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The use of indices and indicators for the conservation of palms in the Amazon, considering global climate change

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ABSTRACT: To identify which species within a group of palm species are most at risk of survival, it is necessary to analyse numerous variables, which must be assessed together. For this, we can use indices and indicators. The objective of this study was to develop indicators and indices to assess the risk of reduction of natural areas (ARI) suitable for the following species: *Euterpe oleracea* Mart.; *Euterpe precatoria* Mart.; *Astrocaryum aculeatum* Mart.; and *Astrocaryum acaule* Mart. The ARI was composed of four variables (indices or indicators): climate threat index (CTI), exposure index (EI), vulnerability index (VI), and demand indicator (DI). Applying these indices to these palms, it was found that the palm with the highest risk of area reduction (ARI) was *A. aculeatum*, while *E. oleracea* had the lowest risk value. The species *A. acaule* and *E. precatoria* had intermediate values. The high risk associated with *A. aculeatum* is mainly due to the greater reduction of favourable areas in future scenarios, as well as the dormancy of its seeds and the low demand for cultivation. The use of this index proved to be quite reliable, easy to understand and apply.
Keywords: comparative indices; species conservation; future climatic scenarios.

O uso de índices e indicadores para a conservação de palmeiras na Amazônia, considerando as mudanças climáticas globais

RESUMO: Para identificar quais espécies dentro de um grupo de espécies de palmeiras estão em maior risco de sobrevivência, é necessário analisar várias variáveis, que devem ser avaliadas em conjunto. Para isso, podemos usar índices e indicadores. O objetivo deste estudo foi desenvolver indicadores e índices para avaliar o risco de redução de áreas naturais (ARI) adequadas para as seguintes espécies: *Euterpe oleracea* Mart.; *Euterpe precatoria* Mart.; *Astrocaryum aculeatum* Mart.; e *Astrocaryum acaule* Mart. O ARI foi composto por quatro variáveis (índices ou indicadores): indicador de ameaça climática (CTI), índice de exposição (EI), índice de vulnerabilidade (VI) e indicador de demanda (DI). Ao aplicar esses índices a essas palmeiras, verificou-se que a palmeira com maior risco de redução de área (ARI) foi *A. aculeatum*, enquanto *E. oleracea* apresentou o menor valor de risco. As espécies *A. acaule* e *E. precatoria* apresentaram valores intermediários. O alto risco associado a *A. aculeatum* está principalmente relacionado à maior redução de áreas favoráveis em cenários futuros, bem como à dormência de suas sementes e à baixa demanda por cultivo. O uso desse índice mostrou-se bastante confiável, fácil de entender e aplicar.
Palavras-chave: índices comparativos; conservação de espécies; cenários climáticos futuros.

1. INTRODUCTION

Climate change primarily results from the burning of fossil fuels and the emission of greenhouse gases (GHGs) into the atmosphere, stemming from both natural and anthropogenic activities (CHAUDHRY; SIDHU, 2022). In Brazil, land-use changes are the main contributors to greenhouse gas emissions into the atmosphere. These changes are also reflected in the increased frequency of extreme weather events, such as droughts, floods, heatwaves, cold spells, and more intense frosts, among others. The impacts of extreme weather events can be severe and pose significant risks to agriculture, ecosystems, and human health (LU et al., 2023), as well as to animal health, causing irreversible losses to ecosystems, leaving them, in many cases, close to the point of no return (IPCC, 2023). Consequently, the growth, development, and productivity of plants will be directly affected. as temperatures above ideal ranges cause thermal stress and interfere with physiological events such as flowering and fruiting, as well as the life cycle and incidence of fungi, bacteria, and insects, potentially lead to the death of plant species (JANNI et al., 2024).

The Amazon is suffering from the consequences of climate change. During the 2015–16 drought in the region, there was a sharp decline in rainfall, leading to a progressive lengthening of the dry season and a reduction in the duration of the rainy season (ALVES et al., 2017). This lengthening, along with changes in the frequency and intensity of drought events, is likely the most critical factor for the Amazon in the context of climate change (GATTI et al., 2014).

Among the main groups of native plants in the Amazon that will be affected by climate change are palms and fruit species widely used in agroforestry systems, which have great potential for expansion of their cultivation. They generate income for producers and can be used for various purposes: food, construction, the making of household items and ornaments, as well as medicinal, cosmetic, and other applications (CORDEIRO et al., 2023; MARQUES et al., 2024).

