A conservation framework for the Critically Endangered endemic species of the Caribbean palm *Coccothrinax*

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Abstract With 30 threatened species (14 categorized as Critically Endangered and 16 as Endangered, sensu IUCN), *Coccothrinax* (c. 54 species) is the flagship palm genus for conservation in the Caribbean Island Biodiversity Hotspot. *Coccothrinax* has its centre of taxonomic diversity in these islands, with c. 51 endemic species. We present a conservation framework for the 14 Critically Endangered species, found in Cuba, Haiti or the Dominican Republic. Only two species (*C. jimenezii*, *C. montana*) occur in more than one country (Haiti and the Dominican Republic). Immediate threats include oil drilling and nickel mining, intrusion of saline water into soil, urban and agricultural development, low population recruitment, uncontrolled fires, interspecific hybridization, and unsustainable ethnobotanical practices. *Coccothrinax bermudezii*, *C. borhidiana*, *C. crinita* ssp. *crinita*, *C. leonis* and *C. spissa* are not conserved in protected areas. *Coccothrinax bermudezii*, *C. jimenezii*, *C. leonis* and *C. nipensis* are not part of ex situ collections. Based on results from a conservation project targeting *C. jimenezii*, we recommend international cooperation between the three range states to implement integrative conservation management plans, plant exploration initiatives, taxonomic revisions, outreach, and fundraising. The ultimate aim of this review is to provide baseline information that will develop conservation synergy among relevant parties working on *Coccothrinax* conservation in Cuba, Haiti and the Dominican Republic. Such collaborations could also benefit through partnerships with botanists working in other countries.

Keywords Antilles, Arecaceae, IUCN, plant biodiversity, red lists, taxonomy, tropical islands

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Introduction

Palms are an iconic feature of the Caribbean landscape and are associated with strong folk and ethnobotanical traditions (Liogier, 1978; Leiva Sánchez, 1999). The Caribbean Islands hold 103 endemic species of palms, with Cuba (65) and Hispaniola (20) hosting the majority (Moya & Leiva Sánchez, 2000; Roncal et al., 2008; Freid et al., 2014). The islands have two endemic palm genera: *Hemithrinax* (four species) from Cuba and the monotypic *Zombia* from Hispaniola. The most widespread genera with endemic species can be divided into two major groups. The first group (c. 18 endemic species in 10 genera) has few species in the Caribbean Islands but many taxa from the Neotropical mainland. The second group comprises genera with their centre of diversity in these islands (c. 80 species in six genera: *Coccothrinax*, *Copernicia*, *Gaussia*, *Pseudophoenix*, *Roystonea* and *Thrinax*) and with few species occurring on the mainland (Zona et al., 2007; Roncal et al., 2008). Among them, *Coccothrinax* is the genus with the highest number of species in the Caribbean Islands.

Coccothrinax is regarded as being taxonomically difficult and in need of further systematic revision (Zona, 1997). Two prior taxonomic revisions focused on species from Cuba (León, 1939) and the southern Greater Antilles (Bailey, 1939). Prior to these two works, Burret (1929) provided a taxonomic account of the taxa on Cuba and Hispaniola. However, Burret's (1929) publication was based solely on material collected by the Swedish botanist and plant collector Leonard Ekman (1883–1931). In the 1980s the Hungarian botanist A. Borhidi (1932–) and the Caribbean botanist O. Muñiz (1937–2007) described new species for Cuba,

resulting in a palm catalogue for the island (Muñiz & Borhidi, 1982). Additional attempts were made to clarify the taxonomy of *Coccothrinax* (Nauman & Sanders, 1991a, b), based on phylogenetic analyses of morphological traits mostly observed from cultivated plants.

The current taxonomic uncertainties within this genus arise, in part, from the work of Henderson et al. (1995), whose influential field guide for New World palms recognized only 14 species. Nevertheless, most palm taxonomists and botanists working on the Caribbean Islands (e.g. Moya & Leiva Sánchez, 2000; Acevedo-Rodríguez & Strong, 2012; Greuter & Rankin, 2016) do not follow that narrow taxonomic view and still recognize many species that were synonymized by Henderson et al. (1995). For instance, *C. jamaicensis* and *C. proctorii* are currently regarded as distinct species endemic to Jamaica and the Cayman Islands, respectively (Proctor, 2012; Duno de Stefano & Moya, 2014). Likewise, botanists from Cuba and Hispaniola still accept *Coccothrinax* species that Henderson et al. (1995) synonomized (e.g. González-Oliva et al., 2014, 2015; Peguero et al., 2015b; Verdecia, 2015).

The current available taxonomic framework for *Coccothrinax* is not the result of a single monographic endeavour, and therefore as a working taxonomy for our contribution we follow the classification system currently accepted by most palm biologists and plant taxonomists working in the region (Fig. 1). Therefore, we consider that the genus has 54 species, with 51 of these endemic to the Caribbean Islands (Fig. 1). These island endemics are restricted to the Bahamas and the Greater Antilles (except Puerto Rico). The taxonomic placement of *C. alta*, thought to be endemic to Puerto Rico and the Virgin Islands (Acevedo-Rodríguez & Strong, 2005), needs further study. In this review, *C. alta* is considered a synonym of *C. barbadensis* following the recent treatment of Acevedo-Rodríguez & Strong (2012).

