A successful approach to mangrove ecosystem restoration in the Mauritanian side of the Senegal River Delta.

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Abstract:

A mangrove ecosystem restoration project was carried for 3 years in the Mauritanian side of the River Senegal Delta where scarce scientific and/or technical references exist on these mangroves located in the northernmost limit on the West African coast. The construction of the Manantali and the Diama dams transformed the once exhuberant delta to an artificial estuary and had dramatically affected the inland mangrove ecosystems. Thousands of mangrove seedlings were grown annually in the PND and community nurseries. A participatory approach was adopted for mangrove plantings where chicken and goat manure was used as biological fertilizer. Finally, 42.000 mangrove trees were planted in 4 sites located in the area of the Park. Two years after planting, the mangrove trees reached a height of about 2 m, and constitute already a source of forage for herds of camels and goats. Success of such project in a fragile and desert environment could set the way for future mangrove restoration projects in Mauritania or other less hostile areas.

Introduction:

Mangrove ecosystems are heterogeneous habitats with an unusual variety of animals and plants adapted to the environmental conditions of highly saline, frequently inundated, soft bottomed anaerobic mud (Macintosh and Ashton, 2002). Most commonly, they are found on the tropics and sub-tropics, on riverbanks and along coastlines subjected to tidal influences, being unusually adapted to anaerobic conditions of both salt and freshwater environments; and to muddy, shifting saline conditions (Auriol et al., 2010). Extensive research has been carried out on the ecology, structure and functioning of mangrove ecosystems. However, the findings have not been interpreted in a management framework, thus mangrove forests around the world continue to be over-exploited, converted to aquaculture ponds, and polluted (Kairo et al., 2001). While mangrove planting and management has a long history in Southeast Asia (Watson, 1928), and West Africa (Grewe, 1941; Chapman, 1977), information on earlier mangrove plantation practices in East Africa is scanty (Kairo et al., 2001; Semesi, 1998). Furthermore, very scarce scientific literature can be found on the Mauritanian mangrove ecosystems (Dahdouh-Guebas and Koedam, 2001; Auriol et al., 2010).

Novel approaches to mangrove planting in desert countries have been published (Sato et al., 2005; Sato et al., 2011). They prove establishing mangrove trees in salty coastal lands is possible providing an appropriate mineral nutrition i.e. nitrogen, phosphorus and iron. Around a million trees have been planted on the Red Sea coast of Eritrea (Sato et al., 2005). Such forests could provide forage for goats and serve as nurseries for fish reproduction. These important findings deserve to be considered for future mangrove plantings and/or mangrove restoration projects in Africa's desert countries.

Mangrove ecosystems at Diawling National Park are biogeographically marginal and have received little attention. These fragile ecosystems' overexploitation for firewood and for boat construction combined with reduced floods caused by dams 'construction and the Sahelian drought have furthermore tremendously increased pressure on these ecosystems by herds of grazing camels and goats. Indeed, infrastructure development, tourism-based disturbance, agricultural development impacts, and habitat loss threatens mangrove ecosystems establishment and its further development. Following the extinction of entire mangrove forest patches from the DNP area (picture 1) and it subsequent dramatic effects both environmentally and economically on locals, the need for restoring the mangrove ecosystem was early documented by some authors (Gonzalez, 2005) and indeed advocated by villagers neighboring the Senegal River Delta.

Consequently, restoring degraded mangrove ecosystems and establishing sustainable management schemes, especially for those located at the Diawling National Park, is fully justified both environmentally and economically. Since very few successful mangrove reforestations have been reported in arid coastal areas (Toledo et al., 2001), we hereby investigate a mangrove restoration project in an extreme environment as can be the Mauritanian desert. Past and present situations of the Senegal River Delta will be analyzed in reference to the existing mangrove ecosystems inland. Also, the methodology and progress of this mangrove ecosystem restoration project will be detailed, and recommendations for similar future projects in desert countries will also be given.

Materials and methods

A project for mangrove ecosystem restoration at DNP, Mauritania has been launched by UNESCO-Rabat Office in Morocco since 2009 and lasted for a period of 3 years. In total, 4 sites located in DNP were selected for this purpose: Gahra, Birette, Dar Essalam, and Dar Errahma, covering an area of 20 ha. In this paper, only mangrove restoration at Gahra and Birette sites will be treated.

