruit has the highest known content of vitamin C (ascorbic acid) concentration, ranging from 845 to 6,100 mg x 100 $gr^{-1}$ in unprocessed pulp (Grigio et al., 2021; Yuyama et al., 2002; Zapata & Dufour, 1993), it also shows high concentration of other interesting compounds

like antocianins, flavonoid compounds, tannins, carotenoides and others (Arellano et al., 2016; Chirinos et al., 2010; Santos et al., 2022; Grigio et al., 2022) which can be used for the food, cosmetic and supplement industries (Grigio et al., 2019, 2021, 2022), it can also be used in the aquaculture industry since its fruits are eaten by fish in its natural habitat (Santana et al., 2016).

Ecologically, camu-camu plants have a high resistance to flooding, shallow soils and frequent disturbance, being able to remain totally submerged up to 4 – 5 months. It seeds don´t loss its ability of germination for up to 7 months submerged in water (Pinedo-Panduro et al., 2012), also it forms oligarchic forests (Peters et al., 1989), i.e., populations that occur at high densities and dominate locally. Its flowers are auto-compatible and are pollinated by stingless bees, and fruit production can be from 9.5 to 12.7 Mg. ha. $yr^{-1}$ (Peters and Vasquez 1987; Yuyama & Valente, 2011).

Agronomic research has concentrated on adapting the species for cultivation on terra firme (Melo et al., 2019; Monteiro et al., 2020; Pinedo-Panduro et al., 2010) and selecting favored traits i.e., higher concentration of vitamin C, larger fruits and resistance to pests (Chagas et al., 2015, Pinedo-Panduro et al., 2010; Yuyama & Valente, 2011). Germplasm collections with specimens from all the Amazon basin are active in Brazil at INPA (Instituto Nacional de Pesquisa da Amazônia) and EMBRAPA, with ex-situ collections in Manaus, Belem and Boa Vista (Nascimento et al., 2013; Sakazaki et al., 2022; Yuyama & Valente, 2011), and in Peru at IIAP (Instituto de Investigaciones de la Amazonía Peruana) from western Amazonia (Pinedo-Panduro et al., 2020; Šmíd et al., 2017). Genetic studies have shown a high intra- and inter-population variability with a high geographic structure (Nunes et al., 2017, Rojas et al., 2011; Šmíd et al., 2017; Souza et al., 2020), which indicates that to conserve the existing genetic diversity it will be needed to sample at large geographic scales.

Rondônia is one of the Amazonian states where high human intervention has occurred, with road construction, high deforestation and fires are occurring since the 1970s. Furthemore, it is one of the Amazonian states where more dams are planned to be installed (Freitas et al., 2022; Winemiller et al., 2016), and therefore it is needed an assessment of camu-camu sites and the design of strategies to save populations that may be useful for the future genetic improvements of this species and also to maintain several ecological services (e.g. fish sustenance, erosion control of river banks, biodiversity maintenance), especially on the scenario of climate change where drier and harsher environments may be prevalent on the future Amazon (Malhi et al.,

2009). The aim of this paper is to assess the vulnerability to anthopogenic stressors like dams, deforestation and fire of the natural populations of camu-camu in Rondônia state.