Two Caribbean species (*C. argentata* and *C. barbadensis*) are found both on the islands and on the mainland, and only one species (*C. readii*) is restricted to the mainland (Fig. 1). The vast majority of Caribbean Island endemic species are single-island endemics, with the exception of *C. fragrans* (found on Hispaniola and Cuba). Reports of the presence of *C. jamaicensis* on the small islands of Providencia, Colombia (Galeano-Garces, 1986), and Swan, Honduras (Nelson & Proctor, 1994), need to be validated by additional taxonomic studies. For intraspecific taxa, *C. alexandri*, *C. clarensis*, *C. crinita* and *C. salvatoris* have one subspecies each, and *C. miraguama* has three subspecies.

Given its high number of species, many with restricted ranges in the Caribbean Islands, *Coccothrinax* provides a good case to study regional species conservation issues in the Caribbean. We provide a review of conservation challenges and perspectives for the 14 Critically Endangered species of *Coccothrinax* that are restricted to the Caribbean Islands, covering (1) relationships between taxonomy and conservation, (2) integrative species conservation management, (3) in situ and ex situ conservation, (4) plant exploration, (5) the role of DNA data in understanding phylogenetic relationships and patterns of genetic diversity, and (6) outreach and environmental education.

Based on our own conservation initiatives we assert that international collaboration within the region provides the best possible approach to deal with these six issues. Similar conservation challenges are faced by other threatened endemics of the Caribbean Islands (reviewed by Maunder et al., 2008, 2011, and Carey et al., 2014), and we propose that conservation initiatives centred on *Coccothrinax* could be applied effectively to other taxa. A main goal of this review is to provide a framework for land managers, conservationists, palm biologists and environmental educators that will offer a regional perspective for what we consider the flagship palm genus for conservation in the Caribbean Islands. This is particularly relevant as this Biodiversity Hotspot comprises several countries with a range of historical and sociological backgrounds (Maunder et al., 2008, 2011).

Data collection pertinent to ex situ conservation of these threatened species in botanic gardens, as well as literature reviews, were conducted during January 2016–March 2017. Field observations were conducted during 2015–2016.

Ecology, biology, and conservation biology of the Critically Endangered species of *Coccothrinax*

Red List assessments of *Coccothrinax* species

Zona et al. (2007) assessed the conservation status of species of *Coccothrinax* of the Caribbean Islands using the IUCN Red List categories and criteria (IUCN, 2001, 2014). Other Red List assessments have targeted *Coccothrinax* and other endemic plant species of the Cayman Islands (Burton, 2008), Cuba (Rankin Rodríguez & Areces Berazaín, 2003; Berazaín Iturralde et al., 2005; González-Oliva et al., 2014, 2015; González-Torres et al., 2016) and Hispaniola (Peguero & Jiménez, 2011; Peguero et al., 2015b). Of the 51 species of *Coccothrinax* endemic to the Caribbean Islands, 16 are categorized as Endangered and 14 as Critically Endangered, with 10 of the latter restricted to Cuba (Fig. 2).

The Cuban endemic *C. camagueyana* was originally described by Muñiz & Borhidi (1981), and is reported from the south of Sierra de Cubitas, Camagüey province (Méndez Santos et al., 1989). It was categorized as Critically Endangered by Zona et al. (2007); however, its taxonomic status is unclear, and more recently it was categorized as Data Deficient (González-Oliva et al., 2015). Field exploration led by CM in 2016 failed to find this species in the location from which it was originally reported (Moya et al., 2017a).

