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Limited impact of several years of pretreated wastewater discharge on fauna and vegetation in a mangrove ecosystem

C. Capdeville[a], K. Abdallah[b], E. Buffan-Dubau[a], C. Lin[a], F. Azemar[a], L. Lambs[a], F. Fromard[a], J.L. Rols[a], J. Leflaive[a,*]

[a] *EcoLab, Université de Toulouse, CNRS, INPT, UPS, Toulouse, France*
[b] *Syndicat Intercommunal d'Eau et d'Assainissement de Mayotte, France*

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ABSTRACT

It was hypothesized that mangroves, tropical wetlands, could be used for the finishing treatment of domestic wastewaters. Our aim was to determine if a nutrient-stressed mangrove could tolerate long-term discharges of pretreated wastewater (PW). Since 2008, in an *in situ* experimental system set up in Mayotte Island (Indian Ocean), domestic PW are discharged into two impacted areas (675 m^2) dominated by different species of mangrove trees. Anthropogenic inputs during > 4.5 years led to an increase in vegetation growth associated with an increase in leaf pigment content, leaf surface and tree productivity. A marked increase in tree mortality was observed. There was no effect on crabs and meiofauna densities, but significant modifications of community structures. These effects may be directly linked to PW inputs, or indirectly to the modifications of the environment associated with higher tree growth. However, our results indicate that there was no major dysfunction the ecosystem.

1. Introduction[1]

Mangroves are coastal forests adapted to an intertidal environment in (sub)tropical areas (Blasco, 1991; Spalding et al., 1997). They are organized in strips of vegetation dominated by tree species arranged along environmental gradients (Robertson et al., 1992; Ball, 1998). These forests are nutrient-poor (Boto and Wellington, 1984) but highly productive and represent a large source of organic matter to decomposer communities (Benner and Hodson, 1985; Komiyama et al., 2000). Mangroves provide a number of ecosystem services like varied food and material resources, and habitats for fishes, prawns and crabs (Aburto-Oropeza et al., 2008; Lee et al., 2014). They also participate to stabilize soils, protect coasts from erosion and cyclones (Blasco, 1991; Alongi, 2008). Moreover, mangroves are sites of major importance for nutrients trapping and organic matter remineralization (Ewel et al., 1998).

In contrast to the low diversity of tree species, the mangrove hosts a high diversity of organisms (Nagelkerken et al., 2008). Among these organisms, crabs received a particular attention because of their role as engineer species (Jones et al., 1994; Lee, 1998). Indeed, their habitat (often a hole) and their bioturbation activity induce physical modifications of their environment. This favors the oxygenation of the sediments (Smith et al., 1991) and the circulation of water and organic matter (Botto et al., 2006; Gutiérrez et al., 2006). Moreover, their feeding habits (burying leaves and propagules into their hole for some species) participate to the enrichment of sediments (Camilleri, 1992) and to the regulation of mangrove tree recruitment (McGuinness, 1997; Dahdouh-Guebas et al., 1999). Within sediments, especially in subsurface layers, meiofauna, *i.e.* benthic invertebrates between 30 and 1000 µm (Giere, 2009), represent another important component of trophic networks because of its intermediate position between the

* Corresponding author at: EcoLab- Laboratoire Ecologie Fonctionnelle et Environnement, UMR 5245 CNRS-UPS-INPT, Université Toulouse III - Paul Sabatier, Bât 4R1, 118 route de Narbonne, 31062 Toulouse Cedex 9, France.
E-mail address: josephine.leflaive@univ-tlse3.fr (J. Leflaive).

[1] PW: Pretreated Wastewater;
Ct-CA and *Ct*-IA: Control and Impacted Area of *Ceriops tagal* mangrove zone;
Rm-CA and *Rm*-IA: Control and Impacted Area of *Rhizophora mucronata* mangrove zone;
DBH: Diameter at Breast Height;
ΔRA: the difference of dead tree Relative Abundance;
AGB: Aboveground Biomass;
BGB: Belowground root Biomass;
SLA: Specific Leaf Area.

