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Degradation and conservation of Brazilian mangroves, status and perspectives

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ABSTRACT

Mangroves are one of the most human-affected coastal ecosystems, despite their important social and ecological roles, and after decades of devastation these forests continue facing different processes of conversion, threatening their global future. Brazilian mangroves are not an exception, despite the existence of severe protection legislation. Conversions to aquaculture, industrial and urban development among others, have destroyed more than 50,000 ha (about 4% of the total mangrove area in the country) over the past three decades. Restoration efforts have somewhat minimized losses, but has recuperated only a 5% of the total degraded area. Despite criticized, monospecific plantings have demonstrated return of some ecosystem structure and functioning, and seems to be a starting point in mangrove restoration. Around 70% of Brazilian mangroves are today inside preserved areas, but the effectiveness of these advances continues impaired by bureaucracy, lack of conservation policies and economic interests. We estimate the status of Brazilian mangroves and review some restoration and conservation efforts, suggesting some management measures like restoration and community-based ecosystem management. Based in a reforested stand in Northeastern Brazil, we assess the environmental cost of mangrove clearing and reforestation results.

1. Introduction

Mangroves are highly productive ecosystems that occupy one of the most human-affected regions of the world, the continent–ocean interface. They cover around 170,600 km^2 of tropical and subtropical coasts worldwide (Lacerda, 2002). Brazil, with 7% of the world's mangroves, is the third country in mangrove extension on Earth (FAO, 2007). Worldwide, at least 35% of these forests have been destroyed in the past decades by human settlements, overexploitation, conversion into salt or aquaculture ponds and other aggressions, disregarding their important ecological and social roles (Alongi, 2002; Barbier et al., 1997; Diegues, 1999; Lugo, 2002; Manson et al., 2005; McLeod and Salm, 2006). Fish and mainly shrimp aquaculture practices were also responsible by nearly half of the total mangrove clearing, in particular in South and Central America and Southeast Asia (McLeod and Salm, 2006; Valiela et al., 2001). For example, nearly 279,000 ha of Philippine mangroves were converted to aquaculture ponds from 1951 to 1988, whereas in Indonesia a similar area (269,000 ha) was also converted between 1960 and 1990 (Primavera, 2000). Nearly 50% of Ecuador's mangroves were converted between 1980 and 2000 attributed to shrimp farm development (Lacerda et al., 2002). In the Gulf of Fonseca, Honduras, about 30% of the native mangroves were substituted by aquaculture facilities, with significant losses in the local fisheries (DeWalt et al., 1996) and conversion continues at an annual rate of 2000–4000 ha (Lal, 2002). Overexploitation of forest products and expansion of coastal human populations have been increasingly important vectors of mangrove destruction. Natural processes such as sea level rise, changes in estuarine hydrodynamics and tsunamis, also threaten mangrove endurance in the Planet (Alongi, 2002). However, effective official policies or strategies to integrally protect mangroves as national and humanity patrimony, despite site specific cases (see Alvarez-León, 2003), are still rare at regional and global scales.

Afforestation and replanting of mangroves carried on in all continents have partially decreased the speed of forest losses (Ellison, 2000; Ferreira et al., 2007; Field, 1996; Kairo et al., 2001; Magris and Barreto, 2010; Menezes et al., 2005; Walters et al., 2008). Some programs afforested areas by planting one or few species, and have been criticized by doing so (Ellison, 2000; Lewis,

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2005; Walters et al., 2008). However, monospecific mangroves can show rapid development and restore some ecosystem structural properties and functioning (Ferreira et al., 2015; Hong, 1996; Macintosh et al., 2002). A *community management* approach was applied in some restoration processes (Ferreira et al., 2007, 2015; Brown et al., 2014; see review by Datta et al., 2012), developing necessary collaboration for larger scale plantings, which are yet scarce due to logistical problems. Sometimes, self-recuperation of mangrove stands is possible, following specific management measures such as hydrological restoration (Lewis and Gilmore, 2007; Matsui et al., 2010; Turner and Lewis, 1997) or simply by protecting measures to avoid new impacts and to allow natural recovering (Field, 1996). On the other hand, several studies reports that mangrove extension has stopped decreasing and even augmented in some previously deforested or new mangrove areas (Benfield et al., 2005; Cavanaugh et al., 2014; Giri et al., 2011; Lacerda et al., 2007; Li et al., 2013; Maia et al., 2006; Martinuzzi et al., 2009; Ren et al., 2011; Schwarz, 2003). Unfortunately, global forests losses are still extensive. For example, between 1975 and 2005, in the tsunami-affected region of Asia, 12% of mangrove forests were converted into agriculture and aquaculture (Giri et al., 2008). This is much larger than afforestation efforts in this same area (Spalding et al., 2010).