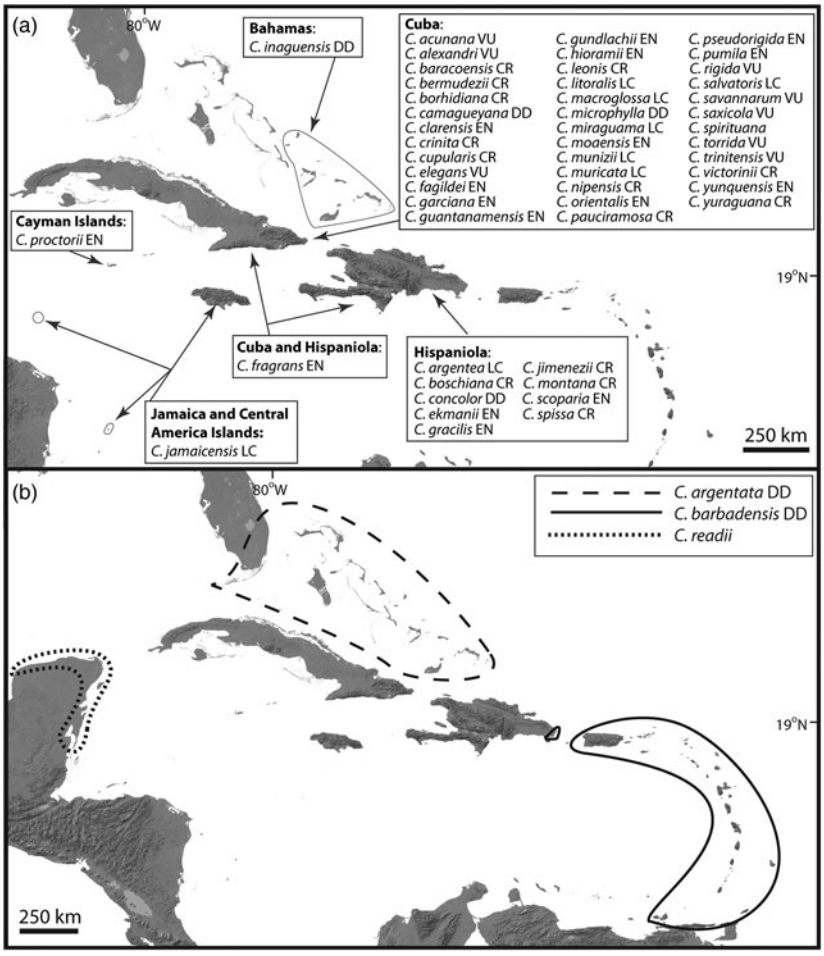

FIG. 1 Geographical distribution and Red List status of *Coccothrinax* species: (a) Caribbean Island endemics; (b) species found both on the Neotropical mainland and on the islands. Red List categorizations (LC, Least Concern; VU, Vulnerable; EN, Endangered; CR, Critically Endangered; DD, Data Deficient) follow the IUCN (2001, 2014) guidelines and come from Zona et al. (2007), Burton (2008), González-Oliva et al. (2014, 2015) and Peguero et al. (2015b). Taxonomy and geographical distribution follow Moya & Leiva Sánchez (2000), Hoyos Fernández & Braun (2001), Acevedo-Rodríguez & Strong (2012), Proctor (2012), Duno de Stefano & Moya (2014), Freid et al. (2014), Peguero et al. (2015a,b), Verdecia (2015), Greuter & Rankin (2016), Moya et al. (2017b) and Jestrow (unpubl. data).

All of the Critically Endangered species have been assigned to this category based on the criteria B1ab or B2ab (IUCN, 2001, 2014; Table 1); i.e. they have an extent of occurrence < 100 km^2 or an area of occupancy < 10 km^2. They are restricted to a single locality or to a fragmented site. In addition, they show continuing decline in their extent of occurrence, area of occupancy, habitat quality, number of sites, or number of mature individuals (IUCN, 2001, 2014). Eight of these species are shown in Plates 1 and 2.

Ecology, distribution and demography

Of the 14 Critically Endangered species of *Coccothrinax*, most occur on limestone soils, with six Cuban taxa (five species and one subspecies) occurring on serpentine soils (Table 1). Only five species occur in coastal environments (Table 1). One of the two populations of *C. jimenezii* occurs on the fringes of Lago Enriquillo in the Dominican Republic, a hypersaline lake 45 m below sea level, which is currently expanding (Romero Luna & Poteau, 2011), and where the wild populations are threatened by saline intrusions (Peguero et al., 2015a).

Among the inland species, the Hispaniolan endemic *C. montana* occurs at the highest elevations, to 1,700 m; it was described from the Cordillera Central in the Dominican Republic and the Massif de la Selle in Haiti (Burret, 1929). However, its distribution is poorly understood, with populations reported from three disjunct sites in the Dominican Republic (Cordillera Septentrional, Cordillera Central, and Sierra de Bahoruco) and two sites in southern Haiti (Massif de la Hotte and Massif de la Selle) (Burret, 1929; Judd, 1987; B. Peguero, unpubl. data). We have no recent data on population size and distribution ranges for *C. montana* except from the Massif de la Hotte, where there are two populations of fewer than seven individuals each (B. Jestrow, unpubl. data), and from Bahoruco, where a single population with very few individuals is known to exist. Fieldwork is needed to determine the taxonomic and distribution status of this species both in Haiti and the Dominican Republic. Reports of the Hispaniola endemic *C. spissa* in northern Haiti (Bailey, 1939) need to be confirmed (Henderson et al., 1990).

We have population estimates for only five of the 14 Critically Endangered species of *Coccothrinax* (Table 1). *Coccothrinax cupularis*, *C. leonis*, *C. nipensis* and

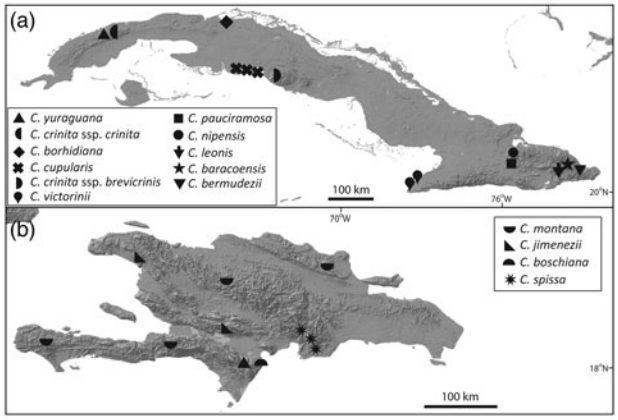

FIG. 2 Distribution of the 14 Critically Endangered species of *Coccothrinax*. (a) Cuban taxa; the three sites for *C. cupularis* represent the distribution range of the highly fragmented population of this species. (b) Hispaniolan taxa.