The four palm species discussed in this study belong to the Arecaceae family. *Astrocaryum aculeatum* Mart. (tucumã-do-Amazonas) and *Astrocaryum acaule* Mart. (tucumã-í) have ecological and extractivist importance in the Amazon (CORDEIRO et al., 2023). *Euterpe oleracea* Mart. (Açaí-do-Pará) and *Euterpe precatoria* (Açaí-do-Amazonas) are considered native fruit species from the northern region and the phytogeographic domain of the Amazon. They have recognized social, commercial, and environmental importance (LAURINDO et al., 2023; SILVA et al., 2023).

Recently, these species have garnered increased attention due to their status as "superfoods," as their fruits are rich in various bioactive compounds that are beneficial to human health. As a result, the export of these products has increased significantly, as has their commercialization in non-extractive Brazilian states (LAURINDO et al., 2023; MARQUES et al., 2024).

The conservation of these species depends on the level of threat they currently face due to deforestation and the use of fire, as well as in the future, due to climate change in the areas where they have been adapted for thousands of years. The comparative and hierarchical assessment of the threats these four species face now and, in the future, can be conducted using indices and indicators.

Indicators are used in various fields, including social, economic, financial, health, and environmental areas. Indices and indicators are essential for the continuous monitoring of ecosystem health. By measuring variables such as biodiversity, water and soil quality, and pollution levels, it is possible to identify changes and trends over time. Indices and indicators help define clear goals, making it possible to assess the environmental conditions of a specific area based on partial information that reflects the state of broader ecosystems (MANOLIADIS, 2002).

The collection of data based on indicators and indices provides quantitative evidence that supports policy decisions and environmental management practices. The data obtained serves as a foundation for the development of public policies and for fulfilling international conservation agreements, such as the goals of the Convention on Biological Diversity (CBD). Ensuring that indicators reliably detect the status of biodiversity is crucial, as they inform policies and management practices.

Although indices and indicators are often used synonymously, they have a distinction. Indices are numerical representations of a set of values that express and quantify a given object or situation through data from indicators (GONÇALVES et al., 2021). Thus, indicators are simpler than indices. However, they also technically support political decisions involving biodiversity and decipher the complexity of data, variables, and other factors, serving as useful communication tools (IPBES, 2018). Indicators can be either quantitative or qualitative and are used to organize and capture relevant information from the elements that make up the object of observation.

The development of indices and indicators is similar to multicriteria analysis methods (MAM), as many variables, both quantitative and qualitative, of different natures are used, and weights are assigned to them according to predefined relevance criteria (PIMENTA, 2019). In this process, the problem to be solved and the attributes to be considered are defined, and then quantifiers are inserted that allow the structuring of decision-makers' preferences (DROBNE; LISEC, 2009). Thus, a hierarchy is created in which, to facilitate decision-making, those with the greatest weight and significance are prioritized (FRANCO et al., 2013).

Among the most widely used multicriteria analysis methods globally, the Analytic Hierarchy Process (AHP) was developed to solve choice (option) problems and applies to various situations involving complex structures. The AHP method has been used in spatial location problems, as well as in land suitability analyses. In this approach, attributes are managed and processed within a Geographic Information System (GIS), where vector or raster data converge to produce a final map (or product) that highlights the strengths or weaknesses, serving as the basis for solving the problem (SAATY, 1990; 2005).

Indices and indicators were developed to assess the risk of reduction of the favourable niche for species, both in the present and in future climate scenarios. More specifically, when employed, they can be valuable analytical tools to aid in understanding the risks to which each is exposed and provide support in formulating public policies aimed at preventing the extinction of these species.

The objective of this study was to develop indicators and indices to assess the risk of reducing the natural areas suitable for the species *Euterpe oleracea* Mart.; *Euterpe precatoria* Mart.; *Astrocaryum aculeatum* Mart.; and *Astrocaryum acaule* Mart. They were utilized comparatively within the phytogeographic domain of the Amazon. Correspondingly, the methodology developed and applied in this study can be improved and adapted to analyze other species and in other locations.

The scope of this study encompasses several elements of Brazil's Sustainable Development Goals (SDGs), which were aligned with the United Nations. Components include integrating measures and information from indices and indicators, as well as strategies and planning, to inform public policy. Other methods also include promoting education through the publication of scientific articles and raising awareness about global climate change (SDGs BRAZIL, 2024). These studies, like ours, assess the threat to conservation and the occurrence of species in the face of global climate change, aligning with SDG No. 13, which seeks to adopt urgent measures to combat climate change and its impacts (SDGs BRAZIL, 2024).

