Some preliminary observations on peat-forming mangroves in Botum Sakor, Cambodia

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SUMMARY

Until recently, peatlands in Cambodia were relatively unknown despite numerous efforts to locate and identify them. In 2012–2014, mangrove vegetation on the south-western coast of Cambodia was found to be growing on top of a peat layer underlain by marine clay. Believing that more mangrove peat might remain to be discovered, additional surveys were conducted in 2015, focusing on part of the east coast of Botum Sakor National Park and the riverine mangroves outside the National Park boundary. A total area of 4,768 ha of mangrove peat was confirmed to be present. Overall, the peat layer within this mangrove area is not very thick, with about half of all measurements in the range 50–100 cm and the deepest record 135 cm. In total, 26 mangrove species were recorded during the survey, including 20 tree species. Most were typical (either true or associate) species and very similar to those found in other mangrove forests in Cambodia and elsewhere in Southeast Asia. Although the mangrove peat area confirmed is small, it nevertheless contributes to the total peatland extent and carbon stock of the ASEAN region. Mangrove peat ecosystems, such as the one studied here, are not common in Southeast Asia and deserve more detailed and in-depth studies.

KEY WORDS: carbon stock, coastal peatland, dwarf mangrove, *Rhizophora apiculata*, tropical peatland

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INTRODUCTION

The extent of peatlands in Southeast Asia has been estimated at 27.1 million hectares by Hooijer *et al*. (2006) and 24.7 million hectares by Page *et al*. (2011). Peatland distribution amongst individual countries remains to be debated. Both estimates include Papua New Guinea, which is not usually included in this region, but exclude Cambodia. Information on peatlands in Cambodia is limited and sometimes contradictory. For example, Joosten & Clarke (2002) gave a figure of 700,000 ha of peatland for Cambodia, while Parish *et al*. (2008) categorised Cambodia as a country with 2.0–5.0 % of peatland by area and Joosten (2010) reported that Cambodia had no peatlands. The discrepancy in the peatland area estimate for Cambodia between Joosten & Clarke (2002) and Joosten (2010) was not explained. There was no mention of peatlands amongst the wetland sites listed under the country profile for Cambodia in the Directory of Asian Wetlands (Scot 1989). However, peatlands were considered to be one of the major types of wetland in Cambodia by Vathana (2003) although no total extent was given in that report, while Theilade *et al*. (2011) reported a previously undescribed evergreen swamp forest in the central part of Cambodia and compared its floristic composition with that of other peat swamp forests in the region.

More recently, Lo *et al*. (2016) reported discovering peatland beneath mangroves in Peam Krasop Wildlife Sanctuary in Koh Kong Province, Cambodia. This discovery of a peat deposit beneath a mangrove ecosystem indicated an unusual pattern of mangrove development for the Southeast Asian region, since these coastal forests usually grow on predominantly mineral soils and peat deposition beneath mangroves has only rarely been reported from elsewhere in the region. In Southeast Asia, mangrove peat has been reported in South Sulawesi, Indonesia (Giesen *et al*. 1991) and the Thousand Islands group off Jakarta Bay (Hardjowigeno 1989).

Mangrove peats are usually confined to salty and brackish habitats along tropical and subtropical coastlines and islands (Cameron & Palmer 1995). It is not unusual to find mangroves growing on rich organic peat, for example in South Florida (Odum *et al*. 1982, Tomlinson 1986) and elsewhere in the Caribbean and western Pacific; see, for example, studies on mangrove peat in Belize

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(Cameron & Palmer 1995, McKee & Faulkner 2000, Macintyre *et al.* 2004, Middleton & McKee 2010), Grand Cayman Island (Woodroffe 1982), Puerto Rico (Medina *et al*. 2010), Honduras and Panama (McKee *et al*. 2007), and Mexico (Ezcurra *et al*. 2016).