C. pauciramosa each have a single but dispersed population comprising scattered individuals; fieldwork is required to confirm their distribution range, population sizes and demographic status.

Population recruitment has been recorded for six taxa (Table 1). Based on preliminary field observations, both *C. yuraguana* and *C. pauciramosa* also appear to have recruitment in their single locations. *Coccothrinax jimenezii* has low levels of recruitment, with seedlings found only in the Dominican Republic population (Peguero et al., 2015a). There are no population size estimates for eight species.

Conservation challenges

Our review identified six major threats (Table 2). Two of these threats (population decline; urban, agricultural and forest development) affect 11 of the Critically Endangered species. Threats from invasive alien plant species, unsustainable ethnobotanical exploitation, and uncontrolled fires are relevant to seven taxa. Poaching for the horticulture trade has been reported only for *C. victorinii*. Four species are at risk because of nickel mining or oil drilling. One species (*C. crinita*) has been detected to hybridize with at least another species of the genus, and one is facing the threat of saline intrusion in soils. Based on our experience in botanic gardens, interspecific hybrids are produced easily in *Coccothrinax*. These threats are likely to intensify in the near future; for example, nickel mining and oil drilling are major development priorities for the Cuban economy (Wacaster et al., 2015). Furthermore, invasive alien plant species are regarded as a major challenge for plant biodiversity management in the Caribbean (Maunder et al., 2008, 2011; reviewed for Cuba by Oviedo Prieto & González-Oliva, 2015, and González-Torres et al., 2016; reviewed for the Dominican Republic by Ministerio de Medio Ambiente y Recursos Naturales, 2012) and will be a major concern for in situ conservation of threatened *Coccothrinax* species. Tourism is an important economic activity in the Greater Antilles (Gayle & Goodrich, 1993), and is a growing industry particularly in Cuba (Hingtgen et al., 2015), where the sector is likely to undergo significant development following the easing of U.S. embargo restrictions and the establishment of formal diplomatic relationships in July 2015 (Hershberg & LeoGrande, 2016). This may result in an intensification of human pressure on Cuban ecosystems, with a potential negative impact on endemic palms (González-Torres et al., 2016).

Five of the Critically Endangered taxa are not recorded from protected areas (Table 1), and those found within protected areas of the Dominican Republic are also of major conservation concern. From our field observations it appears that most of these protected areas (with the exception of Parque Nacional Nalga de Maco and Reserva Científica Quita Espuela) have poor conservation enforcement (Powell & Inchaustegui, 2009; Pasachnik et al., 2016).

Eleven of the Critically Endangered taxa are cultivated in botanic gardens (Table 1). These collections are located in Cuba (five botanic gardens), the Dominican Republic (one), Spain (one), and USA (two) and they are based on wild collected germplasm. Four of the Critically Endangered species of *Coccothrinax* are not held in ex situ conservation collections (Table 1).

Conservation biology research

Only four taxa have been the focus of conservation research that included population size studies, ethnobotanical surveys, ecological studies or seed germination protocols (Table 2). *Coccothrinax jimenezii* is the only Critically Endangered species that has been the subject of conservation genetics studies (Jestrow et al., 2016a). This work was based on microsatellite markers and included the two known populations of the species, with the majority of individuals being sampled. Levels of genetic differentiation between the two populations of *C. jimenezii* are unusually high compared to those reported among populations of other palm species. This suggests that species delimitation within *Coccothrinax* needs to be re-evaluated, and a clear taxonomic framework for conservation initiatives is needed. Despite their small size, both populations of *C. jimenezii* have a relatively large number of unique alleles and there is no evidence of genetic bottlenecks. Only the population in Haiti exhibits evidence of inbreeding, with a moderately high positive inbreeding coefficient value ($Fis = 0.232$ vs $Fis = 0.093$ for the Dominican Republic population). Recent habitat fragmentation coupled with long generation times could explain the unusually high levels of genetic diversity in these Caribbean species (Jestrow et al., 2016a).

TABLE 1 Red List assessment criteria (sensu IUCN, 2001, 2014), ecology, number of populations, demographics, and the in situ and ex situ conservation status of the 14 Critically Endangered species of *Coccothrinax*.