2. MATERIALS AND METHODS

2.1. The species

A. aculeatum is a monopodial, tree-like species with an erect and solitary stem, which can reach heights of 10 to 25 meters. The stem has an average diameter of 12 to 40 cm, covered with black spines that can grow up to 15 cm long, thin, long, and sharp, arranged in rings along the trunk (MOURA, 2024). Its fruits have attractive sensory and nutritional characteristics and are used in Amazonian cuisine. In addition to being succulent and rich in bioactive compounds, the most consumed part is the pulp; however, its core also has uses and is widely employed in local crafts (KIELING et al., 2023; CARVALHO et al., 2024). This palm species is found in areas with less dense forest formations, clearings, savannas, abandoned pastures, and along roadsides, demonstrating high tolerance to degraded soils. The density inside the forest is low, and the species is often found near human settlements, following human occupation (JARDIM BOTANICO DO RIO DE JANEIRO, 2017). The palm tree does not propagate vegetatively, and in the absence of a seed dormancy break, germination can take up to two years, which is likely the main factor limiting its cultivation (FERREIRA; GENTIL, 2006).

The tucumã-í (*Astrocaryum acaule*) produces smaller fruits compared to *A. aculeatum*, and although they are edible, their seeds are predominantly used in the production of bio-jewelry. Its economic potential lies in its leaves, which are used for fiber extraction to produce natural textiles in the Amazon region (LIMA et al., 2020). Additionally, its fruits are consumed by traditional Amazonian populations (HENDERSON et al., 1995) and used as bait for fishing (KAHN; MILLÁN, 1992), being highly appreciated by wildlife in general. The species has an underground stem, which facilitates fruit collection, as the leaves sprout directly from the soil and the peduncle of the spadix, which grows between the leaves that support the fruits (WALLACE, 2014). The stem is solitary, rarely exceeding 1 meter in height, and has 5 to 9 leaves per individual. Propagation also occurs by seeds, and under favorable conditions, the species spreads abundantly, although it is uncommon in primary forests where no disturbances have occurred (HENDERSON et al., 1995).

In general, tucumã-í is found in flooded forests along riverbanks and igarapés, as well as along the margins of streams on moist, sandy soils (KUCHMEISTER et al., 1998). Due to its importance, this species has become the target of extractive practices, especially in secondary forests.

E. oleracea is a palm with a clustered stem, forming large clumps in the adult phase, which can reach up to 45 stems in different stages of growth. The stem is smooth, cylindrical, ringed, erect, sometimes curved, fibrous, and unbranched, reaching heights of up to 30 meters with a diameter of 12 to 18 cm. Along the stem, scars left by the leaves are visible as they senesce and fall, forming nodes and internodes (HENDERSON et al., 1995). This palm is dominant in floodplain forests, where it forms dense concentrations in flooded areas (várzea and igapó), igarapés, and low-lying land, having mechanisms to survive in soils with low oxygen content (QUEIROZ; MOCHIUTTI, 2001). It does not exhibit seed dormancy, and regeneration occurs from a seedling bank. The species tolerates shading only in the juvenile stage. Fruit dispersal is carried out over short distances by small animals and long distances by birds (CYMERYS; SHANLEY, 2005). There are two propagation strategies for *E. oleracea*: sexual (through seeds) and asexual (through tillers). Sexual propagation is the most viable method, as a plant can produce about 6,000 seeds per harvest, enough to plant twelve hectares with a 5 m x 5 m spacing. Asexual propagation, through the removal of tillers, is not applied on a commercial scale due to the low multiplication rate and high labor intensity, resulting in production costs for seedlings that are two to three times higher than those obtained from seeds (NASCIMENTO et al., 2011). The seeds exhibit recalcitrant behavior, characterized by a relatively fast but uneven germination process, with seedling emergence occurring 22 days after sowing (CARVALHO et al., 2024).