This short article presents the results of our initial assessment of mangrove peat in Cambodia based on rapid field surveys combined with remote sensing. We recognise that there are limitations to our assessment in terms of data collection, but we hope that these findings will serve to stimulate further studies of the mangrove ecosystems in this area, in order to explore both their ecology and their vital role in carbon sequestration and storage (Donato *et al.* 2011).

METHODS

The surveys reported here were conducted in the eastern part of Botum Sakor National Park in Koh Kong Province, Cambodia as well as in areas beyond the National Park boundary. The main focus area chosen for field survey was along the coast and four rivers, namely Prek Tak Ouk, Prek Ta Ty, Prek Angdoung Tek and Prek Chik (Figure 1). The survey combined remote sensing with ground truthing. Landsat TM 8 satellite imagery dated March 2015 was used to identify the locations and land cover of potential mangrove peatlands, and a high-resolution map from Google Earth (2014) was used for mapping the spatial features in Botum Sakor. For ground truthing, a soil auger was used to visually check the

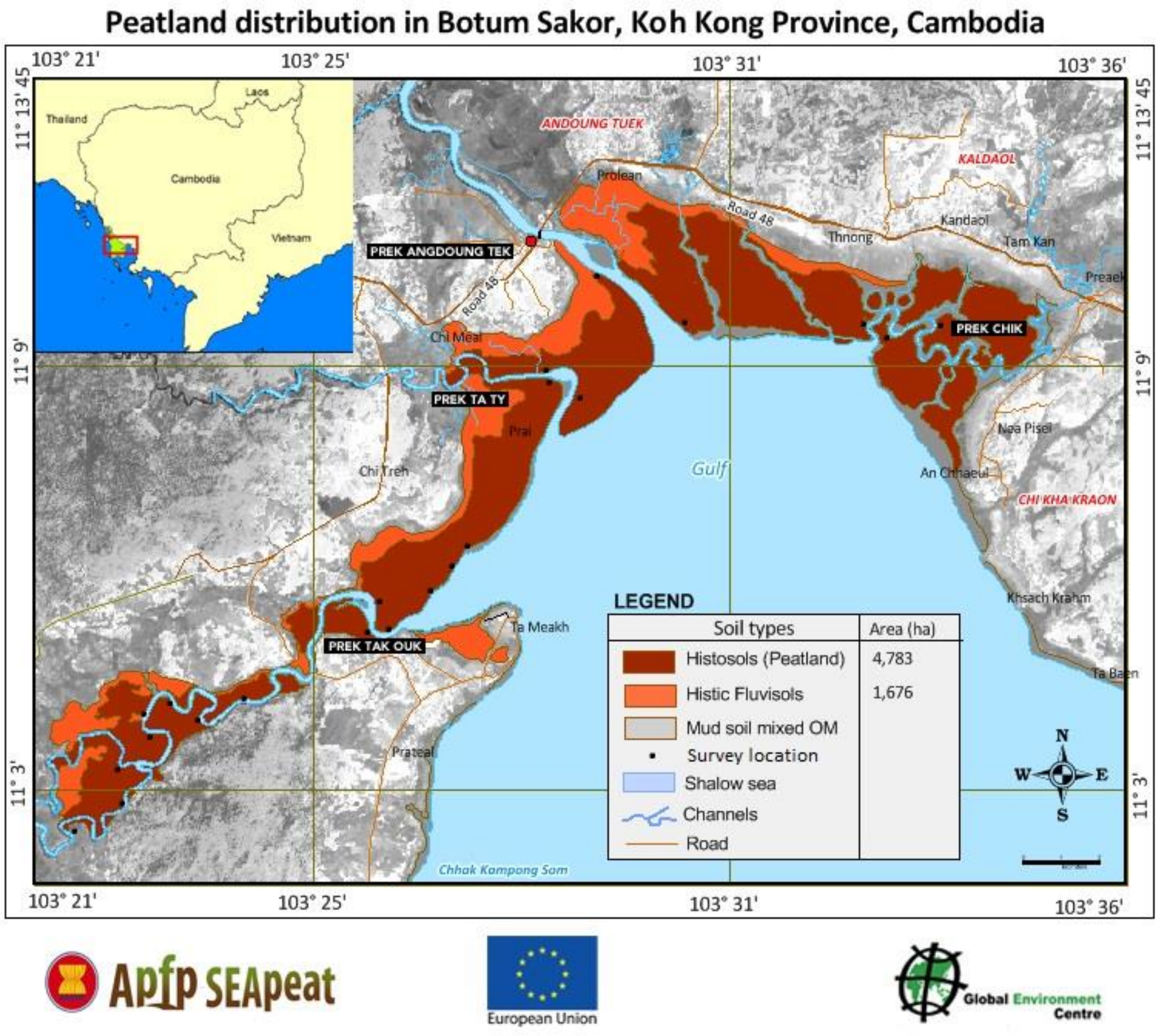

Figure 1: Peatland distribution in Botum Sakor, Koh Kong Province, Cambodia.

composition of soil materials and the thickness of the peat layer. In total, 23 locations were surveyed in this way and 49 peat depth measurements were carried out. At each survey point the thickness of the peat layer was determined, plant residues were identified by naked eye, and simple field tests involving rubbing/squeezing the peat material were used to describe soil texture. Where access allowed, additional measurements were made along a transect starting at the river bank and continuing inland as far as possible or until the peat layer ended, in order to establish the peat depth profile from the river bank.

The plant communities and species in the survey area were recorded by informal survey at each of the 23 survey locations. Identification of mangrove tree species was performed using the keys in Wyatt-Smith & Kochummen (1999) and by referring to voucher specimens in Herbarium Kepong (KEP), Malaysia. ‘True’ and ‘associate’ mangrove species classifications follow the definitions in Tomlinson (1986). True mangrove species occur only in mangrove environments and do not extend into terrestrial communities, whereas associate mangrove species can occur in both mangrove and terrestrial habitats.