Taxon	IUCN criteria for Critically Endangered status	Ecology	No. of populations/ No. of individuals	In situ conservation	Ex situ conservation[1] (No. of individuals)
C. baracoensis	B1ab(i,ii,iii,v)+2ab(i,ii,iii,v)[2]	Scrub on serpentine, 10–200 m (Cuba)[2]	1/Unknown[2]	Cuchillas de Toa UNESCO Man & the Biosphere Reserve	JBT[3]
C. bermudezii	B1ab(ii,iii,v)+2ab(ii,iii,v)[2]	Scrub & pine forest on serpentine, 500–700 m (Cuba)[2]	1[4]/< 10,000[2]	Unprotected	Unprotected
C. borhidiana	A4ace;B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v)[6]	Coastal scrub on limestone, 15–20 m (Cuba)[6]	1[4,5]/338[6,7]	Unprotected	FTBG (4), JBM (7), JBN-C (3), JBT(15), MBC (25), PSCT (15)
C. boschiana	A4acd;Blab(i,ii,iii,iv,v)[8]	Coastal scrub on limestone, 5–200 m (Dominican Republic)[9]	1[5]/Unknown[9]	Parque Nacional Sierra Martín García	FTBG (5)[3], JBN-DR (6), MBC[3], PSCT (11)
C. crinita ssp. *crinita*	B1ab(iii)+2ab(iii)[2]	Scrub on serpentine & human-modified savannah, 20–40 m (Cuba)[10]	1[5]/c. 500[2,10]	Unprotected	JBC (9), JBI (11), JBN-C (70), JBT (20)
C. crinita ssp. *brevicrinis*	A2acde;B1ab(i,ii,iii,v)+2ab(i,ii,iii,v);C1[2]	Semi-deciduous forest & human-modified savannah on limestone, 300 m (Cuba)[11]	1[4]/176[2]	Área Protegida de Recursos Manejados Yaguanabo	JBI (8), JBT (5)
C. cupularis	B2ab(ii,iii,v)[2]	Coastal, sub-coastal scrub & evergreen forest on limestone, 5–15 m (Cuba)[2]	1[4,5]/Unknown[2]	Área Protegida de Recursos Manejados Península de Zapata & Paisaje Natural Protegido Guajimico	JBN-C (11), JBI (7), JBT (4)
C. jimenezii	A2abcd+4abcd;B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v);C2a(i)[8]	Scrub on limestone fringe of hypersaline lake, & coastal scrub on limestone, 45 m (below sea level, Dominican Republic), 70–80 m (Haiti)[12]	1[5]/61[12]	Dominican Republic: Parque Nacional Lago Enriquillo e Isla Cabritos	Unprotected
C. leonis	B2ab(ii,iii,v)[2]	Scrub & human-modified savannah on limestone, 100–600 m (Cuba)[2]	1[4]/Unknown[2]	Unprotected	Unprotected

Table 1 (*Cont.*)

Taxon	IUCN criteria for Critically Endangered status	Ecology	No. of populations/ No. of individuals	In situ conservation	Ex situ conservation[1] (No. of individuals)
C. montana	B2ab(i,ii,iii,iv,v);C1 +2a(i)[8]	Montane evergreen forest, cloud forest, & pine forest on limestone, 500–1700 m (Haiti & Dominican Republic)[13,14]	5[4]/Unknown	Haiti: Parc National Pic Macaya, Parc National Morne la Visite; Dominican Republic: Reserva Científica Quita Espuela, Parque Nacional Nalga de Maco	PSCT (2)
C. nipensis	B1ab(ii,iii,v)+2ab(ii, iii,v)[2]	Scrub & pine forest on serpentine, 400–600 m (Cuba)[2]	1[4]/Unknown[2]	Parque Nacional La Mensura–Pilotos	Unprotected
C. pauciramosa	B2ab(ii,iii,v)[2]	Scrub & pine forest on serpentine, 400–900 m (Cuba)[2]	1[4]/Unknown[2]	Parque Nacional La Mensura–Pilotos	FTBG (4), JBT (5), PSCT (2)
C. spissa	A2ace+4ace;B1ab(i,ii, iii,iv,v)+2ab(i,ii,iii,iv, v)[8]	Scrub on limestone, 20–600 m (Dominican Republic)[15,16]	3[4,5]/4,500	Unprotected	JBN-DR (9), MBC (28), PSCT (9)
C. victorinii	A2c;B1ab(ii,iii,v)+2ab (ii,iii,v)[2]	Coastal scrub on limestone, 0–3 m (Cuba)[2]	2/c. 250[2]	Parque Nacional Desembarco del Granma	JBC (4)
C. yuraguana	B1ab(ii)+2ab(ii)[6]	Scrub & pine forest on serpentine, 30–300 m (Cuba)[17]	1[4]/unknown[6,17]	Área Protegida de Recursos Manejados Mil Cumbres	JBN-C (7), JBT[3]

[1]Botanic gardens with ex situ collections based on wild collected individuals are as follows: FTBG, Fairchild Tropical Botanic Garden, USA; JBC, Jardín Botánico de Cupainicú, Cuba; JBI, Jardín Botánico de Cienfuegos; JBN-C, Jardín Botánico Nacional, Cuba; JBN-DR, Jardín Botánico Nacional, Dominican Republic; JBM, Jardín Botánico de Matanzas, Cuba; JBT, Jardín Botánico de las Tunas, Cuba; MBC, Montgomery Botanical Center, USA; PSCT, Palmetum de Santa Cruz de Tenerife, Spain
[2]González-Oliva et al. (2015)
[3]Ex situ collection has seedlings that have not yet been transplanted to the field
[4]Highly fragmented population(s)
[5]Population(s) exhibit(s) recruitment
[6]González-Oliva et al. (2014)
[7]Enríquez Rodríguez et al. (2006)
[8]Peguero et al. (2015b)
[9]Mejía & García (1997)
[10]Leiva Sánchez et al. (2008)
[11]Suárez Oropesa (2015)
[12]Peguero et al. (2015b)
[13]Burret (1929)
[14]Judd (1987)
[15]Peguero et al. (2011)
[16]Veloz et al. (2011)
[17]Urquiola Cruz et al. (2010)

