Ocean & Coastal Management 110 (2015) 38–45

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Restoration versus natural regeneration in a neotropical mangrove: Effects on plant biomass and crab communities

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ARTICLE INFO

Article history:
Received 19 December 2014
Received in revised form
15 March 2015
Accepted 21 March 2015
Available online 29 March 2015

Keywords:
Biomass production
Crab richness
Functional group
Goniopsis cruentata
Mangrove restoration
Wetland management

ABSTRACT

Mangrove restoration is a powerful tool for reconstructing degraded tropical estuaries worldwide. The level of intervention necessary for rebuilding a mangrove area is still under study because this system is quite dynamic and some degraded areas are able to recover by themselves. We compared a Restored Area planted with *Rhizophora mangle* and a Self-recovered Area, to investigate how they would differ in respect to their plant and crab assemblages. In each area, 10 plots were randomly sampled for measuring tree richness, density, diameter at breast height and biomass, as well as crab richness and density after five years from recover. Plant height and biomass, as well as crab density, were significantly higher in the Restored in relation to the Self-recovered Area. However, tree richness was higher in the Self-recovered Area and crab assemblage reached in five years a similar composition in assisted, naturally recovered and natural areas, showing the high resilience of this important functional group. Active planting of *R. mangle* propagules can significantly improve mangrove recovery in sites with high propagule predation, increasing tree biomass and accelerating the return of animal functional groups such as crabs. However, if resources for active restoration are scarce, passive recovery can be a successful low cost alternative for mangrove restoration that preserves tree diversity and crab assemblages.

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1. Introduction

Mangroves are highly productive biological communities that occupy around 15×10^6 km^2 of tropical and subtropical coasts worldwide (FAO, 2007; Lacerda, 2002). At least 35% of mangrove forests have been destroyed in the past decades by human settlements, wood extraction and shrimp culture (Valiela et al., 2001) leaving many deforested and abandoned areas in need of restoration (Alongi, 2002). However, to restore a degraded ecosystem to a pristine condition is not an easy task, because most ecosystems are in permanent change, and estuarine mangroves are a good example (Alongi, 2009; Wyant et al., 1995). On the other hand, the effectiveness of mangrove restoration programs to significantly improve ecosystem function has been doubted, due to the use of only one or few tree species, a low richness when compared to natural areas (Ellison, 2000; Lewis III, 2005; Rovai et al., 2012; Salmo III and Duke, 2010; Walters, 2000).

Tree development is an important and commonly measured feature of a restored ecosystem, because key ecosystem functions and faunal colonization are dependent on vegetation structure, biomass and diversity. Planted mangroves can reach high tree development in height, diameter or biomass (Hong, 1996; Ferreira et al., 2007; Macintosh et al., 2002), but Ross et al. (2001) found that naturally recovered Neotropical mangroves have achieved similar tree development than planted ones. Choosing a better cost/benefit management procedure in such forests is impaired by scarcity on studies comparing equal lifetime planted and naturally recovered areas. Studied natural stands used to compare with planted were of unknown age or older (Bernini et al., 2013; Martinuzzi et al., 2009; Shafer and Roberts, 2008). Alternatively, the return of faunal functional groups can be an indicator of forest restoration success (Babin-Fenske and Anand, 2010; Gibb and Cunningham, 2013; Gollan et al., 2011; Jansen, 1997). In mangrove forests some studies show evidences that important invertebrate groups like Brachyuran crabs may be more diverse in planted stands despite restoration being implemented with only one or few tree species (Al-Khayat and Jones, 1999; Ashton et al., 2003; Bosire et al., 2004, 2008; Macintosh et al., 2002).

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http://dx.doi.org/10.1016/j.ocecoaman.2015.03.006
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Crabs of the families Ocypodoidea and Grapsoidea (Brachyura; Decapoda) (Ng et al., 2008) are among the most abundant and ecologically significant mangrove dweller animals. They are 'ecosystem engineers' that play important roles on sediment topography and biogeochemistry, vegetation structure and primary production (Jones et al., 1994; Kristensen, 2008; Lee, 2008; Robertson and Daniel, 1989; Warren and Underwood, 1986). Despite their role in affecting overall community structure and ability to serve as important indicators of natural and managed forests conservation status (Ashton et al., 2003; Bosire et al., 2004; Macintosh et al., 2002; Ruwa, 1997), their effects have been rarely assessed in neotropical mangroves (but see Ferreira et al., 2007, 2013). Therefore, the relationship between mangrove development and crab assemblage is a relevant aspect that needs evaluation in mangrove restoration programs. Several studies designed allometric equations for calculate mangroves biomass (see Review of Komiyama et al., 2008), while others compared carcinofauna between natural and reforested stands (see Review of Bosire et al., 2008), but there are not studies comparing both carcinofauna and tree biomass differences between these forests types.

The aim of this study was to compare tree and crab diversities and community structure of two mangrove deforested areas of the same age, one planted with propagules of red mangrove, *Rhizophora mangle*, and the other naturally recovered. Here, we tested the hypothesis that the two areas neither differ significantly in plant richness and biomass nor differ in crab richness or density. A rejection or acceptance of this hypothesis would provide evidence for or against the effectiveness of *R. mangle* monospecific planting for neotropical mangrove restorations.

