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Ecological status and sources of anthropogenic contaminants in mangroves of the Wouri River Estuary (Cameroon)

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A B S T R A C T

Mangroves are critically threatened by human activities, despite the important ecosystem functions and services they provide. Mangroves in Cameroon represent no exception to the worldwide trend of mangrove destruction, especially around Douala, on the Wouri river estuary. In two sites around Douala, we assessed the presence of sterols, PAHs, PCBs, DEHP, DDT and its metabolite p,p'-DDE and potentially toxic metals in sediment samples. As a proxy of ecological quality, we measured the diversity and abundance of macrobenthos assemblages. We detected p,p'-DDE contamination, with concentrations higher than 3 μg kg^{-1} in 16 out of 26 samples which were attributed to recent widespread use of DDT. The detection of sterols revealed faecal contamination. Significant sensitivity of the macrobenthos to contaminants was revealed, with possible implications on the overall mangrove vulnerability to climate change and on the provision of ecosystem services to local populations.

1. Introduction

Mangroves in Africa cover over 3.2 million ha, corresponding to about 20% of their global coastline coverage, with approximately 1.5 million ha located along the Atlantic coast (Giri et al., 2011; Massó i Alemán et al., 2010; Spalding et al., 2010; UNEP, 2007). As a consequence of enormous anthropogenic pressure and multiple threats, western African mangroves have declined by >25% over the past 25 years (Friess and Webb, 2014; Giri et al., 2011). Cameroon harbours approximately 2000 km^2 of mangroves, distributed along the coast of the Guinean gulf (Giri et al., 2011). Although mangroves contribute considerably to the social and economic well-being of the Cameroonian coastal inhabitants, their total surface area has decreased by 30% in 20 years (Spalding et al., 2010), mainly due to rapid and uncontrolled urbanization around Douala (Din et al., 2002; Ellison and Zouh, 2012; Nfotabong-Atheull et al., 2013). With a population of >2 million people, Douala is the largest city in Cameroon and exerts a huge pressure on the nearby mangroves, with uncontrolled sewage discharge detrimentally affecting the whole ecosystem (Simon and Raffaelli, 2012).

Douala is also one of the major shipping ports in the Guinea Gulf that serves the entire central Africa and refuels oil tankers to export locally extracted oil, another significant anthropogenic impact on the Wouri River estuary mangroves (Alemagi, 2007; Duke, 2016; Price et al., 2000; Van De Walle, 1989). Due to the lack of policy regulation in the management of Cameroonian coastal ecosystems, sand mining and wood harvesting also play an important role in reducing mangrove biodiversity and provision of ecosystem services (Ellison and Zouh, 2012; Nfotabong-Atheull et al., 2011).

Although these multiple impacts threaten Wouri River estuary forests, the major socio-economic activity associated with mangroves for local people is in fact still artisanal fishing, with landings estimated between 76 and 106 tons per year (Gabche, 1997). Fisheries play a significant role in small-scale commercial activities and they are vital in providing a source of protein and income for coastal communities (Nfotabong-Atheull et al., 2009). Thus, the modification of both abundance and diversity of mangrove species and the deterioration of

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water quality, due to urban and industrial activities, will surely have detrimental consequences on the well-being of local communities (Alemagi, 2007; Nfotabong-Atheull et al., 2009, 2011). Last but not least, vulnerability to climate change, and especially to sea level rise, proved to be exacerbated by the high level of anthropogenic pressure on the Wouri River estuary mangroves (Ellison and Zouh, 2012). In particular, purported impacts are (i) the increase of frequency and duration of the tidal inundation that may cause the death of the mangrove trees (exceeding the species-specific physiological thresholds; Ball, 1988), (ii) the impact on the inland fresh groundwater with saline intrusion and contaminants dispersal in the intertidal systems (Woodroffe et al., 2016), and (iii) the change of the topography and hydrology of the sediment (Lovelock et al., 2015).

Our aim was to perform the first baseline study on the ecological status and pollution of the strongly impacted Wouri River estuary mangroves, collecting data on both the presence of anthropogenic pollutants in sediments and the structure and diversity of macrobenthic populations as a proxy for healthy ecosystem functioning (Cannicci et al., 2008, 2009). To assess the level of chemical pollution, we targeted the major anthropogenic compounds usually found in peri-urban impacted mangrove forests world-wide, i.e. organochlorine compounds, such as DDT and its metabolites, phthalates such as bis(2-ethylhexyl)phthalate (DEHP), polycyclic aromatic hydrocarbons (PAHs), polychlorobyphenyls (PCBs), heavy metals and sterols (Bayen et al., 2005, 2016; Lewis et al., 2011; MacFarlane et al., 2007; Peters et al., 1997; Vane et al., 2009). Compounds such as coprostanol (5β(H)-Colestan-3 β-ol) can be used in conjunction with other sterols to determine the relative abundance of sewage in sediments. Coprostanol, in particular, is a faecal sterol generated by microbial activity on cholesterol and is considered as a chemical marker of faecal contamination, especially from humans (Bull et al., 2002; Fattore et al., 1996; Mudge et al., 1999; Peng et al., 2005; Sherwin et al., 1993).

