Mires and Histosols in French Guiana (South America): new data relating to location and area

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SUMMARY

Large peatland areas have been identified in French Guiana, an equatorial province (département) of France, but the exact distribution and ecological condition of mires is not well known. Maps of pedological and agronomic units that were prepared between the early 1950s and 1975 enable us to improve on previously published estimates of Histosol areas in French Guiana. Only the non-forested parts of the province have been studied because there are hardly any pedological maps for the portion that lies within the Amazon rainforest. The extent of Histosols recorded in French Guiana is around 975 km², which is 57–60 % of the estimates of peatland area (1620 km² and 1720 km²) reported in the scientific literature. The largest Histosol areas are located near the coast in the north-east of the province, between Cayenne and the border with Brazil. This region receives the highest annual rainfall recorded in French Guiana and provides a particularly favourable hydro-geomorphological setting for peat formation. It will be necessary to explore these large Histosol areas in order to characterise them and to study the associated mire vegetation. Difficult access, combined with the adverse hydro-climatic conditions, will make this a long-term endeavour.

KEY WORDS: cartography; equatorial mires; forest; France; pedology; tropical peatland

INTRODUCTION

It is recognised that tropical mires, especially peat swamp forests, contribute substantially to global biodiversity (Posa *et al.* 2011) and play a vital role in carbon cycling because of the huge quantities of organic carbon stored in Histosols (Immirzi *et al.* 1992, Hooijer *et al.* 2006, Rieley *et al.* 2008). Page *et al*. (2011) estimate the volume of tropical peat to be 1,756 Gm^3. Mires in equatorial and wet tropical zones have been progressively destroyed since the 1950s by legal and illegal logging, development of oil palm plantations (mostly in Indonesia), and agricultural expansion such as the large-scale rice projects in south-east Asia and French Guiana. The disruption of tropical mires by deep drainage and fire leads to the release of large quantities of carbon which contribute to increasing the atmospheric CO_2 concentration and thereby to climate change processes.

Although the importance of tropical mires has been increasingly recognised over the last twenty years, our knowledge of their locations and extent in some regions is very incomplete. Those that have been investigated are situated mainly in south-east Asia, whereas African and South American mires have been insufficiently studied. The estimated area of tropical mires is around 400,000 km², or 11–12 % of the global mire area (Immirzi *et al*. 1992, Page *et al.* 2011), of which 57 % (247,778 km²) is located in south-east Asia. There have been comparatively few studies on mires in tropical South America, and most of these have focused on the Amazonian lowlands of Brazil and Peru (Lappalainen 1996, Lähteenoja *et al.* 2009). Mires have been identified in French Guiana, but are inadequately documented. Agro-pedological maps for the département were published by the Institut de Recherche pour le Développement (IRD) in 2001, but hardly consider Histosols (Leprun 2001).

French Guiana is a territory of 83,530 km^2, located in the equatorial zone of northern South America, with a geodesic latitude of 2–6 °N and a longitude of 51–54 °W (Figure 1). Geologically, it is part of the Guiana Shield, which consists of Precambrian rocks affected by the Transamazonian orogeny during the Paleo-Proterozoic era (2260–1950 Ma). Relative tectonic stability allowed planation of the Proterozoic surface, and a volcanic phase related to the opening of the Atlantic Ocean created numerous Dolerite dykes during the Jurassic period (Théveniaut *et al.* 2011). The platform is partly covered by sediments deposited near the coast since the Palaeocene period, and there are coastal bars and mudflats formed from often unconsolidated Quaternary sand and clay. Altitude ranges from sea level to 851 m a.s.l. at the summit of Bellevue de l'Inini, between Saül and Maripasoula (Figure 1).