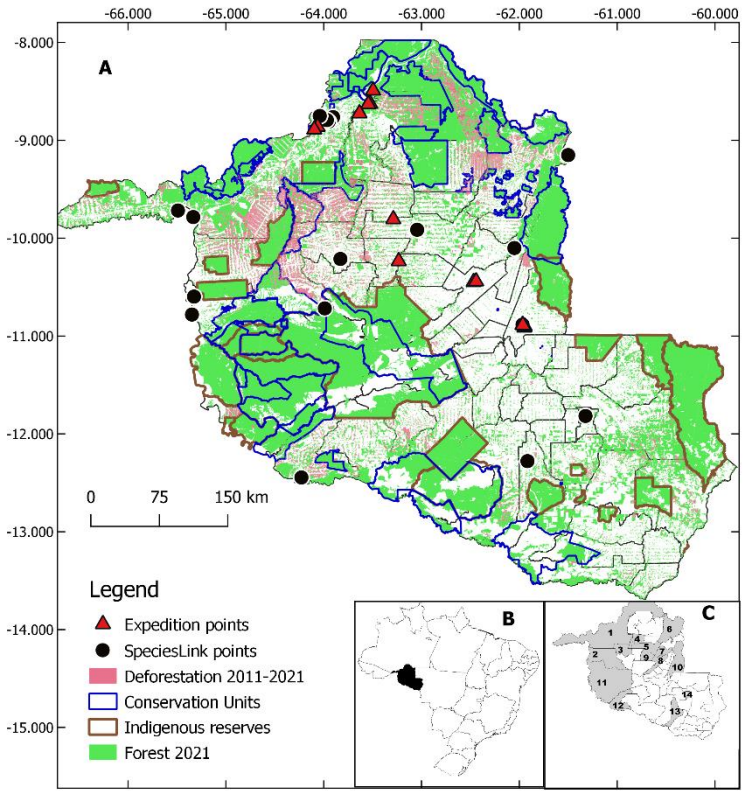
## 2 METHODS

### 2.1 STUDY AREA

Rondônia is a state in the Southwestern Brazilian Amazon, which covers an area of 237 590 km$^2$ between latitudes 7°35′30″ and 13°41′30″ S and longitudes 59°50′4″ and 66°15′00″ W. The predominant original vegetation was “open ombrophylous forest” which is a tropical-seasonal moist transitional forest covering approximately 75% of the state’s area. More dense tropical forest, dense ombrophylous forest”, occurs in the northern region bordering on the State of Amazonas (IBGE 2012). The climate is humid, tropical with a distinct rainy season (usually October to April), with annual average rainfall range between 1400 to 2600 mm and average monthly temperatures above 26 °C (Alvares et al., 2013).

Rondônia experienced a rapid deforestation since the 70s, while in 1978 only 2% of the state’s natural forest was deforested; by 1996, deforestation had claimed 23% of the state’s area (Browder & Pedlowski, 2000), and for 2011 it was around 45% (Piontekowski et al., 2014). In the last 5 years deforestation has increased in the Northern part of the state, as the arc of deforestation moved northward (Alencar et al., 2022), wearisomely deforestation and illegal logging activity had been moving more aggressively into protected areas and indigenous territories (Alencar et al., 2022; Pedlowski et al., 2005; Piontekowski et al., 2014).

Figure 1: A) Camu-camu locations recorded in the bio-prospecting expedition (black circles) and herbaria data (SpeciesLink) (red triangles) at Rondônia state and forest extent (points collapsed for better visualization), B) Rondônia state location in Brazil, C) Municipalities with camu-camu occurrences: 1: Porto Velho, 2: Nova Mamoré, 3: Buritis, 4: Alto Paraiso, 5: Ariquemes, 6: Machadinho d´Oeste, 7: Theobroma, 8: Jaru, 9: Cacaulândia, 10: Ji-Parana, 11: Guajará-Mirim, 12: Costa Marques, 13:Alto Alegre dos Parecis, 14: Primavera de Rondônia




Source: Elaborated by SA with data from IBGE, IBAMA, GFW, MAPBIOMAS & data collected in this research.

## 2.2 SPECIES LOCATION DATA

Species occurrence data were obtained in two ways: First, from bio-prospecting expeditions for the Project "Valuation and Sustenable Use of Economically Undervalued Amazonian Native Fruits" during 2011 – 2012 in the Northern and Central part of the state. Local residents acted as guides in orienting the researchers to locate camu-camu populations along rivers. The methodological procedure of the study consisted of location, identification, characterization and georeferencing of camu-camu populations. In each population, 30 plants were selected, from which, fruit samples were collected and sent to Embrapa – Roraima to integrate the germplasm collection. A second way to obtain information of camu-camu occurrences, was information retrieved from SpeciesLink (https://specieslink.net/) based on herbaria specimens.