A/ Presentation of Diawling National Park (DNP).

The DNP is located on the south-west of Mauritania and extends along the northern side of the Senegal River Delta (16°22’N, 16°23W) (Map 1). Initially a protected area in the 1980’s, the park was created in January 1991 and was later designated by UNESCO as a Ramsar site in 1994. It covers an area of 16.000 ha, and comprises a wide variety of landscapes ranging from islands, tidal mudflats, marshes and mangrove swamps, coastal sand dunes, *Acacia Senegalensis* forests…etc. The geographical location of villages within DNP witnesses the rich historic diversity of the delta settlers and paved the way for the actual social peace reigning in the park area (Gonzalez, 2005).

In the case of the DNP, a range of anthropogenic and natural factors have contributed to the large degradation of the mangrove ecosystems. According to Gonzalez (2005) these factors include i/ cuttings for timber, fuel, and charcoal ii/ over-grazing of mangroves by herds of camels and goats. However, the main reasons stem from the following:

i/ The Senegal river has two large dams along its course, the multi-purpose Manantali Dam in Mali and the Diama Dam just upstream of the delta for preventing access of salt water. Construction of Diama dam, in service from 1986, followed by the enclosure of the reservoir by embankments in 1990 completely disrupted the normal tide hydrology, cutting off water from large areas of the delta. The mangrove forest that once covered almost all the flood plains of DNP (Diawara, 1995), turned to scattered linear bands of mangrove trees matching the contours of the tidal channels (Map 1). In other places, the lack of water and inorganic nutrients brought annually by the flood water resulted in large dry and infertile plains (picture 1). The situation worsened with the Sahelian drought during the 1980's, and by the fact that the water in the Diama reservoir was regularly kept at its maximum level to reduce water pumping costs by local farmers (Hamerlynck and Duvail, 2003). Very high spring tides then carried highly saline waters across parts of the wetlands, causing widespread losses of mangroves and grasslands, with devastating impacts upon local fishing communities (Spalding et al., 2010). The green and productive mudflats turned dry and the Harmattan wind was blowing dust from the bare dry soil surface (Hamerlynck and Duvail, 2003).

ii/ Finally, the huge hydrologic changes operated across time on the delta have turned the so-called pseudo-delta, by opposition to 'active' deltas having a number of distributaries (Duvail, 2001), to the present more like artificial estuary (Hamerlynk and Duvail, 2003).

B/ Description of mangrove ecosystems at DNP.

It is generally accepted that only three of the eight mangrove species existing in West Africa are present in DNP: *Rhizophora racemosa*, *Avicennia germinans*, and possibly very few specimens of *Conocarpus erectus* in association with Avicennia stands (Gonzales, 2005). However, it is worth to note that during our surveys together with the DNP staff members, no *Conocarpus erectus* specimen were spotted anywhere on the Mauritanian side of the Senegal river Delta.

The fewer mangrove species found in the DNP are evidence of a biodiversity transition between two surrounding mangrove habitats: Sine Saloum in Senegal where pristine mangrove ecosystems exist and comprise 6 mangrove species covering 58.300 ha (JICA, 2005); and Banc d'Arguin National Park in Mauritania where mangroves reach their northernmost distribution and are comprised exclusively of *Avicennia germinans* (Dahdouh-Guebas and Koedam, 2001). Hence, it is reported that lower mangrove productivity might be expected in Mauritania where the trees are stunted and at the northernmost limit of their range in West Africa (White, 1983).

Like Sine Saloum delta where pure mangrove forests of Rhizophora spp. are found at the river mouth and riverbanks while *Avicennia Africana* with a high salt resistance is found in inland areas (JICA, 2005), mangroves at DNP show a similar zonation pattern (Figure 1). Rhizophora develops predominantly along the Riverbanks and on the muddy banks of the Delta islands (M'boyo, Diaos) (Map 1, Picture 2B); while Avicennia develops backward of the Rizophora stands (Picture 2A).

