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ORIGINAL PAPER

Diversity, distribution and conservation status assessment of Paraguayan palms (Arecaceae)

Irene Gauto · Rodolphe E. Spichiger · Fred W. Stauffer

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Abstract Indigenous palm species of Paraguay are presented with data on their diversity, distribution, threats and conservation status. The Paraguayan palm flora consists of 23 native species in 11 genera, representing two of the five subfamilies recognized in the group. The palm distribution in the country is strongly related to the different ecoregions present in Paraguay, with number of species by ecoregion being as follow: Cerrado (18), Upper Parana Atlantic forest (6), Wet Chaco (4), Pantanal (2), and Dry Chaco (1). Half of the species display an acaulescent habit reflecting an interesting ecological adaptation to natural fires in the Cerrado. The alarming rate of habitat modification that the country is undergoing since 1940s has put palms under a high risk of extinction in the wild. A GIS model was used to calculate the extent of occurrence and the area of occupancy of the species in order to assess their conservation status applying the IUCN Red List Categories and Criteria. This analysis shows that about 30% of the species are threatened; one species is Critically Endangered, three of them are Endangered, and three are Vulnerable. One species (*Acrocomia hassleri*) is considered Near Threatened, 13 are Least Concern whereas two species are insufficiently known and therefore unable to be assessed. Important areas for palm conservation in Paraguay were identified, revealing the importance of the Amambay department. Conservation measures for the threatened species identified are proposed.

Keywords Area of occupancy · Conservation assessment · Extent of occurrence · GIS · IUCN

I. Gauto
Faculté des Sciences, Université de Genève, 30, quai Ernest-Ansermet, 1211 Genève 4, Switzerland

I. Gauto (✉)
Asociación Guyra Paraguay, Gaetano Martino 215, Asunción, Paraguay
e-mail: irene@guyra.org.py

R. E. Spichiger · F. W. Stauffer
Conservatoire et Jardin botaniques de la Ville de Genève, Laboratoire de systématique végétale et biodiversité, Université de Genève, CP 60, 1292 Chambésy/GE, Switzerland

Abbreviations

GIS	Geographic information systems
IUCN	International Union for Conservation of Nature
EOO	Extent of occurrence
AOO	Area of occupancy
GRASP	Generalized regression analysis and spatial prediction

Introduction

One of the major concerns of our times is the loss of Earth's biological diversity. The world's flora and fauna are facing an alarming decline of its wild populations, mainly due to the loss of their natural habitats (Hails et al. 2008). Palms are not the exception and many species are considered to be under serious risk of extinction in the wild (IUCN 2009). The International Union for the Conservation of Nature (IUCN) has established a system to assess the global conservation status of plants and animals. Hence, the IUCN Red List of Threatened Species has become the most compressive resource identifying species that are at the highest risk of extinction (Rodrigues et al. 2006). Moreover, threat categorizations are an important step to determine conservation priorities (Rodrigues et al. 2006). Many countries have adopted the IUCN classification scheme in order to identify the conservation status of their national biodiversity (Rodriguez 2008). National conservation status assessment of Neotropical palms using the IUCN categories and criteria are available for countries such as Peru (Kahn and Moussa 1994), Ecuador (Basualdo and Soria 1999), Venezuela (Stauffer 2003), and Colombia (Galeano and Bernal 2005). Although these regional assessments do not necessarily match the entire distribution range of the species, they are regarded as extremely powerful tools because they reflect the scale at which must conservation decisions are made and implemented (Gaston and Spicer 2005). Recent assessments have incorporated Geographic Information System (GIS) analysis in the attribution of palm conservation status (i.e. Borchsenius and Skov 1999; Calderón et al. 2005). The Criterion B of the IUCN Red List Categories and Criteria is the most popular for plant conservation status assessment, because of the possibility to easily calculate values for area-based measures with museum and herbarium georeferenced data using a GIS method (Brummitt et al. 2008). GIS-based analysis has been identified as an important tool enabling the assessment procedure (Brummitt et al. 2008).

The palm family (Arecaceae) comprises 2,522 species and 252 genera distributed throughout the tropics and subtropics of the world (Dransfield et al. 2008). In Paraguay 23 species have been reported to occur naturally within the country, with *Butia* (6 species) and *Syagrus* (4 species) as the most diversified genera (Hahn 1990; Henderson et al. 1995; Moraes 1996; Noblick 2006). Species of these two genera, along with some species of *Acrocomia*, *Allagoptera*, and *Attalea,* display a particular acaulescent habit (Pintaud et al. 2008). In Paraguay, three species are known to be endemic: *Butia arenicola*, *Butia campicola*, and *Syagrus campylospatha* (Hahn in prep).

A half of the Paraguayan palm species display this growth habit reflecting an interesting ecological adaptation to natural fires (Gottsberger and Silberbauer-Gottsberger 2006). However, wild populations of Paraguayan palms face the imminent threat of habitat loss as the principal risk of extinction (Mereles 2007); The Eastern region of the country has undergone intensive habitat degradation in the last 70 years (Fleytas 2007). The wood

industry, the establishment of new human settlements, and the deforestation for pasture and agriculture have been identified as the principal causes of habitat modification (Fleytas 2007). A recent assessment shows that the country has lost about 38% of its forest cover during a ten year period (Huang et al. 2009). Moreover, some wild populations of palms are exploited for commercial purposes (e.g. *Acrocomia aculeata*, *Copernicia alba*) (Frestes et al. 1993; González 2003; Mereles 2000; Miranda de Alvarenga 2001); often lacking any kind of sustainable management.

In spite of the interesting phytogeographical patterns and ethnobotanical importance characterizing Paraguayan palms, these subjects have been poorly studied. A complete taxonomical account for the family is available (Hahn 1990) but their ecology and distribution have been rather weakly documented. On the other hand, severe habitat modifications of the country, combined with the overexploitation of some palm populations, have placed indigenous palms under severe threat. This situation led us to start a project on the conservation of Paraguayan native palm species, with the aims to (1) provide a conservation status assessment for all native species, using the categories and criteria recommended by the IUCN, and (2) identify important areas for palm conservation and propose conservation measures for the most endangered taxa. These objectives were only possible to achieve with a thorough revision of the taxonomy, floristics, phytogeography, ecology, and uses of Paraguayan palms, considered as key elements for a better understanding of the family.

Study area

The Republic of Paraguay is situated in south-central South America, between the latitudes 19° and 27° South and the longitudes 54° and 62° West. The neighboring countries are Bolivia in the North, Brazil in the East, and Argentina in the South and West. The climate is essentially subtropical (south of Capricorn Tropic, Fig. 1) with a variation of mean annual precipitation ranging from 400 mm in the northwest, to 1,900 mm in the southeast (Naumann and Coronel 2008). The warm and rainy season goes from October to April with temperatures reaching 40°C or more in some localities. The cold and dry season extends from May to September with temperatures that can reach 0°C (D.G.E.E.C. 2006). The topography of the country is particular because of the absence of true mountain chains. The altitudinal gradient ranges from 35 to 842 m (i.e. Cerro Tres Kandú, Guaira department) (Naumann and Coronel 2008). The Paraguayan rivers system is part of the Río de la Plata basin and consists of tree main rivers: the Paraná, the Pilcomayo, and the Paraguay. The Paraguay River splits the country in two main regions: the Eastern region and the Western region or Chaco.

About 5,099 vascular plant species have been cited to occur naturally in Paraguay to date, with 8% of them being endemics (Zuloaga et al. 2008). This low rate of endemism could be explained by the role of the main rivers acting as migration routes for the flora and fauna, and also by the absence of significant topographical relief that could act as altitudinal belt (Spichiger et al. 2004). These particular characteristics make of Paraguay a meeting point to different biogeographical provinces. The territory has been described as an ecotone between the xeromorphic chaquean forests, the Brazilian Cerrados, and the Paranean flora (Spichiger et al. 1995). Five terrestrial ecoregions are recognized to be present in Paraguay (Table 1): the Chaco (divided into the so-called Dry and the Wet Chaco), the Upper Parana Atlantic Forest, the Cerrado, and the Pantanal (Olson et al. 2001). The palm distribution in the country is strongly related to the different ecoregions

