Chapter 5
Igapó Ecosystem Soils: Features and Environmental Importance

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5.1 Amazonia Wetlands

Wetlands are defined as those areas episodically or periodically flooded by the lateral overflow of rivers or lakes and/or by direct precipitation or outcropping of the water table, so that the biota responds to the physical-chemical environment with morphological, anatomical, physiological, and etiological specific structures and characteristics of those communities (Junk et al. 1989; Cunha et al. 2015). A total of 8.3 and 10.2 million km^2 of the Earth's surface is expected to be made up of these environments (Mitsch et al. 2009; Oliveira 2017), about 30% concentrated in the tropical regions of the planet.

The vegetation in the Amazon is heterogeneous since it is formed by a diversity of highly distinct habitats; it is a unique territory due to the indescribable variety of its flora and fauna. It includes nine countries in South America where Brazil contains the largest share, 63.4% of the total (Ayres 2006). It is bordered by the massifs of the Guianas and Central Brazil to the north and south, respectively, and to the west by the Andes. It shelters the longest river system and with the greatest liquid mass in the world, covered by the largest tropical rainforest. The Amazonas drains more than seven million square kilometers of land and is, by a large margin, the river with the highest liquid mass, with an annual average flow of 200,000 cubic

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meters per second (Molinier et al. 1995). This region corresponds to 1/20 of the Earth's surface, 2/5 of South America's surface, 1/5 of the world's availability of fresh water, 1/3 of the world reserves of broad-leaved forests, and only 3.5 thousandths of the world population, with a density of 2 inhabitants/km^2 (MPEG 2017).

About 20% of the Amazon is occupied by the rivers or flooded in a permanent or seasonal character, whose vegetation is denominated floodplain forest: *várzea* and *igapó*. This system is ruled by the "flood pulse" and is responsible for the seasonal variation, resulting from the rainy season and the Andean ice melt (Junk 2010). This arrival of waters bringing nutrients and changing the environment periodically is also responsible for the formation of the soils, either gleysol or luvisols, the main classes of soils related to Amazon dry land flooded ecosystems.

According to Daniels and Nelson (1987), we must abandon the idea that soils are independent entities occurring at specific points and consider that all parts of the landscape are interrelated. Each of these parts is affected and affects adjacent parts, especially those of a slope toward a water gradient. It is required a better understanding of soil-plant environmental relationships, including the physical basis of soil variability as well as temporal changes in the conditions existing in a particular landscape.

The findings that the fertility level of the rivers reflected in the vegetation led most botanists to adopt the criterion "color of the rivers" to separate the flooded forests into *várzea* and *igapó*. Hence, *várzea* forests are those vulnerable to floods by white water rivers, and the *igapó* forest is that flooded by rivers of clear or black water (Prance 1980). The *várzea* forest is characterized by greater richness in nutrients, while the *igapó* is characterized by the acidity and nutrient poverty, which may be related to the quality of its substrate or soil, since the movement of waters, often daily, carries sediment to these areas or removes sediment from these areas.

The main factors for the maintenance of diversity in these environments are the physical and biological processes, among which the hydrological cycle is one of the basic factors (Parolin 2001) since the vegetation of these environments is adapted to survive long periods of complete or partial submersion (Ferreira 2000).

Plant species occurring in flooded forests present different types of phenological, anatomical, physiological, and morphological adaptations in leaves, stems, and roots to survive the periodic flood gradient caused by the fluctuation in the level of the rivers, such as the development of spaces of air in the roots and stems that allow the diffusion of oxygen from the aerial parts of the plant to the roots, formation of adventitious roots, aerenchyma development, morphological changes in the leaves probably to facilitate the underwater exchange of gases, etc. (Parolin et al. 2004; Mommer and Visser 2005).

The combination of adaptations considering seed germination, seedling development, and structure of the roots, stem, and leaves results in a variety of growth establishment strategies among species. This related to the duration of the flood period, types of soil, flooded area types, and tolerance of the plants to flooding leads to specific distributions of the plant species (Parolin 2012).

