The Cocais Forest Landscape

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Abstract

The Cocais Forest landscape unit is named as such due to the large number of "cocais," the generic word referring to the fruits from the main native species that populate this landscape, the palms. The Cocais Forest is located in the north-northeast region of Brazil, spanning the states of Maranhão, Piauí, and Tocantins. The unit is characterized by great natural beauty and unique biodiversity. It occurs on smooth, molded topographic terrain, predominantly over sedimentary rock from the Parnaíba Sedimentary Basin and is influenced by diverse climates. The vegetation in this landscape is exuberant, with predominance of many palm species that represent a transition biome between the Amazon, the Cerrado (regional name for Brazilian savanna) and the Caatinga (regional name for Brazilian dry, hot steppe). Because of its transitional character, the forest displays a physical complexity that is still poorly understood. Owing to the growing economic potential of the region, primarily driven by the expansion of the agricultural sector, the Cocais Forest landscape is undergoing a number of environmental changes.

Keywords

Cocais forest · Transition zone · Tablelands and plateaus · Northeast of Brazil

8.1 Introduction

The Cocais Forest landscape unit is a mosaic of plant communities associated with a set of geomorphological compartments, the nature of the geological substrate, and specific climatic conditions. It is, above all, an intertropical transitional corridor associated with the contiguous landscape domains known as the semi-humid region, the forested areas of the Amazon, and the semiarid region. This corridor is formed by plant communities characterized by the predominance of diverse palm trees (Fig. 8.1). It is estimated that the flora in the Cocais Forest is comprised of more than 500 species, including the babaçu (*Orbignya phalerata*), juçara (*Euterpe oleracea*), buriti (*Mauritia flexuosa*) and carnaúba (*Copernicia prunifera*), with a high degree of endemism at all taxonomic levels (Pinheiro 2011).

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Fig. 8.1 Vegetation displaying typical palm trees of the Cocais Forest, Urbano Santos municipality (state of Maranhão). *Photo* Helen N. Barreto (2017)

Fossil evidence indicates that the presence and distribution of palms dates back to the Cretaceous (~65 mya) (Lewis et al. 2000) and that these palms originated geographically in South America and dispersed into Africa, Australia and the Northern Hemisphere continents (Moore 1973). The geographical distribution of the Cocais Forest corresponds to a large longitudinal area, spanning the Brazilian states of Maranhão (60%), Piauí, Tocantins, Pará, Ceará, Goiás, and Mato Grosso. However, the core area of the Cocais Forest landscape unit is located on the coast of Maranhão State, extending southwest, north of Tocantins State and northeast of Piauí State. Therefore, the forest extends from the equatorial Atlantic coastline, mostly in Maranhão State, to the highlands of the Piauí-Maranhão Sedimentary Basin Plateau (Fig. 8.2).

The Cocais Forest landscape is part of the Brazilian Legal Amazon and corresponds to compartmentalized sedimentary tablelands and plateaus located at elevations between 30 and 600 m, with interfluves and shallow slopes in the different types of upland. It has a dense drainage network controlled by structural features that influence the drying of the landscape and its soil cover attributes. The climate in the region is a transition among several climate types, resulting in a combination somewhat unique to the Cocais landscape and is determined by the interaction of climate processes, phenomena, and mechanisms; thus, the Cocais Forest is a complex landscape of

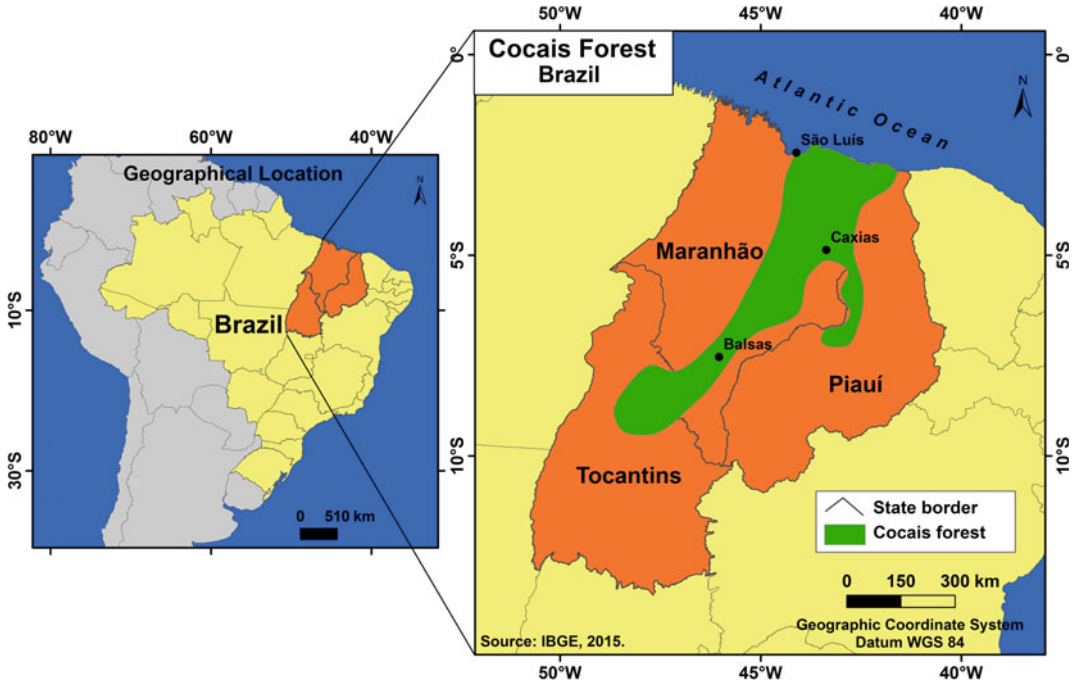

Fig. 8.2 Location of the Cocais Forest in the states of Maranhão, Piauí and Tocantins

singular scenic beauty and great environmental relevance.