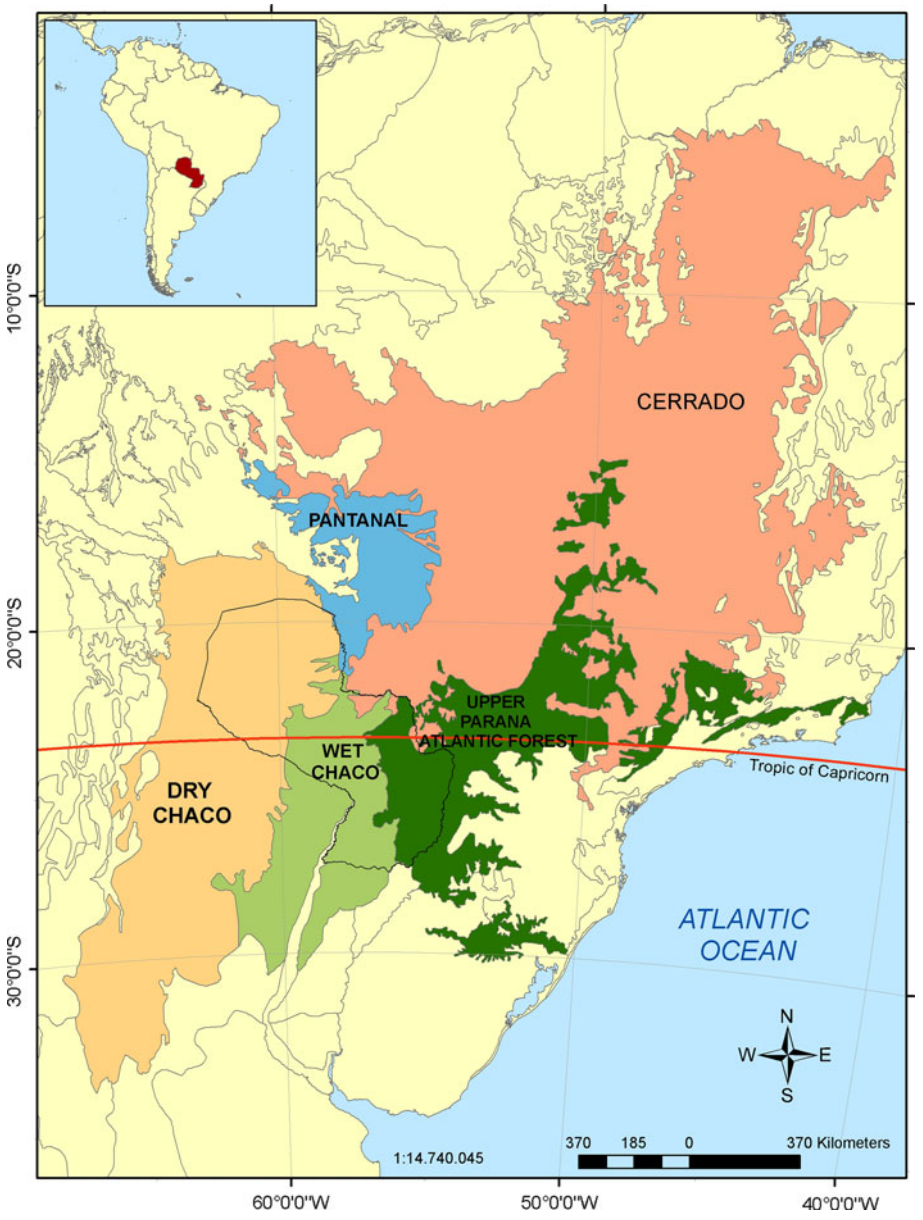

Fig. 1 Natural ecoregions of Paraguay

present in Paraguay, with the Cerrado as the ecoregion with the highest palm species diversity (Hahn 1990; Jiménez and Knapp 1998; Noblick 2006). In fact the Cerrado of Brazil, Bolivia and Paraguay is known to host a particular large number of palm species (40 species, 26 endemics) even though it is regarded as a dry habitat (Dransfield et al. 2008; Pintaud et al. 2008).

Table 1 Definition of Paraguayan ecoregions

Ecoregion	Area (km^2)	Habitat	Climate	Precipitation (mm)	Countries
Dry Chaco	787,000	Xeromorphic forest with ephemeral water courses	Continental	400–900	Argentina, Bolivia, and Paraguay.
Wet Chaco	292,000	Seasonally flooded soils	Continental	900–1400	Argentina, Bolivia, and Paraguay
Upper Parana Atlantic Forest	1,500,000	Semi-deciduous forest with 4–5 strata and a 20–30 height canopy	Warm temperate	1500–2000	Argentina, Brazil, and Paraguay.
Cerrado	2,000,000	Mosaic of different types of vegetation from savanna to open woodland	Tropical	400–2000	Bolivia, Brazil, and Paraguay
Pantanal	160,000	Deciduous or semi-deciduous forest adapted to recurrent flooding	Tropical	1090–1250	Bolivia, Brazil and Paraguay

In precipitation is included mean annual precipitation gradient

Materials and methods

Field work and taxonomic identification

Field work consisted in several field trips within Paraguay that took place from August 2008 to September 2010, with a total of 12 Departments and 30 localities visited. Taking into account that the highest palm diversity has been reported for the Eastern region, especially in the north and central Departments, the field trips concentrated in these areas. During these trips we mapped palm populations recording their geographic position with a GPS device, and collected herbarium specimens of most palm species in order to control their taxonomy.

Taxonomic identification was based on the publications of Hahn (1990), Henderson et al. (1995), Moraes (1996), Lorenzi et al. (2004), and Noblick (2006), as well as the study of specimens deposited at the herbarium of the Conservatory and Botanic Gardens of Geneva (G). The latter contains the largest historical and modern collection of Paraguayan palms, including many type specimens. Specialists William Hahn (Georgetown University, USA) and Larry Noblick (Montgomery Botanical Center, USA), were also contacted in order to verify the identification of critical taxa.

Species distributions modeling

We modeled species distributions using the generalized regression analysis and spatial prediction (GRASP) method with collection data from five herbaria (CTES, FCQ, G, MO, PY) and data from in situ observations gathered during the field trips carried out in Paraguay, with o total of 600 records. The environmental data layers consisted of the BIOCLIM climate datasets of Worldclim (Hijmans et al. 2005), the SRTM digital elevation data (http://srtm.csi.cgiar.org/) and layers of geology and soil data prepared by government Paraguayan institutions. Due to differences in the soil data layer for the Western and Eastern regions we carried out two different analyses for both regions. We used the S-Plus software to obtain the predicted model

and Arcview 3.3 software to map the predictions. Further details on the GRASP method are described in (Lehmann et al. 2002) and in the user manual freely available at www.cscf.ch/grasp. For the palm species presence-absence data, a quasi-binomial model was chosen. A stepwise procedure was used to select the significant predictors. For each species we obtained a bar histogram representing the distribution of all plots, partial response curves from the model, a bar histogram showing the contributions of selected predictors in the model, a graph with the validation values, and a map of potential distribution. The palm species richness was calculated with the Zonation software for spatial conservation prioritization (Moilanen and Kujala 2008). We used the potential distribution map obtained with GRASP and used the additive benefit function to define the areas with the larger number of species. We also performed the additive benefit function assigning a weight to each species; the species with the higher threatened category had the higher weight. The result was the prioritization of areas with the presence of the species with higher weight. More details on Zonation software are provided in the user's manual freely available at www.helsinki.fi/bioscience/ConsPlan.

Conservation status assessment

In order to assess the conservation status we followed the categories and criteria proposed by the International Union for the Conservation of Nature (IUCN; version 3.1; see URL: www.iucnredlist.org/info/categories_criteria2001) (IUCN 2001). We applied the categories critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC), and data deficient (DD). We used the extent of occurrence (EOO) and area of occupancy (AOO) values and confronted them to the criterion B. For *Euterpe edulis* the criterion A was used, due to data available of habitat reduction. In order to delimitate the EOO we reclassified the potential distribution map in two classes. The EOO represents the area where 95% of the presences are explained by the model. The AOO results from the multiplication of the EOO with the Land cover raster. This raster was obtained from the GlobCover project (2005 annual reflectance composite). The pixel value count of EOO and AOO were transformed to km^2 and used in the conservation status assessment.

Results

Diversity

We found 23 species of palms, divided in 11 genera, five tribes, and two subfamilies (Table 2) distributed in different ecoregions of the country. With respect to the diversity, any other species were added to the previous known diversity.

Areas with the larger diversity are essentially found in the northeastern departments of Paraguay, with some localities with as much as 12 species growing sympatrically (Fig. 2). The Department of Amambay displays the highest number of species (15) followed by the department of Canindeyú (12), San Pedro (12), and Concepción (11).

