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ECOLOGÍA

The economic potential of non-timber forest products in the Cerrado legal reserves

El potencial económico de los productos forestales no madereros en las reservas legales de El Cerrado

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ABSTRACT

To promote the sustainable utilization of Non-Timber Forest Products (NTFPs) in the Legal Reserves of the Cerrado biome, we present a five-step conceptual model that was implemented in a local Settlement in Central Brazil. This study assesses the potential for NTFP harvesting by evaluating tree species with high Importance Values through a comprehensive forest inventory. Three species were selected based on their high importance value and commercial potential: *Annona crassiflora* (araticum), *Caryocar brasiliense* (pequi), and *Eugenia dysenterica* (cagaita). Over a period of twelve months, we monitored the phenophases and fruit production in the study area. Linear regressions were employed to predict fruit productivity by utilizing morphometric characteristics of the trees. Canopy diameter emerged as a significant predictor of productivity for *C. brasiliense*. Taking into account regional market prices, the estimated gross revenue from fruit production reached RS 4641.00 (U$ 882.00), which could potentially increase by 340 % through simple manufacturing processes. The production period exhibited minimal overlap among the three species, suggesting enhanced utilization of natural resources throughout the year. Nonetheless, the execution of a strategic plan, including an economic feasibility study, is crucial. This research underscores the necessity for further investigations to gain a deeper understanding of the income generated from NTFPs and their role in rural development. Overall, this manuscript significantly contributes to the comprehension of the economic potential of NTFPs in Legal Reserves, offering valuable insights for sustainable planning and management.

Keywords: Agroecology, Cerrado, *Annona crassiflora, Caryocar brasiliense, Eugenia dysenterica*.

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RESUMEN

Para fomentar el uso sostenible de los Productos Forestales no Maderables en las Reservas Legales del Cerrado, proponemos un modelo de cinco pasos, que aplicamos en un Asentamiento en el Centro de Brasil. El estudio evalúa el potencial de recolección de PFNM al evaluar tres especies arbóreas con Altos Valores de Importancia mediante un inventario forestal exhaustivo y potencial comercial: *Annona crassiflora* (araticum), *Caryocar brasiliense* (pequi) y *Eugenia dysenterica* (cagaita). Durante doce meses, seguimos las fenofases y la producción de frutos en el área de estudio. Se utilizaron regresiones lineales para predecir la productividad de los frutos en función de las características morfométricas de los árboles. El diámetro de la copa resultó ser un predictor significativo de la productividad para *C. brasiliense*. Considerando los precios regionales del mercado, se estimó una ganancia bruta de la producción de frutos de RS 4641.00 (U$ 882.00), que podría aumentar en un 340 % con una fabricación sencilla. El período de producción mostró una pequeña superposición entre las tres especies, lo que podría conducir a una mejor utilización de los recursos naturales a lo largo del año. Sin embargo, es esencial llevar a cabo un plan estratégico que incluya un estudio de viabilidad económica. El estudio destaca la necesidad de investigaciones adicionales para comprender mejor los ingresos generados por los PFNM y su papel en el desarrollo rural. En general, el manuscrito contribuye a la comprensión del potencial económico en las Reservas Legales y proporciona información valiosa para la planificación y gestión sostenibles.

Palabras clave: Agroecología, *Cerrado, Annona crassiflora, Caryocar brasiliense, Eugenia dysenterica*.

INTRODUCTION

Conventional agriculture has been reducing and mischaracterizing the natural areas in tropical regions. In the Brazilian Cerrado, the largest South American savanna, more than 50 % of the natural cover has been cleared (Sano *et al.* 2010), most of which has been converted to agricultural landscapes. Brazilian environmental legislation, specifically the Native Vegetation Law (Law No. 12,651/2012), mandates that rural landowners must maintain a portion of their lands as Legal Reserves to ensure the conservation of native vegetation and ecosystem services (Brasil 2012). The Legal Reserve aims to protect part of the natural ecosystems within rural areas, ensuring the maintenance of the ecosystem services, essential for nature-based solutions (Metzger *et al.* 2019). It is also devoted to ensuring the sustainable economic use of natural resources, improving the conservation and rehabilitation of ecological processes, and promoting biodiversity conservation (Brasil 2012). The Legal Reserve covers up to 20 % of the rural properties in the Cerrado biome, representing potentially 400,000 km².

The current scenario of Legal Reserve utilization in the Cerrado is marked by challenges and conflicts, which can lead to biodiversity loss. The legislation allows for compensatory measures whereby these Legal Reserves can be offset in other properties, which can result in less biodiversity protection (Silva and Ranieri, 2014). It also allows alternative uses of Legal Reserves, such as planting of exotic tree species. This mischaracterization has become a worrying source of changes in natural ecosystems in urban-rural transitional areas, which are important connections for biodiversity (Metzger *et al.* 2019).