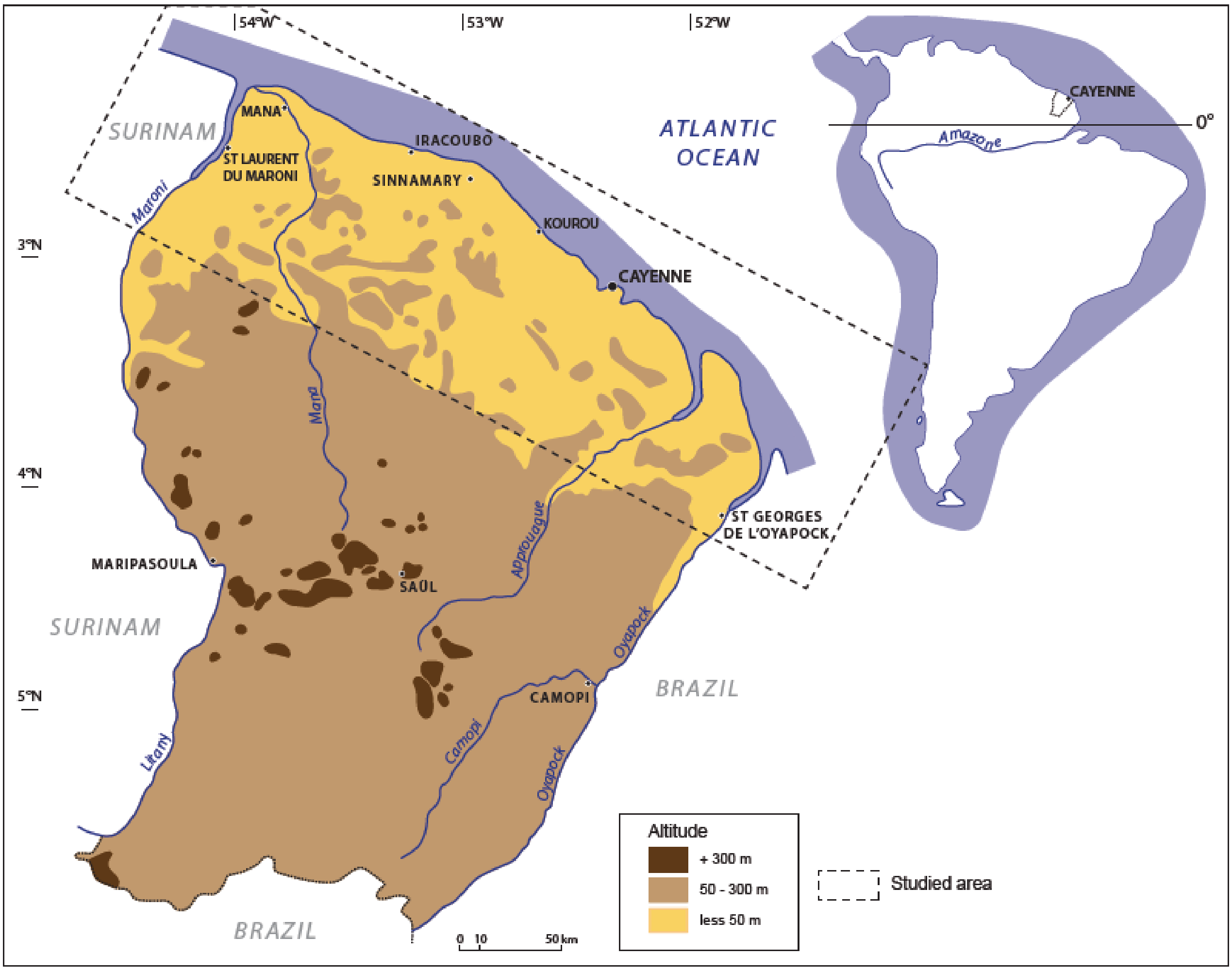

Figure 1. Map of French Guiana showing the focus area for this study. Inset : the location of French Guiana within South America.

In the north-east of the province, average annual rainfall ranges from 3,000 to 4,000 mm, the maximum occurring at the top of the Kaw Mountains (ORSTOM 1975, Pierre 2011) (Figure 1). The climate here is typically equatorial with a very short dry season in October and the beginning of November. Moving south-westwards, annual rainfall decreases to 1,700 mm and duration of the dry season extends to several months.