## 2.3 ANTHROPOGENIC DISTURBANCES

Dams in operation or planned were obtained from Weinmiller et al., 2016 (derived from Zarfl et al., 2015: Dam Global Watch database https://www.globaldamwatch.org/fhred )

The occurrence of fire events within the limits of Rondônia state were estimated using active fire pixels, available from INPE's Center for Weather Forecasting and Climate studies (CPTEC) fire monitoring system (http://www.inpe.br/queimadas). QUEIMADAS fire products use data derived from MODIS (Moderate Resolution Imaging Spectroradiometer) sensor on Aqua satellite, on its afternoon overpasses (Giglio et al., 2003). The MODIS product has a nominal 1 km spatial resolution and a temporal resolution of 1-2 days. The annual number of fires from 2011 to 2021 was quantified as active fire density (accumulated number of active fire counts) by summing the monthly counts within a 10km grid hexagon cell. We chose to use only MODIS Aqua products in order to minimize satellite variation throught the time period following the suggestions on Aragão et al., (2021).

Total deforestation per municipality data for 2011 to 2021 was obtained from the Global Forest Watch (GFW) dashboard (https://gfw.global/3DQgDbe) searching for each of the municipalities where camu-camu were recorded. GFW estimates are based on updated methodology of Hansen et al., 2013 and relies on Landsat series sensors with a spatial resolution of 30m and considering forests as areas with more than 30% tree cover. The percentage loss is calculated with respect to the 2000 reference year (Hansen et al., 2013). Yearly deforestation spatial locations were obtained from INPE PRODES 2022. Other auxiliary data (hydrography, political limits, conservation units, etc.) for GIS representation was obtained from INPE Terra Brasilis gateway (http://terrabrasilis.dpi.inpe.br/downloads/).

## 2.4 DATA ANALYSIS

Camu-camu occurrence data was plotted with QGIS and its spatial relations with anthropogenetic stressors explored at the municipal scale. We selected to use the municipality scale since that is the smallest scale where policy decisions can be made. To assess the prevalence of fire events in the municipalities that contain camu-camu we added the number of fires from 2011-2021 for each municipality and compared the municipalities with and without camu-camu occurrences. We also calculated a fire per area index (hereafter called Fire Index) by dividing the number of fires by the municipality area. The accumulated deforestation from 2011-2021 in the

same municipalities was examined and compared for the municipalities with camu-camu. And to show the interaction between fire and deforestation we performed a correlation between the accumulated deforestation and the Fire Index. All calculations and statistical analysis were performed in R 4.22 (R Core Team, 2022) and the maps were composed using QGIS 3.26 Buenos Aires (QGIS Development Team, 2022)

## 3 RESULTS AND DISCUSSION

### 3.1 CAMU-CAMU DISTRIBUTION IN RONDÔNIA

In the bioprospecting expedition 15 populations were located; in the herbaria collections, recorded at SpeciesLink, we found 40 records but only 19 had georeferenced occurrences. Camu-camu populations were recorded in 14 of the 52 Rondônia municipalities (Figure. 1c), mostly in the central and northern part of the state. In the 2011-12 expedition it was registered in six municipalities (Ji-Paraná, Jaru, Alto Paraiso, Machadinho d´Oeste, Cacaulândia and Porto Velho). While in the herbaria collections, recorded at SpeciesLink, we found 40 records but only 19 georeferenced occurrences were used; they occurred in ten municipalities: Ji-Paraná, Buritis, Nova Mamoré, Guajara-Mirim, Costa Marques, Alto Alegre dos Parecís, Primavera de Rondônia, Ariquemes, Theobroma, and Porto Velho (Figure. 1c, Table 1).