In this context, seeking alternatives that incentivize landowners to keep their Legal Reserves intact is essential, avoiding compensation in other areas. One promising strategy is to promote the sustainable use of Non-Timber Forest Products (NTFP) derived from these Cerrado Legal Reserves (Avocèvou-Ayisso *et al.* 2009, Ros-Tonen 2000). Non-timber forest products encompass a wide range of resources, including fruits, seeds, fibers, essential oils, and medicinal plants, which hold significant economic and cultural potential. The Cerrado has more than twelve thousand species of vascular plants (Mendonça

et al. 2008), and many of them have at least one kind of use by the local population, highlighting faunal attraction for pollination and dispersion, traditional medicine, and woody (Aquino *et al.* 2007).

Among the NTFP, fruit gathering is the main activity developed by rural populations in Central Brazil. When the management of the resource use is adequate, sustainable use of NTFP contributes to the maintenance of biodiversity, preserving ecological interactions, and ecosystem services (MMA 2017). Otherwise, the resource can become altered and degraded (Arnold and Ruiz 2001, Ticktin 2004). At the same time, fruit harvesting contributes to the families' economic incoming in rural areas (Afonso 2008). It is also one of the strategies of Agroecology amplification (Nicholls and Altieri 2018).

By promoting the sustainable use of these non-timber forest products, it is possible to establish a synergistic relationship between biodiversity conservation and the socioeconomic development of local communities. The proper valuation and management of these resources can provide a source of income for landowners, contributing to their continued presence in rural areas. Furthermore, sustainable exploitation of these resources can encourage the adoption of conservation practices and responsible management of natural areas. Thus, by encouraging the sustainable use of NTFP in Cerrado Legal Reserves, we can promote biodiversity conservation, mitigate habitat fragmentation, and foster sustainable development in rural areas.

Despite the current knowledge about the different uses of Cerrado native fruity species, few studies have estimated the amount and seasonality of the income provided by fruit production and evaluated the economic use of the Legal Reserves (Barbosa-Silva *et al.* 2015). To encourage the sustainable use of NTFP in Legal Reserves as a strategy to incentivize its preservation, this article provides a case study of a Legal Reserve potential evaluation and suggests a conceptual model for sustainable planning of fruit usage in Legal Reserves.

MATERIALS AND METHODS

Study area

The study was carried out in the Legal Reserve of the *Pequeno William* Agroecological Settlement (PWAS; Latitude -15.678672°; Longitude -47.706269°), Brasília, Brazil. The PWAS is in the Cerrado biome, central Brazil. The settlement has 22 allotments of 3.8 ha each, with a communitarian Legal Reserve of 60.73 ha, covered by native vegetation (EMATER 2016). The central region of the Cerrado has a remarkable climatic seasonality. The rainy season goes from October to April and a pronounced dry season from May to September (with the mean annual precipitation of 1500 mm). The mean annual temperature is 22 °C (24 °C in the rainy season and 20 °C in the dry season). The predominant vegetation is a savanna kind vegetation, the Cerrado *sensu stricto* on oxisol.

Identifying the landowners' intention

Currently, the families of the PWAS congregate in the *Esperança* Association. We identified the demand for sustainable use of NTFP, specifically the use of regional fruits by accessing the development plan of the *Esperança* association (EMATER 2013) and talking with the families in the PWAS. Their goal is to implement productivity systems (crop and livestock) with ecological bases. They also intend to emancipate families from poverty, including their products in local and regional markets. The community is already exploring opportunistically the fruits in the Legal Reserve, but the uncertainties about the total potential production and seasonality are the main fragilities of this activity. Currently, the success of the fruit's sustainable use is critical for the local community due to limitations in water and inputs for crop production.

Ecological potential of the Legal Reserve for NTFP harvesting

The forest inventory is the first step to planning the NTFP usage, to assess the most important species in the community. We focused on the evaluation of the potential harvesting of tree species with high Importance Values (IV) in the tree inventory conducted by Silva (2017). The IV is a measure of how important a species is in a given plant community, considering the frequency, dominance in basal area, and density (Mueller-Dombois and Ellenberg 1974). We selected the following species with high potential for commercialization: *Anonna crassiflora* Mart. (araticum), *Caryocar brasiliense* Cambess. (pequi), and *Eugenia dysenterica* (Mart.) DC. (cagaita). *Eugenia dysenterica*, despite the low IV in the community (position number 30), has a high frequency in the allotments and has a very important appeal for commercialization. It also has a high germinative potential and survival rate, allowing the increase by planting in the allotments. These

Table 1. The intensity of the phenological phases: leaf exchange, flowering, and fruiting (adapted from Françoso *et al.* 2014).

Intensity	Leaf phase	Flowering	Fruiting
0	Mature leaves	No flower	No fruits
1	Immature leaves or sprout	Flowering ending	Beginning of fructification
2	Leaf senescence	Few flower buds	Immature fruits
3	Leaf fall	Flowering beginning	Developing fruits
4	Canopy cleared	Peake of flowering	Mature fruits

species were chosen because they have high IV and/or are largely used in central Brazil, often consumed *in natura*, but also used in meal preparation.