8.2 Climate

Because it is located in the transition zone between biomes characterized by hot and super-humid (west), hot and dry (east), and hot and semi-humid (south) climates, the Cocais Forest is influenced by three distinct climates: humid equatorial, semiarid tropical, and semi-humid tropical, respectively. Figure 8.3 shows the annual temperature (°C) and rainfall (mm) cycles for the municipalities of Balsas, Caxias, and São Luís, located in the southern, east-central and northern regions of the Cocais Forest, respectively (Fig. 8.2). The wet season begins in the southern section (October through April) and extends to the east-central (December through May) and northern (January through July) sections of the Cocais Forest in response to the higher air temperature occurring in the preceding months (Fig. 8.3).

The humid equatorial climate is hot (annual temperature between 26 and 28 °C) and wet (mean rainfall greater than 2000 mm), characteristic of the westernmost portion of the Cocais Forest (20%), and covers the far west sides of the states of Maranhão and Tocantins. Its proximity to the super-humid equatorial climate of the Amazon makes the vegetation more exuberant on the west sides of these states, with abundant rainfall throughout the year, low annual temperature range, and lack of winter (Marengo and Nobre 2009). However, the occurrence of a short dry season (three months) on the west side of the Cocais Forest characterizes its climate as humid equatorial. The greatest influence of the humid equatorial climate on the Cocais Forest occurs in the summer (December–January–February) and especially in the fall (March–April–May), when negative (positive) anomalies in the sea surface temperature (SST) in the tropical North (South) Atlantic Ocean are observed, respectively, resulting in stronger trade winds from the northeast and greater humidity input to the region.

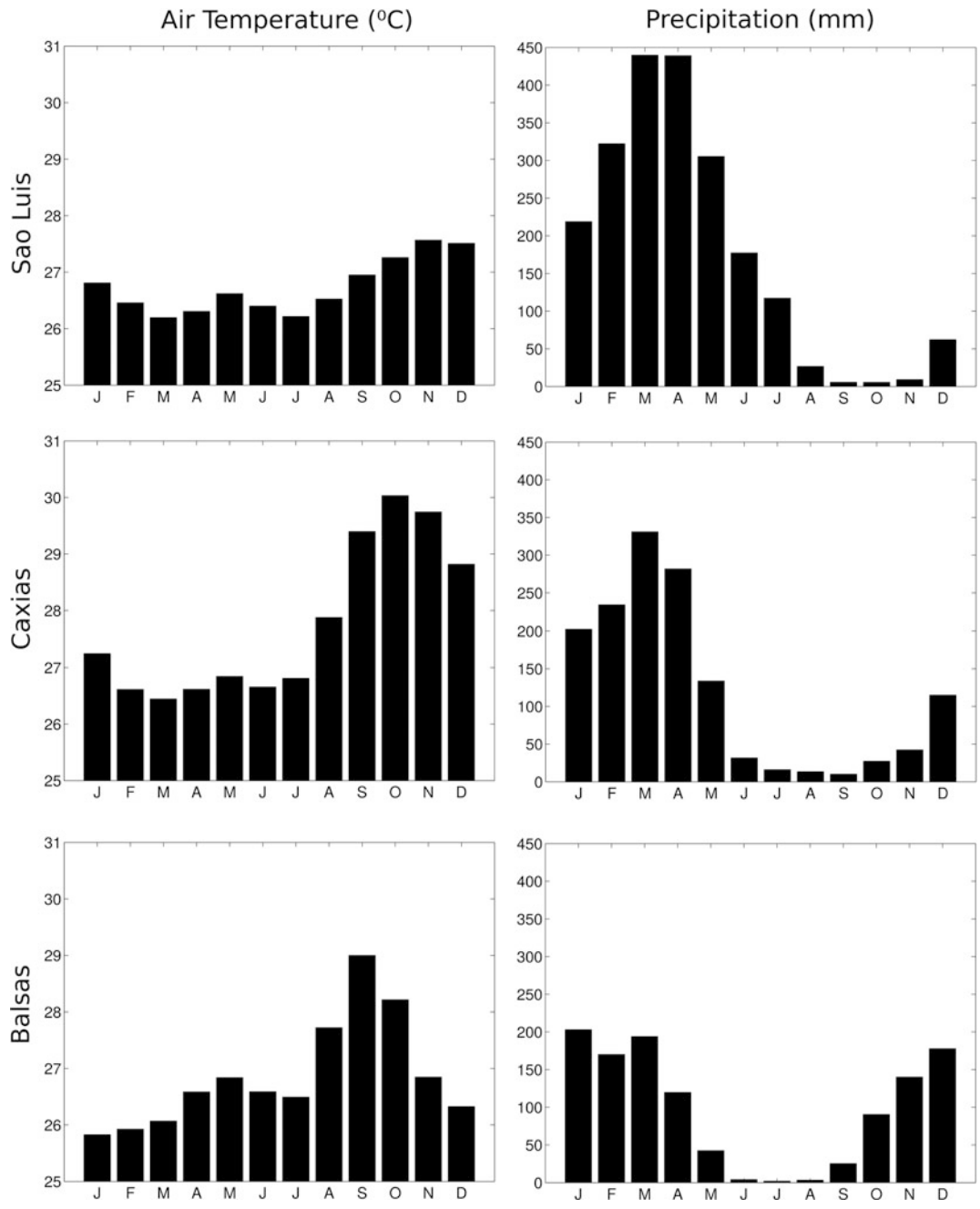

Fig. 8.3 Annual air temperature (°C) (station level) and rainfall (mm) cycles (1980–2016) for the municipalities of São Luís, Caxias and Balsas located in the state of Maranhão, representing the northern, east-central and southern portions of the Cocais Forest, respectively