The larger mangrove extension (around 80%) of South American Eastern margin occurs along the Brazilian coast (Fig. 1). Extensive mangrove areas have been destroyed by human pressure, mainly aquaculture, salt production and changes in sedimentary patterns, along the north and northeastern coast; and chemical and urban pollution, and urban expansion, in the southern coast (Diegues, 1999; Godoy and Lacerda, 2015; MMA, 2006). Despite the larger Brazilian mangrove forests (60–70% of the total area) being located in the Northern region (Fig. 1) and relatively preserved, Brazil has lost at least 50,000 ha of these forests (around 4%) over 25 years (FAO, 2007). Considering that all mangroves in Brazil are legally ‘Areas of Permanent Protection’ (APPs), this illegal deforestation is more serious and unacceptable. Poverty, difficult logistics and Governmental bureaucracy preclude more efficient mangrove conservation, a common feature with other underdeveloped countries (Primavera et al., 2014), and despite several preserved areas were created to protect mangroves, they were not as effective in stopping the degradation of these coastal forests throughout Brazil, mainly due to lack of surveillance on legislation observance. Plantings have been made, but most data on recuperation remains unpublished or reduced to planting techniques, lacking data of mangrove development from medium to long term monitoring (Rovai, 2012). Data from Northeast Brazil, showed high *Rhizophora mangle* propagules survival (70–90%) and aboveground biomass after 5 years planting, showing that planted mangroves (including monospecific stands) can have rapid development and restore some ecosystem functioning (Ferreira et al., 2015; Hong, 1996; Macintosh et al., 2002). Several mangroves are suffering a new wave of conversion, and shrimp ponds built on previously deforested mangroves for salt production and to a lesser extent to agricultural and cattle breeding, contribute to maintain or amplify environmental damage and makes difficult legal actions upon the new developments. Developing of harbors and Industrial facilities remain growing sources of impacts over forests (Lacerda et al., 2002), and continue blindly ignoring ecological (mainly as seedling furnisher), touristic and economical value of mangrove stands. Sometimes, the proper governmental enterprises impact mangrove ecosystems. While natural disasters are uncommon, and in spite of mangroves be substrate builders by efficiently accumulating sediments and therefore resist tidal washing and erosion, sea level rise due to global warming threats directly and indirectly mangrove stands unable to expand landwards, due to geographical constrains in some areas and anthropogenic activities located upstream watersheds (Godoy and Lacerda, 2015).

The conservation status of Brazilian mangroves and major drivers threatening their extension and functioning are mostly based on reactively old literature. Major changes in coastal development as well as on the proper environment legislation towards the management of the coastal zone occurred in the past two decades and updated figures of their impacts on Brazilian mangroves are still lacking (Kjerfve and Lacerda, 1993; Lacerda et al., 2002; FAO, 2007). Major threats such as those from aquaculture and global climate changes are still poorly documented (Godoy and Lacerda, 2015). In this work we update the current status of conservation of Brazilian mangroves, their level of degradation, and

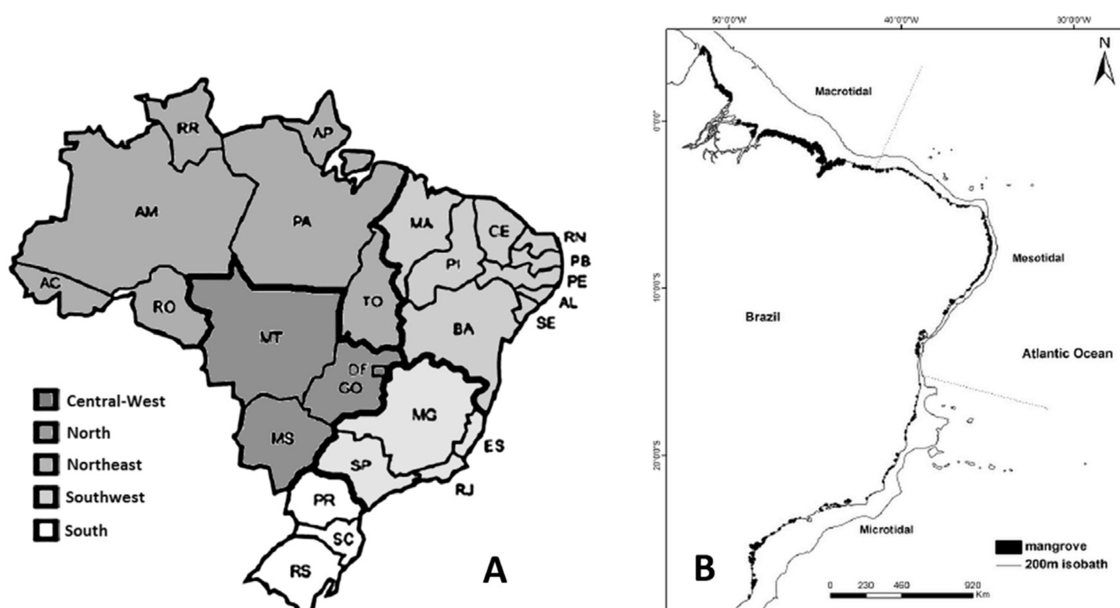

Fig. 1. **A**. Brazilian States and Regions. States are composed by Counties, almost 5.600 in the country. **B**. Mangrove areas at Brazilian coast (from Magris and Barreto, 2010).