Distribution

For the present work we produced distribution maps for 20 species of the Paraguayan palm flora (Figs. 3, 4, 5, 6, 7). Three species: *Butia leptospatha, Desmoncus polyacanthos,* and *Trithrinax brasiliensis* had insufficient georeferenced data and the GRASP analysis could not be performed. The distribution of some species is closely related to the different

Table 2 Taxonomic composition of the Paraguayan palm flora

Subfamily tribe subtribe	Genus	Species
Coryphoideae		
Cryosophileae	*Trithrinax*	*T. brasiliensis*
		T. schizophylla
Trachycarpeae	*Copernicia*	*C. alba*
Arecoideae		
Cocoseae		
Attaleinae	*Allagoptera*	*A. campestris*
		A. leucocalyx
	Attalea	*A. geraensis*
		A. phalerata
	Butia	*B. arenicola**
		*B. campicola**
		B. exospadix
		B. leptospatha
		B. marmorii
		B. paraguayensis
	Syagrus	*S. campylospatha**
		S. oleracea
		S. petraea
		S. romanzoffiana
Bactridinae	*Acrocomia*	*A. aculeata*
		A. hassleri
	Bactris	*B. glaucescens*
	Desmoncus	*D. polyacanthos*
Euterpeae	*Euterpe*	*E. edulis*
Geonomateae	*Geonoma*	*G. brevispatha*

Species marked with * are endemic taxa for Paraguay

ecoregions present in the country: Cerrado (19 species), Wet Chaco (4), Upper Parana Atlantic Forest (4), Pantanal (2) and Dry Chaco (1). Thus, typical Cerrado species showed the characteristic fragmented distribution of the Cerrado vegetation in Paraguay (e.g. *Allagoptera leucocalyx, Syagrus petraea*). Corroboration of the resulting maps were carried out with Paraguayan flora experts in orders to discriminate GRASP analysis errors. Grasslike species are represented by a lower amount of herbarium specimens than caulescent or clearly arborescent palms, which in turn increase possible GIS analysis errors in the final maps due to a low number of data. For these less common species the resulting maps showed numerous possible new localities where they could be found in relation to the similar environmental conditions found by GRASP in others localities near the collected specimens. It is possible that new localities selected as part of the natural distribution of the species may be an overestimation of the method.

Only five species (*A. aculeata*, *Butia paraguayensis*, *C. alba*, *Syagrus romanzoffiana*, and *Trithrinax schizophylla*) are widely distributed in at least one region of Paraguay and may be locally abundant, the remaining species have more or less restricted distribution, normally represented by few departments or punctual localities.

Using the map of potential distribution of all palm species we obtained a map showing the areas of highest palm diversity in Paraguay (Fig. 2). The Amambay, Canindeyú and

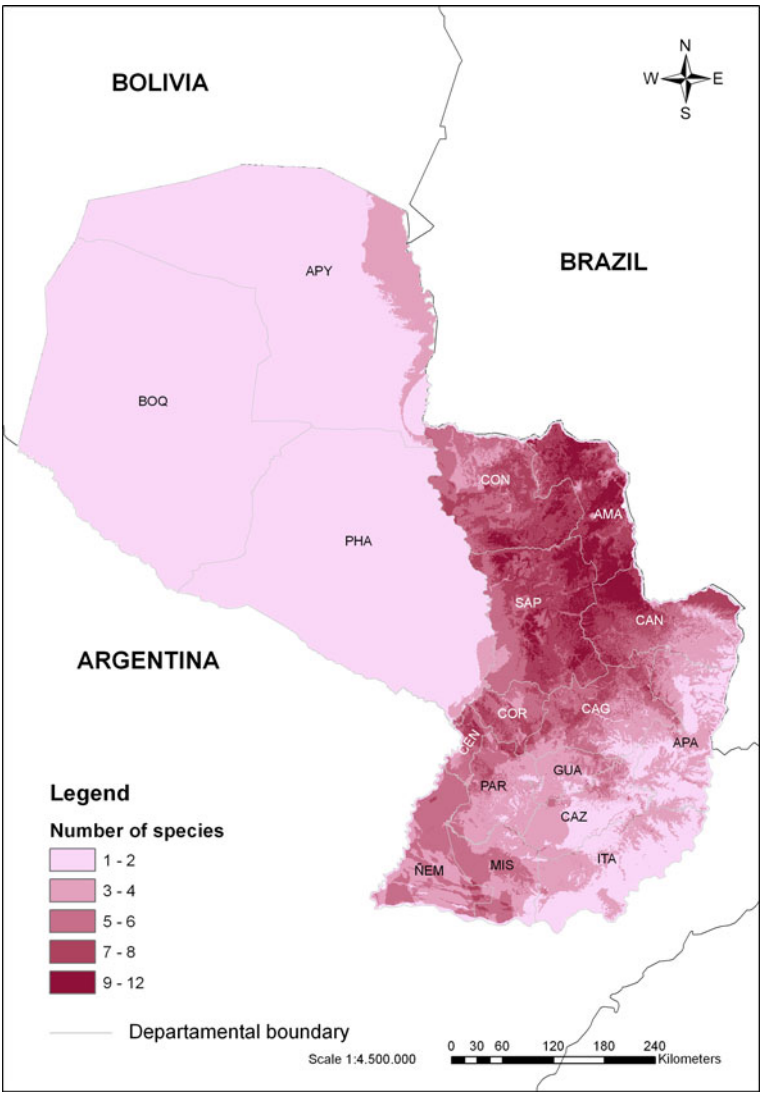

Fig. 2 Species palm diversity in Paraguay (Based on the palm species potential distribution maps of all taxa reported for the country)

San Pedro departments, in the northeast of Paraguay, show by far the highest palm richness areas in the country, with localities where as much as 12 species (52%) can coexist. Important areas for palm conservation in the country were also identified. These are areas in which the presence of threatened species were prioritized. We obtained a map with key areas that included high palm richness combined with areas where threatened species occurred (Fig. 8).

Conservation status assessment

The conservation status was assessed for 23 palm species, resulting in one critically endangered, three endangered, three vulnerable, one near threatened, 13 least concern, and

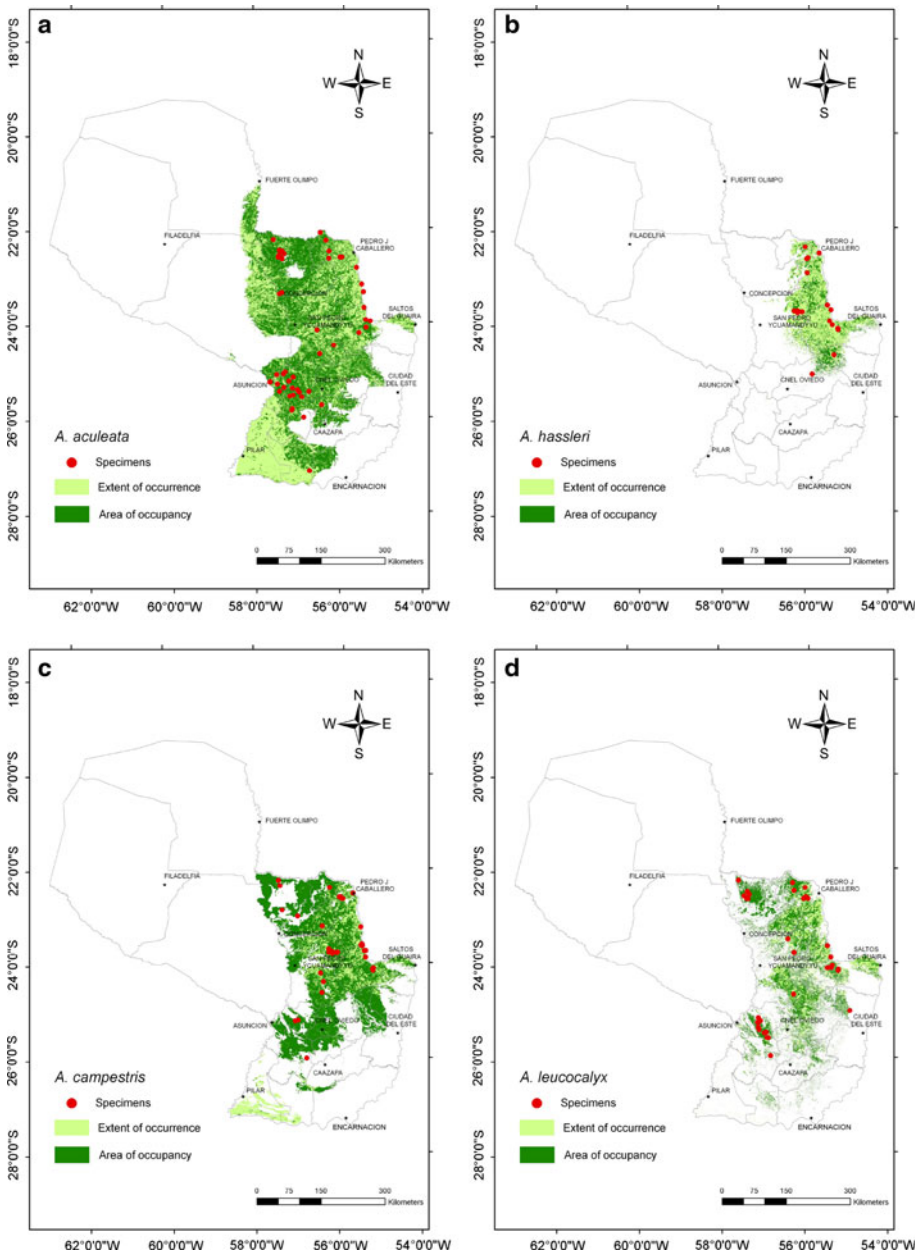

Fig. 3 Extent of occurrence and area of occupancy of Paraguayan palms: *Acrocomia* and *Allagoptera*. Specimen locations are indicated by dots. **a** *Acrocomia aculeata*; **b** *Acrocomia hassleri*; **c** *Allagoptera campestris* and **d** *Allagoptera leucocalyx*

