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Long-term vegetation changes in a tropical coastal lagoon system after interventions in the hydrological conditions

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ABSTRACT

Over a period of 44 years, we observed the vegetation changes in the western part of the lagoon system of the Ciénaga Grande de Santa Marta, which is situated on the Caribbean coast of Colombia and is separated from the sea by a sandy barrier. Since the construction of the Barranquilla-Ciénaga Road between 1956 and 1960, the lagoon system has been exposed to different interventions in its hydrological make-up, as well as changes to the vegetation. During the time of our investigations, four periods with different plant cover were distinguished. In 1965, the road was bordered by dense mangrove forests. The low surface water salinity and the presence of freshwater plants indicated the influence of the Magdalena River. At the beginning of the seventies, the second period was marked by a decrease in the freshwater in-flow from the river, which led to an increase in salinity and a gradual decay of vegetation. In 1988, the areas formerly covered by mangroves had converted into salt flats. The third period began with the reconstruction of several channels (1995–1998) which renewed the freshwater in-flow from the river to the lagoons. The subsequent vegetation development was characterized by the establishment of *Typha domingensis* Pers. In 1999, a year with an unusually high amount of rainfall, this species covered most of the former mangrove area in the western part of the lagoon system. The very low surface water salinity favored its spread. The last period began in 2001/2002, when growth conditions for *T. domingensis* became unfavorable due to an increase in salinity. Instead, conditions for mangrove regeneration improved. This process was slower than expected and is still ongoing. The striking vegetation changes indicate the sensitivity of the coastal lagoon system to hydrological variability.

1. Introduction

Tropical forests have been subjected to destructive human activities all over the world. This is also true for mangrove forests (Farnsworth and Ellison, 1997). With the increased destruction of these forests, interest has grown in finding ways of restoring them, at least in part, to a condition closely resembling the original. Generally, the rehabilitation of tropical forests is considered to be difficult (Brown and Lugo, 1994). According to Lugo (1998), mangrove forests are an exception, because the unfavorable growing conditions in the mangrove habitat itself act as a barrier against the invasion of non-mangrove species. In fact, a natural regeneration toward a vegetation similar to the original one has been observed in many sites where mangroves had been destroyed for various reasons. Some examples are the recovery of the vegetation after its destruction by hurricanes (for additional publications see Piou et al., 2006), the re-colonization of mangrove areas after an oil spill (Lewis, 1983; Martin et al., 1990) and the regeneration of mangroves following the restoration of suitable hydrological conditions (Perdomo et al., 1998). However, natural regeneration has not always occurred. This has been attributed to the rapid spread of *Acrostichum aureum* L. (Chapman, 1976), to the establishment of halophytic herbs in former mangrove areas (Costa and Davy, 1992) and to the absence of propagules (Lewis, 1983; Ellison, 2000; Imbert et al., 2000).

We present another recovery scenario observed after the destruction of mangrove forests in the lagoon system of the Ciénaga Grande de Santa Marta (Colombia) (Fig. 1). Between 1960

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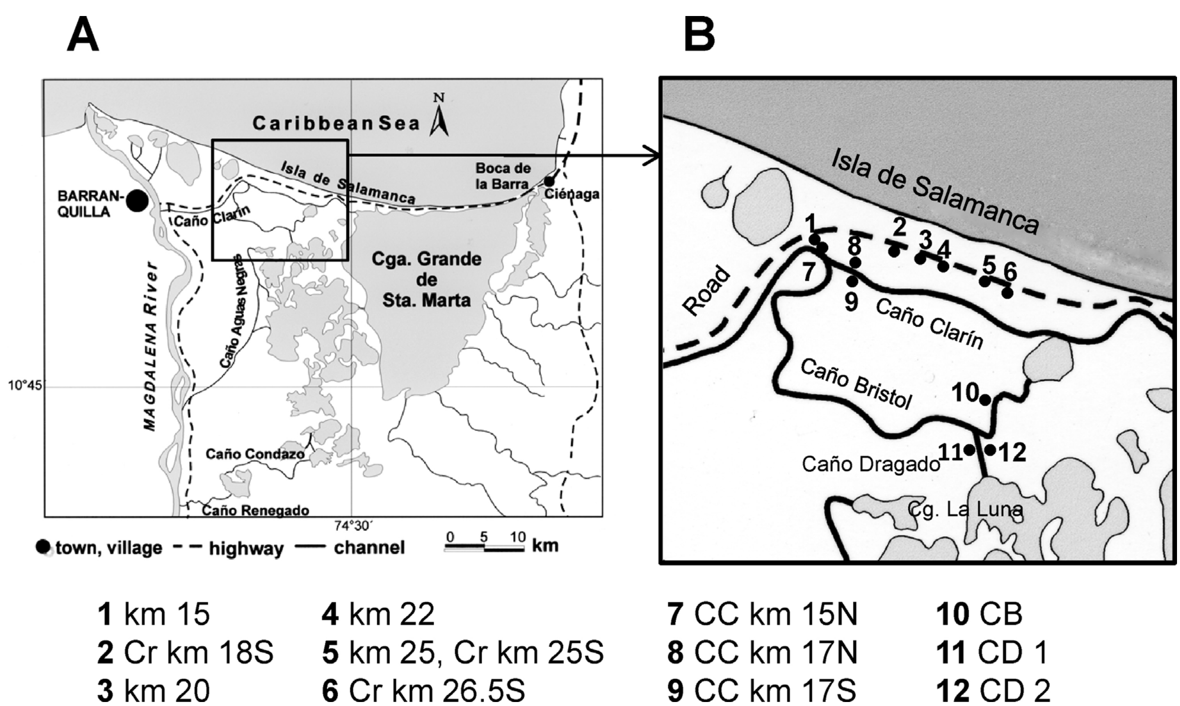