E. precatoria is a solitary-stemmed palm that can reach heights from three to 23 meters and diameters from four to 23 cm, rarely exhibiting clumping growth. Its heart of palm is thin and smooth at the top, with a cone of visible roots. The leaves have flat pinnae, ranging from 1 to 3 cm in width, and can be pendulous or horizontal. The fruits are globose, purple-black when ripe, with a lateral stigmatic residue, and the seeds have a homogeneous endosperm (LORENZI et al., 2004). The precatoria variety is the most common, characterized by a solitary stem, leaves with narrow pinnae that can be occasionally pendulous, green sheaths or green with vertical yellow stripes, and large inflorescences with thicker rachises. The fruits of this variety measure between 1 and 1.3 cm in diameter. The longivaginata variety, on the other hand, has a grayish stem that can be either solitary or clumping; its leaves have wider pinnae and are less pendulous or arranged horizontally. The inflorescences are smaller, with thinner rachises, and the fruits measure from 0.9 to 1.0 cm in diameter (HENDERSON; GALEANO, 1996; LORENZI et al., 2004). The single açaí is of great economic and social importance for extractive communities. Reproduction also occurs through seeds, as in *E. oleracea*.

2.2. Indices and Indicators

The indices and indicators used in this study were conceptually adapted from those present in the Climate Change Impacts Information and Analysis System (AdaptaBrasil). In this system, to assess climate impact risk, the following factors are considered: i) climate threat, ii) vulnerability, and iii) exposure (IPCC, 2021).

In this study, the climate impact risk proposed in AdaptaBrasil was replaced by "area reduction risk." In addition to the three components mentioned, the demand indicator (DI) was added. Thus, the area reduction index (ARI) was composed of four variables (indices or indicators): the climate threat index (CTI), the exposure index (EI), the vulnerability index (VI), and the demand indicator (DI).

Each variable, representing an index or indicator, was transformed into a weight according to a pre-established criterion established by experts in the respective fields, ensuring consistency in the values. In this regard, the characteristics that presented a greater impact or represented a significant threat to the species' existence were assigned lower weights. After this assignment, the variables were multiplied by each other, according to the following equation:

$$ARI=CTI*EI*VI*DI \quad (01)$$

The following provides an explanation of the indices and indicators, including their derivation and application in this study.

2.3. Exposure Index (EI)

The concept of this index is related to the environment in which the species are found, considering whether they are close to or integrated into more anthropized systems, where they are more threatened. This includes roads and highways, urbanized areas, agricultural zones, pasturelands, mining areas, hydroelectric facilities, and other designated areas. In contrast, species located in natural areas, such as forests, tend to inhabit less threatened environments.

This index, like the previous one, was obtained on the platform of a GIS and was based on the ecological niche distribution area for each species. In these areas, the road network and land use and cover were delineated. Information about the road networks was obtained from the DNITGeo data viewer (VGeo, 2024), while data on land use and cover were extracted from the MapBiomas project. MapBiomas uses computational tools and maps of vegetation cover and land use, with gradual improvements in methods and classification levels. The strategy to consolidate advancements involves periodically making the products available in the form of geospatial data collections, each accompanied by documentation on their characteristics, accuracy, potential uses, and limitations (UFRGS, 2024). This information, in the form of layers, was entered into Google Earth Engine. This cloud-based geospatial analysis platform enables users to view and analyze satellite images, quantifying the typologies present in the area (SOUZA JÚNIOR et al., 2020).

After quantifying the typologies for the current ecological niche distribution areas of the species, they were grouped into five impact classes. Natural areas (lakes, dunes, rivers, and rock outcrops) were grouped with natural forests; reforestation areas were associated with perennial crop areas; urbanized areas (cities and residential nuclei) were grouped with roads; agricultural areas were grouped with pastures; and lastly, mining areas.

Each of these groups was assigned a weight, with the lower the weight value, the higher the exposure (system with greater anthropization). The area (in percentage) occupied by each typology was also considered, and weights were assigned based on the combination of land use and cover typologies, as well as the percentage of occupation of these groups. These values were multiplied together.

Thus, more protected and less anthropized areas, such as natural forests, received a weight of 1. In contrast, more exposed areas, such as urbanized areas, pastures, or mining areas, received a weight of 0.10, while reforestation and perennial crop areas were given intermediate weights (Table 1). This approach followed the coherence of the scores from the previous indicator (CTI).

Table 1. Weights assigned to land use and cover typology groups based on the percentage of occupation for the current niche areas of the *Euterpe* and *Astrocaryum* species.
Tabela 1. Pesos atribuídos aos grupos de tipologia de uso e cobertura da terra com base na porcentagem de ocupação das áreas de nicho atuais das espécies de *Euterpe* e *Astrocaryum*.