two data deficient (Table 3). Habitat fragmentation and changes in land use were the principal threats identified. Overexploitation has been identified as an important threat only for one species, *E. edulis*, which historically has been exploited by the palm heart industry

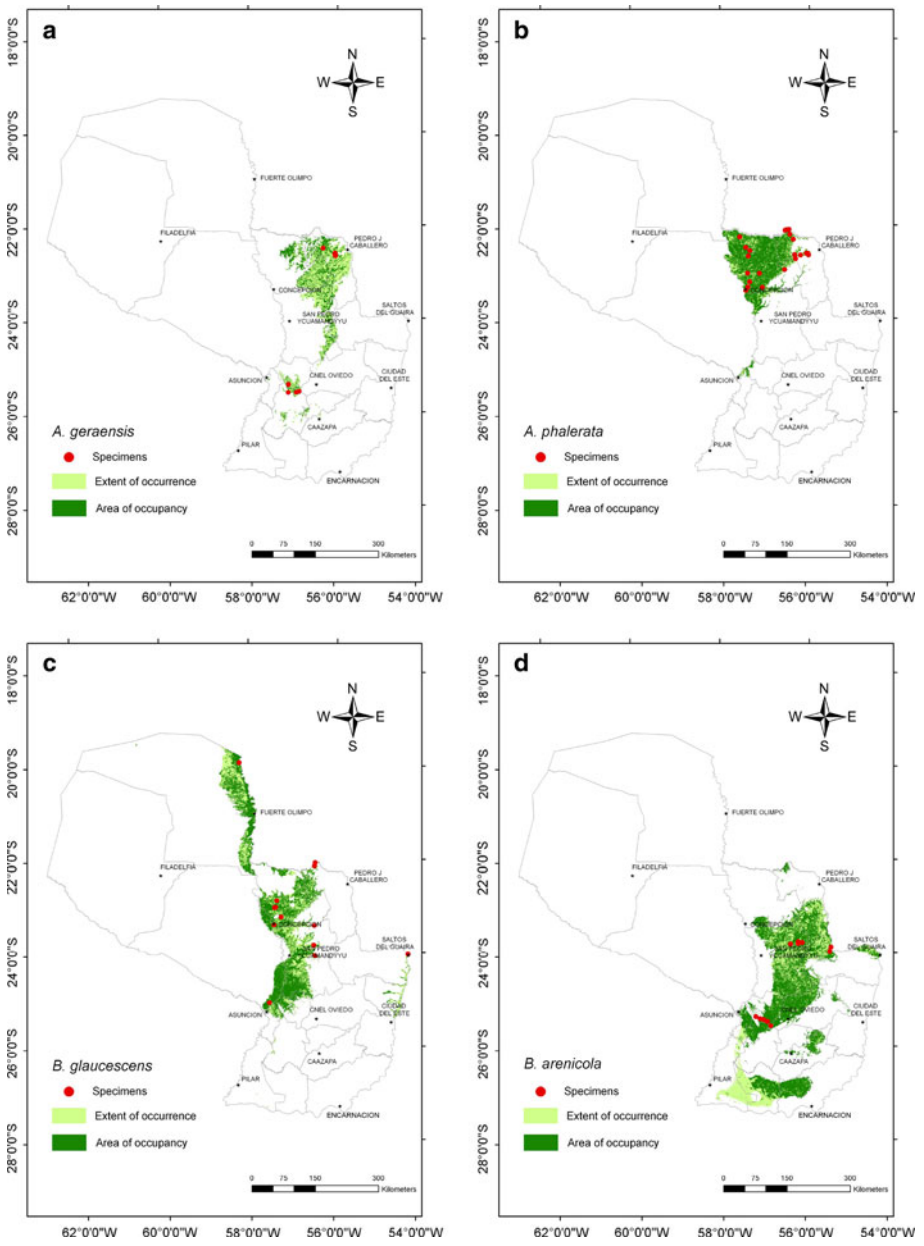

Fig. 4 Extent of occurrence and area of occupancy of Paraguayan palms: *Attalea, Bactris* and *Butia*. Specimen locations are indicated by dots. **a** *Attalea geraensis*; **b** *Attalea phalerata*; **c** *Bactris glaucescens* and **d** *Butia arenicola*

(Bertoni et al. 1994; Jiménez and Knapp 1998). Other species are used for different purposes but the populations seemed not to be affected (Markley 1953; Miranda de Alvarenga 2001; Pin et al. 2009).

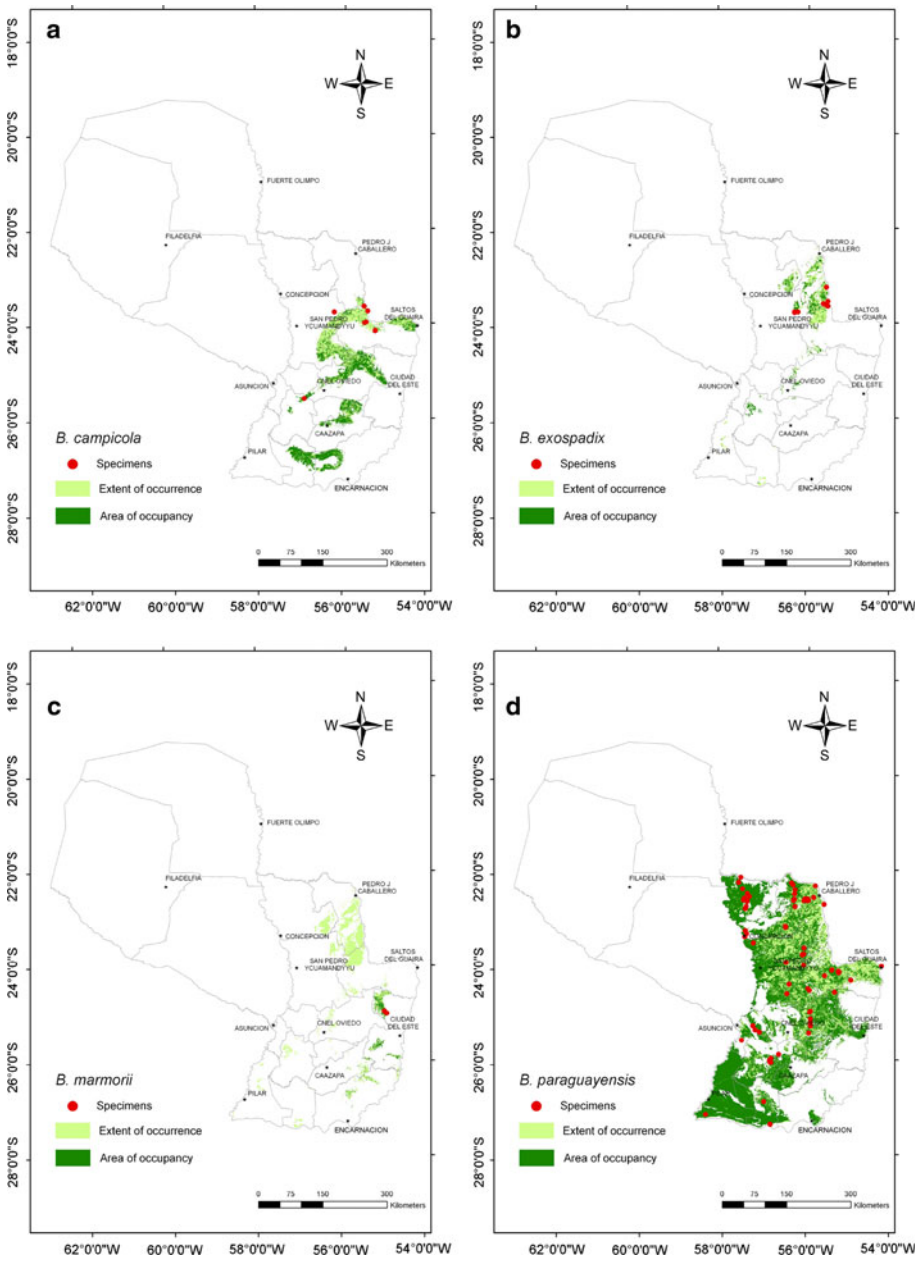

Fig. 5 Extent of occurrence and area of occupancy of Paraguayan palms: *Butia*. Specimen locations are indicated by dots. **a** *Butia campicola*; **b** *Butia exospadix*; **c** *Butia marmorii* and **d** *Butia paraguayensis*