The eastern portion of the Cocais Forest (approximately 15%) is characterized by strong solar incidence, relatively high temperatures and a rainfall regime marked by scarcity, irregularity and concentration over a short period (three months on average), with insufficient water

reserves in the headwaters, thus favoring the predominance of carnaúba palms (Pinheiro 2011). Among the climates influencing the Cocais Forest, the semiarid tropical is the driest (relative humidity approximately 50%), with high evaporation and evapotranspiration rates (between 1000 and 2000 mm per year) and low, irregular rainfall (between 500 and 1000 mm), characterizing the negative water balance in the region. The dry season can last up to 11 months per year, or even persist for several consecutive years in certain locations, which, in association with the high solar incidence, results in mean annual temperatures between 20 and 28 °C (Kayano and Andreoli 2009).

The marked interannual variability in rainfall is one of the main factors leading to the occurrence of drought events in the region, which are characterized by a substantial decrease in the total seasonal rainfall during the wet season. The eastern portion of the Cocais Forest is also one of the regions of South America where seasonal and intraseasonal variability are most evident. Its hot and dry climate is associated with factors such as (i) the displacement of a high-pressure system that diverges the surface air during winter, preventing the convergence of water vapor in the region; (ii) the presence of impermeable rocks that prevent water accumulation in the soil and the subsequent input of moisture to the system; and (iii) the topographic profile, which blocks moist winds from the Atlantic Ocean. Seasonal variations in the magnitude and position of the South Atlantic Subtropical High (SASH), with maximum intensity in July, of the North Atlantic Subtropical High (NASH), with maximum peaks in July and February, and of the equatorial trough (moisture convergence region) determine the climate in the eastern sector of the Cocais Forest (Brito et al. 2007).

The semi-humid tropical climate that influences the south-central portion of the Cocais Forest (65%) is hot but less humid than the humid equatorial and humid tropical (or humid coastal) climates due to its relative distance from the ocean. The mean annual temperature is approximately 21 °C, with daily and annual ranges (the latter from 23 to 36 °C) greater than those observed in the humid equatorial climate. The rains are concentrated in the summer, with total annual rainfall between 1200 and 2000 mm (Torres and Machado 2012).

The coupled (ocean-atmosphere) phenomenon known as the El Niño Southern Oscillation (ENSO) over the central and eastern equatorial Pacific together with the tropical Atlantic regulates a large portion of the interannual variability in the climate of the Cocais Forest. Typically, the Cocais Forest is drier (more humid) relative to normal years in El Niño (La Niña) years, although dry events in the area are not always related to ENSO events (Ronchail et al. 2002; Marengo et al. 2008). The interannual and decadal variability in the climate of the Cocais Forest is associated with SST anomalies that are out of phase between the tropical North and South Atlantic Oceans, which affect the position and intensity of the Intertropical Convergence Zone (ITCZ) over the equatorial Atlantic Ocean, exerting a dynamic control over the beginning and end of the wet season in northern and northeastern Brazil (Nobre and Shukla 1996; Marengo et al. 2001).

8.3 Geology

Geologically, the Cocais Forest landscape is composed mainly of lithological units consisting of clastic material from the Coastal structural province and the Parnaíba Sedimentary Basin province. The coastal structural province corresponds to marine deposits and Pleistocene and Holocene eolian covers that accumulate on the Atlantic coast. The Parnaíba Sedimentary Basin province corresponds to part of one of the largest sedimentary basins in Brazil, with approximately 600,000 km^2 located in the western section of northeast Brazil Rabelo and Nogueira (2015). The basin originated from the subsidence of a large craton formed according to the main fracture systems and successive staggering of faults and fractures (Góes 1995). The intersections at these rupture lines generated large mosaics or blocks responsible for the disposition of the rocky layers in the main NE/SW, NW/SE, and N/S directions. The genesis of the basin is related to the Brasiliano

cycle and resulted in diverse chronostratigraphic units due to a long period of sedimentary deposition and climate diversification (CPRM 1978).

The main lithological substrate in this landscape includes successions of marine deposits and quaternary eolian covers in the coastal area followed by sedimentary and volcanic rocks of Neoproterozoic-Paleozoic age that originated in the intra-craton Parnaíba Basin (Almeida et al. 1981; Brito Neves et al. 1999; Brito Neves and Fuck 2013). These units (IBGE 2011a) correspond predominantly to coastal marine deposits; Holocene eolian covers; Pleistocene colluvium; detritic-lateritic coverages (Miocene-Pliocene); meso-Paleozoic sandstone formations known as Itapecuru, Codó, Grajaú, Corda, and Sambaíba; and the Mesozoic basalts of the Mosquito Formation.