	Occupation of Typologies in the Species' Current Niche Area (%)				
	0-20	20-40	40-60	60-80	80-100
Forested and Natural Areas	0.1	0.25	0.5	0.75	1
Reforestation and Perennial Crops	0.8	0.6	0.4	0.2	0.1
Urbanized Areas and Roads	1	0.75	0.5	0.25	0.1
Agricultural Areas (Annual Crops) and Pastures	1	0.75	0.5	0.25	0.1
Mining Areas	1	0.75	0.5	0.25	0.1

2.4. Vulnerability Index (VI)

The vulnerability index (VI) refers to the intrinsic characteristics of a species or its environment that make it more susceptible to changes, particularly those resulting from climate change or anthropogenic impacts. It encompasses various factors that can influence a species' ability to withstand or adapt to changes, such as biological traits, habitat requirements, and sensitivity to environmental disturbances.

For instance, species with narrow ecological niches, low reproductive rates, or high dependence on specific habitats (e.g., forest types or water bodies) tend to have higher vulnerability (Table 2). In contrast, species with broad ecological niches, high reproductive capacity, or the ability to adapt to different environments are generally less vulnerable.

In this context, VI is a crucial component in determining the risk of species reduction, especially when combined with other indices and indicators, such as climate threat (CTI) and exposure (EI). By evaluating the vulnerability of species, we can gain a deeper understanding of their resilience in the face of challenges such as climate change, habitat loss, and other environmental threats.

2.5. Demand indicator (DI)

This index was selected due to the differences in demand, particularly for the fruits of the palm trees. The logical explanation is as follows: the greater the demand, the greater the interest in preserving the palm trees in natural systems or even in reproducing them in productive systems. Therefore, weights were assigned to demand, which can be classified as low (0.25), medium (0.5), and high (1.0).

Thus, for palm species with greater interest in their products, the weight would be 1.0; for those with lower interest, the weight would be 0.25; and for those with intermediate interest, the weight would be 0.5.

Table 2. Weights assigned to vulnerability characteristics.
Tabela 2. Pesos atribuídos às características de vulnerabilidade.

Characteristics	Low	Medium	High
Number of stems	0.25		1.0
Propagation (seeds or offshoots)	0.25		1.0
Adaptation to different environments	0.25	0.5	1.0

3. RESULTS

3.1. Climate Threat Indicator (CTI)

The creation of indices is similar to a stochastic process, as it involves the interactive combination of variables that exhibit a specific dynamic over a given period. In a stochastic process, the variables may be entirely different but must coexist within the same space. Similarly, in the formula for the Area Reduction Risk Index (RRA), a combination of independent variables (indices) interacts, resulting in a quantitative value. This value can be compared to others obtained in the same manner (using the same formula) and within the same period, but for different species. The result of the Climate Threat Indicator (CTI) for the species considered can be seen in the table below (Table 3).

Thus, all four species will experience a reduction in area; however, the species most threatened by climate change is *A. aculeatum* (CTI of 0.01). The two species of the Euterpe genus are the least threatened, with IAC values ranging between 0.81 and 0.82, while *A. acaule* has a CTI of 0.68, placing it in an intermediate position.

3.2. Exposure index (EI)

Regarding the exposure index (EI), when applying the previously established values (Table 1), no significant differences were found between the species. Additionally, the largest percentages of land use and land cover types in the areas of current ecological niche distribution for the species were composed of natural forests (between 80 and 89%) and short-cycle agricultural areas and pastures (11 to 19%) (Table 4).

3.3. Vulnerability Index (IV)

The results of the Vulnerability Index are presented below (Table 5). It is observed that *E. oleracea* is the least vulnerable species based on the analyzed characteristics, while *A. aculeatum* is the most vulnerable, followed by *A. acaule* and *E. precatoria*. Thus, it can be understood that, due to the development of adaptive evolutionary mechanisms, *E. oleracea* exhibits greater adaptive plasticity compared to the other species.

3.4. Demand Indicator (DI)

Of the four studied, *E. oleracea* is the species with the highest extractive demand, thus generating the most interest among populations for its cultivation and propagation (Table 6). Moreover, there is a demand for the export of its fruits. The other species, in turn, can be important in local or regional markets.

3.5. Area reductions index (ARI)

The results of applying the Area Reduction Index (ARI) for the four risk indices/indicators are shown below (Table 7).