To understand the dynamics of the Amazon depends on knowledge of this ecosystem and the way plants and animals adapt to floodplains, such as the *igapó* forests, which are areas of the Amazonian biome, regularly flooded. According to Ducke and Black (1954) cited by Prance (1980), *igapó* area is characterized as forest on a soil that never gets dry.

5.2 Igapó Ecosystem: Soil Characteristics and Study Case

Igapó forests cover an area of approximately 180,000 km^2 of the Amazon basin and are in areas with low geomorphological dynamics originated from the pre-Cambrian of the Brazilian Shields and Guianas (Melack and Hess 2010; Iion et al. 2010; Furch and Junk 1997). Historically, those forests are associated with rivers that contain low amounts of dissolved sediment, and therefore low fertility, but with high amounts of humic acids and acidic pH (Prance 1980; Furch and Junk 1997; Junk et al. 2015).

The geology of the substrates over which the rivers flow results in differences in the physical-chemical properties of water, which have a direct influence on the vegetation of the floodplain in the Amazon basin (Sioli 1956). In addition to organizing the confusion in the terminologies used in the past, Prance (1979) defined seven major types of forests subject to flooding and restricted the use of the term "igapó" to forests flooded by rivers of black or clear water.

The most important black water river in Brazil is the Negro River, a large tributary on the left side of the Amazon River, which drains tertiary sediments composed of kaolinitic soils. Its waters have a dark color that derives from the high content of humic substances leached from podzolic soils (Sioli 1968, 1975; Furch 1984).

Clear water rivers, such as the Xingu and the Tapajós, drain severely degraded tertiary sediments, composed of kaolinitic soils, presenting large physicochemical variability and considered intermediates, in relation to the nutritive content, between those of black and white water (Sioli 1975; Prance 1979; Ayres 1993).

Overall, all ecosystems characterized as igapó display a low nutritional status due to the small load of nutrient dissolved and suspended by annual floods (Junk et al. 2015). The so-called flooded soils are characterized by presenting varied natural fertility and the occurrence near the riverbanks. These soils are still poorly explored; some still maintain vegetation cover in the natural forest of the várzeas and igapó with their variations related to the altitude of the terrain and duration of the annual flooding period (Table 5.1). These environments are susceptible to periodic inundations caused by flooding of the rivers (flood pulse) that, while helping to maintain its fertility, makes difficult its use since it requires different management and specific crops.

Table 5.1 Main characteristics of Amazon flooded soil

Soil characterization	Land use characterization	Author
Varzea soils	Areas subject to periodic floods caused by river floods, always offering a new and fertile layer. Those rivers carry fertile sediments, rich in nutrients	Cravo et al. (2002); Carim (2016)
Igapó	Those soils are permanently flooded, narrow, and located in low relief near the rivers Relatively low fertility and low productivity environments. Its soil and water contain a very acidic composition due to the large amount of organic matter in transformation present in their area	Santiago (2017); Carim (2016)

5.2.1 Case Study: National Forest of Caxiuanã

The Caxiuanã National Forest (FLONA) is located in the municipalities of Melgaço and Portel in the state of Pará, about 400 km from Belém, near Caxiuanã Bay, located in the morphotectonic compartment of Gurupá, in the channel of the Amazon River, between the Xingu and Tapajós rivers (Bemerguy 1997) (Fig. 5.1).

The relief of the area is flat and undulating without large elevations (Radam Brasil 1974). The predominant vegetation cover is a lowland dense ombrophilous forest with a canopy ranging between 30 and 40 m in height, and to a lesser extent, other vegetation types, such as periodically flooded forests (igapó and várzeas), open vegetation enclaves of savannahs, campinaranas, and anthropic areas, denominated secondary forests (capoeiras) of different ages and succession stages (Ferreira 2011). The flooded forests of igapó and várzea occupy 12% of the Caxiuanã FLONA area (Pereira et al. 2012) bordering water courses in relatively flat areas (Pereira et al. 2012; Behling 2011).