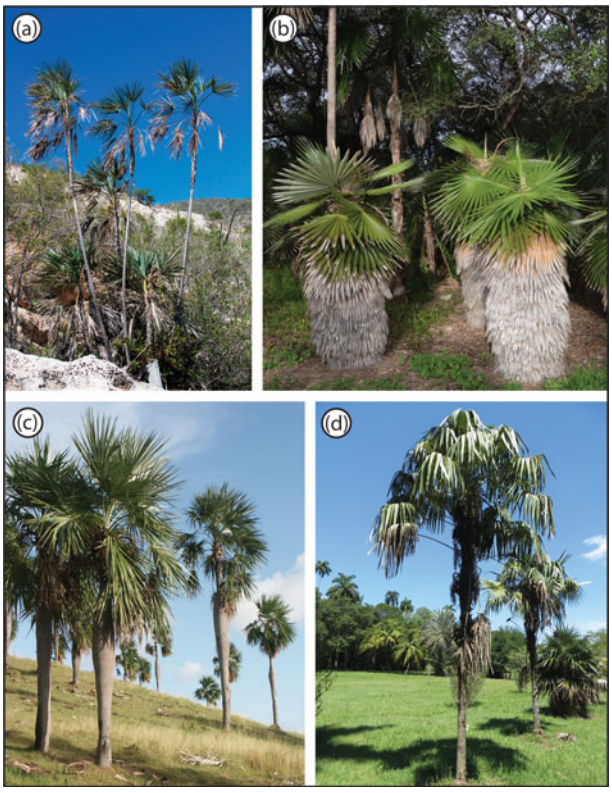

PLATE 1 Critically Endangered species of *Coccothrinax*: (a) *C. jimenezii*, (b) *C. borhidiana* (in ex situ collection of Montgomery Botanical Center), (c) *C. spissa*, (d) *C. victorinii* (in ex situ collection of Jardín Botánico de Cupainicú). Photograph credits: (a) Francisco Jiménez, (b) Patrick Griffith, (c) Scott Zona, and (d) Raúl Verdecia.

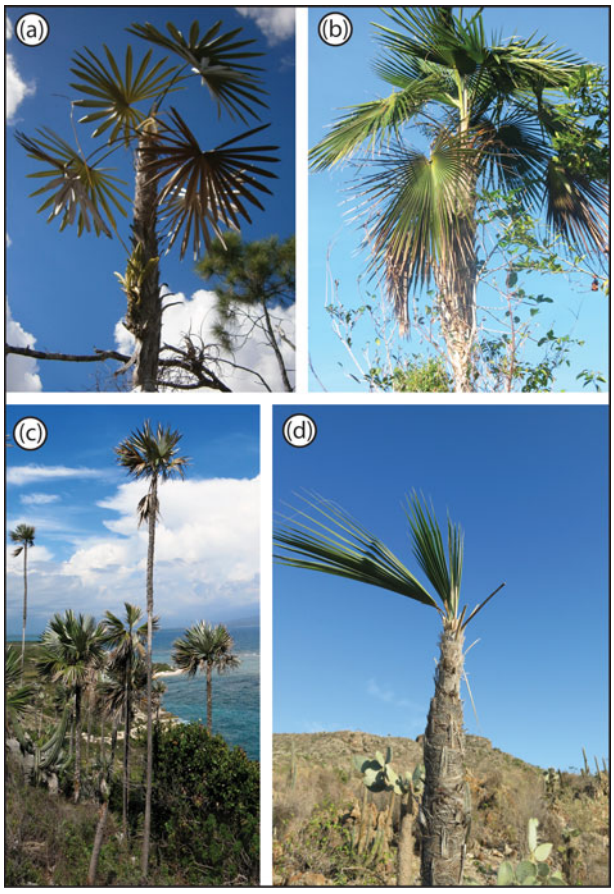

PLATE 2 Critically Endangered species of *Coccothrinax* (all in habitat): (a) *C. yuraguana*, (b) *C. montana*, (c) *C. boschiana*, (d) *C. jimenezii* (heavily harvested to make brooms). Photograph credits: (a) Lisbet González-Oliva, (b–d) Brett Jestrow.

Future genetic studies may find that at least some of the remaining Critically Endangered species of *Coccothrinax* for which there are currently no population genetic data available still harbour high genetic diversity.

Conservation and research agenda

The conservation management of threatened plants faces particular challenges in the Caribbean Islands (Brown et al., 2007; Maunder et al., 2008, 2011; Carey et al., 2014), most notably the diversity of political, cultural and socio-economic systems. We propose the following conservation and research framework for *Coccothrinax*.