Annona crassiflora Mart. (Annonaceae) is a widespread species in the Brazilian territory, typical of the savanna's physiognomy in the Cerrado biome (Flora do Brasil c2020). The tree reaches 6 m high, with a monopodial growth form, cylindrical trunk, and hanging branches. The fleshy fruits have 20 cm in diameter and 0.6 to 2.0 kg (Kuhlmann 2012). The fruits are consumed *in natura* or used in cakes, jelly, ice cream, and others. Species in the same genera (e.g. *A. squamosal* and *A. muricata*) are relished worldwide. *Eugenia dysenterica* (Mart.) DC. (Myrtaceae) occurs in several formations in the Brazilian Cerrado, reaching 4-9 m. The fruits are globose, yellowish, flashy, and simple, with 4-6 cm in diameter. The ripe fruits are extremely perishable, making commercialization difficult. Thus, it is sold immature by the families. *Caryocar brasiliense* Cambess. (Caryocaraceae), a symbol of the Brazilian Cerrado is an iconic species of central Brazil, replaced by three species of the same genera in the marginal areas of the Cerrado biome. The tree crown is leafy and large, reaching 10 m high. The fruits are globose, fleshy, and dehiscent, exposing the core with a yellow pulp. The pulp has a very characteristic taste that is widely appreciated in the local cuisine, and used in salty dishes, often composing recipes with rice or chicken.

Seasonality and Productivity

To evaluate de seasonality of the fruit production we conduct a phenological study. We selected ten mature trees of each species, larger than 5 cm in diameter (measured at 30 cm above the soil level). We observed the 30 individuals monthly for twelve months, from August 2017 to July 2018, recording the intensity of the phenological phases of leaf exchange, flowering, and fruiting (Table 1), adapted from D'Eça-Neves and Morellato (2004), and following Françoso *et al.* (2014). We calculated the average index of each phenological phase for each species monthly. The uniformity of the phases was tested with Rayleigh's Test of Uniformity using the phenological indexes in the circular package (Agostinelli and Lund 2017). The uniformity test evaluates the phase distribution throughout the year in a circular approach (Landler *et al.* 2020).

We also estimated fruit production by selecting randomly two secondary branches to count the fruits. We extrapolated the average number of fruits by the total number of secondary branches to estimate the month's total production (Vilela *et al.* 2008). To estimate the total of fruits potentially collected by residents, we only considered the production of one month, when most of the fruits were in categories three and four (developing fruits of good size or mature fruits). This criterion was used to not overestimate the productivity, due to the high abortion rate of green fruits.

We adjusted linear regressions for each species to predict the productivity of fruits by species that could be used to better estimate the fruit production by allotment since each family has two hectares of natural vegetation. We used the number of fruits in the month of the highest production as a response variable. The explanatory variables were diameter, total height, commercial height (up to the main bifurcation), the number of main branches, mean diameter of the branches, canopy projection area, and canopy volume. The trunk and branches diameter were measured using a tree caliper, the total and commercial height were measured with a graduated rod, and the canopy projection and volume were calculated by the average diameter of the smallest and the largest canopy diameter, using the equations of the area and half-volume of the circumference. We excluded the variables highly correlated (> 75 %). The best model was selected by the Akaike information criteria, us-

ing the function stepAIC. All the statistical analyses were performed in the R software (R Core Team 2021).

Estimating the gross revenue of the Legal Reserve production

We arbitrarily excluded 20 % of the total fruit production, reserved for fauna consumption and dispersion, keeping the ecosystem integrity. We also considered 20 % of loss in the total harvesting process. The potential gross revenue was estimated considering how the fruits are commercialized in the region by the families of the PWAS. They sell the entire fruit of *A. crassiflora* and *E. dysenterica* by weight. To sell the *C. brasiliense*, they remove the core from the external part of the fruit.

We estimated the gross profit by multiplying the price by fruit, by the average number of fruits per tree, and by the density of the species assessed in the forest inventory (Silva 2017). We used in our calculations the prices established by the local markets and by the *Central do Cerrado* cooperative (https://www.centraldocerrado.org.br/). The *Central do Cerrado* is a non-profit organization that intermediates the commercialization of natural products in the large region of the Cerrado. We also consulted up-to-date literature at that time to estimate the prices of the products (Orioli 2017, Ribeiro *et al.* 2019).

We estimated the incomes of the commercialization considering the minimum processing of the fruits of each species to estimate the gross revenue increase. For *A. crassiflora* and *E. dysenterica*, the pulp must be separated using a pulper. The processing of *C. brasiliense* consists of removing the fleshy from the core manually and bottling it in a compote of water and salt. We consulted the weight of the fruits and pulp in the literature (Bueno *et al.* 2017, Fagundes 2017, Orioli 2017, Silva *et al.* 2001, Vera *et al.* 2005).

RESULTS

Seasonality and Productivity

All the phenological phases had significant uniformity, with a well-marked peak (Table 2), showing accentuated seasonality (Fig. 1). The peak was especially pronounced for *E. dysenterica* and *A. crassiflora*. *Annona crassiflora* changed de leaves from April to September with higher intensity in the last two months. Its flowering and fruiting had a less marked peak, and the fruits maturated in the middle of the rainy season (December to February). All the phenological phases of *Eugenia dysenterica* were remarkably fast, with flowering occurring predominantly in July and fruit maturity in September. *Caryocar brasiliense* had long phases. All the species changed their leaves during the dry season (April to September). The flowering occurred from the middle to the end of the dry season and the fruiting started at the beginning of the rainy season. The three species produced fruits during half of the year, with little overlap (Fig. 2).