Pollen analyses of lacustrine deposits indicate that the flooded forests in the Caxiuanã FLONA appeared in the Holocene due to paleoenvironmental changes caused by the neotectonic activities associated with the increase of the level of the Atlantic sea and consequent flooding of terra firme areas (Costa 2002; Behling 2011). Additionally, at the end of the Holocene, the increase in annual precipitation also contributed to the formation of a passive fluvial system and a marked expansion of those flooded forests. These events profoundly modified the geomorphology and hydrodynamics of the Anapú River and its effluents, promoting the blockage of river drainage and the consequent emergence of the Caxiuanã Bay and the chemical change of the rivers in the region (Behling 2011; Costa 2002; Behling and da Costa 2000).

Currently, the Caxiuanã River Basin is classified as a fluviolacustrine environment (Melo et al. 2002), characterized by the absence or low presence of suspended matter (Costa 2002), with a hydrological system classified as monomodal in which fluctuation of the water level is seasonal, influenced by annual and polymodal precipitation regimes influenced by daily tidal regimes with annual fluctuations of 17–21 cm between low and high tide and 33 cm in intertidal regimes (IBGE 1977; Hida et al. 1998).

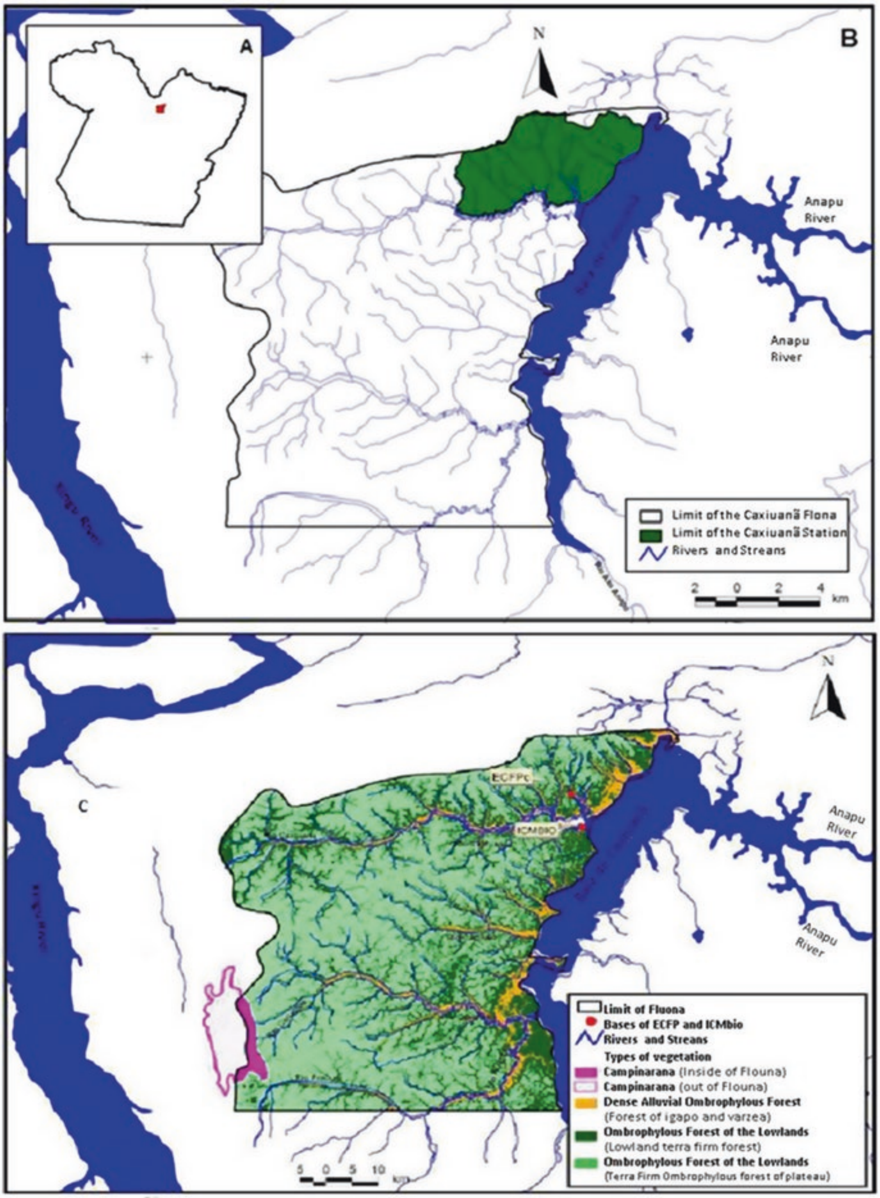

Fig. 5.1 Caxiuanã National Forest in the state of Pará (**a**), the location of Estação Científica Ferreira Penna in relation to Caxiuanã National Forest (**b**) and the vegetation types at Estação Científica Ferreira Penna (**c**)