RESULTS

Extent of mangrove peat

On the basis of field survey and remote sensing we confirmed the presence of mangrove peat in Botum Sakor and estimated its extent, in both coastal and riverine locations in the vicinity, at 4,768 ha (Figure 1).

Characteristics of the peat

The soil collected using the auger clearly showed a very high organic content, unlike the mineral-rich muddy soil of a typical mangrove community. The peat soil samples showed great variation from location to location, in terms of both colour and texture (Figure 2). Colour ranged from reddish brown to dark brown. Texture was mostly fibrous and some samples contained a network of fine, uniform roots.

Figure 2: Peat samples from the survey, showing: partially decomposed plant residues mixed with roots (top left); networks of uniform fine roots (top right); organic material mixed with clay (middle right); and dark greyish plant residues (bottom).

Other samples consisted of a mixture of plant residues with fragments of roots and leaves. Some were distinctively comprised mainly of organic materials whereas others were mixed with clay. In some locations the peat layer was seen to be piling up around the bases of tree trunks (Figure 3).

Measurements were taken in all but one of the areas with recorded peat layers. Peat depth was not uniform and varied greatly from location to location, ranging from 20 cm to 135 cm, with shallow peat occurring mostly beside the river. About 26 % of the peat depth measurements were in the range 20–50 cm, while 72 % were in the range 50–100 cm. Peat depth exceeded 100 cm at only one location. These results indicate that the peat layer was predominantly very shallow. Where peat depth was measured along transects, 80 % of the measurements showed peat depth increasing with distance from the river.

Plant species composition

During the survey, 26 plant species belonging to 21 genera and 18 families were recorded (Table 1). Of these, 20 were trees, three were palms, two were ferns and one was a shrub. About 77 % were true mangrove species and the rest were mangrove associates. Field observations indicated that *Rhizophora apiculata*, *Bruguiera sexangula*, *Bruguiera gymnorrhiza* and *Xylocarpus granatum* were the most abundant mangrove species in the area.