The morphometric characteristics of *A. crassiflora* did not explain the fruit production, since the empty model was selected by the Akaike information criteria. The model that better explains the *E. dysenterica* production was the number of branches, but the variable was not significant (Table 3). On the other hand, the canopy diameter significantly explained the *C. brasiliense* production (Table 3). The canopy diameter could predict in 64 % of *C. brasiliense* productivity (Table 3) using the Equation 1, where Y is the number of fruits and X is the canopy diameter in meters. The morphological data could not explain the productivity of *A. crassiflora* and *E. dysenterica*.

Equation 1. $Y = 2.5\ X - 78$

Estimating the gross revenue of the Legal Reserve production

We estimated the total fruit yield of *A. crassiflora*, *C. brasiliense*, and *E. dysenterica* available for harvest, with 40 % excluded due to a fauna reserve (20 %) and loss in productivity (20 %). The estimated yields per hectare

Table 2. Rayleigh's Test of Uniformity.

Species	Phenological stage	Z	p
Annona crassiflora	Flowering	0.82	**< 0.001**
	Fruting	0.86	**< 0.001**
	Leaf changing	0.67	**0.0027**
Eugenia dysenterica	Flowering	0.80	< 0.001
	Fruting	0.81	**< 0.001**
	Leaf changing	0.85	**< 0.001**
Caryocar brasiliense	Flowering	0.57	**0.016**
	Fruting	0.68	**0.0023**
	Leaf changing	0.67	0.0027

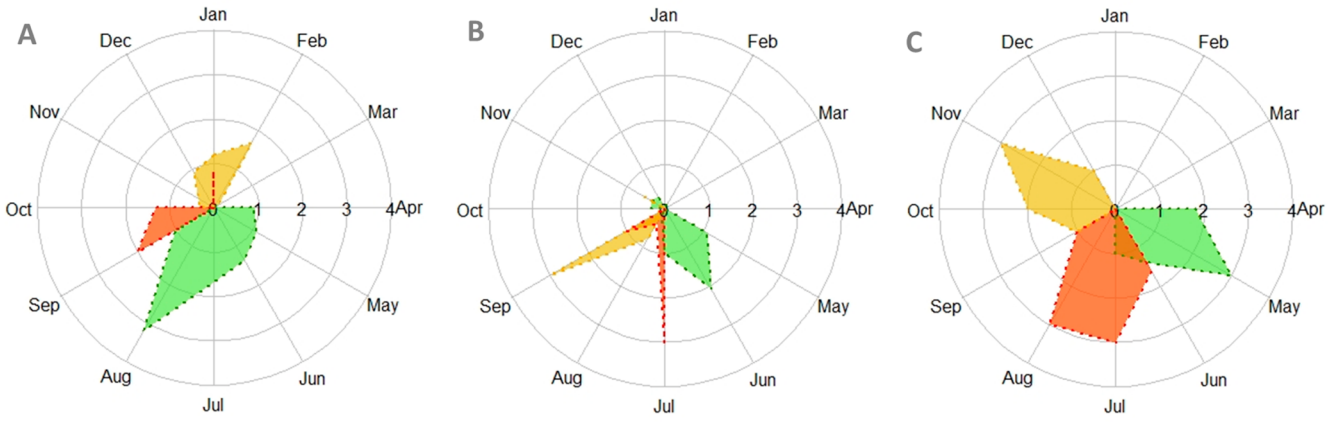

Figure 1. Intensity index of the phenological phases leaf exchange (green), flowering (red), and fruiting (yellow) for the tree species (A) ***Annona crassiflora***, (B) ***Eugenia dysenterica***, and (C) ***Caryocar brasiliense***, studied from September 2017 to July 2018 in the ***Pequeno William*** Agroecological Settlement in the Cerrado biome, Brasília, Brazil.

were 295, 3188, and 3431 fruits, respectively, totaling RS 4641.00 (US$ 882.32) in revenue per hectare (in the local currency at that time) (Table 4). Using the phenological calendar, families can predict monthly revenue. After the dry season, *E. dysenterica* can generate R$ 453.00/ha (US$ 86.00) in August and September. Next, *C. brasiliense* increases revenue by R$ 1185.00/ha (US$ 255.00) from September to December. From November to February, *A. crassiflora* production generates income of R$ 2952.00 (US$ 561.22) per hectare. When considering simple fruit processing, the expected gross revenue increases by 340 % per year compared to the sale of fresh fruits (Table 5). Taking into account the 66-ha Legal Reserve used by 22 families and the 2-ha voluntary reserve for each family, the total budget per family per year could reach 23 thousand reais (US$ 4372.62), only by selling fresh fruits, while the minimum wage per year is below fifteen thousand reais (US$ 2851.71).