Because of the geological and hydrological characteristics, the floodplain forests of Caxiuanã present features, like in other regions, related with hydro-geochemistry, soil, and associated vegetation.

Fig. 5.2 General (**a**) and inner (**b**) aspect of igapó forest in Caxiuanã National Forest

Igapó forests in Caxiuanã National Forest are mainly located on the banks of the Curuá River and Caxiuanã River, both effluents of Caxiuanã Bay (Fig. 5.2). These rivers contain a high concentration of humic compounds, low concentration of dissolved oxygen due to the low abundance of photosynthetic organisms in the water, low conductivity indicating poor salt water, high amount of dissolved organic matter, and acidic pH due to the high content of organic acids from the decomposition of organic matter of terrestrial origin (ICMBIO 2012; Melo 2013).

Due to these characteristics, the Curuá and Caxiuanã rivers were described as an environment composed of a heterotrophic community with a likely predominance of an input of organic matter of terrestrial origin (Melo 2013). In addition, the hydro-geochemistry of these rivers is strongly influenced by the intense soil weathering of the drainage basin, mainly consisting of kaolinite, resulting in the prevalence of Na2 + ions in these rivers (Melo et al. 2002; Costa 2005).

The soil of the igapó forest in Caxiuanã is classified as silt-textured gleysol, with low drainage, poor in nutrients, and highly fragile (Piccinin and Ruivo 2012). Gleysol is formed of recent sediments from the Holocene period, being partially or completely flooded during a great part of the year, which facilitates the constant and progressive deposition of suspended particles in the water (Vieira 1975). Morphologically, they are deep soils and imperfectly drained, gray colored, and with silt texture (Costa 2005).

The granulometry of this soil is predominantly formed with clay and mainly silt fractions and is chemically poor since it presents low contents of sum of bases and base saturation, carbon, and cation exchange capacity. Tables 5.2 and 5.3 show average values of the chemistry and grain size of studies of soils carried out in igapó forest in the Brazilian Amazonas. Studies indicate this contribution of nutrients as a determinant factor of species composition and structure of communities in flooded forests (Ferreira et al. 2013, 2005).

Caxiuanã igapó forests are characterized by the great abundance of *Ruizterania albiflora* (Warm.) Marc.-Berti and *Carapa guianensis* Aubl. individuals (Ferreira et al. 2005) and for presenting a higher density of individuals, richness, and diversity of species when compared to Caxiuanã várzea forests (Ferreira et al. 2013) which is uncommon in the Central Amazonia where várzea forests present greater richness and diversity (Prance 1980; Kubitzki 1989; Wittmann et al. 2010; Assis et al. 2014). Results of the monitoring in permanent plots indicate that the Caxiuanã igapó forests presented a higher annual rate of recruitment than mortality, resulting in an increase in the number of individuals per plot over the years inventoried.

5.3 Social Importance of Igapó and the Ecosystem Protection Policies

The Amazon is formed by a diversity of habitats thoroughly distinct and is a unique territory by the indescribable variety of its flora and fauna. About 20% of the Amazon is occupied by the rivers or flooded in a permanent or seasonal character, whose vegetation is denominated of forests of flooded areas: the várzea and the igapó. The findings on the impact of the fertility level of the rivers on the vegetation led most botanists to adopt the criterion “color of the rivers” to separate the flooded forests into várzea and igapó. Hence, flooded forests are those forests likely to be flooded by white water rivers, and forests of igapó are those flooded by rivers of clear or black water (Sioli 1985). The várzea forest is characterized by greater richness in nutrients, while the igapó is characterized by the acidity and poor level of nutrients.