The quaternary lithological units correspond to the Holocene eolian covers and the coastal marine deposits. Eolic covers (40–80 m) are fine- and medium-grained sand with cross-stratifications that form the majority of the conservation unit known as Lençóis Maranhenses National Park. Marine deposits (0–40 m) are medium-grained, unconsolidated sandy accumulations. In the Cocais Forest, these accumulations are located in the southeastern section of Maranhão State, mainly on Maranhão Island and near the mouths of the Mearim, Itapecuru and Periá rivers.

Paleogenic lateritic covers on tablelands (100–200 m) occur in the subcoastal portion of Maranhão State and have underlying contact with the Itapecuru Formation (Cretaceous). This formation is composed of reddish sandstone and siltites and grayish shales, with predominance of argillites, and occurs primarily in the transition from the tablelands to the dissected plateau (200–350 m) at the middle Itapecuru, Mearim and Munim rivers and the lower Parnaíba River. Sparse patches of the Codó Formation (early Cretaceous) occur in this region, particularly near the municipality of Presidente Dutra (Maranhão State). This formation is composed of dark-gray, black and greenish shale interspaced with siltite, sandstone, limestone, and gypsite.

The lithological units associated with the transition from the dissected plateau of the middle Itapecuru and Mearim rivers to the tablelands at the upper Itapecuru and Parnaíba rivers (350–550 m) consist predominantly of sandstone formations with the presence of basalts. The Itapecuru Formation (Cretaceous) is located at the top of the regional sequential sandstone formations and has a distinct composition in this compartment, essentially consisting of fine- and medium-grained quartz sandstone that originated from river channel deposits from a riverine deltaic depositional system (Nascimento and Góes 2007). These sandstones occur predominantly in the south-central portion of Maranhão State and outcrop in the escarpments of the Itapecuru Mountains and in the Alpercatas and Itapicuru river valleys.

In addition to the Itapicuru Formation, lithological sandstone units interbed and outcrop clearly along the west-central portion of Maranhão State where tablelands (known as chapadas) occur. Among these units is the Grajaú Formation (early Cretaceous), consisting of yellow sandstone that occurs along the upper Mearim River and one of its main tributaries, the Grajaú River. The Corda Formation (Jurassic), at the lower border, consists of fine sandstone associated with the deposition from a humid desert system in the area Rabelo and Nogueira (2015). The Sambaíba Formation (Triassic-Paleozoic), also of desert origin (Vaz et al. 2007), is composed of massive reddish sandstone with eolian-derived sediments.

The tholeiitic basalts of the Mosquito Formation that correspond to an extensive ($\sim 10^5$ km^2) magmatic event related to the opening of the North Atlantic Ocean during the Triassic-Jurassic occur at the upper border of the Corda and Sambaíba Formations. The basaltic extrusions in the west-central area of Maranhão state are $\sim$175 m thick (Baksi and Archibald 1997) and are part of the expressive Central Atlantic Magmatic province. $^{40}Ar/^{39}Ar$ dating indicated an estimated age of $\sim$199 mya (Marzoli et al. 1999; Merle et al. 2011). Both formations occur mainly in the upper Mearim and Parnaíba river basins and in the middle Tocantins Depression.

At the highest elevations, between 450 and 600 m, which correspond to the tablelands at the Upper Itapecuru (Maranhão), Parnaíba (Piauí/Maranhão) and middle Tocantins rivers, sandstones

are covered by tertiary detritic–lateritic deposits that are associated with the superficial hardening and preservation of the tableland features. In the lower portions, there is accumulation of Pleistocene colluvium, which is aggregated and laterized sandy-clayey sediments of colluvial-alluvial origin that cover extensive erosion surfaces.

8.4 Geomorphology

With elevations varying from 50 to 60 m from the coast to the interior, the Cocais Forest is composed of flat plateaus and smooth escarpments, sculptured predominantly in sandstone substrate and sandy soils. The smooth compartments are located in a portion of the coastal and subcoastal areas, where tableland and hilly features are observed. Highlands predominate in the higher elevation interior portions in the south-central and southeastern areas of Maranhão State and north of Tocantins State.

The Cocais Forest landscape unit has morphological compartments that differ from the Atlantic coast to the interior due to the degree of dissection of the terrain. The main landscapes in these compartments were described in the geomorphological mappings performed by IBGE (2011b) at a regional scale (1:1,400,000). These compartments are part of two large morphostructural units: the Quaternary sedimentary deposits and the Phanerozoic sedimentary basins and covers. The main landscapes in these compartments are as follows: (i) Lençóis Maranhenses; (ii) Subcoastal Tablelands; (iii) the Dissected Plateau of the middle Itapecuru and Mearim rivers; and (iv) the Plateaus of the upper Itapecuru and Parnaíba rivers (Figs. 8.4, 8.5 and 8.6).

Fig. 8.4 Dunes and lagoons at Lençóis Maranhenses, municipality of Barreirinhas (Maranhão State). *Photo* André A. R. Salgado (2013)

Fig. 8.5 Terrain characterized predominantly by smooth features in the tableland and subcoastal hill compartments in the southeast area of Maranhão State, municipality of Vargem Grande. *Photo* Helen N. Barreto (2017)

The Lençóis Maranhenses geomorphological unit (Fig. 8.4) is part of the Quaternary Deposits morphostructural unit on the southeast coast of Maranhão State, between São Luís Bay and the Parnaíba River Delta. The terrain is sustained by the sedimentary rocks of the Barreiras Group with a lower degree of lithification. In this landscape, the contrast between mobile dunes and fixed dunes is noteworthy. The mobile dunes are of great scenic beauty and reach 30–40 m in height on the more remote areas along the coastline. The fixed dunes span through coastal tablelands and/or quaternary plains on extensive flat surfaces with elevations between 20 and 80 m and become progressively larger toward the interior. Lagoons are formed between these dunes.