Species zonation

Mangrove zonation was not very clear-cut in the Botum Sakor area, but field observations showed that a *Rhizophora* zone could be distinguished from a *Lumnitzera*-*Xylocarpus*-*Bruguiera* zone. There were also areas with mixtures of species from both zones.

At river mouths, where tidal influence was greatest, the fringing mangrove species was predominantly *Rhizophora apiculata* (Figure 4), sometimes with a belt of *Nypa fruticans* palms on the ‘seaward’ side. Moving upstream, the species compositions on opposite banks of a river often exhibited stark differences. The dominant species on the side with mudflat accretion was always *Rhizophora apiculata*, while on the opposite bank there was a mixture of species, the most common including *Bruguiera sexangula*, *Bruguiera gymnorrhiza* and *Xylocarpus granatum* (Figure 4). Other species such as *Lumnitzera littorea*, *Excoecaria agallocha*, *Heritiera littoralis* and *Intsia bijuga* could also be seen along the banks.

Moving away from a river bank, *Bruguiera sexangula* remained the dominant species, most often occurring with *Phoenix paludosa* and *Lumnitzera littorea*. Other species co-existing with these three varied from location to location; and included *Excoecaria agallocha*, *Heritiera littoralis*, *Lumnitzera littorea* and, sometimes, *Melaleuca cajuputi* (Figure 4). In the few locations where *Bruguiera sexangula* was absent, it was replaced by *Lumnitzera littorea* or *Sonneratia ovata*. Moving farther ‘inland’ from the river, *Melaleuca cajuputi* became dominant, often forming pure stands but sometimes occurring with an undergrowth of *Acrostichum speciosum*.

At two locations a dwarf form of *Rhizophora apiculata* (Figure 4) was found on the inland area, often with *Lumnitzera littorea*. The *Rhizophora apiculata* was only 3–5 m tall whereas the *Lumitzera littorea* was 10–15 m tall. It is important to note that *Rhizophora apiculata* was growing on peat rather than on the usual mangrove muds at these locations.

Figure 3. Example observations of peat piling up at the bases of tree trunks, showing coarse, loose organic matter (left) and more-consolidated organic matter (right).

Table 1. Mangrove species found in Botum Sakor, Cambodia. Key: T/A = True or Associate mangrove species; n-m = non-mangrove; *indicates species shared with Chantaburi province, Thailand (Suk-ueng *et al*. 2013); # indicates species shared with Singapore (Yang *et al*. 2011); *** Khmer name/sound follows UNEP (2008).