DISCUSSION

The sustainable use of NTFP can contribute to biodiversity conservation, preserve ecological interactions, and provide economic income for rural communities. Our findings highlight the significance of NTFP, particularly fruit gathering, as an economic activity for rural populations in Central Brazil. The NTFP harvesting is effectively sustainable if the plant parts collected are fruits or seeds, the species is resilient, has a wide distribution range, high reproduction rates, and is used predominantly in local markets (Hall and Bawa 1993, Ticktin and Shackleton 2011). Accomplishing all the requirements the evaluated fruits have the potential to promote the sustainable use of NTFP in Legal Reserves, establishing a synergistic relationship between biodiversity conservation and the socioeconomic development of local communities.

In the Cerrado, the use of non-timber products stands out over woody products. The usage of native plants is an important strategy to promote both, food security and biodiversity conservation (de Boef *et al.* 2012), unlike the establishment of monocultures (Negi *et al.* 2011). It is an important alternative for food production, for the inclusion of native species in the human diet, and for-profit increase for the families in the rural areas. This mechanism also helps the Legal Reserve maintenance, tackle climate change, and rural communities fighting poverty (Bortolotto *et al.* 2017).

A conceptual model for sustainable use planning of Legal Reserves

Using a case study, we brought a conceptual model (Fig. 3) for the sustainable utilization of NTFPs in Legal Reserves within the Cerrado biome. This framework provides a systematic approach that includes understanding the species with potential for exploration, productivity seasonality, gross revenue estimative, and perspectives for adding monetary value for the NTFP.

The framework starts with the identification of the landowners' primary aspirations, which guides ecological studies. In this case, we used the development plan of the Esperança Association (EMATER 2013). The document

Table 3. Selected models to predict the fruit production based on the morphometric characters of the species sampled in a phenological study at the *Pequeno William* Agroecological Settlement in the Cerrado biome, Brasília, Brazil.

Species	Best model	F	R^2	p-value	Equation
Annona crassiflora	productivity ~ 1	-	-	-	-
Eugenia dysenterica	productivity ~ number of branches	1.892	0.24	0.218	-
Caryocar brasiliense	productivity ~ canopy diameter	10.46	0.64	**0.018**	Y = 2.5 X -78

points out the affinity of the families with fruit commercial activities. Subsequently, ecological studies are conducted to identify the potential NTFPs available in the area. In our study case, we used the forest inventory conducted by Silva (2017). Ideally, the vegetation must be long-term monitored to detect population fluctuations, mortality, or another threat. The third step is the productivity estimative of the focal NTFP. Through field monitoring, we provided the first estimative of fruit production of the three focal species in the PWAS. The gross revenue estimative is the fourth step in our framework. It provides crucial information for feasibility studies. To determine the gross revenue, we assessed local market prices and the total of fruits estimative, which enabled the calculation of gross revenue per hectare per year. For the landowners, it is crucial to predict the seasonality of the income. As our focal NTFP are fruits, we monitored selected trees to access fruits seasonality. By integrating gross revenue with a phenological calendar, landowners can anticipate the temporal distribution of income derived from NTFPs.

The final step proposed in this framework is strategic planning, which encompasses the evaluation of various scenarios using tools such as SWOT and economic feasibility analysis. In this sense, our study was limited in suggesting strategies for enhancing the value aggregation of non-timber production, aiming to maximize economic benefits. However, strategic planning is an extensive and participatory process that must be led by the landowners. In its turn, the strategic plan can include amelioration in aspects of production processes, suggestions of new NTFP products to be evaluated, and strategies for increasing production. The new aims will reevaluate the ecological studies goals, restarting the framework.

Gross revenue seasonality

Considering the NTFP, fruit production has the potential to increase the revenue to the families in the PWAS. The higher potential income is of *A. crassiflora*. However, all the fruits observed in our study had boring insects and were not suitable for consumption, representing a loss of R$ 2688.00 (US$ 511.03) per hectare. The fruits are often attacked by the fungi *Cercospora annonifolii* (Almeida *et al.* 1998) and insects, mostly by *Bephratelloides pomorum* (Hymenoptera-Eurytomidae) and *Cerconota anonella* (Lepidoptera-Oecophoridae) (Braga-Filho *et al.* 2007).

Table 4. Estimated fruit production and gross revenue of the extrapolated value of fruit per hectare in the Legal Reserve of the *Pequeno William* Agroecological Settlement in the Cerrado biome, Brasília, Brazil. The values of the fruits were obtained in local markets.

Species	The average number of fruits per tree	Species density (n/ha)	Estimative of fruits per hectare	Loss (20 %) and fauna reserve (20 %)	Total of fruits available	Fruit average weight (kg)	Estimated production (kg/ha)	Price in local currency per kilo (real)	The potential income per hectare in local currency
Annona crassiflora	4	112	448	179	269	1	269	R$10.00	R$2,688
Caryocar brasiliense	161	33	5313	2125	3188	0.027	86	R$10.00	R$861
Eugenia dysenterica	340	17	5780	2312	3468	0.021	73	R$15.00	R$1,092
							Total per hectare		**R$4,641**