Rainforest, which is generally well preserved, covers 94 % of the French Guiana territory. Other habitats including savannah, grassland, mangrove and wetland, as well as agricultural and urban areas, are found mostly near the coast and along the largest rivers. Especially in the north-east, the combination of landscape morphology and high rainfall has led to peat formation and, thus, to the development of mires in at least some of the wetland areas. Undisturbed examples are typically forested peatland, as observed at the margins of the River Kaw floodplain (Figure 4).

Several authors estimate the total area of wetland at 4,000 km², or about 6 % of the province (e.g. Chaneac & Legrand 2009), but without elaboration of the hydrological, pedological, botanical and phytosociological criteria that were used to characterise and distinguish them. Indeed, the limitations of the literature prevent the identification of vegetation types that are specific to the mires of French Guiana (oral communication by the Director of the “Herbiers de Guyane”, IRD, Cayenne). Shier (1985), referring to the FAO/UNESCO 1971–1981 world soil map at 1:5,000,000 scale, mentions a “mire area” of 1,620 km^2, corresponding to coastal marshes. Bord na Móna (1985) and Andriesse (1988) also estimated the area of organic soils at 1,620 km², and these figures were borrowed for mires by Immirzi *et al.* (1992) and Pfadenhauer *et al.* (1993). Sieffermann (1988) and Sieffermann *et al.* (1988) mapped coastal peat, and the annotated world soil map shows 1,720 km² of Histosols and 420 km² of gley soils (van Engelen & Huting 2002).

For a region where fieldwork is extremely difficult due to access problems, it would be astonishing that researchers working independently could find such similar areas of Histosols, and it seems much more likely that successive authors simply borrowed data from earlier publications without ever verifying them. Furthermore, the mapped areas of Histosols include the whole coastline, which we know is widely occupied by mangroves growing on soils such as Thiosols and Sulfatosols, even if intercalated peat layers can be found. The thickness of the peat layer can be highly variable, but is reported to reach nine metres in some areas although locations are not defined nor named. No scientific publication describing peat coring has been found.

Therefore, it seems important to produce a more accurate assessment of mire areas in French Guiana, and imperative that this should be supported by the collection of complementary field information. This article describes the development of a new cartography using pedological information collected by the French authorities but never analysed in relation to Histosols and mires, from which a more accurate estimate of the extent of Histosols within the province is derived; it places these peatlands in the context of environmental conditions; and it reports some field observations made in November 2011.

METHODS

Cartography

The new cartography of mires in French Guiana was prepared from two types of maps that were made in the late 1960s and early 1970s by the pedologists of ORSTOM (Office de la Recherche Scientifique et Technique Outre-Mer), which was superseded in 1998 by IRD (Institut de Recherche pour le Développement) (Leprun 2001). These were:

1. Soil maps at scale 1:50,000, which were produced between 1968 and 1974 after numerous fieldwork excursions to French Guiana dating back to the early 1950s. The classification of soils is based on that used by ORSTOM (Aubert 1965).
2. Maps of agronomic units at scale 1:100,000, produced in 1975. The purpose of this cartography was to support the "general plan of development for Guiana" launched in 1975 by the French Agriculture Minister, Mr Olivier Stirn, and it was used in this context.

All of these maps are still available on paper; but can now also be downloaded in PDF format from the database "Horizon", which can be accessed free on IRD's website (http://www.ird.fr/).

In this study, the previously collected cartographic data were analysed using ArcGIS 10.1. All the maps of pedological and agronomic units were assembled and a file opened in ArcMap, with a new layer called « histosol ». Histosols were digitised from the source maps and mapped using the projection RGFG_1995_UTM_22N whose data are found on D_RGFG_1995.

The soil maps clearly show Histosols, coloured blue and integrated with "oligotrophic peaty soils", which are themselves included in "organic soils". "Organic soils" are, in turn, integrated into the large family of "hydromorphic soils". The pedologists distinguish two sub-facies: a pyrite-rich sub-facies and a modal sub-facies. These "oligotrophic peaty soils" are linked either to old continental organic deposits or to clayey and/or sandy marine deposits. When the peat layer is recent and rather thin (less than 50 cm), as generally occurs in the coastal plain, it is classified as "gross mineral soils" and not considered to be a Histosol.