2. Materials and methods

2.1. Study area

The study was performed in a mangrove area in Jaguaribe River (35°14′06″ W/5°45′42″ S), tributary of the Potengi River in Natal, Rio Grande do Norte, Brazil (Fig. 1A). The climate is tropical, with air temperatures between 20 and 31 °C and total precipitation around 1900 mm. The Potengi River is a temporary river (rainy season March–July) with a catchment drainage of 3180 km^2 (Silva et al., 2007) receiving wastewaters from Natal and other smaller towns throughout the year. The estuary is covered by 15.61 km^2 of mangrove forests (Maia et al., 2005) dominated by the red mangrove *R. mangle* L., but white mangrove *Laguncularia racemosa* Gaertn. and black mangrove *Avicennia schaueriana* Stapf. & Leech. also occur in lower abundance (Ferreira and Sankarankutty, 2002).

Many mangrove areas have been cleared for intensive exotic shrimp culture (*Penaeus vannamei*), but this economic activity has decreased in recent years. Shrimp ponds are constructed enclosing a mangrove area with dams (aprox. 2 m height) constructed with mangrove wood and mud; trees are chopped and retired, and chemical products added to increase soil pH to levels compatible with shrimp development. Surveying the river we found an area cleared in 2003 but abandoned before ponds were completely implemented (Fig. 1B). This experimental area encompasses a mosaic of preserved mangrove, shrimp ponds and secondary riparian forest. Partially constructed dams did not impaired hydrologic features of area, which receives brackish water from high intertidal fringe and experiences semidiurnal tides. However, during the tree clearing the soil was physically altered and populations of crabs greatly affected. The area was originally dominated by *R. mangle*, with far lower abundance of *L. racemosa*. In spite of high numbers of *R. mangle* and *L. racemosa* propagules being brought by tides from surrounding mangroves, only very sparse (<0.004 individuals m^{-2}, when 3.2 individuals m^{-2} in mature forest - Silva et al., 2007) seedlings and small trees (0.3–0.7 m height) were established naturally 3 years after deforestation, by the time the experiment started.

2.2. Experimental design and parameters measures

The study area encompasses two adjacent areas (Fig. 1B) both deforested 3 years before the experiment started, so collection of any data on soil structure and tree development before deforestation was not possible. However, neighbor native forest was used as reference (Fig. 1B). Unfortunately, no area available for replication was found at the start of the experiment. Large scale experiments are sometimes hard to replicate decreasing power of conclusions, but they may be more realistic than experiments performed at lower scales, a trade-off imposed by costs and scarcity on experimental ecosystems (Carpenter, 1989; Hurlbert, 1984). Additionally, peculiarities of the mangrove ecosystem and features of the studied areas imposed methodological limitations for dividing areas in more than one experimental unit without suffering from treatment

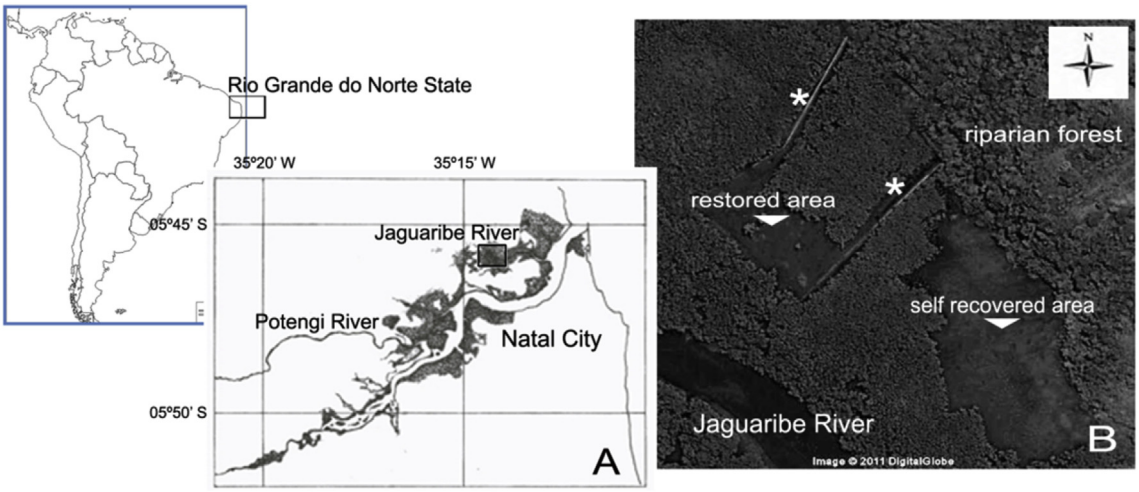

Fig. 1. Study area at Potengi estuary, northeast Brazil. A. Shaded areas indicate mangroves in Potengi River estuary. B. Satellite image of studied areas in Jaguaribe River. Arrows show the restored and self recovered experimental areas deforested, before experiment starting. Asterisks (*) show small creeks formed laterally to constructed dams. Areas are surrounded by native mangroves.

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