some present changes and transformations. Using experimental data from a restored mangrove stand in Northeast Brazil we estimate the economic loss by forest clearing, and consider forest managing options based on positive ecological and social effects of restoration. We exemplify some governmental and scientific initiatives and results in conservation, and some of their advances and limitations.

2. Material and methods

An evaluation of the conservation and environmental threats of Brazilian mangroves is presented based on a review of the recent published literature, Government information from articles and official websites, data from Aquaculture stakeholder's websites, and case studies of mangrove reforestation initiatives. More specific and detailed information is provided when unpublished data are discussed. To assess the value of mangroves we used the method created by Galli (1996), where a range of categories quantifies impacts over ecosystem components (air, water, soil, fauna, flora and landscape) and attributes higher values according to damage persistence, extension and gravity. These categories summed give a *multiplying factor*, which multiplied by the cost of restoration of the stand gives the environmental impairment of deforestation.

This work does not attempt to review in detail all existent information about Brazilian mangroves; instead, it intends to organize and update current situation, examples and possibilities of successful management and multiple factors involved in the managing of these ecosystems.

3. Current degradation, restoration and conservation benefits of mangroves at Brazil

3.1. Present degradation status

Around 40% of Brazilian population lives in coastal areas, which increase the pressure over coastal ecosystems such as mangroves and adjacent buffer ecosystems. Brazil has a legally consolidated environmental policy including legislations such as the 'Forest Code', the 'National Plan of Coastal Management', and the 'National System of Nature Conservation Units' created by Federal Laws in 1965, 1988 and 2000, respectively (Magris and Barreto, 2010; see a Review in Marroni and Asmus, 2013). Despite this, it has been unable to stop coastal ecosystems degradation. Several areas of the coasts and many estuaries, mainly along the southeastern and northeastern regions, are critically or moderately degraded, and mangrove forests in these areas have suffered severe damages (Diegues, 1999; Magris and Barreto, 2010; MMA, 2010). Even the present expansion of mangroves in the northeastern coast of Brazil (Lacerda and Marins, 2002; Maia et al., 2006) is still too site specific and suffer from using different measuring methodologies, hampering a regional evaluation and the design of conservation policies. Studies show that reported mangrove extension in Brazil varied from 1.38 million (Kjerfve and Lacerda, 1993) to 962,683 ha (Giri et al., 2011). Within this range, FAO (2007) reported around 1 million hectares, whereas Magris and Barreto (2010) estimated forests extension of about 1.11 million hectares. The amount of deforested area, however, varies little among authors, most of them considering that 50,000 ha disappeared over the last 25 years, mainly along the more urbanized southeastern coast. This means that taking into consideration the different estimates of total mangrove forest cover, the reduction has varied from 3.6 to 5.2% of the total mangrove forest extension. This area is proportionally lower than in other countries (FAO, 2007), but a step coastline in the southeast and semiarid conditions in the northeast limit the landward extension of these forests restricting them to a narrow fringe along the Brazilian coast (Fig. 1B). This makes losses in ecosystem and biodiversity services proportionally higher in these regions.

Penaeid shrimp farming is one of the main drivers responsible for mangrove destruction in northeastern Brazil (Ferreira et al., 2015; Lacerda et al., 2002; Maia et al., 2006). In the last three decades, exotic Pacific shrimp *Litopenaeus vannamei* culture expanded to several coastal States and the northeastern region was responsible in 2011 by 98% of the Country's total shrimp production with 19,845 ha of active ponds, being two States (Rio Grande do Norte (RN) and Ceará (CE), Fig. 1A) responsible for 71.6% of total production (ABCC, 2011). At least 15% of the total shrimp pond area is from converted mangrove forest, whereas an unknown fraction was lost by opening of canals, changes in hydrological dynamics of coastal plains and due to sedimentation and erosion of tidal creeks and river banks (Meireles et al., 2007). Although only 3% of the Brazilian mangrove area is in these two northeastern states (Maia et al., 2006), forest loss, although relatively small in absolute terms, is proportionally more relevant than in other regions, comprising up to 10% of their mangrove forest cover, at least 2–3 times larger than the country's deforested area. Shrimp aquaculture is presently at stagnation, and several ponds are being deactivated in northeast and all over the Country. In some Northeastern areas a new tide of transformation is in course, and cattle grazing and human occupation advance over mangroves areas degraded by aquaculture. After hard years, salt industry is supposed to recuperate and expand again throughout this region, mainly in Rio Grande do Norte State (Nunes et al., 2011), and several areas are being transformed into salt ponds (Fig. 2B), increasing the soil degradation and in most cases still expanding over remnant mangroves. Yet, exotic *L. vannamei* escaped to estuaries and extensively inhabits them today (Ferreira and Sankarankutty, 2001), with still not assessed ecological consequences.