Nonetheless, the identification of mires and Histosols required some interpretation of the information provided. Preparation of the source maps took several decades and involved numerous people (Leprun 2001). Because there were few established communication routes in the 1950s and 1970s, travelling through forests and wetlands was very difficult. The method adopted involved one team cutting a trail through the vegetation and a second team (including pedologists) coring along the trail at more or less regular intervals, depending on the aspect of the terrain. Therefore, one should not expect great precision from these maps at local scale. On the other hand, they allow good estimation of the areas of different soil types and their related ecosystems at the scale of the whole of Guiana. We encountered three main difficulties when using them, as follows:

1. The soil maps referred almost entirely to the non-forested part of French Guiana, and covered only some very small sectors of the Amazonian rainforest. Consequently, we worked exclusively on the northern part of the territory, from the Maroni River in the north-west to the Oyapock River in the south-east. The area studied covers about 30,000 km² from Mana and Saint-Jean du Maroni to Ouanary and Saint-Georges (Figure 1). From a geological point of view, the studied area corresponds to the Tertiary and Quaternary sediments which cover the old shield.
2. There are no soil maps for several sectors of even this northern territory, in particular for the section from Organabo to Kourou. Consequently, we used soil maps when they were available and agronomic units when they were not.

3. Numerous pedologists worked on the soil cartography over the course of the 1950s, 1960s and 1970s. The scale of maps, cartography methods and reference basis for soils that they used all changed during this period.

Other documentation

Documented climatological and geomorphological information for French Guiana is not abundant. Most is contained in published and unpublished reports by the French administration: BRGM for geomorphology and geology; IRD (ORSTOM before 1998) for soils and vegetation; and Météo-France for meteorological data. One of the best libraries we used was that of IRD in Cayenne. Meteorological data were obtained from the Météo-France database (http://publitheque.meteo.fr/okapi/accueil/okapiWebPubli/index.jsp).

Field observations

Fieldwork in French Guiana was undertaken by the authors of this article during the period 15–24 November 2012. Our mission had three aims:

1. to confirm the existence of mires in French Guiana and to validate our cartography;
2. to explore other parts of Guiana, especially the rainforest, in order to discover new mires; and
3. to start to define their typology.

We prospected with a pedological corer in six of the areas indicated in Figure 2 and Table 1. These were Kaw/Régina, Roura, Cayenne, Kourou, Sinnamary and Mana. Peat surfaces were mapped by ORSTOM pedologists in the Marshes of Kaw (2) in the east, and the rice plantations of Mana (9) in the west. Five additional locations that were mapped as mires by ORSTOM could not be reached during this mission, due to lack of time and access difficulties. These were, from west to east (Figure 2): Pointe de Béhague (1); the southern part of the Kaw/Régina sector (2); the Island of Cayenne (4); Iracoubo/Organabo (7); and, especially, the eastern part of the Amana National Natural Reserve near Organabo. We also explored four areas where ORSTOM did not document the presence of peat, namely: hydromorphic depressions in the heart of the primary forest of la Pointe Maripa, 50 km to the south of Cayenne close to Road Number 2 which leads to Saint-Georges de l'Oyapock; mangroves of Kourou; wet savannahs of Galion; and Pripris de Yiyi close to Sinnamary.