The Subcoastal Tablelands (Fig. 8.5) are located past the Lençóis Maranhenses dunes and occupy portions of the lower Mearim, Itapecuru and Parnaíba rivers. These highlands correspond to sedimentary structures dissected into tableland with rounded edges, forming shallow sloped hills. The highlands are underlain by sediments of the Barreiras Group or, secondarily, by the highly eroded, thick sandstone regoliths of the Itapecuru Formation (Cretaceous). The elevation varies from 100 to 200 m.

The Dissected Plateau of the middle Itapecuru and Mearim rivers is a terrain unit that represents the transition between the low hills of the subcoastal area and the large plateaus in central Maranhão State. The plateau is characterized by extensive flat surface areas with shallow slope gradients sculpted on unconsolidated sedimentary covers, where hills and tableland interfluves with little topographic contrast are prominent. The smooth wavy terrain represented by isolated conical hills, as well as the absence of typical tablelands in this area, differentiates it from the

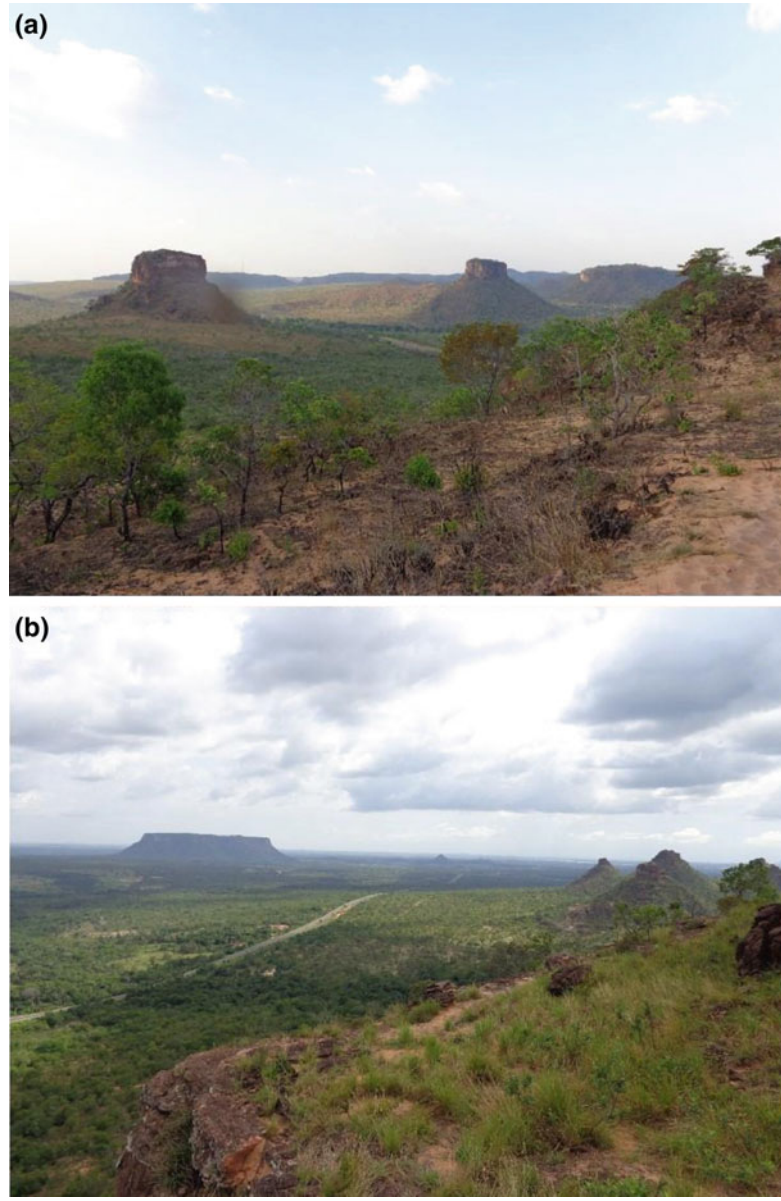

Fig. 8.6 Dois Irmãos Table (A) and Chapéu Table (B), residual terrains of the Chapada das Mesas at the middle Tocantins River, municipality of Carolina (Maranhão State). *Photo* Helen N. Barreto (2017)

other regional terrain units. The elevation typically varies from 200 to 350 m.

The plateaus of the upper Itapecuru and Parnaíba rivers (Fig. 8.6) represent the domain characterized by extensive residual terrains, particularly the plateaus of the upper Itapecuru River and the middle Tocantins depression. In this tableland landscape, the formations known as Serra do Itapecuru, Serra das Alpercatas, Chapada do Agreste, Serra Vermelha, Croeira, and Chapada das Mesas are the most prominent. The residual terrains, regionally dominated by mesas, become progressively more isolated near the middle Tocantins River at the regional base level of southwest Maranhão State and northern Tocantins State. The geological structures are generally covered by extensive packages of altered sandy material, forming flat surfaces that extend from the bottom of the plateaus to the river valleys. The elevation varies from 400 to