	Family	Species name	Habit	T/A	Khmer name/sound ***
1	Acanthaceae	*Acanthus ebracteatus* Vahl #	Shrub	True	Trochjiek cragn slekweng/trochjiekcragn pkapor sar
2	Acanthaceae	*Acanthus ilicifolius* L. #	Shrub	True	Trochjiek cragn Slekbanla/trochejiekcragn pkapor svay
3	Acanthaceae	*Avicennia marina (Forssk.) Vierh.**#	Tree	True	Kbagnsor/Sman/Mouroujsrotorb
4	Arecaceae	*Nypa fruticans* Wurmb #	Palm	True	Chark
5	Arecaceae	*Phoenix paludosa* Roxb.	Palm	Associate	Peng
6	Arecaceae	*Oncosperma tigillarium* (Jack) Ridl.	Palm	Associate	
7	Combretaceae	*Lumnitzera littorea* (Jack) Voigt *#	Tree	True	Krognyeppka krohom/Krognyepkrohom
8	Combretaceae	*Lumnitzera racemosa* Willd. *#	Tree	True	Krognyep pkasor/Krognyep sor
9	Combretaceae	*Terminalia catappa* L.	Tree	Associate	
10	Euphorbiaceae	*Excoecaria agallocha* L. *#	Tree	True	Tatom/Chheu chhor
11	Fabaceae	*Intsia bijuga* (Colebr.) Kuntze *	Tree	Associate	Krokosteukpray/Krongnungteukbray
12	Lythraceae	*Sonneratia caseolaris* (L.) Engl. *#	Tree	True	Ampea
13	Lythraceae	*Sonneratia ovata* Backer *#	Tree	True	Ampea
14	Malvaceae	*Hibiscus tiliaceus* L. *	Tree	Associate	Dawm-beus/Kabbaspreyteukbrey
15	Meliaceae	*Xylocarpus granatum* J. Koenig *#	Tree	True	Tabonsor
16	Meliaceae	*Aglaia cucullata* (Roxb.) Pellegr.	Tree	Associate	
17	Pteridaceae	*Acrostichum aureum* L. #	Fern	True	Brong
18	Pteridaceae	*Acrostichum speciosum* Willd. #	Fern	True	Brong/Khnagn
19	Rhizophoraceae	*Ceriops tagal* (Perr.) C.B. Rob. *#	Tree	True	Smerkrohorm
20	Rhizophoraceae	*Bruguiera gymnorrhiza* (L.) Savigny. *#	Tree	True	Basac Kroahom
21	Rhizophoraceae	*Bruguiera sexangula* (Lour.) Poir. *#	Tree	True	Basacsor
22	Rhizophoraceae	*Rhizophora apiculata* Blume *#	Tree	True	Kongkangslektoch
23	Rhizophoraceae	*Rhizophora mucronata* Lam. *#	Tree	True	Kongkang slekthom
24	Rubiaceae	*Scyphiphora hydrophyllacea* C.F.Gaertn. #	Tree	True	
25	Sterculiaceae (Malvaceae)	*Heritiera littoralis* Aiton *#	Tree	True	Kann-kai/Dawmklai/Semornsakmot
26	Myrtaceae	*Melaleuca cajuputi* Powell *	Tree	n-m	

Figure 4. Some of the mangrove species mentioned in the text: *Rhizophora apiculata* at the fringing area (top left); three common tree species found in study area, namely *Bruguiera sexangula* (top right), *Bruguiera gymnorrhiza* (middle left) and *Xylocarpus granatum* (middle right); a *Melaleuca cajuputi* stand (bottom left); and the dwarf form of *Rhizophora apiculata* (bottom right).

DISCUSSION

During our study in Botum Sakor National Park and adjacent areas, a peat layer was found mostly beneath mixed mangrove stands (more than three species), although in some locations fewer (2–3) species were recorded, notably *Lumnitzera littorea*, *Ceriops tagals* and stunted *Rhizophora apiculata*. In this preliminary assessment, we did not determine which species contributed to peat formation. However, studies from other regions may provide useful clues. For example, some mangroves grow on their own root remains to accrete vertically and thus keep pace with sea-level rise (Ezcurra *et al*. 2016). Odum *et al*. (1982) generalised that the red mangrove (*Rhizophora mangle*) primarily forms mangrove peat with predominantly root material, which can accumulate to a thickness of several metres in Florida. This is mostly the case also for Caribbean mangrove peat (Mckee *et al*. 2007, Medina *et al*. 2010), although here the black mangrove (*Avicennia germinans*) may contribute to peat formation (Cameron & Palmer 1995). Ezcurra *et al*. (2016) identified both black mangrove (*Avicennia germinans*) and red mangrove (*Rhizophora mangle*) as species responsible for peat formation in Baja California, Mexico.

Peat depth

The thickness range (0.2–1.35 m) recorded for mangrove peat in this study is similar to the range (0.44–2 m) reported from Peam Krasop Wildlife Sanctuary, Cambodia (Lo *et al*. 2016). This result is also comparable to the limited available data on mangrove peat in Indonesia; *e.g*., the Lariang–Lumu mangrove in South Sulawesi often occurs on peat 0.5–2.5 m deep (Giesen *et al*. 1991). At another location on the same island, peat depth beneath the Malangke–Malili mangrove is 0.3–2.0 m in small areas and deeper (1.5–2.0 m) peat occurs over larger areas (Giesen *et al*. 1991). On Pulau Seribu off Jakarta Bay, Indonesia, a 30–50 cm thick Histosol with an organic matter content of 62.1 % has been recorded (Hardjowigeno 1989).