Fig. 1. (A) Map of the lagoon system of the Ciénaga Grande de Santa Marta. The study area is marked by a rectangle. (B) Map of the study area and location of the study sites.

and 1995, the reduction of freshwater in-flow from the Magdalena River (Fig. 1A), caused the death of 225.8 of originally 511.5 km^2 of mangrove forests in this area, due to an increase in salinity up to 60 PSU in channels and lagoons (Giraldo et al., 1995; Sánchez-Páez et al., 2004). At the beginning of the 1990s, plans were elaborated for the restoration of historical hydrological conditions. At the same time, a series of investigations started to document the effects of the hydraulic works on flora and fauna. Of general interest was the reduction of the very high salinity (Perdomo et al., 1998; Blanco et al., 2006; Rivera-Monroy et al., 2006, 2011). Concerning botanical aspects, particular attention was paid to mangrove regeneration at different sites (Perdomo et al., 1998; Rivera-Monroy et al., 2006). Studies were conducted on propagule production and spread (Ensminger, 1996; Schubert, 1999) as well as seedling establishment and growth (Elster et al., 1999; Perdomo and Schnetter, 2004). Remote sensing data were used to assess the expansion of mangroves (Sánchez-Páez et al., 2004; Ibarra et al., 2013) and to produce a canopy height map (Simard et al., 2008). Models were elaborated to predict the future development of the mangrove forests (Twilley et al., 1998; Rivera-Monroy et al., 2006).

Soon after the beginning of the restoration measures in 1995, it became clear that regeneration in the eastern, more saline part of the lagoon system and the western part differed. While mangroves recovered step by step to the original species composition and zonation in the eastern part, establishment of new mangroves was slow in the western part. Instead, a rapid spread of herbaceous freshwater plants was observed (Perdomo et al., 1998; Alvarez-León et al., 2004; Sánchez-Páez et al., 2004). Among the most frequent species was *Typha domingensis* Pers. (cattail), a native of the freshwater wetlands near the Magdalena River (Romero-Castañeda, 1971). Within three years *Typha* beds occupied large parts of former mangrove areas. But it was not clear how this species had been able to establish itself in still very saline sediments (Alvarez-León et al., 2004). An establishment of *T. domingensis* after the death of mangrove vegetation was already reported by Rubin et al. (1998). But in this case it was restricted to sites with low salinity (1–2 PSU). Therefore the successful expansion on saline sediments raised our curiosity, and we wondered whether persistent *Typha* beds would prevent mangrove recolonization. Our hypothesis was that mangrove regeneration would be delayed as long as cattail occupied the former mangrove areas.

To answer this question we started a series of studies in 1999 aimed at determining the prevailing factors that enabled *T. domingensis* to become established in these areas. We hypothesized that the low surface water salinity together with the presence of large bare areas allowed the establishment of *T. domingensis* and that variations in salinity of surface water influenced its growth. The influence of the cattail on the growth of mangrove trees was tested with *Rhizophora mangle* L. seedlings planted in the year 2000 at km 22 south of the Barranquilla-Ciénaga Road (Fig. 1B) (Sánchez-Páez et al., 2000). Our hypothesis was that low light intensity inside the *Typha* beds would influence the growth of the seedlings. These studies were completed by data of surface water salinity and vegetation composition recorded in irregular intervals at three sites south of the Barranquilla-Ciénaga Road (Fig. 1B) from 1965 to 2009. The comparison of plant lists made it possible to demonstrate similarities and differences between the original vegetation and that which became established after the restoration of suitable hydrological conditions. Moreover, the data enabled us to look for correlations between the different plant cover and the respective hydrological conditions. We hypothesized that variations of surface water salinity were particularly important for vegetation changes. Therefore we tested the influence of different environmental factors together with time on state and extent of the three vegetation types: mangroves, *T. domingensis* and freshwater herbs without *T. domingensis* (w.*T.d.*). These analyses should help us to answer our hypothesis about the possible delay of mangrove regeneration by the presence of *T. domingensis*.

2. Materials and methods

2.1. Study area and study sites

The lagoon system of the Ciénaga Grande de Santa Marta (10°30′–11°15′ N; 74°15′–74°45′ W) (Fig. 1A) is characterized by numerous lagoons of different sizes, sandy dunes and alluvial