Establish a regional conservation approach

Regional cooperation is required to utilize and coordinate the existing skills and resources of the various Caribbean nations more effectively. With endemic Critically Endangered species in three countries, a comprehensive regional approach to the conservation of *Coccothrinax* will require collaboration between managers and plant biologists from Cuba, the Dominican Republic and Haiti. Conservation efforts for *C. jimenezii* have been structured within the context of broad international cooperation led by the Jardín Botánico Nacional (Dominican Republic) and Jardin Botanique des Cayes (Haiti) in association with botanists from South Florida (Fairchild Tropical Botanic Garden, Montgomery Botanical Center, U.S. Department of Agriculture, and Florida International University). There have been extensive plant exploration expeditions in both Haiti and the Dominican Republic, including demographic studies and conservation assessments (Peguero et al., 2015a). Outreach outputs included the production of printed educational material presented during the *VI Simposio Flora de La Española* in June 2015 at Santo Domingo, Dominican Republic. Furthermore, we have established joint initiatives for professional progression of young Caribbean botanists, including two workshops on plant systematics in Haiti, training of one graduate student from the Dominican Republic at Florida International University (Rodríguez, 2014), and developing grant-supported projects for palm conservation through the Prince Bernhard Nature Fund,

TABLE 2 Main conservation challenges and conservation biology research conducted for the 14 Critically Endangered species of *Coccothrinax* (Table 1).

Taxon	Nickel mining or oil drilling	Invasive alien plants	Population decline	Urban, agricultural & forest developments	Uncontrolled fires	Unsustainable ethnobotany	Other challenges	Conservation biology research
C. baracoensis	Nickel[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	No[1]		
C. bermudezii	No[1]	No[1]	Yes[1]	Yes[1]	No[1]	No[1]		
C. borhidiana	Oil[2,3]	No[2]	Yes[2]	Yes[2]	Yes[2]	Yes[2]		Ecology[3]
C. boschiana[4,5]	No[4,5]	No[4,5]	No[4,5]	No[4,5]	No[4,5]	No[4,5]		
C. crinita ssp. *crinita*	No[1]	Yes[1]	No[1]	Yes[1,6]	No[1,6]	Yes[6]		Ethnobotany[6], ecology[7,8]
C. crinita ssp. *brevicrinis*	No[1]	Yes[1]	Yes[1,9]	Yes[1]	Yes[1]	Yes[1]	Hybridization[10]	Ecology[9]
C. cupularis	No[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]		
C. jimenezii	No[4]	No[4,11]	Yes[4,11]	No	No[4,11]	Yes (Plate 2)[11]	Saline intrusion in soils[11]	Conservation genetics[12], ecology[11]
C. leonis	No[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	No[1]		
C. montana	No[4]	No[4]	Unknown	Yes[4]	Unknown	Unknown		
C. nipensis	Nickel[1]	No[1]	Yes[1]	Yes[1]	Yes[1]	No[1]		
C. pauciramosa	Nickel[1]	Yes[1]	Yes[1]	Yes[1]	Yes[1]	No[1]		
C. spissa[13,14]	No[4]	Unknown	Yes[13,14]	Yes[13,14]	No[13,14]	Yes[13,14]		Ecology[13,14], ethnobotany[13,14], seed germination[13,14]
C. victorinii	No[1]	Yes[1]	Yes[1]	Yes[1]	No[1]	Yes[1]	Adult plants are transplanted to gardens in urban & resort developments	
C. yuraguana	No[2,15]	No[2,15]	Yes[2,15]	Yes[2,15]	No[2,15]	Yes[2,15]		

[1]González-Oliva et al. (2015)
[2]González-Oliva et al. (2014)
[3]Enríquez Rodríguez et al. (2006)
[4]Peguero et al. (2015b)
[5]Mejía & García (1997)
[6]Martínez Betancourt & Miranda (2009–2010)
[7]Leiva Sánchez et al. (2008)
[8]Martínez Betancourt (2016)
[9]Suárez Oropesa et al. (2013)
[10]Suárez Oropesa (2015)
[11]Peguero et al. (2015a)
[12]Jestrow et al. (2016b)
[13]Peguero et al. (2011)
[14]Veloz et al. (2011)
[15]Urquiola Cruz et al. (2010)

the International Palm Society, and the Mohamed bin Zayed Species Conservation Fund.

Botanists from the Dominican Republic have developed successful protocols for seed germination of *C. spissa* (Peguero et al., 2011; Veloz et al., 2011), which may also be applicable for the Critically Endangered species from Cuba. Across the distribution range of *Coccothrinax* there are field botanists and palm taxonomists who are familiar with its ecology and morphology. Their preliminary surveys suggest that hybridization detected in botanic gardens is also common in areas where species overlap (Suárez Oropesa, 2015). Caribbean island conservation biologists working with this genus have also gained experience regarding unsustainable ethnobotanical practices, and are familiar with the challenges faced by land managers and administrators regarding implementation of effective protection in the protected areas of Cuba, the Dominican Republic and Haiti. Preliminary molecular results suggest that the microsatellite loci used for *C. jimenezii* (Jestrow et al., 2016a) are also applicable to other species of this genus. The experiences already gained by individual teams provide a framework for development of a biodiversity strategy for *Coccothrinax* in the region.