The regional IUCN Red List guidelines were used in order to establish a final conservation status (IUCN 2003). Any previously established conservation status has changed after the revision of the regional IUCN red list guidelines. The threat of

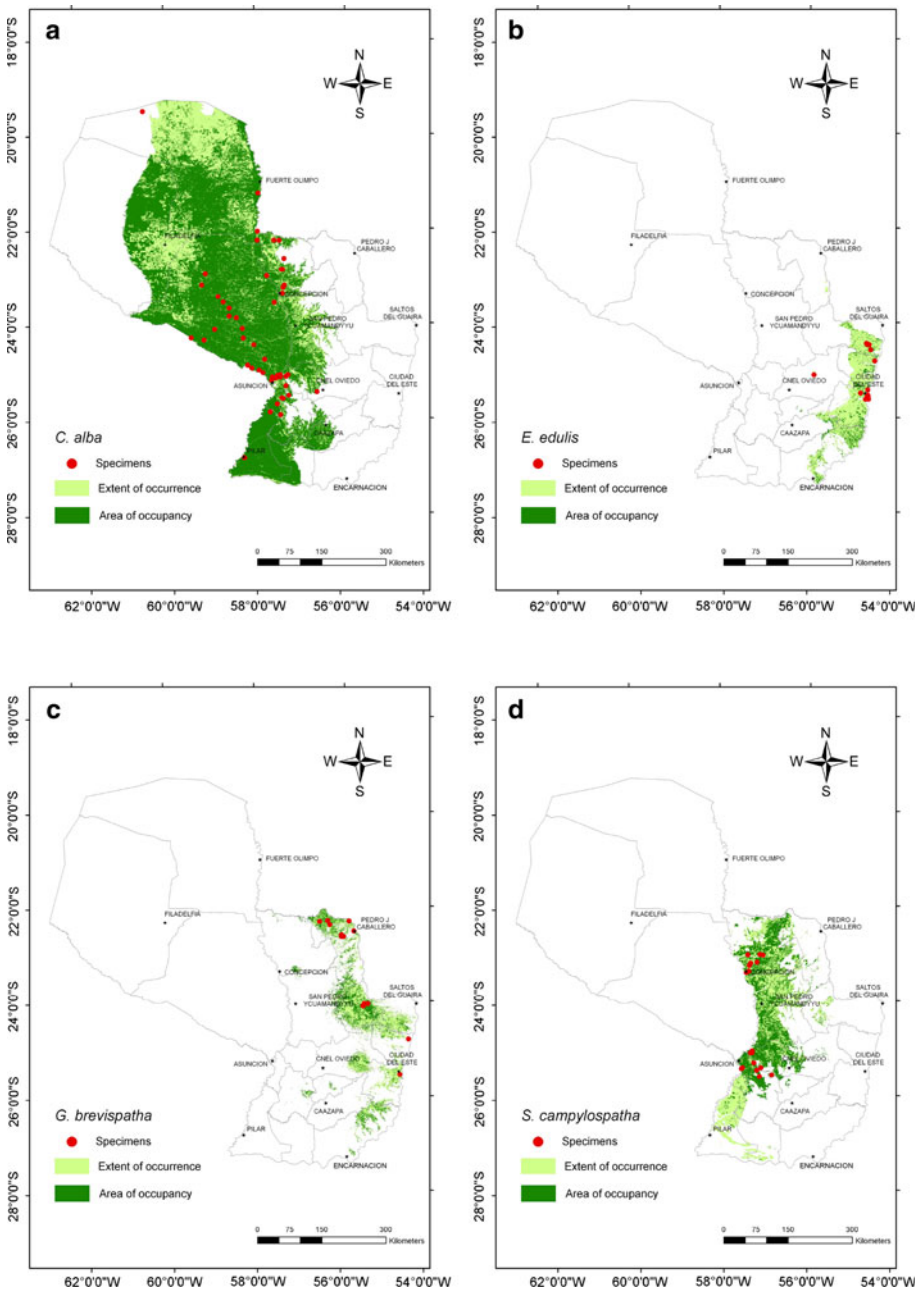

Fig. 6 Extent of occurrence and area of occupancy of Paraguayan palms. Specimen locations are indicated by dots. **a** *Copernicia alba*; **b** *Euterpe edulis*; **c** *Geonoma brevispatha* and **d** *Syagrus campylospatha*

habitat degradation and modification is in most cases irreversible and completely prevents the survival of breeding adults or the reproduction of immigrating propagules.

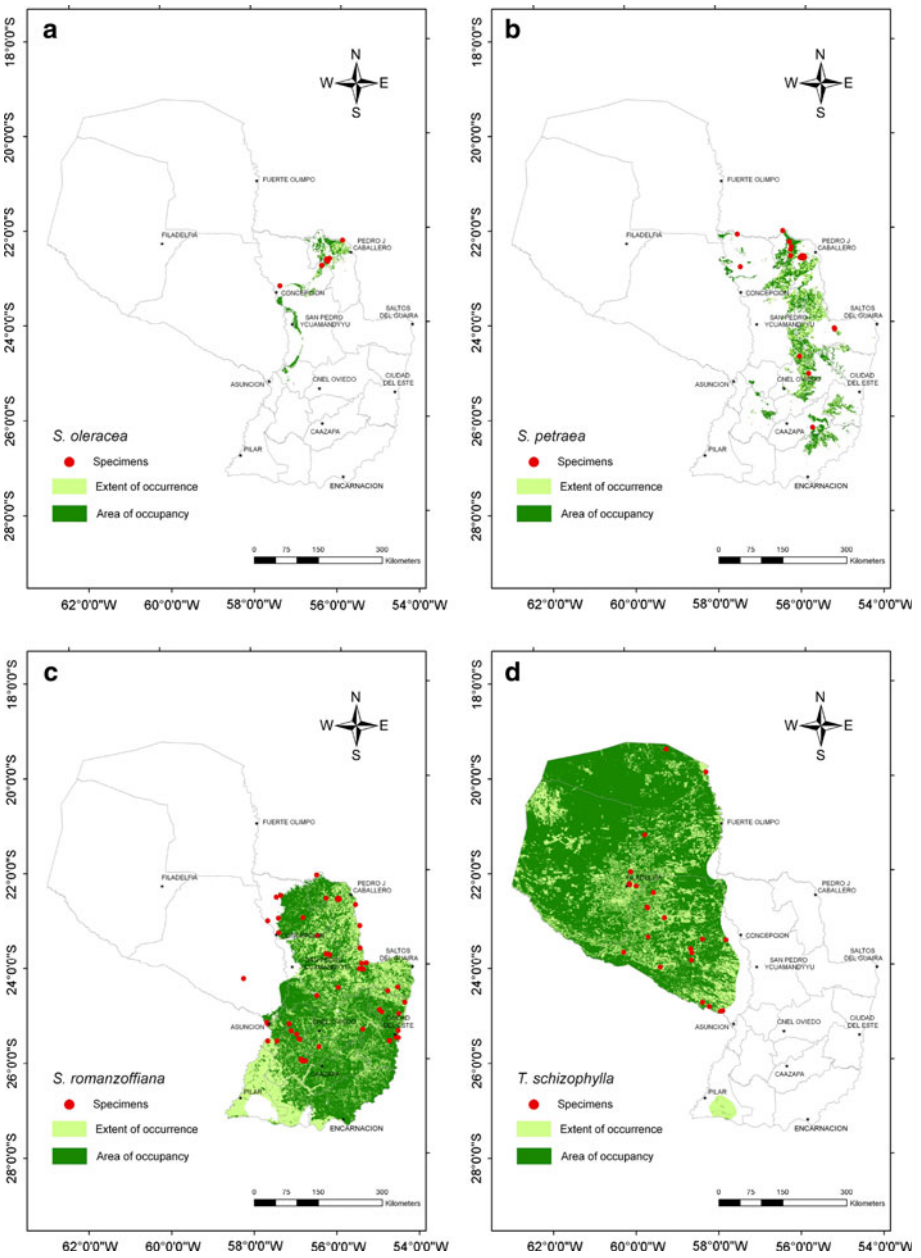

Fig. 7 Extent of occurrence and area of occupancy of Paraguayan palms: *Syagrus* and *Trithrinax*. Specimen locations are indicated by dots. **a** *Syagrus oleracea*; **b** *Syagrus petraea*; **c** *Syagrus romanzoffiana* and **d** *Trithrinax schyzophylla*