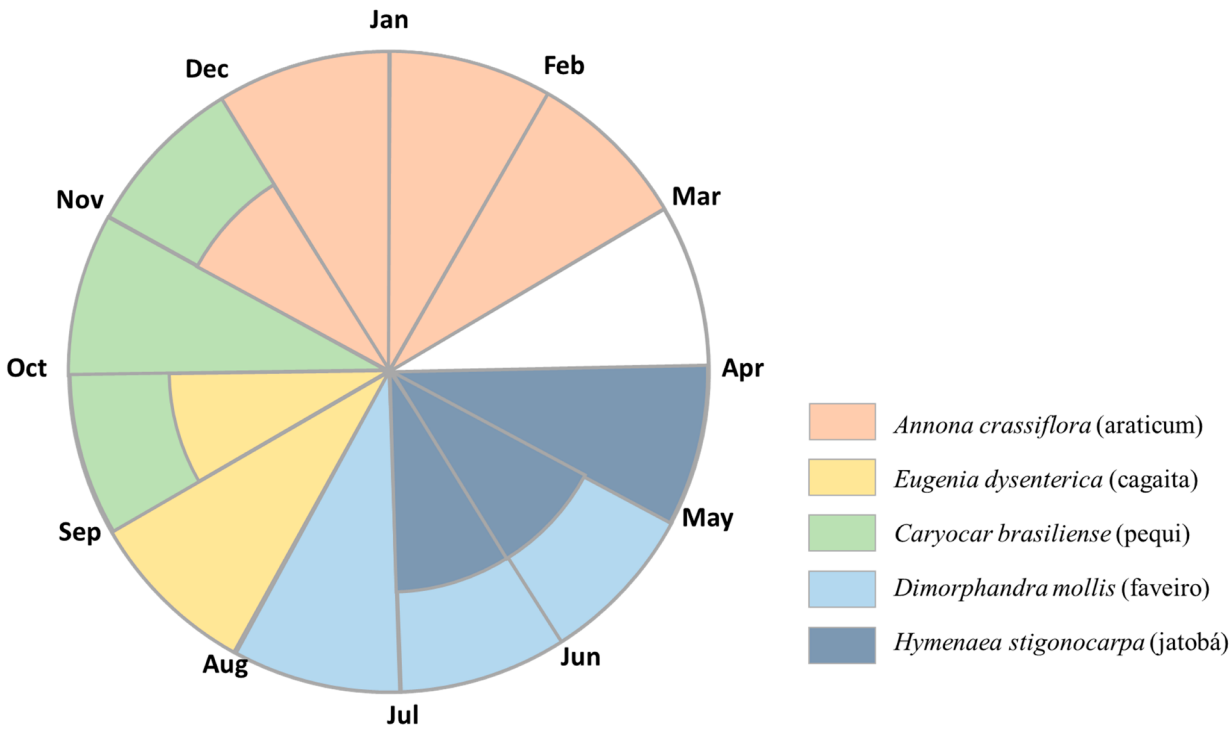

Figure 2. Fruit calendar considering the phenological studies conducted in the Pequeno William Agroecological Settlement (***Annona crassiflora***, ***Eugenia dysenterica***, and ***Caryocar brasiliense***) including two suggested focal species (***Dimorphandra mollis*** and ***Hymenaea stigonocarpa***) with fruiting season estimated in the literature.

We included the values of *A. crassiflora*, even if all the fruits were debilitated because we are interested in quantifying the potential revenue per hectare. Sanitary control is essential for insurance the families' provision.

Eugenia dysenterica maturity started in September as described in the literature (Silva-Júnior 2012), which is the early rainy season. However, in the current year, the rain was delayed, starting in November. The mismatch between climate patterns and biological activities may lead to lower fruit productivity (Beard *et al.* 2019). In this case, the extremely perishable seeds may not find ideal conditions for germination during dry months, compromising natural regeneration. In tropical regions, local populations manage the agricultural and natural areas to increase the number and density of useful species, especially those with cultural and economic relevance (González-insuasti and Caballero 2007, Pinedo-Vasquez and Sears 2010). *Eugenia dysenterica* provides important income, which potentially can be increased by enrichment planting and population monitoring. The enrichment of the Legal Reserve by planting focal species increases the success chance of sustainable development, not compromising the regeneration of the exploited species (Arnold and Ruiz 2001, Felfili et al. 2004, Ticktin and Shackleton 2011).

We observed high productivity of *C. brasiliense* and *E. dysenterica*, which is extremely important for the families in the settlement. The productivity of *C. brasiliense* is higher than recorded in the literature for the same region (Fagundes 2017) but lower than in Paraopebas, Minas Gerais, where the fruit productivity was from 23 % to 84 % higher (Pinto *et al.* 2019). *Cariocar brasiliense* showed a narrow flowering phase (August to October) than indicated in the literature (July to January) (Almeida *et al.* 1998). Phenological fluctuation can be related to climate change (Vitasse *et al.* 2022), water availability, or natural oscillation, which can lead to population-level consequences (Iler *et al.* 2021), threatening the families' income. We also could estimate the number of fruits of *C. brasiliense* using the canopy diameter, which can be useful to evaluate the potential of each allotment. Beyond the canopy diameter, soil parameters, radiation, and competition are also important to explain *C. brasiliense* productivity (Bruzinga 2017), the most important NTFP resource in the Cerrado biome (Giroldo and Scariot 2015).