Establish a scientific framework for conservation

A phylogenetic analysis and taxonomic review would clarify the conservation status of *Coccothrinax* taxa. For instance, *C. jimenezii* was described as a new species in 2013 (Mejía & García, 2013) but molecular studies revealed uncertainties in the taxonomy of the two populations of this species (Jestrow et al., 2016a), highlighting the need for a comprehensive taxonomic revision for *Coccothrinax*. The morphological phylogenetic study of the genus undertaken by Nauman & Sanders (1991a,b) identified three major groups, each one including Critically Endangered species, with high levels of homoplasy for the morphological characters. Molecular phylogenetic reconstructions for *Coccothrinax* (Roncal et al., 2008) did not resolve major clades. However, the conservation genetics study of *C. jimenezii* (Jestrow et al., 2016a) demonstrated the utility of microsatellite DNA markers for insights into both genetic diversity and taxonomy. There are still many gaps in knowledge of the biology of the species, and there have been no studies focused on breeding systems, plant–animal interactions, competition from invasive alien plant species, or population viability analyses.

Assess and monitor wild populations

There is a need to expand botanical field work in the range nations, particularly in Hispaniola, where there are still under-collected areas, mostly in Haiti. Although Cuba and the Dominican Republic have maintained a tradition of botanical fieldwork and research, Haiti has not had sustained support for field botany. Both the Dominican Republic and Haiti have a single botanic garden, and are key to developing a framework for future conservation initiatives. Through our inter-institutional collaborations (mostly supported by the Mohamed bin Zayed Species Conservation Fund), members of our team have been exploring areas of Haiti seldom visited since Ekman was there in the 1920s (Jestrow et al., 2016b). Fieldwork led by RV resulted in the rediscovery of *C. rigida* on limestone cliffs near Sagua de Tánamo (Holguín province) in 2014 (Verdecia et al., 2014). This species had not been seen since it was described by Grisebach (1866) based on material collected by the American plant explorer Charles Wright (1811–1885). Recent plant exploration activities led to the discovery of a new species, *Coccothrinax spirituana*, in Cuba by CM and RV (Moya et al., 2017b). This new species is currently known in a single locality in the province of Sancti Spiritus in an area of serpentine soils. Studies focusing on its demography and distribution range are in progress.

There are four *Coccothrinax* species that have not been located since they were originally discovered. The first, *C. acunana*, was described by León (1939), and plants of this species were reported to occur only in the highest mountains of Cuba, near Pico Turquino, in the province of Santiago de Cuba. The species is categorized as Vulnerable on the Red List for the Cuban flora (González-Torres et al., 2016); however, its conservation status needs to be reassessed. The second species, *C. microphylla*, is another Cuban endemic, described by Muñiz & Borhidi (1981). It appears to be restricted to limestone cliffs of Abra de Mariana in the lowlands of Guantanamo province. The third species, *C. concolor*, is known from only one herbarium collection, by Ekman in 1926. The species was described by Burret (1929) and reported from low-elevation areas with volcanic soils near Jacmel, southern Haiti (Bailey, 1939). The fourth species, *C. camagueyana*, not only has an uncertain taxonomic status but has not been found since it was described (Moya et al., 2017b).

Ensure wild populations are protected in situ, with supporting ex situ collections

The Critically Endangered species of *Coccothrinax* are facing a variety of threats. Five of the species are not present in protected areas, and four are not included in ex situ germplasm collections. An integrative approach to conservation is the most immediate priority (Esposito, 2002; Petriello & Wallen, 2015). We are aware that in many cases official protected areas are not sufficiently resourced to ensure viability of wild populations; however, both Cuba and the Dominican Republic have protected areas with effective

conservation management. Ex situ conservation is necessary in some cases; for instance, the Dominican Republic population of *C. jimenezii* is facing an immediate threat from the increasing water level of the hypersaline lake Lago Enriquillo, and the small population in Haiti is overharvested.

Establishing an ex situ resource should be part of an integral approach for conservation planning that involves all stakeholders (Pritchard et al., 2012; McGowan et al., 2017). Ideally this resource would be held primarily in the range state, and should ensure adequate genetic representation (Oldfield, 2009). There are botanic gardens located outside the Caribbean Islands that have ex situ conservation of palms as a mission priority (Maunder et al., 2001). Several of these (e.g. Fairchild Tropical Botanic Garden, Montgomery Botanical Center, and Palmetum of Tenerife) are already collaborating with botanists from Hispaniola and Cuba to develop representative living collections that hold duplicates of living germplasm collections and can mitigate issues regarding limited space and resources for ex situ conservation.

Conclusions

This review is derived from a 15-year collaboration focused on the palm diversity of the Greater Antilles. Based on the results of our research of the conservation biology of palms, we have proposed specific initiatives for the conservation of the most threatened species of *Coccothrinax*. Our collaborative approach to integrative plant conservation provides a model for other groups of conservation concern. This model is based on regional collaboration, building a framework for genetic conservation, and ensuring the professional progression of new Caribbean botanists. We acknowledge the need for increased conservation awareness of these species, particularly in the communities where they occur.

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Author contributions

BJ, BP, FJ and WC led field work in Hispaniola and reviewed conservation challenges for Haiti and the Dominican Republic. CEM, RV and LGO led field work in Cuba and reviewed conservation challenges for Cuba. MPG made significant contributions pertinent to ex situ conservation. AWM provided insights regarding conservation genetics. BJ, JFO and MM developed the proposed conservation and research agenda and wrote the first draft of the article. BJ and JFO led grant proposals to undertake this project, and designed and developed the structure of this study.

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