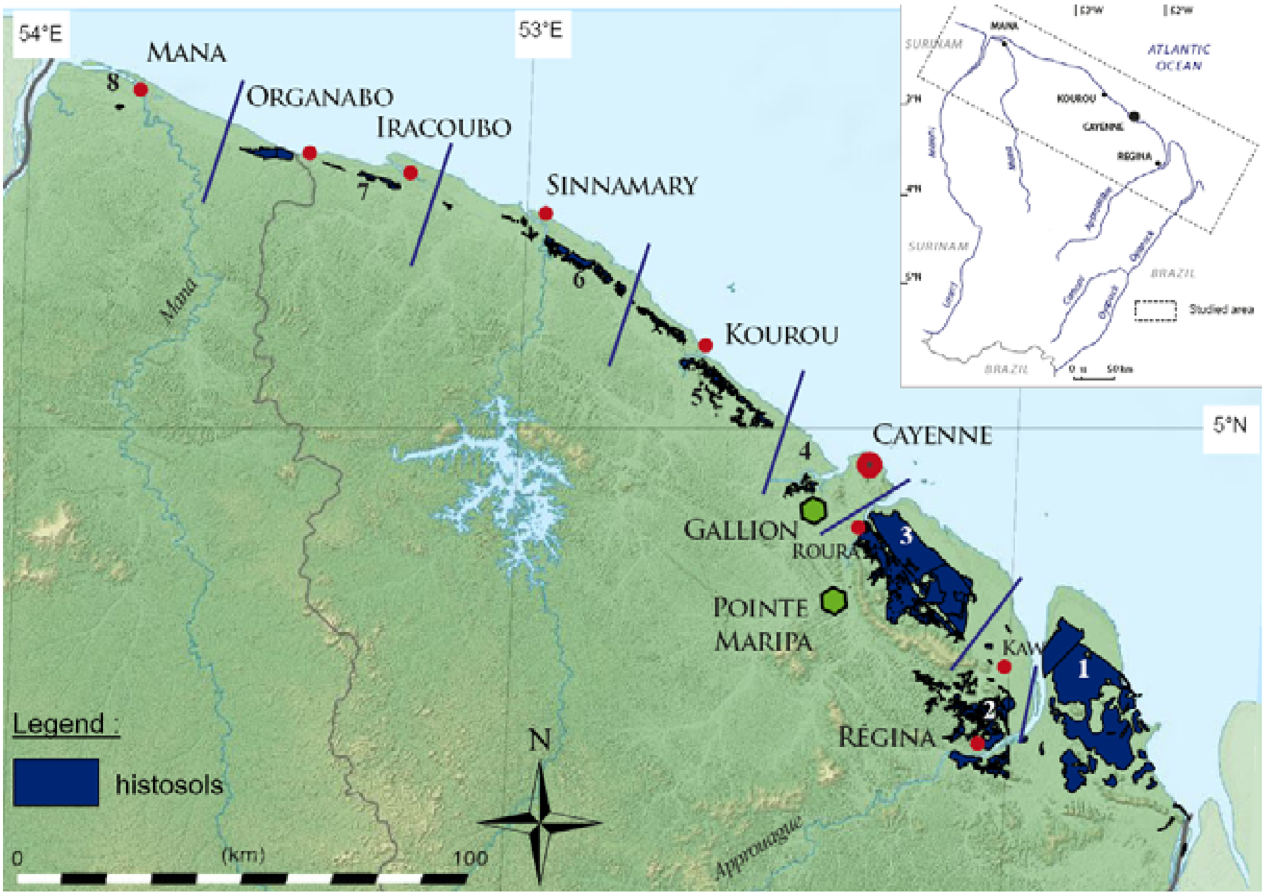

Figure 2. Distribution of Histosols in French Guiana, derived by combining maps of soils (scale 1:50,000) and agronomic units (scale 1:100,000) produced by ORSTOM from the 1950s to 1975. The green hexagons indicate coring locations. Inset : simplified version of Figure 1 to provide locational context.

Table 1. Histosol areas in French Guiana derived in GIS by combining maps of soils (scale 1:50,000) and agronomic units (scale 1:100,000) produced by ORSTOM from the 1950s to 1975.

Location reference (Figure 2)	Regions	Area (km²)
1	Pointe de Béhague	404.1
2	Kaw/Régina	119.2
3	Roura	356.4
4	Cayenne	6.2
5	Kourou	36.9
6	Sinnamary	31.0
7	Iracoubo/Organabo	20.7
8	Mana	0.8

RESULTS

Extent and distribution of mires

Acording to calculations from the ArcGIS database, the area covered by Histosols in French Guiana is 975.3 km² (Figure 2). Mires occur irregularly along the whole of the coastal strip, although their areas show a diminishing trend from the banks of the River Oyapock in the east to those of the Maroni in the west (Figure 2, Table 1). The largest peat bodies are located at Pointe de Béhague (404.1 km^2), Roura Marshes (356.4 km²) and Kaw/ Régina (229.2 km^2). To the north-west, mires are reduced to narrow strips running parallel to the seashore behind the dune and mangrove systems. In the vicinity of Mana, Histosols occur only in patches of a few km².