Amazonian rivers are classified in white, clear and black, depending on the amount of suspended sediment, high sediment rivers typically coming from the Andes are called white rivers, rivers originating in Cerrado or savanna areas carry less sediments and are called clear rivers, while black rivers originated in sediment poor areas with few sediments and rich in phenolic compounds which gave them their black color (Sioli, 1984). In the bio-prospective expedition camu-camu populations were mainly found in clear waters rivers (Urupa, Machado, Jaru, Massangana, Candeias and Jamari) but also in the Madeira, a white water river, although only in specific locations: rocky outcrops in or near “cachoeiras” (rapids and waterfalls). In the Peruvian Amazon camu-camu populations have been reported mainly in black rivers and lakes (Villachica, 1996), while in the Brazilian Amazon have been reported in all three types of rivers (Chagas et al., 2015; Yuyama & Valente, 2011).

Although most of the collections are in the Northern and Central part of the state, we can not discard the historical existence of the species in the Southern part since we actually find two disjunct on the municipalities of Alto Alegre do Parecis and Primavera de Rondônia (Figure. 1).

Although records of the species in the state date back to the 1886, being first collected in Rondônia by Henry H. Rusby, from the New York Botanical Garden, at the "falls of Madeira", (although initially misidentified as a Guttiferae, the original collected specimen can be seen at NYBG virtual herbaria (https://sweetgum.nybg.org/science/vh/

specimen-details/?irn=1728103) was later identified as *M. dubia* in Britton et al.,1888: 47). Most of the collections in the past and even today are highly clustered around big cities and transport routes, a phenomenon know as collector bias, which affect most of the Amazon flora (Hopkins, 2007). This may preclude the assessment of the historical distribution of the species. Furthermore, 30% of all localities where tree specimens were collected have been already deforested (Stropp et al., 2020).

It was also found that fruit production tend to occur earlier in central Rondônia (rivers Machado, Urupá and Jaru) between the end of September and November. While in the North of the state (rivers Jamari and Candeias), production start later in November and continue until January (RCL personal observation).

## 3.2 ANTHROPOGENETIC STRESSORS

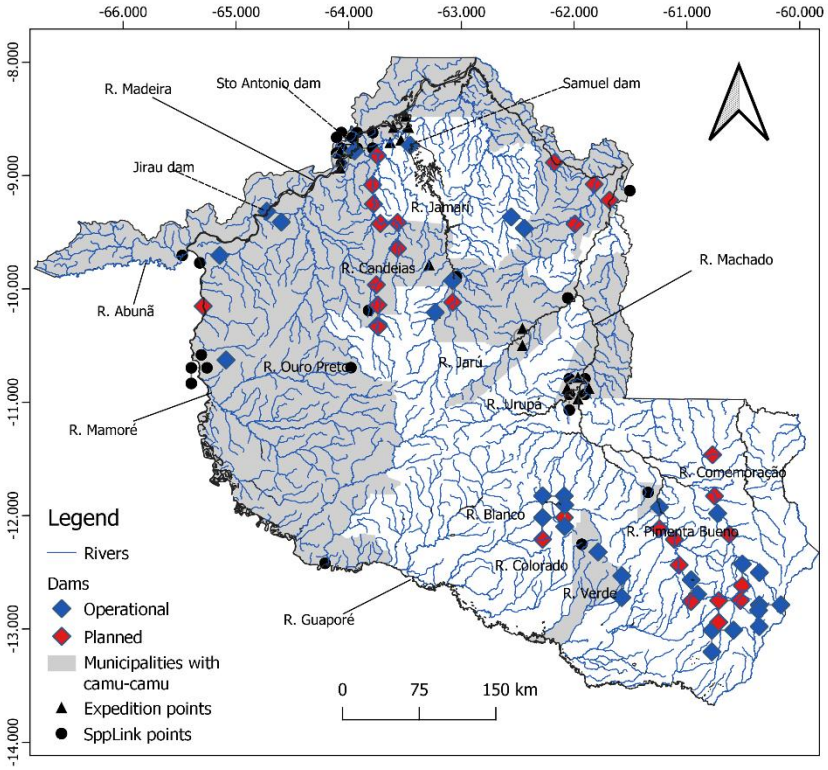
Potential impact to camu-camu populations is stronger by the dam construction by permanently flooding its habitat and by alteration of the flooding regime of rivers and tributaries. Proposed and active dams occur in most of the municipalities with camu-camu occurrences with the exception of Jaru, Theobroma, Ji-Paraná and Costa Marques (Figure. 2). The municipality of Porto Velho has nine active and planned dams, in the Madeira basin (Figure. 2). Followed by the municipalities of Machadinho d´Oeste (4), Buritis, Alto Paraiso, Alto Alegre do Parecis, each with three, while the rest (Nova Mamoré, Ariquemes, Cacaulandia, Guajará Mirim, Primavera de Rondônia) have 1 or 2 each. The river basins more affected by dam construction are the Comemoração and Pimenta Bueno, Blanco and Verde rivers, in the South. While Jamari, Candeias and Machado rivers in the North have the highest number of planned dams(Figure. 2).