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microorganisms and higher trophic levels. These communities enhance organic matter biomineralization and the recycling of nutrients and organic carbon, enriching the coastal waters and making nutrients available for marine benthic communities (Chinnadurai and Fernando, 2007).

In addition to being continuously affected by natural pressures such as salinity gradients, soil instability, tidal cycle, light, temperature, and alternating seasons (Feller et al., 2010), mangroves are also often subjected to anthropogenic pressures because of their common proximity with urban and industrial centers, aquatic farms and ports (Delabie et al., 2006; Prasad, 2012; Zhang et al., 2014). Among the organisms living in mangrove ecosystems, mangrove trees and benthos are directly in contact with the pollutants potentially accumulated in the sediments such as heavy metals, organic contaminants, pesticides (Lewis et al., 2011; Zhang et al., 2014), oil spills (Duke, 2016), domestic or industrial wastewaters (Bartolini et al., 2011; Molnar et al., 2013). The reports of the impact of anthropogenic pollution can be very contrasted. It has been shown that oil spills and chemical compounds, contained in runoff from urban, industrial and agricultural areas, strongly affect the ecological functions and stabilization of mangrove ecosystem (Lewis et al., 2011; Zhang et al., 2014), and cause a lot of damages on vegetation and fauna (Olguin et al., 2007; Lewis et al., 2011). In contrast, several studies demonstrated a bioaccumulation of heavy metal from sewages in crab tissues (Banci et al., 2017) without any effect on crab genetic diversity. In certain cases, the presence of pollutants can also induce positive effects on some organisms. For instance, organic pollution from human installations led to an increase of crab density for the fiddler crabs (Ocypodidae) while most of the macrobenthos (crabs and gastropods) was impoverished by the disturbance (Lee, 1995). Excess of nitrogen and/or phosphorus also stimulated the vegetation growth (Lovelock et al., 2004) and increased nematode density while an increase of organic carbon increased the density of meiofauna (Gómez Noguera and Hendrickx, 1997; Zhou et al., 2015).

Because of their visible resistance to certain pollutions, their peri-urban localization and their ability to absorb nutrients, it has been proposed to use mangroves as a finishing treatment for pretreated or untreated wastewaters (Wong et al., 1995, 1997). Several studies have considered the potential consequences for mangrove trees or fauna, with constructed mangrove in mesocosms (Penha-Lopes et al., 2009, 2010; Tam et al., 2009), in peri-urban mangroves exposed to a diffuse pollution (Cannicci et al., 2009) or along a pollution gradient of treated wastewaters (Wear and Tanner, 2007). In most cases, a positive effect (growth increase) was observed for the vegetation, while it was more contrasted for crabs. However, Lovelock et al. (2009) have shown with several long-term (3–12 years) nutrient-enrichment (N/P) experiments that an increase of nutrients could lead to higher tree mortalities and a canopy loss, which could severely impair the functioning of the whole ecosystem. This was observed in sites with low rainfalls and high salinity. Our hypothesis is that a nutrient-stressed insular mangrove, with a medium salinity, receiving a discharge of pretreated domestic wastewater (*i.e.* input of organic C, N, P and freshwater) during several years should respond by an increase of vegetation growth, along with little modification of fauna, since the latter appears rather resistant in literature. To demonstrate this hypothesis, mangrove compartments were followed with an *in situ* experimental system set up in Mayotte Island (Indian Ocean). This system uses mangrove as a receptacle/finishing treatment for PW discharges to avoid the direct discharge of wastewaters into the lagoon. Two different zones of mangrove daily receive a discharge of pretreated domestic wastewaters. A first survey of the vegetation after 6 to 12 months of PW discharge has revealed an increase of vegetation growth, leaf pigment content and photosynthesis (Herteman et al., 2011). Here we present the response of vegetation after 4.5 to 6.5 year periods of PW discharge and the long-term responses of the crab community and meiofauna. To our knowledge, this is the first experience performed in a natural mangrove, in controlled conditions, which allows to evaluate the consequences of using mangroves as a receptacle for pretreated domestic wastewaters.