In the rainforest, areas reported to be potentially peaty were the "Pinot palm" (*Euterpe oleracea*) formations ("açaí palm" in Portuguese). These occur in very humid depressions between the hills, termed "pinotières" in French (Ricci 1990), forming "orange-segment" patterns which are the most structured morphological elements of the Guiana plateau. In November 2011, we visited one pinotière in primary rainforest within the Pointe Maripa sector, 50 km south of Cayenne (Figures 2 and 3). Unfortunately, pedological coring here did not show peaty soil, but an organic gleysol with a gley horizon overlying an accumulation of wood. As we were located on a small alluvial plain, we suspect that we fortuitously cored through old channels in which wood gathered by the creek in wet seasons had accumulated. Further investigation is required.

Environmental controls

Factors that potentially explain the observed distribution of Histosols are mainly climatic and geomorphological. Average monthly temperature is around 26 °C and shows little variation between seasons or from one region to another. However, we noted excellent correlations between the distributions of Histosols, precipitation and duration of the wet season. The largest areas of Histosols are found in eastern Guiana, between Cayenne and the Oyapock, where the mean annual rainfall is highest at 3000–5000 mm. For example, the long-term (1955–2011) average annual rainfall at Régina Meteorological Station, which is located at an altitude of 3 m a.s.l. near the Approuague River, was 3778 mm with a minimum of 2609 mm in 1964 and a maximum of 4979 mm in 1990. Rainfall differences can explain changes in hydro-morphology, and both show trends from the south-east to the north-west of French Guiana.

The geomorphology of the coastal strip appears also to play an important role in mire genesis. All of the mires overlie stabilised sandy sedimentary formations of Tertiary and Quaternary age on the most ancient parts of the coastal plain (Chaneac & Legrand 2009). In these locations, the accumulation of organic matter under anoxic conditions is favoured by the multitude of small depressions associated with former dune formations, river and marine terraces, and old channels. Therefore, we find very fibric Histosols on the floodplain of the River Kaw, in the heart of the forested peatland 20 km upstream from the village (Figure 4).

Figure 3. The pedological coring area at the heart of the *Euterpe oleracea* station at Pointe Maripa, 50 km to the south of Cayenne, with insets showing the peat sample (left) and a close-up of the forest floor (right).

Figure 4. Peat sample (inset right) obtained within the peatland forest (inset left) at the margin of the floodplain of the River Kaw (largest photograph), 20 km upstream from Kaw Village (Figure 2).

The final aspect to be considered in building an understanding of the present distribution of mires is the human factor. French Guiana has a population of approximately 230,000, giving an average population density of 2.7 per km²; but there are huge local variations because the majority of people live close to the 300 km long coastline and very few, apart from indigenous populations and legal or illegal gold miners, in the forest (Insee 2010). The development of colonial agriculture was accompanied by numerous drainage works in the lowest-lying parts of the coastal plains (Guisan 1788, Le Roux 1990). We do not know how these hydraulic works may have affected the hydrology and ecology of mires, except at a very local scale. Former polders are clearly visible on aerial imagery and are now being mapped and studied. It will be necessary to compare their locations with the distribution of Histosols in order to appreciate how far mires could have been impacted upon by the hydraulic works.

We do know that the last stage of drainage on Guiana's wetlands was very destructive. This began in 1995, when the government of President Valéry Giscard d'Estaing launched a vast programme to develop rice cultivation in the Mana region. Because a peat layer just 50 cm thick prevents rice from growing, in some areas a 50 cm layer of peat has been removed or burnt. The observations we could make in the field, alongside the No. 1 National Road to St-Laurent-du-Maroni about 10 km west of Mana, showed that Histosols remained only on strips up to 80 cm wide around the edges of rice fields (Figure 5). Radiocarbon dating of wood-rich sapric peat found at the bottom of one of these layers gave an age of 4635 ±35 BP, or 5460–5298 cal. yr. BP (Lyon-15803, Centre de Datation par le Radiocarbone, Lyon 1 University, France).