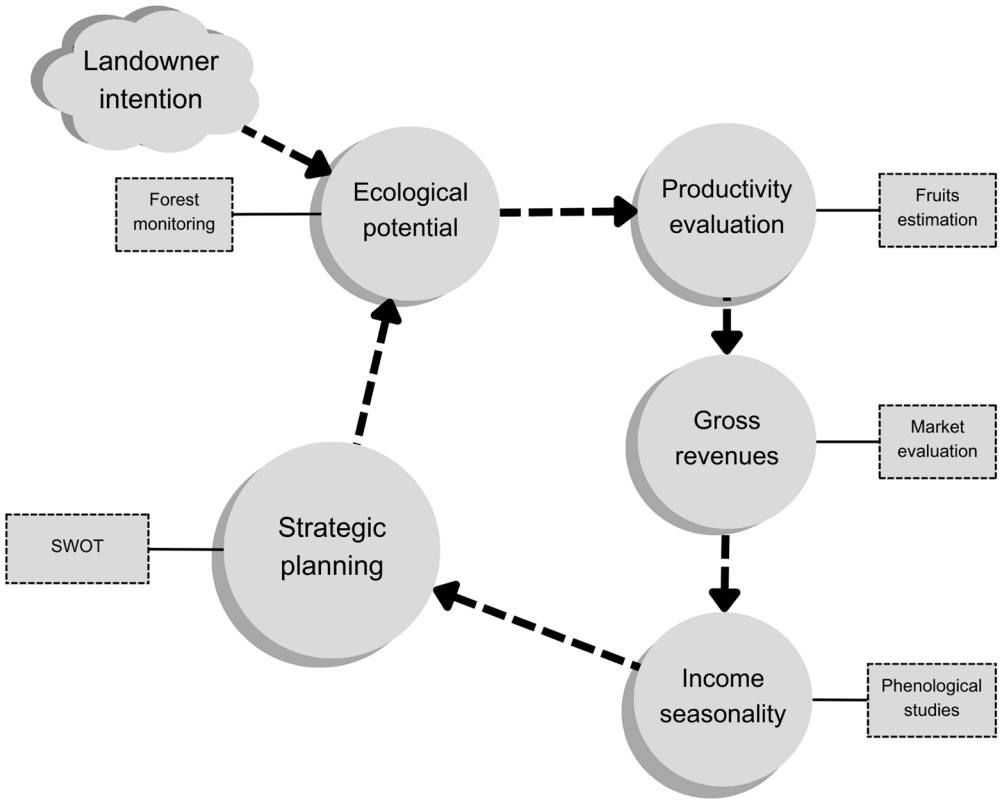

Figure 3. Schematic diagram showing the five-steps conceptual model proposed for sustainable use of Legal Reserves.

Increasing the production

We propose a phenological calendar (Fig. 2) allowing the families to carry out the harvesting planning and organize production activities throughout the year. An iconic example of a synergetic experience between the natural processes and planning is the activity of the indigenous community in the Alto Xingu region. They use the knowledge about the phenological cycles to plan all other tasks related to the commercialization of *C. Brasiliense* fruits, seeds, and oil, in addition to the crops and household duties (Villas-Bôas *et al.* 2017). Beyond helping the activity planning, the phenological calendar also allows the predictability of income throughout the year.

The main species for the NTFP in the PWAS community is ripe from September to April. The results show that the selected tree species exhibit distinct seasonality patterns, with little overlap in their fruiting periods. This finding suggests that by diversifying fruit tree species within Legal Reserves, it is possible to maintain a more continuous supply of fruits throughout the year, increasing the economic potential for local communities. Also, the likelihood of achieving ecological and economic sustainability increases if there is diversification, granting independence to an exclusive product (Belcher and Schreckenberg 2007).

We suggest, for example, *Dimorphandra mollis* (faveiro) to be included in the families' calendar to diversify the production. It is the 28th species in VI, fruits from May to August (Filizola 2013), and it is used in the cosmetic industry (Caldeiras-Júnior *et al.* 2008). A second species herein suggested is the *Hymenaea stigonocarpa* (jatobá), the 32nd in VI, producing from April to July (Almeida *et al.* 1998). The dry pulp extracted from the fruit is used as flour in the regional food industry (Silva *et al.* 1998) and can be used for making bread and cakes. Both species could be planted in the allotments to increase production. However, the diversification of NTFP requires information on species values and broad planning to promote their sustainable use and commercialization (Bottazzi *et al.* 2014).

Currently, the local families sell the fruits *in natura*. However, the simple processing of the fruits could increase the gross revenue by 340 %. We estimated the profit of jam production for the three studied species. It is relevant to highlight that for jam production it would be necessary

Table 5. Estimated gross revenue per hectare considering simple processing of the fruits in the Legal Reserve of the *Pequeno William* Agroecological Settlement in the Cerrado biome, Brasília, Brazil. The product values were obtained in online shops, local markets, and independent farms.