2. Material and methods

2.1. Study site

Since April 2008, an *in situ* experimental system has been running in the mangrove of Chirongui Bay, South-West of Mayotte Island, a French department located in the Mozambique Channel, South-West of Indian Ocean (12°55′S, 45°09′E). This island is characterized by a high tidal amplitude for an oceanic island, reaching up to 4 m in spring tides. The mangrove areas followed in the present study and the experimental system were the same as those described by Herteman et al. (2011). Shortly, domestic wastewaters from Malamani village (250 inhabitants-equivalent) are pretreated in a horizontal primary settlement tank with integrated sludge digester. The mean flow rates treated during the years 2013 and 2014 for wet and dry seasons were 27.3 and 24.7 $m^3{\cdot}d^{-1}$, respectively. Then, pretreated wastewater (PW) is carried through a pipe network to two mangrove areas, respectively dominated by the mangrove trees *Ceriops tagal* (Perr.) C.B. Robinson and *Rhizophora mucronata* Lam. PW are discharged once a day during the low tide for 1 h (10 m^3 per area) in each mangrove areas (around 675 m^2 for each area), giving an hydraulic loading rate of 14.8 $L{\cdot}m^{-2}{\cdot}d^{-1}$, which is equivalent to a rainfall event of 14.8 mm. Near these two "impacted" areas (IA) (at about 15 m), two other areas not subjected to PW discharge were used as "control" areas (CA). The *R. mucronata*-dominated control and impacted areas (*Rm*-CA and *Rm*-IA) are closer from the edge of the lagoon (at about 400 m) than the ones dominated by *C. tagal* (*Ct*-CA and *Ct*-IA) which are less subjected to tides (at about 500 m from the lagoon). The mean duration of immersion (calculated with the tidal model of the French Hydrographic and Oceanographic service of the Marine and the digital elevation model provided by the French Institute of Geographical Information Litto3D) is 1583 h per year (4.3 h per day) in the *R. mucronata* mangrove and 324 h per year (53 min per day) in the *C. tagal* mangrove zone. The *C. tagal* mangrove zone is a shrubby mangrove, stressed by environmental gradients, where the mangrove trees have a weaker development than in continental mangroves and are characterized by a significant foliage yellowing (personal observations). The PW were mainly composed of organic matter, nitrogen and phosphorus nutrients, discharged in the mangrove areas with surface loading rates (respectively wet season/dry season, in $g{\cdot}m^{-2}{\cdot}d^{-1}$) of 3.26/4.14 for Chemical Oxygen Demand, 1.2/2.74 for Biological Oxygen Demand after 5 days, 1.17/1.27 for Suspended Solids, 0.44/0.71 for total Nitrogen and 0.093/0.173 for total Phosphorus (data obtained in 2013 and 2014 from SIEAM, Mayotte, France). The main physicochemical parameters of mangrove areas in sediment and porewater are summarized in Table 1. The sediments were sampled between the surface and 9 cm depth, and the porewater was sampled in piezometers placed in each mangrove area. The corresponding analysis was performed by the ARVAM laboratory (La Réunion, France) and by the physicochemical analysis platform (PAPC, EcoLab laboratory, France).

The long-term impact of PW supply was evaluated between October 2012 and October 2014, 4.5 to 6.5 years after the beginning of PW discharges, during the dry season (May–October) and the wet season (November–April), on three main compartments of the mangrove ecosystem: vegetation, crabs, and meiofauna (Fig. 1). We have chosen to evaluate some parameter of the ecosystem (tree productivity, crab community and meiofauna) during a long period rather than at one date in order to integrate the variations linked for instance to meteorological events or to seasonal dynamics. The structure of the vegetation, which is less variable at a small temporal scale, was assessed at one date, after 6.5 years of PW discharges (in October 2014) and compared to data obtained after 6 months (in October 2008) in the same plots (short-term effect).

The plots used for the study of crab and meiofauna were positioned