Despite the differences in geographical location, the result for Cambodian mangrove is also very similar to peat thickness ranges reported from Pelican Cays, Belize (0.2–1.65 m) (McKee & Faulkner 2000) and Pohnpei Island, Micronesia (0.7–1.2 m) (Fujimoto *et al*. 1995), but slightly lower than the record of 2 m thick mangrove peat accumulated in the lagoon area on Kosrae Island, Micronesia (Fujimoto *et al*. 1996). Medina *et al*. (2010) reported deeper (1–6 m) peat under mangrove in Nuevo Mundo Bay, Puerto Rico; Woodroffe (1982) probed mangrove peat more than 4 m deep on Grand Cayman Island; while Lovelock *et al*. (2004) reported 6 m of mangrove peat on the Bocas del Toro archipelago in eastern Panama. The Cambodian mangrove peat reported here is much shallower than the 9 m and 10 m deposits found, respectively, at Twin Cays in Belize (Macintyre *et al*. 2004, McKee *et al*. 2007) and on Tobacco Range Island (Cameron & Palmer 1995).

Plant species composition

Most of the species that are present in mangrove forests in Cambodia were recorded during our survey in the Botum Sakur area. However, because this study was not primarily focused on documenting plant species diversity, the true number of species is likely to be under-represented. The number of mangrove species (26) found during this study was fewer than the 42 species that have been recorded previously in the mangrove forest of Koh Kong province (DNCP 1995 as cited in UNEP 2008).

Overall, the species composition shows a strong affinity to mangrove communities elsewhere in Southeast Asia. For example, of the 35 mangrove species found in Singapore (Yang *et al*. 2011), 70 % are shared with at least one other location, and about 50 % are shared with Chanthaburi Province, Thailand (Suk-ueng *et al*. 2013) and Sematan, Sarawak, Malaysia (Ashton & Macintosh 2002) (Table 1).

The tree species found in this study are not comparable to those found in mangrove forests in the Caribbean region, since the two regions fall into different biogeographic groups - the eastern and western mangrove groups, respectively - as described by Tomlinson (1986).

Zonation

Cambodian mangrove can be categorised into four zones, namely the *Avicennia-Sonneratia* zone, the *Rhizophora* zone, the *Bruguiera-Kandelia-Ceriops* zone, and the *Lumnitzera-Xylocarpus-Bruguiera* zone (UNEP 2008). The mangrove zones at Botum Sakor showed similarities with two of these, namely the *Rhizophora* zone and the *Lumnitzera-Xylocarpus-Bruguiera* zone. Although *Avicennia, Sonneratia*, *Kandelia* and *Ceriops* species are found in this area, they are not sufficiently abundant to form zones.

Compared with the zonation observed by Lo *et al*. (2016) in the Peam Krasop Wildlife Sanctuary, which is mostly comprised of small islands, creeks and waterways where the fringing zone is dominated by a single species (*Rhizophora apiculata*), in the Botum Sakor mangrove area *Rhizophora apiculata* dominates only along the coast and on river banks where mudflats are accreting. On the opposite banks, away from the mudflats, a different mixture of species occurs (see Results). *Rhizophora apiculata* often does not mix with the other species and is rarely found farther inland.