The mangrove ecosystems at the PND cover an area of less than 1 km^2 and are composed of stunted trees not exceeding 2 m height. Most of the inland *Avicennia germinans* are in the Ntiallakh basin, essentially forming scattered linear bands matching the contours of the tidal channels (Map 1). Exceptionally, some few dispersed specimens (less than a hundred) thrive far from tidal channels in the year-most dry Bell basin (Picture 3A), and Hassi Baba sites (Map 1, Picture 3B). These remnant trees from a past exuberant mangrove ecosystem witness both the huge hydrological system change after the construction of the Diama dam and the unusual capacity of mangroves to grow in dry spots out of water for a long period of the year. This recalls the fact that Avicennnia are not hydrophilic but halotolerant trees (Imebert, 2002 cited by Tandia, 2011). In this context, our observations suggest that Avicennia is geographically constrained by the ability of propagules to germinate in less humid environments.

The DNP inland display lower natural regeneration potential associated with restricted fertility; relative to other West African mangroves, which makes them very fragile regressive ecosystems (Diawara, 1995). In fact, most of the trees in the Ntiallakh basin produce no propagules even though these are flowering profusely. Similar observations were reported by

Dahdouh-Guebas and Koedam (2001) at Band d'Aguin National Park quoting Duke (1990) who hypothesized that plant species at their biogeographical limit display a decreased fertility. However, the situation is reversed on the muddy banks of the delta islands where mangrove trees produce propagules abundantly. A similar situation was also observed by Wang'ondu et al., (2010) in Kenya, who concluded that zonation may have had an influence in fruiting of *Avicennia marina* since sites that were frequently inundated (seaward) supported prolonged budding and fruiting relative to those that were less inundated (landward sites).

In view of the above limitations, Gonzalez (2005) recommended an active restoration of the mangrove system at the PND. There are several advantages of using artificial regeneration: the species composition and distribution can be controlled, genetically improved stocks could be introduced, and pest infestation can be controlled (Field, 1998); provided simple and economically feasible reforestation techniques are adopted (Thorhaug, 1990).

C/ Propagule collection and nursery procedures.

Avicennia germinans (L.) reproduces by producing propagules through the process of cryptovivipary, which requires a significant energy investment (alleman and Hester, 2011). Hereafter, the same term will be used to refer to *Avicennia* seeds to keep with an abundant literature on the subject. For this project, propagules were collected annually from the Delta islands (M'boyo, Diaos), when these were in-season. The latter extends from July to September.

Nursery installment and a preliminary irrigation of the pots were done before propagule collection, so that propagule planting is not delayed and takes place the following day. Planting is done by inserting a third of the propagule lower part into moist soil. Through this process, propagules must be kept moist to avoid any drying. Frequent daily irrigation of the nursery was adopted because an air and/or sun exposure of 24 hours is sufficient to kill the propagules (Dahdouh-Guebas and Koedam, 2001).

Sato et al., (2005) supplemented mangrove seedlings on the Eritrean coast with N, P, and Fe. By fertilizing saplings, they were able to grow nearly one million trees on the muddy coast of Eritrea. In this case, we opted for manure fertilization for the following 2 reasons i) as a protected area, the park administration was apprehensive of the use of industrial fertilizer ii/ the price of fertilizers in Mauritania was prohibitive for use of thousands of trees.

D/ Restored mangrove sites and planting approach.

Both Gahra and Birette sites were chosen for mangrove restoration operations (Map 2) with a planting density of 2 x 3 m spacing. The two sites display different features:

- Gahra site is relatively isolated and therefore protected from animal grazing. Also, this site is subject to high water salinity levels, especially at summertime (Map 2). It is located along N'tiallakh basin and so is connected to both sea and river waters resulting into brackish to salty water at certain periods.

- Birette is located immediately downstream of Diama dam and on the fringe of the border post to Senegal and so is subjected to frequent grazing by passing herds of cows and goats. Water salinity is lower than at Gahra site (Map 2).

Regular meetings with locals were organized in the two nearby villages to discuss the opportunity of such a project and the environmental and economic benefits for local villagers. Our participatory approach for mangrove plantings proved somehow difficult to apply since we were in difficulty to gather the 70 workers required for the hard work such as digging holes and planting the 5.000 mangrove saplings within 3 days frame at most, since the local population was mostly composed of women and children. In fact, adult men had in their majority immigrated to nearby capitals (Dakar and Nouakchott) for work.