Table 5.2 Mean of the chemical components of soils collected in igapó forests of some studies carried out in the Brazilian Amazon

Chemical composition				mg/dm^3		$cmol_c/dm^3$				mg/kg			
Local	Reference	Depth	pH	P	K	Ca	Ca + mg	Al	H + Al	Cu	Mn	Fe	Zn
Uauaçú Lake, Purus river region, central-western	Haugaassen and Peres (2006)	0–20	4.6	2.2	59.7	0.14		3.28	8.08		40.5	418.8	10.4
Jari River, Amapá	Carim (2016)	0–20	4.4	9.75	0.11	0.052	1.71	1.24	5.9	3.7	370.96	551.08	6.11
Curuá River, Caxiuanã National Forest, Pará	This study	0–20	4.5	7.25	10.19	0.13	0.25	3.48	26.30	15.94	0.89	1095.98	4.79

Table 5.3 Average values of the major physical characteristics of soils collected in igapó forests of some studies carried out in the Brazilian Amazon

Particle size			g/Kg				
Local	Reference	Depth	Thick sand	Fine sand	Sand	Silt	Clay total
Caxiuanã National Forest, Pará	Costa (2002)	0–12	5	90		785	120
		12–20	5	80		755	160
Uauaçú Lake, Purus river region, western Amazônia	Haugaassen and Peres (2006)	0–20	7.5	28		47	16
Jari River, Amapá	Carim (2016)	0–20			80.14	16.78	2.96
Curuá River, Caxiuanã National Forest, Pará	This study	0–20	13	10.375		873.4	103.75

To understand the dynamics of the Amazon depends on knowledge of this ecosystem and how plants and animals adapt to floodplains, such as the igapó forests, which are regularly flooded areas in the Amazonian biome. The igapó areas represent the banks of clear water rivers such as the Xingu River, at the height of Altamira, southwestern Pará, a source of survival and socioeconomic utilization by the river people, fishermen, natives, extractive communities, and potters who give territoriality to it.

Prior to the installation of the Belo Monte Hydroelectric Plant, these activities were well marked by seasonality. During the Amazonian winter, the flood pulse of the river made the igapó an environment that promotes artisanal fishing of species such as tucumaré (*Cichla melaniae*) and surubim (*Pseudoplatystoma fasciatum*). It should be reminded that many fish species depend on floods for feeding and reproduction, invading the flooded forest (igapó) to eat fruits and spawn in protected environments. In the Amazonian summer, management of palm trees such as açaí (*Euterpe oleracea*, Mart) and buriti (*Mauritia flexuosa*) and clay exploitation in the Gleissolos of the fluvial plains of Xingu effluents are carried out for the manufacture and commercialization of bricks in the potteries (Oliveira 2017).

5.4 Final Considerations

The wetlands in the Amazon are associated with the dynamics of the seasonal rise and fall of river waters and mark a morphological adaptation, reproduction, and dispersal by the biota. In the Caxiuanã basin, the study of the igapó areas presents greater complexity since the flood pulse is monomodal and polymodal, responding to the seasonal variation of the precipitation and daily variation of the influence of the tides.

This dynamics originates soils with high humidity, predominantly gleysols, in the Curuá River National Forest, area where the study was developed. Morphologically, the soils present grayish colors and a massive structure. Physically, fine fractions such as silt and clay predominate. Chemically, it presents low levels of K, Na, Ca, and Mg and consequently low sum of bases and base saturation, giving them a dystrophic character. Similar results were obtained by Costa (2002) in Caxiuanã National Forest, Pará, and by Haugaassen and Peres (2006) in Uauçú Lake, in the Purus river region with predominantly silt-textured and chemically poor soils, differing from soils along the Jari River in Amapá with more intense geomorphological dynamics, with the predominance of soils with sandy fractions.

The importance of this type of study is indispensable for the use of these environments by the riverside population, who depends economically on these and areas by means of vegetal extractivism and artisanal fishing, and for the conservation of the igapó that comprise important biological reserves and important centers of interdisciplinary research in the Amazon.

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