Species	Product	Estimated production (kg/ha)	Percentage of the fruit used in each product	Estimated pulp/nut weigh (kg/ha)	Price in local currency (R$/Kg)	The potential income per hectare in local currency
Annona crassiflora	jam	269	45.9 %	123.4	R$90.00	R$11,104
Caryocar brasiliense	jam	86	8.5 %	7.3	R$133.30	R$979
	nut	86	2.2 %	1.9	R$69.90	R$132
Eugenia dysenterica	jam	73	80.0 %	58.3	R$142.00	R$8,273
					Total per hectare	**R$20,488**

the establishment of a small agroindustry, including basic inputs and legal arrangements. *Cariocar brasiliense* has great potential for processed products in the local markets, especially jam, which is produced most out of the Distrito Federal (Cunha 2014), although its consumption is locally common. Besides jam, nuts (also included in our estimative), oils, butter, and other products can be extracted from *C. brasiliense* (Carrazza and Ávila 2010). The processing of the fruits is important to aggregate the value of the products, expand the commercialization for other localities, and increase the availability, allowing the sale throughout the year.

If the families invest in fruit processing, the gross revenue could reach 100 thousand reais per year, considering the available area for fruit gathering. However, these values may be taken with caution, despite giving a clue about the importance of processing the NTFP before commercialization. Thus, we call attention to some aspects. It is essential to proceed with economic feasibility analysis, calculating the net present value, the internal rate of return, the benefit-cost ratio, and the equivalent annual cost (Costa *et al.* 2016). The analyses must combine different products presented herein, both fresh and processed fruits, and include the costs with the implantation of agroindustry, transportation, and basic inputs. The agroindustry planning must attend to the environmental and sanitary policy (Nascimento *et al.* 2012) and the benefit-sharing according to the Law on Genetic Heritage and Associated Traditional Knowledge (Brasil 2015). Despite the benefits of moving from subsistence to commercialization, it is a complex process (Ingram 2009) that needs to be extremely well-planned.

Study limitations and recommendations

Despite the importance of understanding the seasonality and the productive potential, we estimated the gross revenue using fruit size and weight data from the literature. Ideally, the calculation should consider the fruits in the same site to avoid misestimates because the biometric parameters may differ among communities (Silva and Scariot 2013). Measurements of fruit in loco are important to adjust the estimated revenue values.

Fruit productivity also may differ from allotments since the species are not evenly distributed on the landscape. In the PWAS they face an extra challenge because people out of the community collect the fruits opportunistically as there are no fences or control at the entrance of the settlement. Eventually, the families can face a decrease in income due to external collectors.

To improve and ensure security in the NTFP usage, we recommend the community makes systematic notes on phenological phases and the harvest over time. These annotations may indicate no-annual seasonal patterns with multi-annual fluctuations in fruit production (Melaas *et al.* 2018) and changes in phenological periods according to climatic conditions.

We presented the potential income of *A. crassiflora*. Using our results, the community can decide if it is worth investing in the phytosanitary control of *A. crassiflora*. As a preliminary control, we recommend covering the fruits with protection bags as soon as the flowers are pollinated. Once the fruit of *A. crassiflora* ripes, it must be collected from the tree to avoid contact with the soil microorganisms in eventual falling. *Eugenia dysenterica* requires immediate

cooler conditioning because it is very perishable (Scariot and Ribeiro 2015). Both *A. crassiflora* and *E. dysenterica* demand investments for species propagation. It is also necessary to diversify the use of NTFP.

CONCLUSIONS

The manuscript sheds light on the economic potential of NTFP in Legal Reserves, specifically fruit production in the Brazilian Cerrado biome. The findings contribute to the understanding of the economic benefits of NTFP and provide valuable insights for policymakers, landowners, and local communities interested in sustainable land use and rural development.

Our study demonstrates a considerable economic potential for the sustainable use of Legal Reserves in the Cerrado biome and encourages sustainable practices. The profitability derived from the sustainable use of NTFPs underscores the importance of preserving native vegetation, thereby aiding in the maintenance of the region's original vegetation cover.

Our observations revealed a pronounced seasonality in the fruiting patterns of the studied species, with minimal overlap in their harvest seasons. This characteristic offers the opportunity for year-round utilization of these resources. Consequently, it becomes feasible to coordinate the gathering, preparation, and sale of various species, fostering continuous economic activity and complementing other community-based endeavors. Additionally, possessing knowledge about the timing and quantity of fruit production facilitates the establishment of commercial contracts with industries and local shops. Further research and studies are needed to explore the economic potential of other NTFP and their role in promoting sustainable livelihoods and biodiversity conservation.

By implementing the framework outlined in this study, landowners and stakeholders can effectively manage NTFPs in Legal Reserves within the Cerrado biome. This approach ensures the adoption of sustainable practices while maximizing socio-economic benefits. Furthermore, the framework contributes to the conservation of the region's unique ecological characteristics, fostering the long-term viability of the Cerrado biome.

AUTHORS CONTRIBUTIONS

MLB: Investigation, Conceptualization, Resources provision, Data Curation, Writing - Original Draft. CQB: Investigation, Data Curation, Writing - Review & Editing. RDF: Conceptualization, Methodology Design, Formal analysis, Resources provision, Writing - Original Draft, Writing - Review & Editing, Supervision.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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