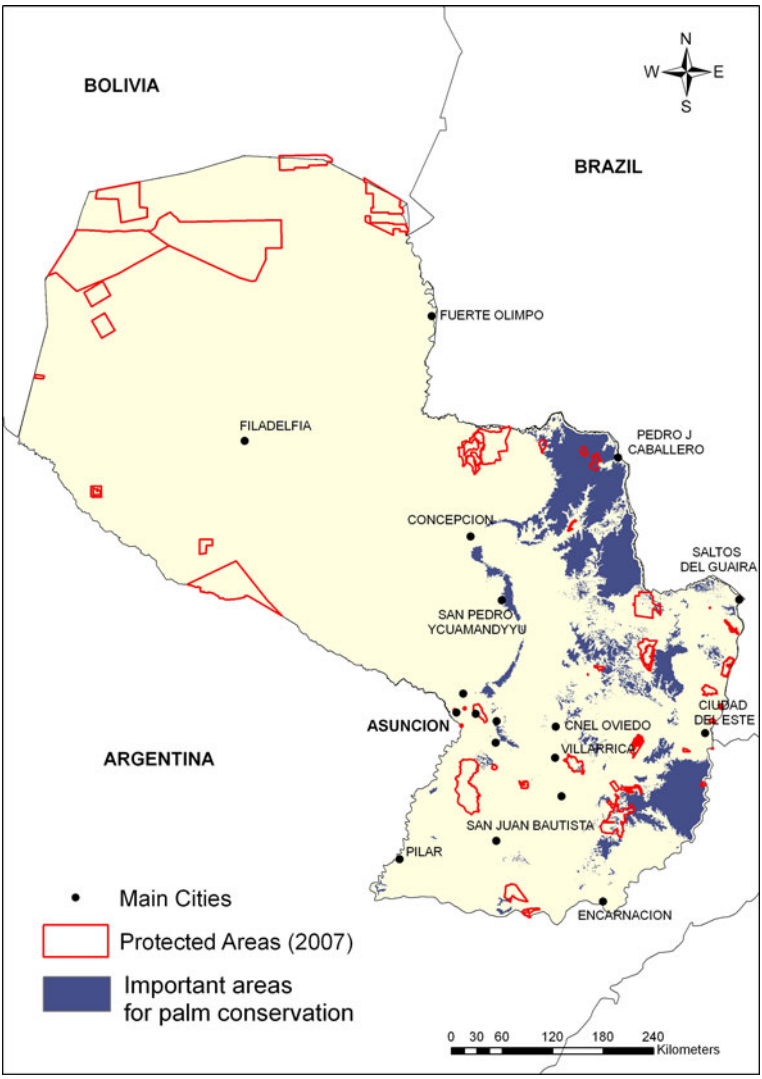

Fig. 8 Main areas identified for palm conservation in Paraguay. Information is compared with the current protected areas system

Discussion

Diversity pattern

Previous and most recent works including Paraguayan palms have shown slightly different taxonomic compositions. The recent paper of Pintaud et al. (2008) cited 10 genera and 28 species for the Southern Cone of South America, to which Paraguay is one of the members. In the Checklist of vascular plants of the Southern Cone 10 genera and 23 palm species are cited for Paraguay (Moraes 2008). Hahn (1990) described 12 genera and 18 species. Our

Table 3 Category and criterion assessed, extent of occurrence (EOO), and area of occupancy (AOO) for the Paraguayan palm species

Category	Species	Criteria	EOO (km^2)	AOO (km^2)
Critically endangered (CR)	*Trithrinax brasiliensis*	B1a	–	–
Endangered (EN)	*Butia marmorii*	B1b(ii)	3.023,2	1.074,0
	Euterpe edulis	A2c	18.347,1	3.758,5
	Syagrus oleracea	B1b(ii)	4.617,4	3.129,8
Vulnerable (VU)	*Attalea guaranitica*	B1a	18.678,5	7.994,9
	Butia campicola	B1a	19.785,9	10.422,0
	Butia exospadix	B1a	7.002,4	2.707,3
Near threatened (NT)	*Acrocomia hassleri*		24.603,8	7.969,5
Least concern (LC)	*Acrocomia aculeata*		128.950,5	66.307,7
	Allagoptera campestris		71.608,1	54.498,4
	Allagoptera leucocalyx		41.474,6	26.244,3
	Attalea phalerata		20.725,4	15.887,2
	Bactris glaucescens		37.106,2	22.995,5
	Butia arenicola		49.181,6	32.168,6
	Butia paraguayensis		94.646,2	68.589,2
	Copernicia alba		218.771,0	156.014,6
	Geonoma brevispatha		24.693,1	9.585,7
	Syagrus campylospatha		43.283,9	21.115,1
	Syagrus petraea		24.157,4	14.642,3
	Syagrus romanzoffiana		144.434,3	90.179,1
	Trithrinax schizophylla		232.750,6	177.667,3
Data deficient (DD)	*Butia leptospatha*		–	–
	Desmoncus polyacanthos		–	–

Definition of criteria: A2c, Reduction of the population size based on a decline in area of occupancy, extent of occurrence and quality of habitat observed over the last ten years; B1a, Extent of occurrence estimated to be less than 100 km^2 indicated by severely fragmented habitat or known to exist at only a single location; and B1b(ii), Extent of occurrence estimated to be less than 100 km^2 and continuing decline observed in area of occupancy

study follows the taxonomic classification proposed by Hahn (in prep) and Henderson et al. (1995) and recognizes 23 species in 11 genera to occur naturally within the country, with *Butia* (6 species) and *Syagrus* (4 species) as the most diversified genera.

The Paraguayan palm flora belongs to the austral palm flora region of South America, which extends south of the Amazon and east of the Andes and is characterized by an adaptive radiation in genera such as *Allagoptera, Astrocaryum, Attalea, Butia*, and *Syagrus* (Pintaud et al. 2008). This region comprises four endemic genera (*Allagoptera, Butia, Lytocaryum*, and *Trithrinax*) and has poor representation of more tropical genera such as *Bactris, Euterpe,* and *Geonoma* (Pintaud et al. 2008). The genus *Butia* is widely distributed and reaches, along with *Trithrinax*, the southernmost limit of palms in the continent (35°S) (Dransfield et al. 2008; Pintaud et al. 2008). The presence in Paraguay of a higher number of species in the genera *Butia* and *Syagrus* is related to the Cerrado palms diversity. Although palms are mostly rain tropical forest elements, some drier habitats such as the

Cerrado of Brazil, Bolivia and Paraguay have been recognized as high palm diversity habitats (40 species, 26 of them endemics) (Dransfield et al. 2008; Pintaud et al. 2008).

Distribution pattern

In Paraguay palm species are heterogeneously distributed throughout the country with the highest number of species concentrated in the northeast (Fig. 2), and the distribution is closely related to the different ecoregions present in the country (Fig. 1). The Cerrado displays the largest number of species (19); it is distributed in disjunct areas within the Eastern region of the country and this is well illustrated by the distribution of typical Cerrado species such as *Acrocomia hassleri*, *Allagoptera campestris*, *A. leucocalyx*, *Attalea geraensis, Butia exospadix,* and *S. petraea* (Figs. 3, 4, 5, 6, 7). Typically in Paraguay can be found patches of Cerrado intermingled with the Upper Parana Atlantic Forest and with the Wet Chaco along the east coast of the Paraguay River (Basualdo and Soria 2002; Mereles 2007; Spichiger et al. 1995). Nevertheless, we found also an important area of Cerrado vegetation in the North of the department of Alto Paraguay in the Chaco (Navarro et al. 2006). In this area the Cerrado is mixed with Dry and Wet Chaco flora elements. Specimens of *A. leucocalyx* and *A. aculeata* had been collected or reported from this region and probably more cerrado palms species will be reported there as long as more floristic inventories are carried out in this part of the country. Populations of *Butia* and *Syagrus*, although strongly associated to Cerrado vegetation, tend to be enclosed by patches of Upper Parana Atlantic Forest and are though isolated one of the other (Basualdo and Soria 2002).