The dwarf form of *Rhizophora apiculata* which was found at two locations in Botum Sakor is similar to the dwarf version found in Peam Krasop Wildlife Sanctuary, where Lo *et al*. (2016) observed that stunted *Rhizophora apiculata* occupied an area 100–150 m from the edge of the island. Dwarf *Rhizophora apiculata* is found only in areas with peat and shows marked differences from specimens found at the river bank, which usually grow to more than 10 m in height. According to FAO (2007a), dwarf *Rhizophora apiculata* of height 2–3 m with a thick tangle of aerial roots dominates the mangrove ecosystem where the sediment surface is above floodwater height. The soil description (blackish, very moist and criss-crossed by a mesh of fine roots) provided by the FAO report could reflect the presence of peat in this ecosystem, as was found for dwarf *R. apiculata* in the Botum Sakor area. It is not presently clear what causes this dwarfism, although a combination of growing in areas farther inland with less tidal influence and a peat substrate seems a plausible explanation. However, *Lumnitzera littorea*, which occupies the same habitat, appeared to be unaffected, often reaching a height of 10 m or more. In addition, *Rhizophora mucronata* seems to grow very well on top of a 3 m peat layer in Sulawesi (Giesen *et al.* 1991). Woodroffe (1982) observed that the distribution of stunted *Rhizophora* sp. on Grand Cayman Island coincides with a deep basin of mangrove peat. Thus, there may be a correlation between dwarfism in *Rhizophora* and peat thickness.

Stunted growth in mangrove species can be due to high salinity (FAO 2007b), disturbance or site impoverishment (Tomlinson 1986). Dwarf *Rhizophora mangle* is common in the Caribbean (Medina *et al*. 2010, McKee *et al*. 2002) and has been noted on the Bocas del Toro archipelago in eastern Panama by Lovelock *et al*. (2004). In these locations the dwarf trees usually occur farther inland than the taller specimens fringing the sea, and all three of the studies mentioned have singled out phosphorus as a limiting factor for growth. Medina *et al*. (2010) also highlights the combination with seasonal water stress, whereas both McKee *et al*. (2002) and Lovelock *et al*. (2004) conclude that nitrogen deficiency could also play a role. Woodroffe (1982) reported dwarfism in both *Rhizophora* and *Avicennia* on Grand Cayman. In Florida, dwarfed forms of the four common species (*Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemosa* and *Conocarpus erecta* have been found in environments with nutrient limitation (Lugo & Snedaker 1974). Ezcurra *et al*. (2016) reported stunted *Avicennia germinans* in Baja California, Mexico, but did not explain the cause. In South Africa, Naidoo (2006) reported dwarfism in another mangrove species (*Avicennia marina*) which is not found on mangrove peat.

The presence of *Melaleuca cajuputi*, sometimes occurring with *Bruguiera sexangula*, on the ‘inland’ part of the Botum Sakor study site is not unusual since *Melaleuca cajuputi* tends to dominate areas with limited tidal influence where seawater penetration occurs only during spring tides (FAO 2007a, UNEP 2008). It was observed that *Melaleuca cajuputi* occurred only in areas with a very shallow organic layer and not in areas with mangrove peat.

Implications and recommendations

Although we did not collect any data on sediment carbon stocks or peat accumulation rates in Botum Sakor, it is relevant to consider potential implications in this regard. Donato *et al.* (2011) consider mangrove to be the most carbon-rich forest type in the tropics, containing on average 1,023 Mg C ha^{-1}, with the organic soil contributing 49–98 % of the carbon storage in these systems. Fujimoto *et al*. (1999) estimate that a 2 m thick layer of mangrove peat contains 1,300 Mg C ha^{-1}, whereas Ezcurra *et al*. (2016) report an average below-ground carbon content of 1,130 Mg C ha^{-1}. Therefore, the mangrove peat we have identified in Cambodia, covering an estimated 4,768 ha and up to 1.35 m deep in Botum Sakor, may contribute significantly to the total carbon stock of the region.

Although valuable information has been obtained from this very preliminary investigation, it only scratches the surface of this unique ecosystem. Further detailed investigation is recommended, including studies focusing on: the carbon content and carbon dating of the peat layer to estimate carbon stock and accumulation rate; the origin of the mangrove peat and the species contributing to peat formation; long-term monitoring of the stunted mangroves and the causes of dwarfism; which plant litter fractions are most important in terms of peat accumulation (*e.g*. root material *versus* other litter inputs); and the fauna occurring in this habitat. Perhaps most importantly, we hope that future studies can help to explain why peat developed in the Botum Sakor mangrove area yet not in other places, and what factors contributed to this development?

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