Mangrove degradation continues in the Southeast (with 30% of Brazilian mangroves extension) involving much larger areas and having as major drivers coastal development, urbanization and pollution, mostly from inadequate solid waste disposal and oil spills. More than 42% of the Brazilian population concentrates in this region (IBGE, 2010) increasing the pressure upon mangroves. Mangrove areas were and are continuing being converted by development of cities outskirts fed by migration of country dwellers (IBGE, 2010). More recently, huge investments of more than 7.5 billion dollars, were available for upgrading and enlargement of several Ports along the Brazilian coast, most in coastal sites harboring extensive mangrove forests (among them, Rio de Janeiro (RJ) and Santos (SP) in the Southeast; Recife (PE), Salvador (BA), Natal (RN) and Fortaleza (CE) at in the Northeast) (GFRFB, 2014). These new developments add to the already serious existing threatens to several local mangrove remnants and regionally to other areas along ship routes. In spite economical fluctuations, policies oriented to enlarge maritime commerce will persist in Brazil, enhancing the necessity of long-term protecting measures.

3.2. Advances and unresolved issues in mangrove conservation and restoration

Mangroves need to be protected and the devastated ones restored. If hydrological and soil conditions are preserved, deforested mangroves are able to self-recover (Lewis, 2001, 2005), although displaying lower growing rates compared to artificially planted stands (Ferreira et al., 2015). Simpler solutions than planting, such as restoring hydrology and/or preserving or promoting natural propagules recruitment, may be effective for restoration of some stands (Ferreira et al., 2015; Kamali and Hashim, 2011; Lewis, 2005; Lewis and Gilmore, 2007). An

Fig. 2. **A**. Shrimp ponds in converted mangroves; **B**. A deactivated saline pond, showing marginal growth of mangrove impaired by hypersaline soil; **C**. Community collaboration in planting mangrove; **D**. Restored mangrove in a deactivated shrimp pond; in the right, a dyke made for enclosing the pond. **A**, **C** and **D**, Potengi estuary (RN State); **B**, Pacoti River (CE State).

inventory of mangrove areas potentially able to self-recovering in Brazil and the implementation of measures leading to protect them is an urgent and cheap shortcut to recuperate the lost time (Ferreira et al., 2015). For example, removing remnants of dykes in abandoned shrimp farms and salt ponds promotes improvement of water and soil conditions and allows the establishing of waterborne propagules. At the Pacoti estuary, NE Brazil, 17 ha of mangroves converted into salt ponds were naturally recuperated after 20 years from shutting off salt production in the area (Lacerda et al., 2007). These extremely simple measures, however, are being ignored by different governance levels in several estuaries, showing few concerning (i.e. policies) on mangroves conservation in practical terms. Bureaucracy, lack of specialists and boundary conflicts with different governance levels are common impairments at County (citizen) level.

Planting mangrove stands can recuperate goods and services furnished by the ecosystem. Some restoration efforts have offset the losses, and despite 40% of the plantings had survival rates below 20%, only 5% of the degraded area was recuperated until 2010 in Brazil, with the larger plantings in the North and Northeastern regions (Rovai, 2012). Yet, most plantings have not been long monitored, remain undocumented, or are resumed and fragmented in Proceedings, and there are few data about the return of biodiversity and functionality of restored mangroves. Reforestation programs have been criticized by planting one or few species (Ellison, 2000; Lewis, 2005; Walters et al., 2008). However, it seems that at least in low tree richness neotropical mangroves, the planting with *R. mangle* may show attributes of a pristine ecosystem (Ferreira et al., 2007, 2015; Ross et al., 2001; SER, 2004) and certainly would largely contribute as a carbon sink helping mitigating anthropogenic carbon dioxide emissions (Siikamäki et al., 2012).