Table 3. Niche Distribution (km²) and Climate Threat Indicator (CTI) considering the most pessimistic scenario for the species of *Euterpe* and *Astrocaryum* in the Amazon biome.
Tabela 3. Distribuição de Nicho (km²) e Indicador de Ameaça Climática (IAC) considerando o cenário mais pessimista para as espécies de *Euterpe* e *Astrocaryum* no bioma Amazônico

Species	Current Niche (km²)	Niche in Future Scenario (km²)	Area Change (%)	CTI
E. precatoria	3,309,481.7	2,701,197.6*	-18.38	0.82
E. oleracea	3,705,476.7	3,010,012.9*	-18.77	0.81
A. acaule	3,516,371.5	2,379,608.5**	-32.33	0.68
A. aculeatum	4,029,337.7	20,271.7**	-99.5	0.01

*SSP 585 (MARQUES et al., 2024); *RCP 8.5 (CORDEIRO et al., 2023).

Table 4. Exposure Index (EI) for the palm species *Euterpe* and *Astrocaryum*.
Tabela 4. Índice de Exposição (IE) para as espécies de palmeiras *Euterpe* e *Astrocaryum*.

Species	Land Use and Occupation Types	% Area Occupied	Weight Assigned
E. precatoria	Forests, natural formations, and water	84.2	1
	Reforestation and perennial crops	0.2	0.8
	Urbanized areas and roads	0.2	1
	Agricultural areas and pastures	15.4	0.75
	Mining areas	0.1	1
E. oleracea	Forests, natural formations, and water	80.1	1
	Reforestation and perennial crops	0.2	0.8
	Urbanized areas and roads	0.2	1
	Agricultural areas and pastures	19.5	0.75
	Mining areas	0.1	1
A. acaule	Forests, natural formations, and water	87.8	1
	Reforestation and perennial crops	0.1	0.8
	Urbanized areas and roads	0.1	1
	Agricultural areas and pastures	11.9	0.75
	Mining areas	0.1	1
A. aculeatum	Forests, natural formations, and water	82.5	1
	Reforestation and perennial crops	0.1	0.8
	Urbanized areas and roads	0.2	1
	Agricultural areas and pastures	17.1	0.75
	Mining areas	0.1	1

This table shows the percentage of area occupied by different land use and occupation types for each species, along with the assigned weight based on the degree of anthropization for each land category.

Table 5. Vulnerability Index (IV) results for the considered species.
Tabela 5. Resultados do Índice de Vulnerabilidade (IV) para as espécies consideradas.

Species	Number of Stipes	Weight	Reproduction	Weight	Suitable Environments	Weight	Final Weight
E. oleracea	Many stipes	1.0	Seeds	1.0	Flooded areas, dry land	1.0	1.0
E. precatoria	Monocaule	0.5	Seeds	1.0	Flooded areas, dry land	1.0	0.5
A. aculeatum	Monocaule	0.5	Dormant seeds	0.5	Open areas	0.5	0.125
A. acaule	Monocaule	0.5	Seeds	1.0	Flooded areas	0.25	0.125

Table 6. Results of the demand indicator for the considered palm species.
Tabela 6. Resultados do indicador de demanda para as espécies de palmeiras consideradas.

Species	Weights
E. precatoria	0.25
E. oleracea	1.00
A. acaule	0.25
A. aculeatum	0.25

Table 7. Area Reduction Index (ARI) results for the considered palm species.
Tabela 7. Resultados do Índice de Redução de Área (IRA) para as espécies de palmeiras consideradas.

Species	CTI	EI	VI	DI	ARI
E. precatoria	0.82	0.6	0.5	0.25	0.062
E. oleracea	0.81	0.6	1.0	1.0	0.486
A. acaule	0.68	0.6	0.125	0.25	0.0123
A. aculeatum	0.01	0.6	0.125	0.25	0.0002

4. DISCUSSION

The smaller the value of the index ARI, the higher the risk of area reduction for the respective species' populations. Thus, among the species considered in this study, *A. aculeatum* presents the highest risk of area reduction, while *E. oleracea* has the lowest risk. The species *A. acaule* and *E. precatoria* have intermediate values.