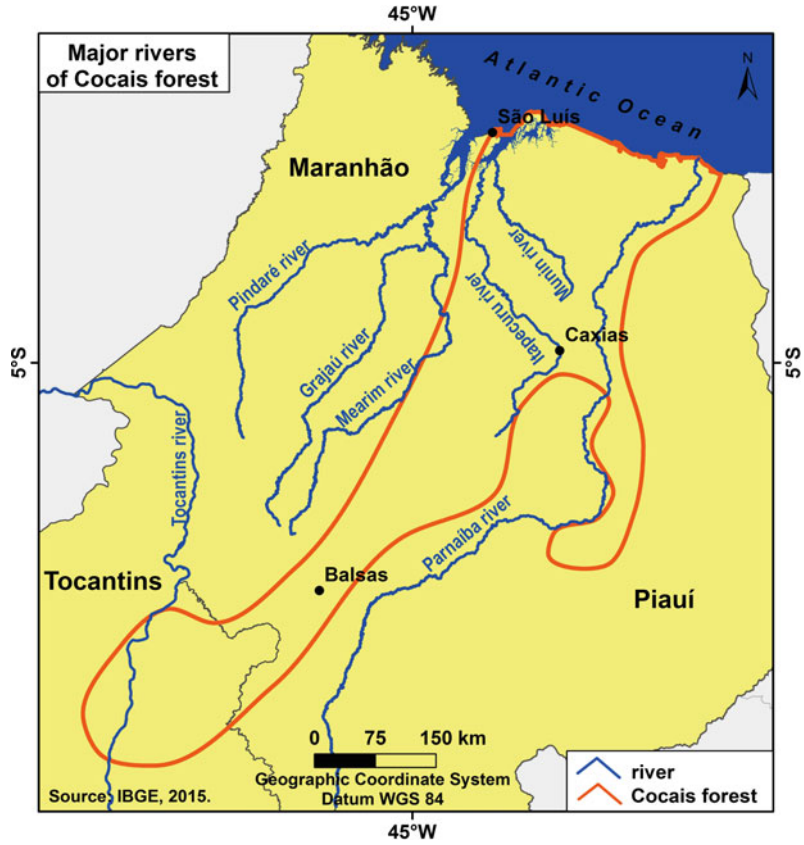

Fig. 8.7 Major rivers in Maranhão State

550 m. The region is characterized by arches, caves, canyons, and ruins, where typical karst processes are important morphogenetic mechanisms (Martins et al. 2017).

8.5 Hydrography

The hydrographic network of the Cocais landscape is characterized by large rivers that flow across the southwestern and central portion of Maranhão State, north portion of Tocantins State and northeast portion of Piauí State. The nearly 190 km long regional boundary of four large river basins—Mearim, Itapecuru, Tocantins, and Parnaíba—is located southwest of Maranhão State (Fig. 8.7). The Parnaíba and Tocantins rivers are among the largest rivers in this unit, but their headwaters are located outside of the unit boundaries. The Mearim and Itapecuru river basins occupy the largest part of the landscape unit, occurring at topographic elevations of up to 600 m, and their valleys have extensive surfaces that extend from the bottom of the plateaus to the valleys' respective watercourses. An exuberant gallery forest is present at the bottom of the valley, where sediments and organic matter residues accumulate and the humidity is high, leading to occasional flooding.

The middle Tocantins River is bordered by a group of plateaus sustained by sandstones from the Sambaíba Formation and represents the regional base level between the states of Tocantins and Maranhão. On the right margin, the main tributaries are the Farinhas and Manoel Alves Grande rivers, with headwaters in the Serra do Gado Bravo. These rivers drain the largest part of the Chapada das Mesas National Park. The Farinhas River and its tributaries form several rapids, and waterfalls, such as the Prata and São

Romão waterfalls. In this area, the headwaters of the middle Tocantins, Parnaíba, Mearim and Itapecuru rivers represent a regional orographic.

The set of tableland features is divided by broad, flat-bottomed river valleys that correspond to the channels of the Itapecuru, Alpercatas, and Parnaíba rivers. The headwaters of the Itapecuru River are located in the Serra do Itapecuru within the conservation unit known as Mirador State Park, and its main tributary is the Alpercatas River. The Mearim River headwaters are located in the Serra da Croeira. The Mearim and Itapecuru rivers run parallel, and both flow into the Atlantic Ocean at a coastal strip formed predominantly by a dune field. The Parnaíba River also flows into the Atlantic Ocean at the border between the states of Maranhão and Piauí, forming an extensive estuarine floodplain (IBGE 2011b) with sandy islands in numerous channels. The Parnaíba River Delta is the largest open sea delta on the South and North American continents.

In addition to being a water divider, the drainage system is generally associated with geological structures of different orders. In this regard, the lithostructural features play a critical role in the organization of the regional drainage network, which is adapted to the structural lineaments of densely fractured sandstone formations (Barreto et al. 2015). These structures form a rectangular and sub-rectangular drainage pattern and provide a large water infiltration and storage capacity. The topographic slope develops into beautiful canyons, gorges, and waterfalls. The magnitude of the landscape and the peculiar terrain features represent an important geomorphological heritage that has fueled the tourism industry in the region.

The current drainage network represents the evolution of the relief dissection phases since the formation of the Parnaíba river basin. Overall, the morphogenesis is predominantly mechanical and dissection appears as flat-topped ridges. The degradation of the lateritic cover that sustains the residual relief at the Cocais Forest and, consequently, the exposure of sandstone layers with high degrees of alteration, intensify the river dissection process. Moreover, many river valleys, particularly those that have canyons, were created as a result of the collapse of ancient caves and underground conduits, evidencing the occurrence of typical karst processes in the river morphology. Thus, river capture phenomena multiply in the main regional hydrographic boundaries. Another important aspect associated with mechanical erosion is the accelerated silting of waterways. In addition to the natural tendency toward erosion, anthropogenic activities, such as burns, deforestation, and expansion of soybean and sugarcane plantations, have caused significant impacts on the river dynamics and the region's water regime.