We restored a stand originally of *R. mangle* cleared by shrimp breeding in Potengi River (northeastern RN State) and verified high survival rate of planted propagules (70–90% in the first 2 years), rapid recovering (Fig. 2C, D) and high aboveground biomass after 5 years. Growth rates and biomass increment (60.43 $t.ha^{-1}$) were higher than plantings of similar age *Rhizophora* elsewhere (Ferreira et al., 2015). The rapid development of roots and canopy of *R. mangle* (Ross et al., 2001) promoted the early return of a key functional group of Grapsoid and Ocypodoid Brachyuran crabs, inhabitants of these forests, including the man-gathered "Uçá" crab *Ucides cordatus*, an important resource for native fishermen. Planting of *R. mangle* can be therefore used to start ecological functioning of deforested neotropical mangroves or elsewhere, when ecological factors like high desiccation or propagule predation by crabs impair natural seedling establishment (Ferreira et al., 2007, 2015). This tree showed to be a key species, corroborating evidences that the restoration of specific ecosystem traits and natural functions can increase chance of a successful restoration (Lewis, 2005; Ferreira et al., 2015). Yet, it shows that different management measures, from planting to self recovering, can be applied together regarding stand structural characteristics (Ferreira et al., 2015).

In parallel with restoration programs, conservation of extant forests in Brazil had, fortunately, followed the increasing trend at the global level (Cavalcanti et al., 2009; Chen et al., 2009; Fan et al., 2013; Ferreira et al., 2007; Lacerda et al., 2007; Li et al., 2013). The mangroves of the North coast, among them those situated in the Amazon delta, constitute between 60 and 70% of the total Brazilian mangrove forest extension, and the mangroves situated in Pará (PA) and Maranhão (MA) States constitute the largest continuous belt of these forests of the Planet, extending by around 700,000 ha. The Parque Nacional do Cabo Orange ("Cape Orange National Park") protects mangroves in the Oiapoque River (extreme northern Brazilian frontier) and along the coast of Amapá State (AP), being an important RAMSAR site (Table 1). More 88,598 ha of these forests are under protection also in this State (Magris and Barreto, 2010). In spite of relatively preservation (FAO, 2007) and with some stands under sustainable use, these forests are already being impacted by overexploitation and human expansion, and require urgent enforcement of the protection and management measures (Menezes et al., 2008). In 2014, a marine reserve coastal area (Araí-Peroba, PA State) was increased, including other pre-existent reserves, from 213,000 to 322,000 ha (Portal Brasil, 2015). In the Northeast region, several urban Parks with mangroves were created, which save mangroves still not devastated by shrimp culture. Other example exists in Florianópolis (SC) (Sovernigo, 2009) (Table 1). South and Southeast are the most degraded areas, but some forests are relatively well preserved, as some regions between São Paulo (SP) and Paraná (PR) States (Fig. 1) including the Cananéia-Iguape and Paranaguá Coast Protection Area (Cunha-Lignon et al., 2011; Diegues, 1999) (Table 1) which are important examples of them. Other coastal protected areas with mangrove ecosystems are summarized in Magris and Barreto (2010).

Cavalcanti et al. (2009) showed higher development of forest on effectively protected areas relative to not protected areas at Southeastern coast in Rio de Janeiro (RJ) State, strengthening the importance of conservation measures. According MMA (2006), 132 "Conservation Unities" (CUs) containing mangroves exist in Brazil, 58% in the Northeast and 32% at Southeast. Most CUs (60%) are government-owned; in the North Federal Unities predominates, whereas in the Northeast and Southeastern predominates State-owned CUs. It is noteworthy the lack of County-managed CUs, a level where, theoretically, would be easier to define and preserve natural areas. Although the Federal Forest Code states that all mangrove areas are under permanent protection this is not observable in practice, even with ample protection initiatives promoted in collaboration with global Organizations (MMA, 2006, 2010). Magris and Barreto (2010) stated that 77% of mangroves are inside really protected zones when considered all levels of governance (Federal, State and Counties). However, like other underdeveloped countries, conservation initiatives of unprotected (and protected) areas in Brazil are still impaired by bureaucracy (including governance jurisdiction conflicts between Federation, States and Counties), lack of knowledge, logistics, enforcement and economic interests (Diegues, 1999; MMA, 2006).