Fencing was adopted for all mangrove restored sites to avoid predation by animals (camels, cows, and goats) since young saplings seemed more palatable to the animals than adult trees; an observation also reported by Gonzales (2005). However, Fencing was successful at Gahra but failed at Birette which is frequently subjected to grazing by passing herds of cows and goats. Finally, the fence rusted, and frequent breakouts were observed (Picture 4).

Results and discussion

A/ Seedling growth at nursery

During the first two years of the project, mangrove seedlings survivals in the nursery were 98 and 93% respectively for the first and second year. Under optimal nursery management conditions (fertilization and irrigation), mangrove seedlings develop very well. In a period of 3 months, seedlings had an average plant height of almost 1 m and approximately 8 leave pairs (Figure 2). Under adequate growth conditions, the rooting system which is extremely important for future development of the seedlings after planting in the field (picture 5), is well developed and roots maybe protruding from the pots.

Success of the present terrestrial nursery could provide an alternative to experimental nursery systems in a laboratory or flooded nurseries supplemented with NaCl (Wakushima et al., 1994) even though these were not transferred to the swamps for survival assessment.

B/ Growth evaluation of restored areas.

Two years after planting, a study was carried to assess overall situation at the two mangrove restored sites (Tandia, 2011). It focussed mainly on measuring tree height, tree diameter, and vegetation cover following a phyto-ecological transect in the two sites.

A number of Avicennia trees were sampled inside a 2.500 m² plot, at each of the two restored sites: 224 trees at Gahra and 102 at Birette. According to Tandia (2011), most tree heights ranged between]1 – 1,5 m] and]1,5 – 2 m]: 78 % and 88 % respectively at Gahra and Birette sites (Figure 3). Fewer trees exceeded 2 m height at Gahra restored site (6 %) but none at Birette. Overall, tree height evolution was similar within the 2 sites and averaged 1,34 m and 1,23 m respectively at Gahra and Birette after 2 years, which resulted in an annual increase of 0,67 m/year and 0,61 m/year respectively comparable to values of 0,6 m/year and 0,51 m/year were reported by Louppe et al. (2008) in Ghana and Ndour et al. (2009) in Senegal respectively.

Considering tree diameter, it was reported that 71 % of trees at Gahra had diameters falling within]0,5 – 1 m] while 80 % of those at Birette did not exceed 0,5 m diameter. According to the same author, tree diameter between the two restored sites were statistically different. Despide optimal salinity levels at Birette, trees diameter was significantly affected by grazing animals. In fact, Birette had never been tightly fenced and could not because of its location contiguous to border road. Under conditions of Gahra, only 2 % of trees could have diameters within]1 – 3 m], showing most probably potential tree diameter that could be achieved under DNP conditions.

C/ Monitoring of restored areas.

Growth results above confirm the differences of vegetation cover between the two restored sites. Overall vegetation cover was higher at Gahra than at Birette for the reasons explained earlier (Figures 5A and 5B). Although, it's reported that water salinity levels play a key role in shaping *Avicennia* cover distribution along different sequences of a phyto-ecological transect (Tandia, 2011), we believe it's more about the hydrological conditions of each of the sequences. Accordingly, we think zonal distribution of *Avicennia* is dictated by the water depth at which underwater pneumatophores can thrive without the tree being asphyxiated, thing that Rhizophora can easily manage following the tide with it very long and tangled roots. Finally, to our understanding, zonal distribution is not shaped by competition between the two species but more by optimal habitat for each of the species.

Yearly evolution of reforested sites is shown in pictures 6 and 7. Growth of the *Avicennia* trees was a success but animal predation remains among important factors to be considered. Trees were having abundant foliage, produced propagules and neighboring areas were harboring young saplings probably dispersed from the mother trees. Assuming this, we can conclude that our project has produced vector areas for mangrove propagules which will enhance natural regeneration along the N'tiallakh basin. Such results left us optimistic about the future of the mangrove ecosystem in the N'tiallakh basin. During the third and last year of the project, fences were rusting, and multiple breakouts were noticed from where goats and cows were accessing the restored areas. However, at this stage mangrove trees were sufficiently grown to thrive with grazing pressure from camels, goats…etc.

D/ Discussion.