Only five species (*A. aculeata, B. paraguayensis, C. alba, S. romanzoffiana,* and *T. schizophylla*) have a wide distribution in Paraguay (Figs. 3, 4, 5, 6, 7). Jiménez and Knapp (1998), and Michalowsky (1958) state that *A. aculeata* and *B. paraguayensis* are present along the Eastern region of Paraguay in almost all kind of vegetation except for tall and closed forests and flooded plains. They are often found in a high number of individuals. *A. aculeata* could also be considered a pioneer as it appears rapidly in abandoned agricultural lands (Mereles 2007). *C. alba* is a characteristic species of the seasonally flooded plains of the Wet Chaco, where it forms vast palm forests (Mereles 2000). The species is particularly abundant in the Pantanal and along the banks of the Paraguay and Pilcomayo rivers (Ramella and Spichiger 1989). In the Eastern region it forms patchy populations in areas such as the Apa river, Ypacaraí and Ypoá lakes, and in the Paraguay-Parana delta (Spichiger et al. 1991). *S. romanzoffiana* grows on a variety of habitats. The species is found as part of the canopy in the Upper Parana Atlantic forest, where it can be very abundant (e.g. Alto Paraná department) (Spichiger et al. 1992). It is also present in the so-called *cerradão*s of the Cerrado ecoregion and in gallery forests of the Wet Chaco near the banks of the Paraguay River (Presidente Hayes department) (Peña-Chocarro et al. 2006). *T. schizophylla* occurs in the xeromorphic forest of the Dry Chaco dominated by *Aspidosperma quebracho-blanco* (Apocynaceae) and *Ceiba insignis* (Bombacaceae) (Spichiger et al. 1991).

Some species such as *Attalea phalerata* and *Bactris glaucescens* from the peripheral zone of the Amazonia and *D. polyacanthos* from the Amazon and Orinoco basins penetrate into Paraguay in the gallery forests of the main rivers and their tributaries, and are found only in this type of forests (Pintaud et al. 2008). Although *T. brasiliensis* and *Syagrus oleraceae* present a marginal distribution in Paraguay, both have a wider distribution in Brazil where they could be found in dense populations (Lorenzi et al. 1996; Reitz and Klein 1974; Sano et al. 2008).

The northeast of Paraguay should be regarded as the most diverse area with respect to the palm Family. Amambay department was recognized as extremely rich regarding the entire Paraguayan flora (Zuloaga et al. 2008). In this region the Cerrado vegetation meets the South-east and South Brazilian floras and is enclosed by the Upper Parana Atlantic forest (Spichiger et al. 1995). The description of a new species (*B. exospadix*), the rediscovery of another species (*B. leptospatha*) and the identification of new populations in recent years illustrate the importance of this region (Basualdo and Soria 1999; Noblick 2006).

Another interesting region not highlighted in the map is in the north of the Alto Paraguay region, near the border with Brazil and Bolivia (Johnson 1996) where patches of Cerrado vegetation are present (Navarro et al. 2006; Spichiger et al. 1995). Recent surveys have shown that one not yet identified palm species is present in these Cerrado patches (Acuña, "personal communication"). The Alto Paraguay region is indicated by Johnson (1996) as a poorly known forest with high palm diversity. Recommendations made for Paraguay mentioned the necessity of surveys in the northern regions (especially Alto Paraguay) for other species.

The calculation of potential distribution of each species suggested new areas where the species may have a high probability to be found. Figures obtained on the extent of occurrence and the area of occupancy based on the potential distribution could represent an overestimation if compared to the actual distribution. However, the fact that new populations were found during field work efforts demonstrates the probable accuracy of the potential distributions calculated. No doubt that further field work and collections are needed in order to optimize the models proposed in our study. Biogeographical data are especially needed for the poorly collected acaulescent palms, which display disjunct areas of distributions due to the particular configuration of the Cerrado in Paraguay.

Conservation

From all species occurring naturally in Paraguay seven of them (30%) meet at least one criterion under a threatened category. One species is critically endangered, three are endangered and three are vulnerable. The restricted distribution and continuous decline of the area of occupancy were the principal causes of the resulting categories. Main features on the conservation status of each threatened species are provided here below.

Trithrinax brasiliensis (CR) is known to exist at only one single location near the Refugio Biológico Pikyry (Alto Paraná department). The extremely reduced population is not protected by the reserve. *T. brasiliensis* qualifies as critically endangered under the B1a criterion. Brazilian wild populations are distant and the immigration of propagules seems difficult. Further the species is rare despite is wide distribution in South Brazil and is considered endangered (Anonimous 2003; Pingitore 1978; Reitz and Klein 1974).

Butia marmorii (EN) is a recently described species, known only from two close populations in the same region of Paraguay (Noblick 2006). The analysis of the potential distribution highlighted other possible locations where the species may occur expanding its AOO. Hence, it meets the B1b (ii) criterion of the endangered category. The area of occupancy may be overestimated and the species may qualify as critically endangered if the species is confirmed to be present in only one reduced area within the country. Therefore, further work is needed to evaluate the actual distribution of *B. marmorii* in Paraguay. Additionally more information is needed about the Argentinean wild populations of this species; Noblick (2006) mentioned the presence of the species in the province

of Misiones, Argentina; but the current status of protection or abundance of the species is not known.

Euterpe edulis (EN), an Atlantic forest species, qualifies as endangered under the A2c criterion (Reduction in population size based on an observed, estimated, inferred or suspected population size reduction of >70% over the last 10 years or three generations). Estimations account that only 25% of forest cover remains in the Atlantic forest of Paraguay (Huang et al. 2007). Consequently, this species suffers a dramatic decline of its area of occupancy. Moreover, the species has faced an intensive exploitation between the 1970s and the 1990s (Bertoni et al. 1994; Jiménez and Knapp 1998; Johnson 1996). The species occurs currently in highly fragmented populations.

Syagrus oleracea (EN) qualifies as endangered under the B1b (ii) criterion. This species has a restricted distribution in the northeastern departments of Paraguay, with an extent of occurrence estimated to be less than 5,000 km^2 and suffering a steadily decrease of its area of occupancy due to habitat modification.

Attalea geraensis (VU) is classified as vulnerable in Paraguay. This species presents disjunct populations in different departments of the country. Its extent of occurrence is estimated to be less than 20,000 km^2 with a continuing decline of its area of occupancy. The species was first known to occur in no more than three different localities, but other surveys reported new populations in the department of Amambay (Basualdo and Soria 1999). In the present work we also identified a new locality for the species (along the Bella Vista Norte Highway, 22 km N of the intersection with the Highway No. 3, Amambay department). The fact that new populations can still be found highlights the importance of the potential distribution analysis as a tool to identify localities where further field work should be carried out.

Butia campicola (VU) is considered as vulnerable by the B1a criterion. This endemic species of Paraguay has been collected in the departments of Canindeyú, Amambay, San Pedro and Cordillera. However, new potential localities have been identified in our analysis. With its grasslike appearance this species is very inconspicuous and easily overlooked by collectors (Jiménez and Knapp 1998).

Butia exospadix (VU) meets the B1a criterion of the vulnerable category. This species has been recently described by Noblick (2006) and displays a very restricted distribution with few localities currently known. A new population of this palm was identified in the present work (Reserva Natural Laguna Blanca, Distrito Santa Rosa del Aguaray, San Pedro department).

Two species, *B. leptospatha* and *D. polyacanthos* were classified as "data deficient". *B. leptospatha* was rediscovered in 1994 near the city of Pedro Juan Caballero (Amambay) by A. Schinini (CTES) (Noblick 2006). Unfortunately we were unable to find the species in the field as no geographical coordinates were associated to the type collection. The lack of georefereced points combined to the lack of data on the population status of the species did not allow us to assess the conservation status of *B. leptospatha*. A similar situation was found for *D. polyacanthos;* only two disjunct locations are known for this species in Paraguay and hence, data was insufficient to carry out the GIS analysis. More field work aiming to identify new localities is urgently needed for these two taxa.

One species, *A. hassleri* is close to qualify as threatened due to its small area of occupancy and was therefore classified as nearly threatened. Thirteen species are considered not being threatened in Paraguay and were classified as least concern. These species have larger distribution ranges and some of them (e.g. *A. aculeata*, *C. alba* and *S. romanzoffiana*) are present in high densities in their natural habitats.

Butia arenicola, considered a synonym of *B. paraguayensis* by Henderson et al. (1995), is recognized as a valid taxon in this work. The species has been collected from four departments in Paraguay, but the potential distribution shown in the GIS-analysis suggested a wider distribution. This can be an overestimation and the species may be currently threatened. More collections are needed in order to determine whether or not the species is currently under serious threat.