Since their establishment, some CUs attained partially the aim to acquire knowledge and promote scientific research, also being potentially also used for leisure and/or tourism. However, several CUs face problems due to incomplete legal regulation and lack of a proper management plan, which allows the continuity of degrading activities. Indeed, government management planning in most areas fails to involve native mangrove dwellers and fishermen communities, when ideally a *community based management* should be implanted to manage these forests (Brown et al., 2014; Ferreira et al., 2007; Walton et al., 2006; see a Review in Datta et al., 2012). This framework implies the native communities' participation in the management of ecosystem, respecting the native use and management practices but also emphasizing conservation, since the goods and services furnished by mangroves are only possible if forests are preserved and/or restored. Ferreira et al. (2007) reported the engagement of riverine community in mangrove restoration, since most of them were crab-gatherers, affected directly by crab's habitat destruction by shrimp farms (Fig. 2C). Mangroves' conservation needs both people's comprehension about the goods and services given by forests and firm government enforcement of the protection legislation. Public can visit the mangrove (as in the "Parque Ecológico do Cocó"), which contributes to ecosystem knowledge and promotes conservation interest with a huge metropolitan area, Fortaleza city, with nearly 3 million inhabitants. Scientific knowledge can help protecting, recuperating, preserving key species and establishing limits to visitor's flux according ecosystem rehabilitation. In the case of mangroves, weakness in supervision and control of illegal occupation at all levels of governance stays impairing solid advance, and environmental policies still need to invest in applying, overseeing and punishment of environment regulations infractions.

3.3. Environmental costs and benefit assessment

Goods and services furnished by mangroves need to be more accurately valuated, but studies assessing forests economical value are scarce, beyond site specific. Governmental agencies of environmental control argue a lack of practical methods to assess degradation and calculate fines for charge to devastators. Aiming to quantify some services given by mangroves, we assessed the ecosystem environmental and economical loss associated to conversion of mangroves into shrimp farming ponds at the Potengi River (City of Natal, RN State). The Potengi River is temporary (rainy season March–July) with catchment drainage of 3180 km^2 (Silva et al., 2007). Applying the method of Galli (1996) by using the cost of restoration of the stand by us in 2006, and corrected with Brazilian inflation rate since this year, we obtained the environmental impairment of deforestation. The amount reaches between

Table 1
Examples of some urban and not-urban Protected Areas to compare extension, jurisdiction and location. Ordered by region. See the abbreviation of States in Fig. 1.

Name	Extension (ha)	Location (state)	Created	Jurisdiction	References
Cananéia-Iguape and Paranaguá Coast Protection Area	202,308	PR – SP	1985	Federal	Cunha-Lignon et al., 2011; Diegues, 1999
Parque Nacional do Cabo Orange ("Cape Orange National Park")	around 51,000	Oiapoque River and North coast (AP)	1980	Federal/ RAMSAR site	Magris and Barreto, 2010
Parque Ecológico do Cocó ("Cocó River Ecological Park")	1155	Cocó River/Fortaleza (CE)	1989	State-owned	SEMACE, 2010
Parque Estadual dos Mangues do Potengi ("State Park of Potengi (river) Mangroves")	782	Potengi River/Natal (RN)	2006	State-owned	IDEMA, 2011
APA (Environmental Protection Area) Bacia do Cobre/São Bartolomeu	1134	Salvador (BA)	2001	State-owned	INEMA, 2015
Parque do Manguezal de Itacorubi ("Itacorubí River Mangrove Park")	150	Itacorubi and Sertão Rivers/ Florianópo-lis (SC)	2002	State-owned	Sovernigo, 2009
Parque dos Manguezais ("Mangrove Park")	320	Pina and Jordão Rivers/Recife (PE)	2010	State-owned	SEMAM, 2014

U$S 4.2 and 4.6 million per hectare (depending use of lower or higher estimations of accumulated value of inflation rate). This is, in other words, the value of fines debt by devastators, and same calculation can be applied to other cleared estuarine mangrove areas. Translated to the total Potengi mangrove extension of 15.61 km^2 (Maia et al., 2006), and using the lower value, the environmental degradation at the river by shrimp breeding would cost about US$ 6.1 billion, if shrimp diseases and other sanitary problems related to water quality would have not hampered shrimp culture at estuary. On the other hand, Brazilian cultured shrimp exports reached a maximum of US$ 30.7 million in 2004 (ABCC, 2015), showing that the profit of shrimp market is small in comparison to environmental damage. Additionally, fisheries can generate approximately US$ 4.01 million y^{-1} (fisheries volume data extracted from Brazilian Environmental Protection Institute – IBAMA) at the Potengi estuary. Despite every initiative being welcomed, the Mangrove GEF Project, a partnership between Brazilian Environmental Ministry (MMA) and United Nations Development Programme (UNDP) through Global Environment Fund (GEF), for example, applied only US$ 5 million in Brazilian mangroves conservation during 4 years (MMA, 2006), much less than what would be require to balance mangrove destruction.