E. oleracea presented a CTI lower than 20% in future scenarios, which, combined with the interest in the species, makes it less vulnerable to area reduction due to climate change. Additionally, it is essential to note that açaí has gained significant popularity, and the demand for its pulp has increased substantially in the Southeast and Central-West regions of Brazil, as well as internationally, particularly in the USA. To meet this demand, Brazil has become the leading producer and exporter, generating over $9 billion annually in revenue solely from açaí (LAURINDO et al., 2023). The popularization of this fruit has encouraged the development of new research, including agroclimatic zoning studies, as knowledge of the species' occurrence in non-native soils in other states of the country already exists (CORDEIRO et al., 2023; LAURINDO et al., 2023; MARQUES et al., 2024).

The palm species that showed the lowest ARI was *A. aculeatum*, mainly due to the CTI and VI; there will be a significant reduction in the area favorable to this species with climate change. Combined with the difficulty in reproducing this palm due to seed dormancy, this makes the species highly vulnerable.

The index proposed in this study demonstrated sensitivity and responsiveness in detecting changes, which are important characteristics of indicators (ARROZ; ROCHET, 2005). In the context of this paper, it allowed for distinguishing the species with the highest risk of area reduction.

Of the indices or indicators used, three of them (climate threat, exposure, and demand) can change over time. The exposure index, for example, changes in response to alterations in land use and land cover, whose dynamics can be influenced by protection policies (or nature conservation policies) or incentives for production, road construction, and urbanization.

The climate threat impact indicator can also be altered when considering different dates and constructing new models that capture climate changes more effectively, incorporating new projections from the IPCC. The demand index, in turn, can shift if the demand for the fruits of the palm species changes, such as greater or lesser interest in the fruits of a particular species with the discovery of important compounds, like other bioactive substances.

The only index that remains unchanged over time is vulnerability, as it is inherent to the species and reflects its adaptation over thousands of years. Therefore, it should remain constant. In this study, only the adaptive plasticity of the species was considered. Other aspects, such as the degree of endemism and the need for pollinators, may also be relevant, but specialists in the fields of conservation and forest management should suggest these.

Given the relative dynamism of the three indices (CTI, EI, and DI), which can change over time, the area reduction index (ARI) for the species should be re-evaluated within a certain time interval. According to Rowland et al. (2020), five-year intervals are currently recommended for ecosystems and species, as they represent a more realistic timeframe than annual re-evaluations, allowing for the capture of impacts from highly stochastic and rapid threats. The authors state that, when five-year intervals are not feasible due to resource constraints, ten-year intervals may still be sufficient to identify declines. Still, they will make timely intervention actions more difficult when necessary.

It is essential to note that the sensitivity and responsiveness of the indices are influenced by the choices made during their construction, particularly the weights assigned. Experts in related fields, such as land use and occupation, climatic zoning, biology, and species adaptation, among others, generally define these weights.

Another advantage of this index is that new information can be incorporated into the existing formula in the form of new variables (indices) as needed, always in collaboration with a multidisciplinary team. This enables the index to remain current and relevant, reflecting changes in environmental conditions and evolving conservation needs.

5. FINAL CONSIDERATIONS

The palm species with the highest area reduction risk (ARI) is *A. aculeatum*, while *Euterpe oleracea* had the lowest risk. The species *A. acaule* and *E. precatoria* presented intermediate values. The high risk associated with *A. aculeatum* is mainly due to the greater reduction in the favorable area in future scenarios and the dormancy of its seeds, in addition to the low demand for planting.

This index has proven to be both reliable and easy to understand and apply. It can be used comparatively between species within the same area, as well as in an evolutionary manner, considering the same species over time in a specific area. Additionally, the index can be applied in different areas for the same species, allowing for the identification of areas where there is a higher risk of species reduction.

The Area Reduction Index (ARI) can be improved over time without compromising the values obtained in previous years. This can occur in two ways: by incorporating more up-to-date indicators or by adding new indicators, as well as by modifying the weight values.

One of the advantages of using this index is the possibility of associating other indicators, such as species, with a management plan or mapped species populations. This information is valuable for species conservation and can be integrated into the index.

Although this study focused on four palm species, the method can be applied to any species, depending on demand or interest. In cases where many species are involved, the resulting index values can be grouped into categories based on the ARI, classifying them as high, medium, and low area reduction. This classification can be done through cluster analysis. Once the three class groups are defined, each group can be addressed specifically about mitigation, adaptation, and conservation measures.

Although labor-intensive, these indices can be utilized within a program that incorporates Artificial Intelligence (AI), enabling the creation of predictive models for the risk of area reduction for multiple species simultaneously, thereby saving time and enhancing the efficiency of the models.

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