Diversity and abundance of crab and mollusc populations were recently shown to be key-determinants of the maintenance of mangrove ecosystem function and services (Cannicci et al., 2008; Duke et al., 2007; Lee, 2008), such as the provision of nursery sites for fish stocks which is of great importance for the local economy. Crabs and molluscs form an important link between primary detritus at the base of the food web and consumers at higher trophic levels (Sousa and Dangremond, 2011). By consuming litter, crabs can promote nutrient mineralization and recycling within the forest. Furthermore, their bioturbation activities undoubtedly alter the physico-chemical characteristics of soil (Kristensen, 2008) and enhance below-ground organic carbon retention (Andreetta et al., 2014). Finally, since mangrove macrobenthos diversity and functioning are known to be strongly impacted by contaminants (see Cannicci et al., 2009; Bartolini et al., 2011; Penha-Lopes et al., 2011 for east African mangrove benthos), their abundance and diversity is useful in assessing the degree of bioavailability of anthropogenic pollutants and the actual impact on the biological components.

2. Material and methods

2.1. Area description

The study was carried out in two peri-urban mangrove forests located at different sites along the Wouri estuary: Wouri Bridge forest (4°4′ 19.10880″N; 9°42′5.81312″ E, hereafter WB) and Bois des Singes forest (4°0′49.67706″N; 9°40′ 28.10325″E, hereafter BS), located north-west and south-east of Douala, respectively (Fig. 1), with a distance between them of 11 km. Both of these stands are at about 10 ha in extension and are largely affected by the uncontrolled expansion of urban areas due to the rapidly increasing population of Douala city (Simon and Raffaelli, 2012). Thus, they are representative sites to assess the possible presence of pollutants in peri-urban mangroves.

The climate of the region belongs to the Equatorial regime (Din and Baltzer, 2008), characterized by a long rainy season (March–November) and a short dry season (December–February). Heavy rainfall (approximately 4000 mm per year), stable high temperatures (annual average temperature is 26.7 °C) and high humidity throughout the year (approaching 100%) are typical for this region. The tidal regime is semi-diurnal with an average amplitude of 2.5 m. Soils are grey or black muds, of silty, sandy or clayey texture, derived from fluvial sediments relatively rich in organic matter with a high C:N ratio due to the reduced biological activity (Campo and Darius, 2004). Annual salinity variation in the region ranges between 0 and 20‰. During the long monsoon season, mangrove water salinity is consistently <10‰. During the dry season, salinity varies between 4 and 20‰ (Din and Baltzer, 2008).

According to a survey by Saenger and Bellan (1995), the floristic composition of Wouri Bridge forest, a 40 year old stand, is dominated by *Avicennia germinans*, *Rhizophora racemosa*, *Rhizophora mangle* and *Rhizophora harrisonii* and the mangrove associate *Pandanus* sp. Bois des Singes is an older stand and has a different floristic composition, represented only by the three *Rhizophora* species listed above. Hereafter, the belts studied will be referred as Avicennia belt, Pandanus belt and Rhizophora belt.

In these systems the faunal composition includes vertebrates, such as mammals like the sirenian species *Trichechus senegalensis* and several cetaceans. There are birds, of which particular significance is the high abundance of african skimmers, grey pranticoles, open-billed storks and common green shanks, reptiles such as four species of sea turtles (see Diop et al., 2014), and fishes (many of them of commercial importance), and a wide range of invertebrates, mainly crabs (belonging to the families Sesarmidae and Ocypodidae) and molluscs (extensively described by Ngo-Massou et al., 2012), which constitute the bulk of benthic diversity in the these mangrove ecosystem.

2.2. Sediment sampling

A total of 20 sediment samples were collected in September 2009 in the two mangrove systems for trace metals and organic compounds analysis, choosing five random replicates in each forest. Five samples from BS and five from WB were taken from the upper layer of superficial sediment (0–10 cm) and other five samples from BS and five from WB were taken from the layer underneath (11–20 cm). The sediment cores were collected using an Eijkelkamp Multisampler™ piston corer (10 cm diameter). The samples were then placed in glass jars, covered with aluminium foil and immediately transferred to a portable freezer and stored at −20 °C until analysis.

2.3. Analytical methods

2.3.1. Solvents, chemicals and standards

The solvents used were acetone, hexane, dichloromethane and isooctane, obtained from Sigma Aldrich and Fluka Co., Steinheim, Germany. Standard reference materials for trace metals analysis were supplied by the Community Bureau of Reference Sample (BCR): Certified Reference Materials CRM 277 and CRM 320 and 142 R. Analytical standards for a mixture of PCBs (IUPAC nr. 28, 52, 101, 118, 138, 153, 180), a mixture of PAHs (anthracene, benzo[*a*] anthracene, benzo [*jbk*]fluoranthene, benzo [a] pyrene, benzo [ghi] perylene, chrysene, fluoranthene, indeno[1,2,3-*cd*]pyrene, phenanthrene, pyrene), bis(2-ethylhexyl)phthalate (DEHP) and the internal standards anthracene-d_{10} and perylene-d_{12} were purchased from Dr. Ehrenstorfer GmbH, Augsburg, Germany. Analytical sterol standards, Coprostan-3-ol, 5 α-Cholestan-3β-ol, cholesterol and 5 β-Cholestan-3α-ol, analytical Bis(trimethylsilyl)trifluoracetamide (BSTFA) with 1% trimethylchlorosilane (TMCS), used for sterols derivatisation, and analytical standards for 1,1,1-trichloro-2,2-di(4-chlorophenyl)ethane (DDT) and 1,1-*bis*-(4-chlorophenyl)-2,2-dichloroethene (p-p'DDE) were purchased from Sigma Aldrich and Fluka Co, Steinheim, Germany.