The use of mangroves as natural filters as an alternative management for sewage treatment (including that from shrimp ponds) has been proposed, due to mangrove capacity of nutrient retention and transformation in biomass (Primavera et al., 2007; Souza and Silva, 2011; Zhang et al., 2011). Using again Potengi mangroves data and considering that they are able to retain around 7571 tons of N in sediment and trees (Silva et al., 2007), and that 3.54 tons of ammoniacal N are spilled in Potengi by day (CAERN, 2007), mangroves could theoretically retain around three orders of magnitude more N than the produced within the Potengi watershed. Based on the capacity of a wastewater treatment plant planned by the "Water and Waste Company of Rio Grande do Norte" (CAERN) to treat around 0.67 tons of N from a part of Natal City by day, at a cost of more than U$S 6.47 million (CAERN, 2007), and the fact that more than 5 of such plants are needed to completely treat the daily input of N spilled in Potengi river, gives the magnitude of the value of nutrient retaining service by mangroves. Indeed, Souza and Silva (2011) have estimated ecological services of water treatment by area in US$ 15,500 h^{-1}, which means more than US$ 29.4 million for the whole estuary. All costs presented here were transformed to present values by accreting Brazilian inflation rate. However, caution is necessary, because increase of waste spilling in estuaries is associated to mangrove degradation and bioaccumulation of metals (Chen et al., 2009; Silva et al., 2001, 2006), reduced ecosystem structural complexity and abundance of fish and invertebrates, and accumulation of toxic sulfides (Anton et al., 2011). The accumulated C produced by enriched primary production in the water column can enhance release of CO_2 to atmosphere by organic matter decomposition (Sanders et al., 2014).

3.4. Ancient responses to present challenges

Some mangrove areas in Brazil have increased their extension (Lacerda et al., 2007; Maia et al., 2006), as observed elsewhere (Benfield et al., 2005; Cavanaugh et al., 2014; Giri et al., 2011; Martinuzzi et al., 2009; Li et al., 2013; Ren et al., 2011; Schwarz, 2003). Some littoral areas are being colonized either over deactivated aquaculture or salt ponds mostly constructed by clearing mangroves (Lacerda et al., 2007), or over new sedimentary areas resulting from land use changes in the watersheds (Godoy and Lacerda, 2015). But recovering at deactivated salt production ponds is delayed by soil hypersalinity, taking several years of tide cycles to return to plant-tolerable physico-chemical conditions (Fig. 2B). New sedimentation areas appear by changes in estuarine dynamics induced by sea level change, and also by changes in sedimentary patterns due to river damming, sediment extraction and deforestation (Lacerda and Marins, 2002; Marins et al., 2002). However, under some circumstances, new substrate areas can be short-lived, and mangrove patches can further disappear due to erosion.

A consequence of changes in sedimentary patterns is the primary establishing of *Laguncularia racemosa* forests, typical of high disturbed or degraded areas in process of restoration (Bernini et al., 2014; Soares, 1999) preceding the dominance of *R. mangle* as in more aged Neotropical stands (Ball, 1980; Duke et al., 1998). Indeed, this patchy establishing dynamics of mangrove is proper of intertidal conditions and probably assured persistence of these tree assemblages through the Pleistocene Ocean level changes to present. Rising of sea level and other consequences of global warming can impact mangroves, since there are no neotropical mangrove trees evolved to occupy the intertidal belt upstream their optimal ecological space (Duke, 1993). Still, human occupation limits mangrove expansion toward higher littoral areas. Both human and natural factors have no perspective to decrease, tending instead to increase and requiring urgent effective measures to protect mangrove remnants and reforest the degraded stands. Recently, it have been showed that some mangroves are expanding also in geographic range and over other ecosystems as marshlands (Cavanaugh et al., 2014; Godoy and Lacerda, 2015; Perry and Mendelssohn, 2009), and this can be a way for the ecosystem persistence, at least for some species. So, evidences indicate that impacts of global warming at mangrove stands can vary locally, resulting in mangrove expansion or disappearing from an interaction between rising sea level and changes in the watershed, including changes of the continental runoff due to altered rainfall regime (Godoy and Lacerda, 2015).

4. Concluding remarks

This work is focused on Brazilian mangroves, presenting updated information about multiple advances and unresolved issues of forest conservation and management, plus conflicts between development and environmental preservation common to other developing countries. The "run for gold" of shrimp culture at mangroves showed that the claims of the capital justifying environmental damage to fight poverty and "create jobs" were, naturally, false. Abandoned ponds and destroyed forests are the common (and repeated) final of extensive shrimp culture as was performed, leaving enormous damage for countless artisanal fishermen, regional fisheries and for environment. The conflict *economical development vs. preserved environment* is false, and coastal degradation proved to be far more economically harmful than the decrease of limited seasonal employments offered by shrimp farming enterprises. Until recent, aquaculture and salt production ponds substitute one another, impairing the return of natural hydrological and soil features in occupied lands by decades. Several remnant mangroves are currently suffering a new wave of conversion for agriculture and cattle breeding, and threatened by a relative development from the start of 21st century in Brazil, with harbors, industries and human occupation. It is possible that human development whether advantages taken from nature goods and services are managed responsible and seriously, but Brazil (and unfortunately too many other Countries) is failing this approach, when the time to preserve planetary geochemical cycles is nearly exhausted.