The largest dams in the state have been constructed in the North. Samuel dam, in operation since 1988, in the Jamari river, it flooded 420 $km^2$ of forests (Fearnside, 2005). Santo Antonio and Jirau dam complex, in operation since 2011 and 2013, respectively, in the Madeira river have flooded 468 $km^2$ of forest, flooding 52% more land than planned (Cochrane et al., 2017). Large dam projects have a large ecological, economic and social impacts which includes

loss of floodplain habitat (Fearnside, 2014). An aggravating factor is that dams are preferentially located at rapids and waterfalls in order to take advantage of the height difference, which were also the location of most of the recorded populations in the Madeira river, have dissapeared by the Santo Antonio and Jirau dam complex construction.

Although large dams posse a threat for camu-camu populations, its numbers are limited and are subject to strict environmental regulations. More alarming is the spread of medium and small dams in the Amazon. Most of the existing dams in Rondônia are medium and small which are more concentrated South of the state, although more are being planned for the North (Figure. 2) (Freitas et al., 2022; Winemiller et al., 2016). Small Hydroelectric Plants (PCH in Portuguese), have been touted as less environmentally damaging. However, recent studies have pointed that in the aggregate may be as damaging as large hydroelectric dams, because they a) can cause river fragmentation which may affect fish migrations, b) modify river structure altering required habitat for fishes, c) alter river flooding patterns, and d) have less legal environmental control (Couto et al., 2021; Freitas et al., 2022). For camu-camu populations dams are a direct threat since its habitat, floodplain forests (varzea), are directly affected, upstream due to flooding, and downstream because irregular flooding patterns and less nutrient input (Fearnside, 2014; Li et al., 2021). Another effect is river fragmentation which isolates fish population and potentially disrupting fruit dispersion. Dam construction have already affected sampled populations on the Madeira river (as indicated above) and in the Massangana river (RCL, pers. obs).

Figure. 2: Existing and proposed dams in the state of Rondônia. Grey area mark the municipalities where camu-camu populations were recorded. Main rivers and larger dams are named.