Two years after planting, *Avicennia* trees achieved optimal growth at Gahra and Birette sites: tree height averaged 1,34 m and 1,23 m; and most tree diameter fell within]0,5 – 1 m] and]0 – 0,5 m] respectively. Growth differences between the two sites were due mostly to intense grazing by animals at Birette site. This site had never been tightly fenced and could not because of its location contiguous to border road. Salinity had no major effect on *Avicennia* trees growth. In fact, higher salinity levels were recorded at Gahra than Birette, however the former site displayed much better vegetation cover than the last one. Instead, grazing caused the main growth differences.

None of the reforested sites comprised *Rhizophora* specimen. However, *Avicennia* trees displayed the same zonal distribution as that of the pristine mangrove ecosystem on delta islands. This suggested that zonal distribution of *Avicennia* is dictated more by the water depth than by competition with *Rhizophora* stands.

One of the most important outputs of the present mangrove reforestation project was the fact that these areas provided a seedling stock for the entire basin. In fact, newly naturally regenerated areas were reported (Tandia, 2011) since propagules were abundant and spread following the tide to other bare and infertile areas.

Conclusion and recommendations:

The present experience is unique in Mauritania, but hopefully will draw more attention to conservation and further development of these ecosystems at their northernmost limit in the future. Like the Manzanar project in Eritrea which achieved planting nearly one million trees on the muddy coast, this project advocates for a "science for development" approach where simple observations and empirical methodology can lead to major breakthroughs in the field of greening highly deprived environments as deserts.

At the end of the present project, 42,000 mangrove trees have been planted at DNP. In the future, these forests will harbor numerous bird species, fish nurseries, and provide forage for local herds of camels, goats…etc. They will constitute in the future a source of wealth for the impoverished park population and remediate the negative effects of the hydrologic changes operated by construction of dams.

The community-based approach for restoring degraded ecosystems is foremost. Village's youngsters did not witness the pristine state of mangrove ecosystems at DNP, and therefore feedback from older villagers were important to get them involved in rehabilitating their environment. One of the most important limitations to the project's success was the extreme poverty and isolation of the park community. In fact, the population usually expects immediate benefits and is not willing to wait a few years for mangrove exploitation. In this sense, fencing reforested areas was capital to ensure proper development of the mangrove ecosystems.

Visual documents on the mangrove restoration project at Diawling National Park can be viewed on the following links:

http://www.youtube.com/watch?v=mqlo7OzLMvg for early mangrove reforestation campaigns.

http://www.youtube.com/watch?v=TMJbcfR17ac about 2 years after mangrove plantings.

for early mangrove reforestation campaigns.

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We thank Dr. Mallé Diagana and all staff of Diawling national park for hosting us, and working with us. We also thank Oussmane Mballo, Alyfaye Baldé, and Mustapha Haidara, whose field work contributed greatly to the project success. Finally, thanks are due to late Hassan Zeggaf Tahiri who pushed me writing this paper.

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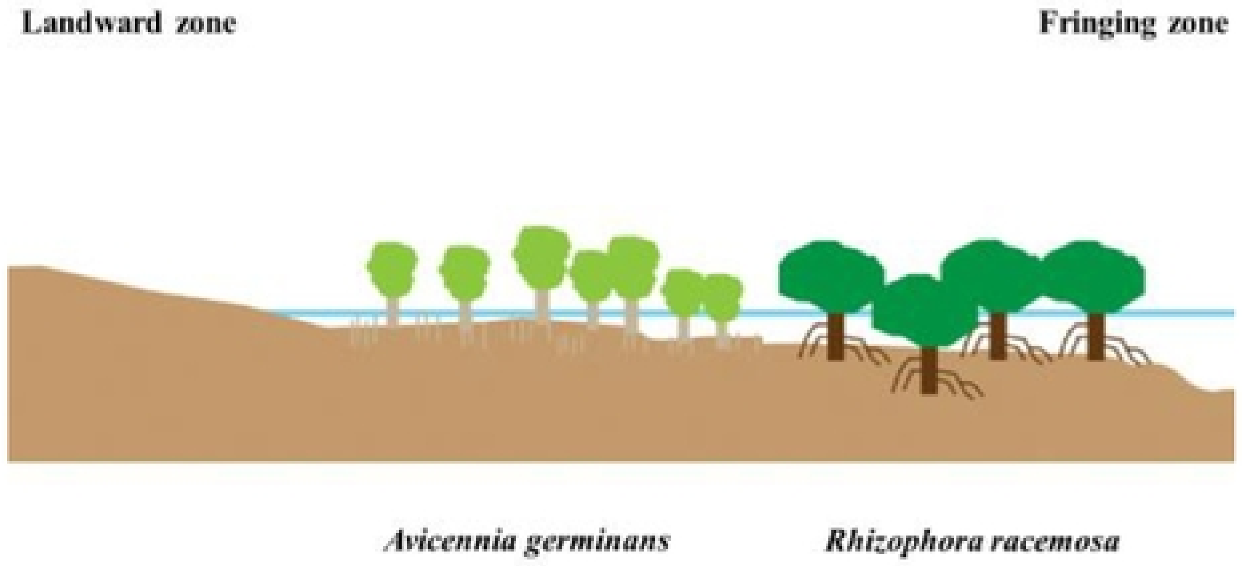