Ideally, the whole regional realm in which mangroves are embedded needs to be protected. Estuaries are dynamic systems and forests are a patchwork of different tree assemblages and developmental stages fragments (Alongi, 2009). It is necessary to preserve ecosystems contiguous to mangrove forests, such as subtidal benthic habitats, coral reefs, upstream river environments and upper littoral sandbanks (Ferreira et al., 2007). Although abundant and quite restrictive, the present legislation fails to include buffer habitats to protect mangroves from human drivers. An integrated management is ideal, since these environments are functionally linked through the biogeochemical processes at the continent–ocean interface (Lundberg and Moberg, 2003; Sheaves, 2009). An inventory of areas potentially able to self-recovering in Brazil (and also in other Countries) and the implementation of measures leading to protect them is an urgent and cheap shortcut to recuperate the lost time (Ferreira et al., 2015). More and larger areas need to be planted, and multispecific planting is facilitated by low number of Neotropical tree species (3–8) and strongly encouraged when the aim is to restore originally multispecific stands. However, fragile propagules of *Avicennia* sp. and *L. racemosa* can be decimated if not protected from crabs and desiccation or burying, rising logistic costs (Ferreira et al., 2013). Our data show that planting *R. mangle* can be used as a first step to decrease the speed of environmental changes, and restarting at least in part mangrove goods and services, but stressing that application in other sites still need clear purposes and cautiously analysis of management measures. Data on comparative development of planted or restored mangroves (biomass, growing, Carbon capture and storage) through longer periods are still scarce in data banks. More long-lasting monitoring projects and/or funds may ensure collection of long-term data series. Monitoring of key functional groups return is important as a measure of ecosystem recovering (Jansen, 1997; Ferreira et al., 2015).

Integration of native communities (in particular those depending on mangrove goods and services) and other society sectors through community based management is important, although a proper valuation of these mangrove benefits are still very preliminary at the country's level. NGOs, government agencies, academic institutions and funding agencies are important agents of action and awareness generation (Datta et al., 2012). A comprehension of these facts seems timidly to orientate present Brazilian coastal policies (MMA, 2010). From the start of the past decade, Brazil's government is encouraging society to a shared management of river basins through participation of different social sectors and stakeholders at “Basin Committees” (PNRH, 1997), but such policies are still initiating and in general fail to include the coastal area within their frameworks. Planting, monitoring and conservation can be actions shared with community. It is noticeable that mangrove plantings can leave an important legacy of people (child, native communities, students, scientists, environmental control agencies) with more knowledge and concerns about mangrove conservation and management (Ferreira et al., 2007; Kairo et al., 2001; Walters, 1997) (Fig. 2C).

There are countless mangrove areas to preserve which could be more practical and effectively protected under Brazilian Counties responsibility. It is at this level of governance where laws are applied, but it suffers with bureaucracy, lack of specialists, insufficient funding and boundary conflicts with other governance levels. Capacity of Counties to apply and supervise environmental laws need to be enhanced, avoiding from irregular advances of the human activities over forests to high magnitude development projects and any environment impacting activity that lacks a plan of conservation and management. The protection of Northern region mangroves and their high ecological significance needs to be reinforced before severe impacts reach those ecosystems (Menezes et al., 2008). In the other regions, mangrove need to be effectively protected, for example, definitively prohibiting the establishment of salt and aquaculture ponds in mangrove areas, to avoid return of deforestation if cultured shrimp market recuperates. A larger part of the Brazilian shrimp farming, on the other hand, is losing the opportunity in use natural services given by mangrove forests and estuaries to produce shrimp in a sustainable way, which would add value to their product in a growing “nature-friendly production” market segment. Government still need to pay attention to scientists, promote and support more researches, and only allow public (or private) initiatives that preserve mangroves and their importance for coastal ecology and economy. Partnership with scientists at Universities and mangrove research groups need to be increased, to found and apply better management measures for mangroves. Unfortunately, funds to finance environmental studies and sustainable projects, which are nearly totally from the Government, are still insufficient and very sensible to economical fluctuations, beyond wrong applied. There is an urgent need to involve the private sector and other stakeholders in the funding process. A lesson that emerges is that it would be more practical to develop urgent conservation and restoration initiatives at the base, promoted and performed by social protagonists (community) with science partnership, than wait by governmental initiatives, which are slow and entangled in bureaucracy. It is expected that these and other ecosystems approaches be implemented urgently, since even their initial results may preclude a significant loss of Brazil's great wetland heritage.

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