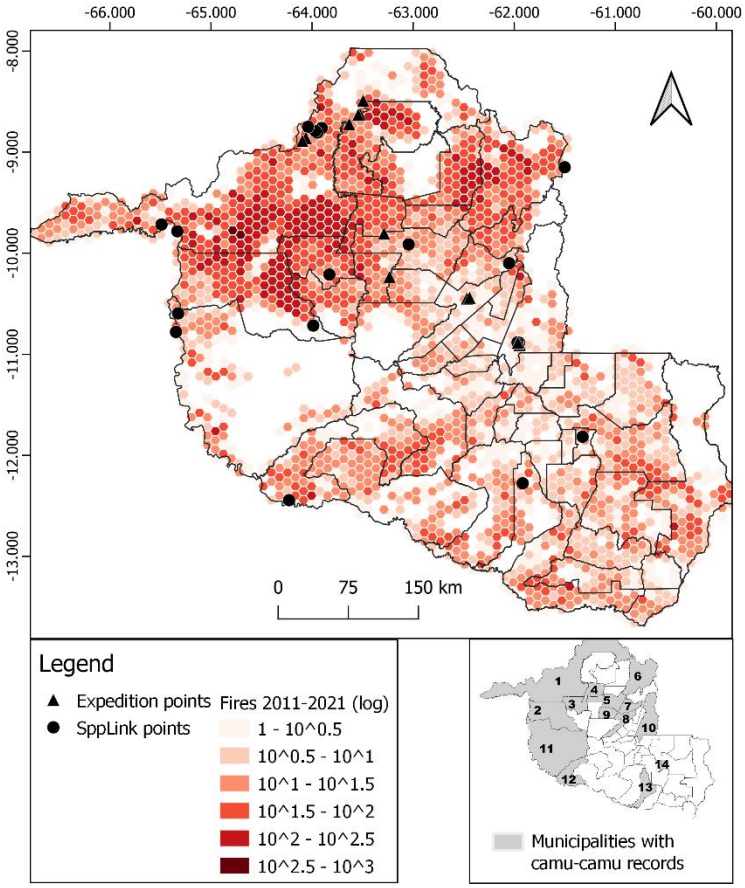



Source: Elaborated by SA with data from ANA, Dam Global Watch & data collected in this research.

With respect to fire incidence, the total number of fire events during 2011-2021 in Rondônia state was 104,899, 62% of which occurred on the 14 municipalities with camu-camu presence (Figure. 3, Table 1). The number of fires at the state level have been increasing since 2011. Different geographical patterns are present in each municipality, as deforestation is moving northwards to areas not yet totally deforested (Figure. 3). There was three patterns in the fire trends between 2011 to 2021: Municipalities were the number of fire events have increased, like Porto Velho and Nova Mamoré, municipalities where the number of fires have remain relatively constant: like in Machadinho d´Oeste and where it has decreased like in Theobroma and Primavera de Rondônia (Figure.3). The decreased number of fire events usually occurred in municipalities already extensively deforested by 2000 (Table 1), which are mainly in the South part of the state. The number of fire events per $km^2$ in the municipalities where camu-camu occur was higher than in the municipalities where they were not recorded (average ± standard deviation: 0.49 ± 0.43 vs 0.27 ± 0.29, respectively) which is statistically significant (t-test = 2.12, p = 0.03).

Although with high geographical variation, it could be said that camu-camu populations are more exposed to fire events in the municipalities where they were recorded.

Figure 3: Fire events from 2011-2021 accumulated on 10km diameter hexagons (log transformed). Occurrence points have been collapsed for better visualization. Inset: Municipalities with camu-camu occurrences (abbreviations as in figure.1)




Source: Elaborated by SA with data from INPE, IBGE & data collected in this research.

Deforestation is also higher in the northern municipalities: Porto Velho and Nova Mamore are the municipalities with the highest area lost (Table 1). Municipalities in the Central and Southern region have loss less tree cover since 2011 because much of the municipalities were already heavily deforested by 2000 (Table 1). This is concordant with the historical trend of deforestation moving northwards, since the southernmost municipalities were the first to be deforested since the 70s, thus these municipalities also have a larger percentage of area under not forest cover e.g. Alto Paraiso and Buritis (Table 1). The trend of deforestation to move northwards since the 2000 had been pointed by other researchers (Alencar et al., 2022;

Piontekowski et al., 2014), a possivle explanation may be that deforestation is being pushed by the incursion of soy cultivation in the Southern part of the state, displacing the cattle ranching activities and land speculation northwards (Alencar et al., 2022; Song et al., 2021).

Table 1: Municipalities with camu-camu occurrences. † Data from the 2011-2012 bio-prospective expedition. ‡ Data from Species Link. * Municipalities with records from both.