8.6 Soils

The soils in the Cocais Forest are influenced by the characteristics of the sedimentary lithology dominant in the states of Maranhão, Piauí, and Tocantins. The soils also vary according to the terrain features, climate types, water availability, and vegetation cover. This variability spans from the unique characteristics of the flatter coastline to the highest regional plateaus of the upper Itapecuru, Parnaíba and middle Tocantins rivers. In this landscape, a variety of soils are predominant according to the most recent surveys by the Mineral Resources Research Company (CPRM 2013) at a 1:750,000 scale and the Brazilian Institute of Geography and Statistics (IBGE 2011c) at the 1:400,000 scale.

Quartz-rich Arenosols occur westward of the coastal plain of Maranhão State (Lençóis Maranhenses) in smooth terrain (elevations ranging from 20 to 40 m), where dunes underlain by sedimentary rocks of the Barreiras Group are predominant. These soils correspond to deep quartz soils with sandy texture and low water and nutrient retention capacity. Iron–humus Podzols occur in areas of greater organic matter accumulation at depth. The large Parnaíba River Delta is located on the east side of the coastal plain, at the border between the states of Maranhão and Piauí, with extensive depositional facies. In this area, riverine, marine and eolian sediments accumulate, along with the occurrence of clay and sand-clay terrain covered by mangroves, where Gleysols are predominant.

Eutrophic fluvic Arenosols with high natural fertility occur in the river floodplain, where there is greater organic matter accumulation.

The transition from the coastal area to the interior plain (60 km) of the Subcoastal Tablelands is higher in elevation (100–200 m). This stretch is characterized by flat to wavy topography and lithological substrate of the Barreiras Group and predominantly by sandstone of the Itapecuru Formation. These soils display characteristics associated with the depositional facies of the Itapecuru Formation (IBGE 2011a) and are classified as well-drained, high fertility soils varying between argic/luvic Plinthosols, petric Plinthosols and red–yellow Acrisols. In flooding areas of the main river valleys and in depression areas, hydromorphic soils, such as Gleysols, are predominant.

Sandstones of the Corda and Itapecuru Formations with a high degree of weathering and capped by a lateritic layer are predominant on the tableland surfaces of the Dissected Plateau in the middle Itapecuru River. Deep, well-drained and low-fertility yellow Ferralsols occur at the highest elevations (350–450 m) in these regional surfaces. These soils are associated with concretionary, deep and iron-rich petric Plinthosols that indicate past alternation between droughts and floods, creating a horizon with reddish and yellowish patches. Yellow and red–yellow Ferralsols develop in the hills and lower plateaus (300 m) of the Mearim river basin. This area is highly dissected by Mearim River, which is underlain by fine sandstone from the Grajaú Formation and sandstone and argillite from the Itapecuru Formation.

The sandstone of the Sambaíba Formation and volcanic-derived basalt of the Mosquito Formation are predominant at the highest elevations (450–600 m) in the Cocais Forest, which correspond to the plateaus of the Upper Itapecuru and Parnaíba rivers. The plateau surfaces at this level are capped by lateritic crusts that sustain these structures. Two types of soil occur in extensive areas of the plateaus. Deep, well-drained and low-fertility soils such as dystrophic red–yellow Ferralsols predominate in areas with Sambaíba sandstone. High-fertility soils, such as eutrophic red Nitisols occur in areas covered by Sambaíba sandstone and are associated with volcanic extrusions. The abrupt, weathered and silicified escarpments of the Itapecuru Formation develop from the top of the plateaus toward the river valleys (200–300 m). Shallow soils, such as protic Arenosols, Lixisols, Plinthosols, and rock outcrops prevail in these areas. Yellow Ferralsols, red Ferralsols, and quartz-rich Arenosols predominate on the flat surfaces of river valleys where sandy sediments from the sedimentary weathered rocks accumulate.

The favorable conditions of the terrain and the regional climate historically allowed the use of the land for extensive cattle farming. Cocais Forest land is currently used for agriculture, particularly soybean and corn cultivation, and silviculture. These practices compete with extractivism in areas such as those areas of babaçu production and preserve the existing palm trees to an extent. In the last twenty years, the agricultural and livestock farming expansion transformed the area into a new agricultural frontier for the country, and consequently, deforestation increased soil erosion. Even in flat areas with smooth terrain, water erosion has impacted the soil due to the use of machinery and inappropriate management practices. The main impacts of agricultural expansion to the soil are associated with water erosion, the natural fragility of some soil types, use of machinery and improper management practices. These factors cause silting of waterways and increase the number of eroded areas in the rural zone, such as gullies and rills.

8.7 Vegetation

The Cocais forest is a typical landscape of Maranhão State and Piauí State, although it occurs within a transitional zone between several phytogeographic domains (Rios 2001). Rios (2001) highlighted that the Cocais Forest is interspaced with grassland areas to the north, Cerrado vegetation to the south and east, and forest fragments to the west.