Figure 1: Zonation pattern of mangroves in Diawling National Park, Mauritania.

Figure 1

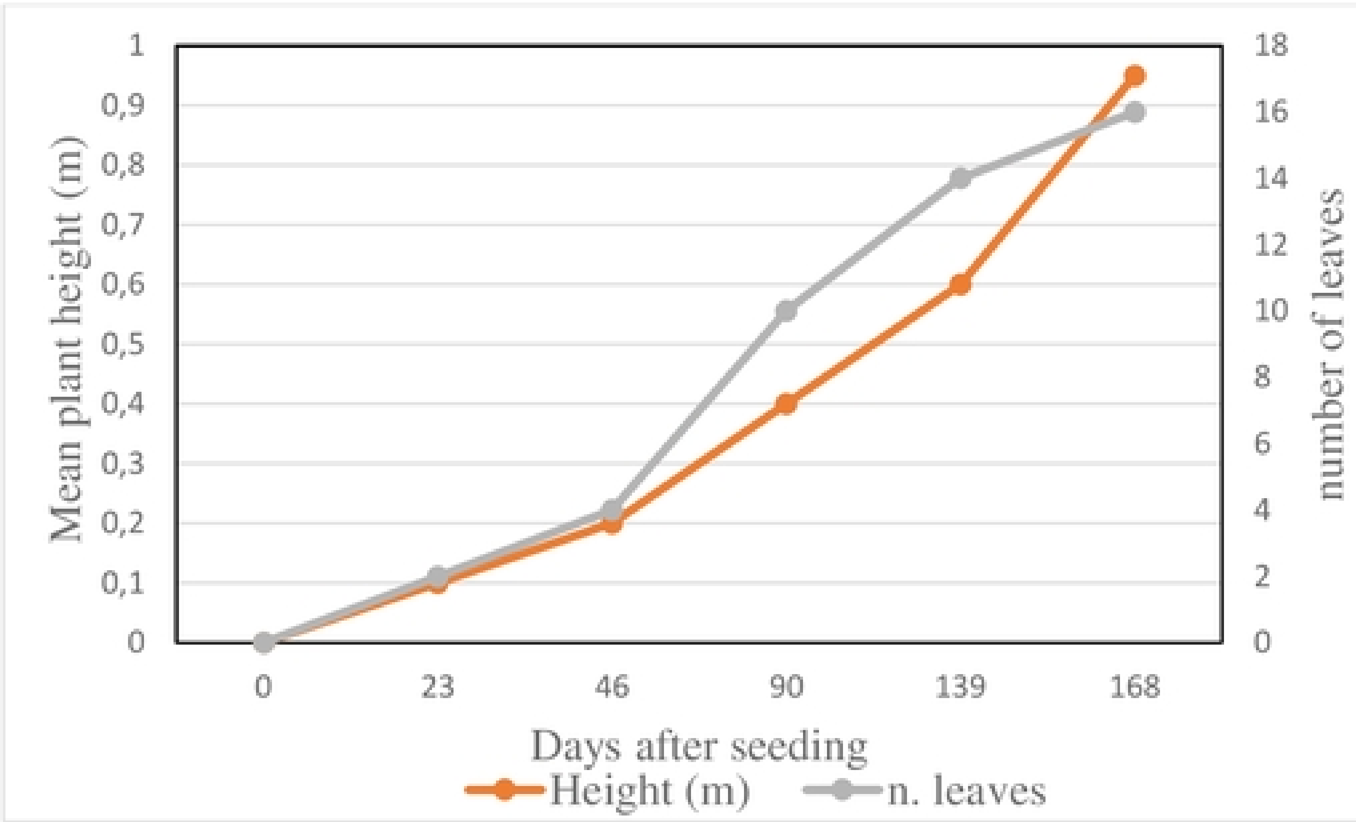


Figure 2. Average mangrove seedlings growth through time (days after planting) in the nursery.