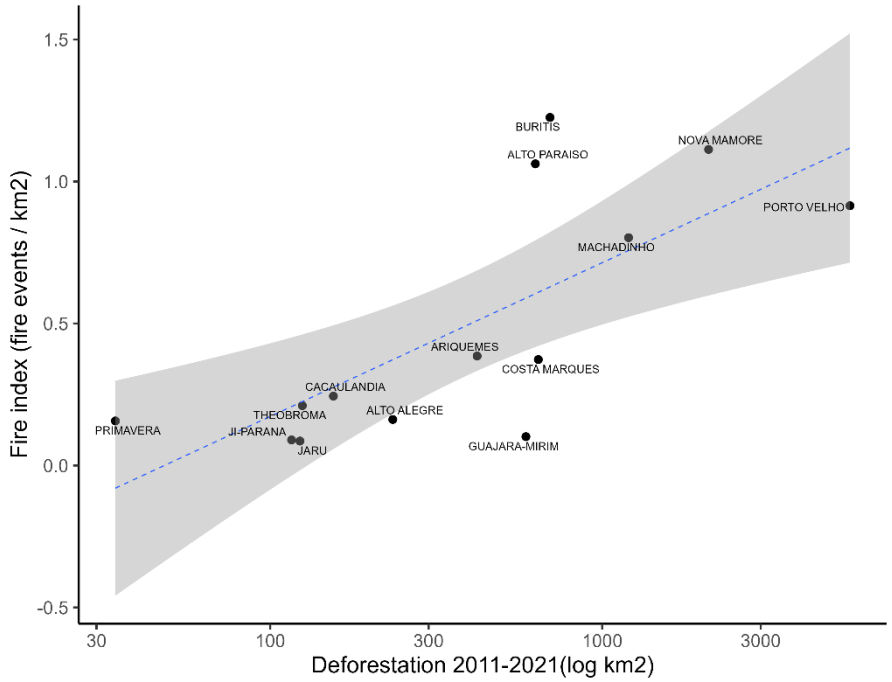
| Municipality with camu-camu occurrence | Municipality area ($km^2$) | Total number of fire events (2011- 2021) | Index fire per area (fire events/ $km^2$) | Accumulated Deforestation 2011-2021 ($km^2$) | Percentage of forest loss % |
|---|---|---|---|---|---|
| Alto Alegre dos Parecís ‡ | 3958.27 | 641 | 0.16 | 234 | 22 |
| Alto Paraiso † | 2651.82 | 2817 | 1.06 | 629 | 62 |
| Ariquemes ‡ | 4426.57 | 1706 | 0.38 | 420 | 39 |
| Buritis ‡ | 3265.81 | 4003 | 1.22 | 696 | 70 |
| Cacaulandia † | 1961.78 | 479 | 0.24 | 155 | 40 |
| Costa Marques ‡ | 4987.18 | 1860 | 0.37 | 642 | 19 |
| Guajara Mirim ‡ | 24856.88 | 2520 | 0.10 | 589 | 4.1 |
| Jaru † | 2944.13 | 253 | 0.09 | 123 | 36 |
| Ji-Parana * | 6896.65 | 620 | 0.09 | 116 | 6.5 |
| Machadinho D´Oeste ‡ | 8509.27 | 6826 | 0.80 | 1200 | 35 |
| Nova Mamóre ‡ | 10070.49 | 11209 | 1.11 | 2090 | 38 |
| Porto Velho * | 34090.95 | 31185 | 0.91 | 5570 | 31 |
| Primavera de Rondônia ‡ | 605.69 | 95 | 0.15 | 342 | 27 |
| Theobroma ‡ | 2197.41 | 463 | 0.21 | 125 | 42 |

Sources: Elaborated with data from IBGE 2021, INPE, Global Forest Watch (GFW) & this study.