Syagrus campylospatha, endemic to Paraguay, has a particular distribution with respect to other Cerrado palms in Paraguay. This species is considered as not threatened due to the wide distribution that results from the GIS-analysis. Its distribution appeared to be along the east shores of the Paraguay River even though no collections have been made in departments such as San Pedro. However, relatively few collection efforts have been undertaken in this department.

A half of the species of the genus *Butia* (3 species) are threatened and *B. leptospatha*, now classified as data deficient, may certainly qualify as threatened too. The genus *Butia* is considered as a genus of a recent evolutionary radiation (Couvreur, "personal communication") and Paraguay with six of the ten species currently recognized for the genus may be an important center of speciation. This situation makes of the genus *Butia* one of the top priorities for palm conservation in Paraguay.

Unfortunately, few of the important areas for palm conservation highlighted by our analysis are currently included in protected areas. The threatened palms species identify in this work are poorly protected. The creation of new natural reserves in the departments of Amambay, Canindeyú and Alto Paraná that will preserve populations of endangered taxa are among the most urgent conservation measures that need to be implemented.

Threats

The situation of some Paraguayan palm species is alarming. The proportion of palm threatened (30%) in the country is remarkably higher than the one found in other countries with a conservation status assessment available for their palm flora (e.g. Colombia 18%, Peru 20%) (Galeano and Bernal 2005; Kahn and Moussa 1994). For Paraguayan palms habitat modification represents the main threat (Fleytas 2007). The changes are unevenly occurring in different ecoregions of the country, with the Upper Parana Atlantic forest and the Cerrado displaying the highest rates of habitat modification (Huang et al. 2009). In Brazil the Cerrado is in rapid decline because of the expansion of modern agriculture (Klink and Machado 2005). Fifty-five percent of Brazilian Cerrado has already been cleared or transformed for human uses and only 2.2% of the territory is currently under protection in Brazil (Machado et al. 2004). More alarming is the 60% of the original vegetation loss in Mato Grosso do Sul state (Silva et al. 2006); this state is adjacent to the northeast departments of Paraguay and may share most of the palm species present in the country. Huang et al. (2009) mentioned 13% of change in forest cover for the period of 1990–2000 in the Cerrado ecoregion of Paraguay. The Atlantic forest sensu lato is considered as one of the most threatened tropical forests of the world (Galindo-Leal and Gusmão Câmara 2003). In Brazil only 7.6% of the original vegetation forest remained by year 2000 (Mollerato and Haddad 2000). In Eastern Paraguay, for the same year, less than 25% of the original forests cover remained of the Upper Parana Atlantic forest (Huang et al. 2007). The Chaco ecoregion and the Pantanal have suffered less habitat transformation than the other two ecoregions (Huang et al. 2009). Unfortunately, periodic monitoring is showing that the rate of deforestation in the Chaco is rapidly increasing (Rodas and Yanosky 2009).

In order to ensure the conservation of wild population the creation and reinforcement of the Paraguayan protected areas system has been the principal strategy adopted by the country (SEAM 2007). To date, 14.9% of the country territory is under a protection category with a total of 31 public protected areas, 25 private reserves and three biospheres reserves. However, public protected areas suffer from serious implementation problems, mainly because of disputes with land owners and the lack of financial resources (Cartes 2003). In fact, the government owns only a part of lands on public reserves and national parks; the other part is in private hands. This model of land ownership has been one of the most serious problems for Paraguay environmental strategies implementation (Cartes 2003). Most palms species (82%) are currently included within at least one protected area. However, to date four species have not been reported to occur in any of them: *B. leptospatha*, *B. marmorii, D. polyacanthos,* and *S. oleracea*. Four species are currently protected only in one protected area: *B. arenicola* (Parque Nacional Lago Ypacarai), *B. campicola* (Reserva Natural del Bosque Mbaracayu), *B. exospadix* (Reserva Natural Laguna Blanca), and *S. campylospatha* (Parque Nacional Paso Bravo). It should be pointed out that, except for *B. paraguayensis*, the other five species in the genus are extremely poorly protected. Moreover, the three endemic Paraguayan palm species are currently present in only one protected area.

Most of the threatened species identified are rare and with restricted distribution. The presence of disjunct and small populations of these species makes them even more vulnerable to local extinction. The implementation of an ex situ conservation program for the rare species is essential to guarantee their survival. To date any of the Paraguayan palm species are part of an ex situ conservation program in the country. Only some individuals of *B. paraguayensis*, *E. edulis*, and *S. campylospatha* are in cultivation in the Botanic Garden of Asunción.

We propose here some conservation measures aiming to promote the survival of the most threatened palm species in Paraguay. (1) Urgent ex situ conservation for *B. campicola*, *B. exospadix*, *B. marmorii,* and *T. brasiliensis.* (2) Creation of new private reserves in the departments of Amambay, Canindeyú and Alto Paraná that will preserve populations of threatened taxa. (3) Establishment of management strategies for *E. edulis* and promotion of a sustainable palm heart industry. The appraisal of this species as an economically important non-timber product with the implementation of a sustainable management plan has demonstrated positive results for the conservation of this species in some regions of Brazil (Fantini and Guries 2007; Sedrez dos Reis et al. 2000), and same measures could be implemented in Paraguay.

Even though *B. arenicola* and *S. campylospatha* were considered as not threatened, it would be important to include wild populations of these two endemic species within more protected areas. As recommended by Johnson (1996) ex situ conservation of *A. geraensis* and *S. campylospatha* will also contribute not only to guarantee the long term survival of these species, but also to the improvement of the knowledge of the acaulescent palm flora of Paraguay.

Conclusion

This work highlights the important role that Paraguay must play in the conservation of *Butia* species. The country hosts 60% of the species currently recognized in this genus and still conserves important areas of the original Cerrado vegetation in contrast to some states of Brazil (60% of the natural vegetation is lost in the state of Mato Grosso do Sul)

(Silva et al. 2006). Evidences suggest that Paraguay could host even more species of *Butia* that are waiting to be described (Noblick 2005); however, most species of this genus (either endemics or sub-endemics) are currently threatened and are poorly protected. Urgent conservation measures are needed to ensure the survival of wild *Butia* populations, either by in situ conservation measures, via the establishment of new protected areas, or ex situ conservation measures through cultivation programs for the threatened species (*B. campicola*, *B. exospadix*, and *B. marmorii*).

The Cerrado is particularly important for palm conservation in Paraguay due to its high palm diversity (19 of the 23 Paraguayan palm species are present in this ecoregion). Accordingly the department of Amambay plays a major role by hosting 15 palm species and important wild populations of threatened taxa. The departments of Alto Paraná and Canindeyú have also important areas for palm conservation especially for *B. marmorii* and *T. brasiliensis* (Alto Paraná), and *E. edulis* (Canindeyú and Alto Paraná). The northeast region of the department of Alto Paraguay presents Cerrado areas that have been poorly explored and could potentially host new palm species for Paraguay and important wild areas for palm conservation in general (Johnson 1996).

The remarkable presence in Paraguay of a high number of acaulescent palm species (11 species) concentrated in a relatively small area (Northeast departments) place the country in a privileged position for the study of the biology and evolution of these particular taxa and the unique ecological conditions where they grow.

Paraguay is a country rich in natural resources and has a great potential in the ornamental plant market and the exploitation of non-timber forest products. Many palm species of the native flora are exploited for economic purposes (e.g. *A. aculeata*) (Frestes et al. 1993; Miranda de Alvarenga 2001; Molas 1989). However, economically important species lack management plans that could guarantee long term survival of wild exploited populations. The country urgently needs the implementation of politics promoting the sustainable use of its natural resources.

Although a high proportion of Paraguayan palms are threatened the country could play a major role in the conservation of Cerrado and Chaquean species. These two ecoregions still preserve a high proportion of its natural vegetation and host large protected areas such as the Parque Nacional Defensores del Chaco (720,000 ha) and the Parque Nacional Paso Bravo (103,000 ha). In contrast, the Upper Parana Atlantic forest is characterized by the presence of highly fragmented areas and intensified efforts must be undertaken in order to ensure the survival of threatened species of this particular ecoregion (Huang et al. 2007).

Efforts must be also focused towards wide public education. Very little is known about Paraguayan palms by the population, and only economically important palms are easily recognized. This lack of knowledge is a major constraint for conservation, because people seldom preserve resources that they do not know (Colchester 2003). To guarantee the long term success of the conservation measures implemented, the population must be incorporated and taken into account into the process.

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