Azevedo (2002) noted the existence of two types of forests in the state of Maranhão, a

Fig. 8.8 Palm species of the Cocais Forest. Preguiça river basin, municipality of Barreirinhas. *Photo* André A. R. Salgado (2013)

rainforest, which extends from the Gurupi River to the Mearim River, and a decidual forest, located east and south of the rainforest. The babaçu palm (*Attalea speciosa* Mart. ex Spreng.) is predominant in the decidual forest areas, characterizing a secondary vegetation; the presence of palms may be indicative of environmental disturbance either by deforestation or burns (Sampaio 1933; Viveiros 1943).

Farias and Castro (2004) also noted that the Cocais Forest is located in an ecotonal zone, influenced by the Amazon sub-humid climate and by the northeastern semiarid climate. Moreover, the forest is characterized by an extensive vegetation mosaic in the states of Piauí and Maranhão, with different palm species (Fig. 8.8) and a structural arrangement that is not observed in other parts of the country (Santos-Filho et al. 2013).

Different authors highlight the ample distribution of palm populations (family Arecaceae) both in Piauí and Maranhão, including the *babaçuais*—composed by *Attalea speciosa* Mart. ex Spreng., *carnaubais*—represented by *Copernicia prunifera* (Mill.) H. E. Moore, and *buritizais*—due to the presence of *Mauritia flexuosa* L. f. Other species are also observed but to a lesser extent, such as tucum—*Astrocaryum vulgare* Mart., bacaba—*Oenocarpus minor* Mart., macaúba—*Acrocomia aculeata* (Jaqc.) Lodd ex Mart., pati—*Syagrus cocoides* Mart. and catolé—*Syagrus comosa* (Mart.) Mart (Romariz 1996; Lorenzi et al. 2004).

According to Veloso and Strang (1970), *Babaçuais*, or babaçu formations, are known as Open Ombrophilous Submontane Forests with palm trees, which are also recognized by the IBGE (2012). Ribeiro and Walter (2008)

classified palm formations as a feature of the Cerrado biome. In recent studies on the vegetation physiognomy of the Piauí State coast that include palms, Santos-Filho et al. (2010) described the features observed in the area "as carnauba palms interspersed with herbaceous fields".

Babaçuais in the northwestern portion of Piauí State and northeast portion of Maranhão State are concentrated in areas of higher humidity, occurring in transition zones bordering the equatorial latifoliate forest (Romariz 1996) and between several phytogeographical domains (Rios 2001) in different regions of Brazil (Santos-Filho et al. 2013). The dominance of babaçu is due to the fast development of the species, among other factors (Nunes et al. 2012). *Carnaubais* are found in the northern portion of Piauí State, with vegetation extending to the northeast of Ceará State, following the coastline (Santos-Filho et al. 2010) and reaching the area northeast of Rio Grande do Norte State (Ab'Saber 2006). *Buritizais* develop along water courses, forming vegetated tracks (known as *veredas*), and are typical of the Cerrado (Romariz 1996; Ribeiro and Walter 2008), as observed in Piauí State.

Based on reports by Gardner (1975), Santos-Filho et al. (2013) noted that the high density of palms that characterizes the Cocais Forest could be a result of economic anthropogenic activities, particularly deforestation for the expansion of pastures for cattle raising and wood extraction, which occurred between the eighteenth and nineteenth centuries. Moreover, the region considered an ecotone, mainly in Maranhão State, was characterized by a pre-Amazon forest. However, studies on these palm species and their respective recruitment and ecological succession characteristics showed that the large populations palm species in the region are due to intensive degradation of the original forest.

Despite the rich biodiversity in the Cocais Forest, there are currently many negative impacts caused mainly by anthropogenic activities, such as expansion of the agricultural frontier with soybean and sugar cane plantations; the opening of pasture areas for extensive cattle farming (Fig. 8.9); silviculture for extraction of some palm species, among others. This landscape is subjected to high vegetation degradation due to rapid anthropogenic occupation, which results in loss of biodiversity.

The variety of genera and species of palms play an important role in the local economy. Extractivism in *babaçual* areas is an important source of income for family-based farmers who rely on the sale of *babaçu* nuts and oil. Moreover, babaçu palm generates several subsistence products, such as coal and crafting and building materials (Pinheiro 2011).

The conservation units located within the Cocais region in the state of Maranhão include the Lençóis Maranhenses National park (156,584 ha, northeast area), Mirador State Park (437,845 ha, south-central area), Chapada das Mesas National Park (159,951 ha, southwest area), Upaon-Açu/Miritiba/Alto Preguiças environmental protection area (1,535,310 ha, northeast area) and the Morros Garapenses environmental protection area (234,768 ha, lower Parnaíba River). However, the implementation of management plans for these conservation units and the implementation of other means of support for the communities via sustainable development strategies are needed to ensure the survival and protection of the Cocais Forest.

8.8 Final Considerations

The Cocais Forest landscape unit is a transitional area of great environmental relevance and longitudinal extension. The diversity of palm species and derived products ensure a source of income and sustainability for the local communities. The landscape harbors a remarkable geomorphological heritage, including the headwaters of the main rivers and great tourist attractions, such as the Lençóis Maranhenses National Park and the Chapada das Mesas National Park. In turn, the flat plateaus favor the implementation of large agricultural projects, particularly soybean and sugar cane plantations, and extensive livestock farming. In that regard, the unit today is threatened by the expanding agricultural frontier, which leads to native forest and soil degradation.

Fig. 8.9 Deforestation and implementation of pasture areas for cattle and goat farming in the municipality of Itapecuru-Mirim (Maranhão State)

However, scientific studies have been conducted to better understand the environmental and social dynamics and to provide a basis for government action and programs related to the use, occupation and conservation of the Cocais Forest.

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