Deforestation and fire occurrence are intrinsically linked. Municipalities with high accumulated deforestation show also higher fire occurrence (Figure. 4) (correlation $r = 0.69$, $t = 3.27$ $p = 0.006$). Porto Velho and Nova Mamoré are the municipalities which have shown the highest fire activity as well as the highest loss of forest cover. Especially on the lasts years, this correspond with the northward movement of the arc of deforestation. Fire in the Amazon is either directly or indirectly linked to human activity, it is directly linked to deforestation since it is used to eliminate dry biomass after trees are fallen, or indirectly as it is part of pasture maintenance activities and slash and burn practices of traditional agriculture (Alencar et al., 2022; Barrow et

al., 2020). Furthermore escaped fires can also affect more vulnerable fragmented and degraded forests (Barrow et al., 2020).

Figure 4: Correlation between number of fires per km$^2$ and deforestation (log km$^2$) by municipality where camu-camu was recorded for the period 2011-2021.




Sources: Elaborated with data from INPE & Global Forest Watch (GFW) & this study.

Another anthopogenic stressor is mining exploration, especially gold mining are extremely damaging for floodplain habitats in which camu-camu populations exist. Rondônia is one of the Amazonian states with more mining concessions in the Brazilian Amazon (Rudke et al., 2020) which further endanger the camu-camu populations.

## 3.3 VULNERABILITY OF CAMU-CAMU POPULATIONS

Rondônia populations of camu-camu are at the edges of its geographical distribution. Species populations at the edges of its distribution are characterized by: 1) increased genetic isolation, 2) genetic differentiation, and 3) variability in individual and population performance (Sexton et al., 2009). Indeed, populations of camu-camu in Rondônia have been genetically characterized as very different from the ones in Amazonas and Roraima (Chagas et al., 2015; Rojas et al., 2011).

Environmental conditions in Rondônia are drier than in the rest of the Amazon, and we may expect that populations are locally adapted to those conditions. Although, further genetic analysis are needed since geographical space does not always correspond to niche space (Pennington et al., 2021), these locally adapted populations at the edge of distribution may serve as the source for breeding population more adapted for the drier conditions under climate change (MacDonald et al., 2017; Šmíd et al., 2017).

This advantage may make these peripheral populations extremely important for the eventual domestication and improvement for commercial varieties. However a balance between genetic gain and conservation must be attain (Cornelius et al., 2006). This is particular difficult with tropical trees with long life spans, long maturation until fruiting and dependency on biotic interactions for pollination and dispersion. Which makes participative conservation more apt to maintain camu-camu in the landscape.

In participative conservation, farmers needs are put forward and selection and agronomic decisions include farmer´s local and traditional ecological knowledge, together with specific market studies, these strategies may have higher success than the conventional ex-situ conservation and state sponsored programs (Penn, 2006). Focusing in services that camu-camu can provide to rural communities like with vitamin C supplements to improve diets to help figurehting prevalent anemia (Fishman et al., 2000), provide fish rations in aquaculture ponds (Santana et al., 2016) and erosion control of river banks and protection of water bodies en general, and integrated design of interventions with the objective of improve rural landscapes and livelihoods might have better chance to conserve camu-camu populations in Rondônia.

## 4 CONCLUSION

Camu-camu occurrences were recorded mainly in the Northern and Central part of the state, in clear water rivers. These populations are at the Southern limit of the species natural distribution and are currently endangered by fires and deforestation, since the municipalities where they occur are in the way of the advancing arc of deforestation.

In addition to deforestation and fires, there are other drivers of camu-camu population extinctions like dam construction and mining. Camu-camu plants are vulnerable to flooding of their habitat by dam construction: at least two populations in the Madeira and Massaranga rivers have dissapeared as consequence of the construction of dams (RLC pers. obs.). More worrisome

is the proliferation of Small Hydroelectric Plants since they are subject to less environmental control (Freitas et al., 2022), and will affect a larger area of potential camu-camu habitat.

Focusing on participative conservation, stressing environmental services and sustainable livelihoods, especially under the prospect of climate change might have better chance to conserve camu-camu populations in Rondônia.

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