From the point of view of nature conservation, an important portion of Guiana's mires are included in protected areas under different French national laws and rules. Thus, Kaw Marshes, the largest mire area in Guiana and in France, is theoretically protected by France's largest (94,700 ha) Nature Reserve. The mires of the Reserve de l'Amana, between Organabo and the estuary of Maroni River (Figure 1), are recognised by the Ramsar Convention on Wetlands. The difficult access to these mires is certainly the best protection, and isolation is currently the only protection enjoyed by the mires of Pointe Béhague and the Régina region. Both the statutory authorities and nature protection organisations have focused more on forests, mangroves and (more recently) savannahs than on peaty wetlands, about which scientific knowledge consequently remains very scarce. The implementation in 2011 of a conservation initiative for natural areas in Guiana could provide an opportunity to increase the awareness of competent authorities, as well as that of the public, about the responsibility of France for the protection of these equatorial mires.

Figure 5. A clearing alongside the road from Mana to St-Laurent-du-Maroni where earthworks revealed the presence of a Histosol. Inset: a detail of fibrous to mesic facies.

DISCUSSION

It is important to remember that our estimate of the area of Histosols in French Guiana (975 km^2) does not include any that may occur in the forested part of the province. Moreover, the precision of this number should not hide the fact that, despite the quality of the ORSTOM pedologists' work, the delimitation of the different soil types is extremely difficult in the field. The distance to roads and dirt tracks and the difficulty of movement in wetland areas lead to simplification in the cartography. Nevertheless, 975 km^2 is a much more convincing figure than the 1620 km^2 (Andriesse 1988) and 1720 km^2 (van Engelen & Huting 2002) given by the international literature in light of our field observations, which suggest that the previous estimates include mangrove swamps and even flooded savannahs without peat layers. Thus, the area of mire in the Département of Guiana is similar to that in the European part of France, which is reported to be approximately 1000 km^2 by Joosten & Clarke (2002).

One cause of uncertainty is the way that pedologists use the local term *pégasse* for an organic layer of variable thickness and composition. According to Marius (1973), *pégasse* is a more or less fibrous and spongy acidic peat whose thickness can be very great so that, in his opinion, its study is more appropriate to geology. Nevertheless, on the Cayenne SW / Roura map, Marius (1973) does not explain the basis of his distinction between "oligotrophic peat soils on marine alluvium of Gabrielle Savannah" and *pégasse*, which overlies "gross mineral soils of non-climatic origin" such as the ones mapped immediately adjacent to Montagne Gabrielle. We prefer to follow Delhumeau (1974) and Leprun (2001), who consider *pégasse* to be peat when the thickness of the organic layer exceeds 50 cm. Below this thickness, *pégasse* is regarded as an organic deposit constituting the upper horizon of hydromorphic soils such as the humic gleys shown on the Roura map (Delhumeau 1974). The thicknesses noted are variable but can be large, for example three metres in Savanne Angélique. In the legend of the maps of agronomic units, *pégasse* corresponds to the number 5 when the thickness of the organic layer is less than or equal to 50 cm and to the number 6 when it exceeds 50 cm.

Further fieldwork will be necessary to more precisely locate the Histosols of French Guiana. This fieldwork will be time-consuming, due to difficult access in some areas. The exploration of coastal plains must continue, and the history of the hydraulic works should be studied. But most especially, investigations must be extended into the forest, as we do not yet know whether mires developed there.

In addition to inventory work, it is important to elucidate the expected specificity of mires in this French equatorial territory, by thoroughly characterising the linked attributes of vegetation and soil conditions. This deepening of knowledge is a necessary pre-condition for proper conservation management. If isolation and low population density have so far combined to preserve the mires of French Guiana in relatively intact condition, the French authorities now carry responsibility for maintaining the present situation. This could expediently be approached by enabling the acquisition of knowledge and conservation management in tandem.

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