Figure 2

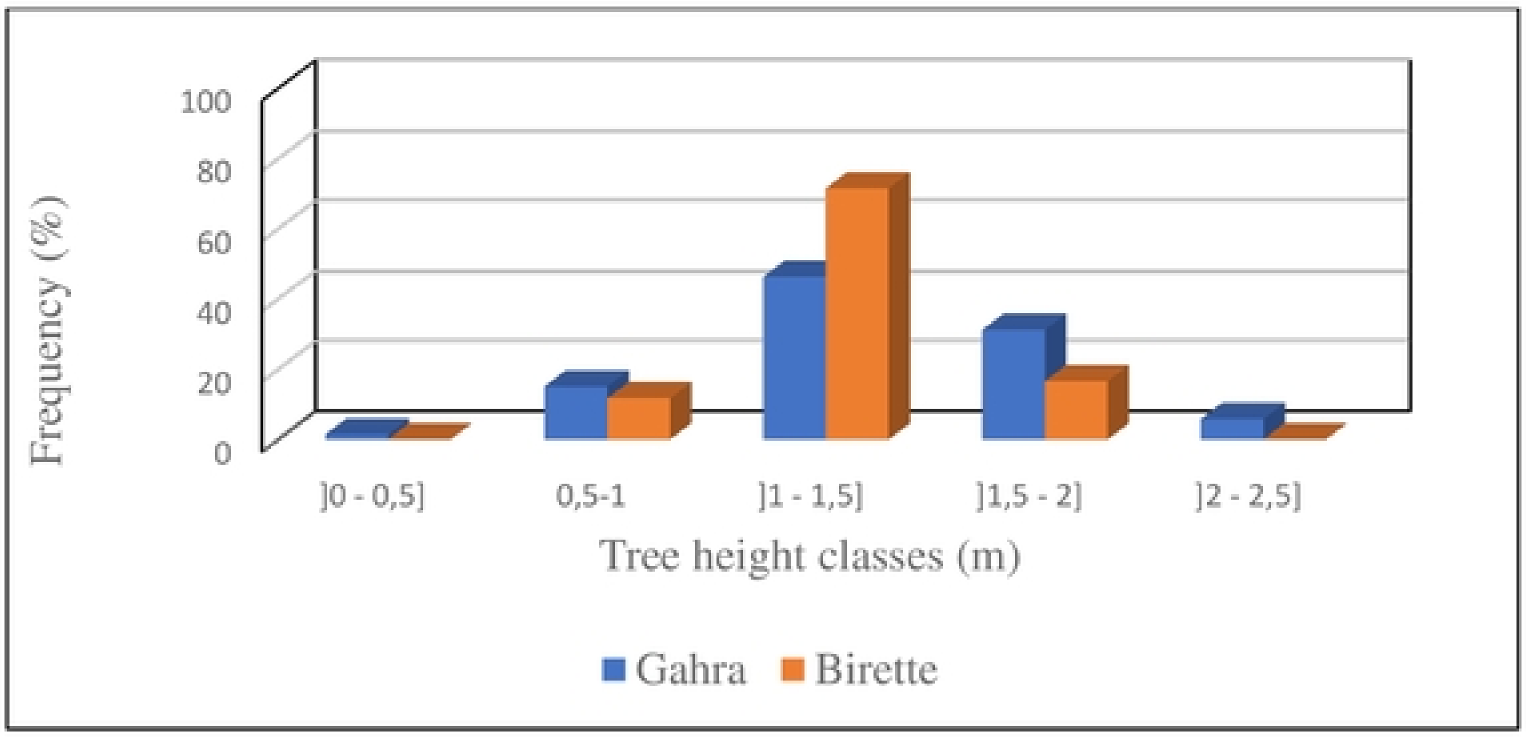


Figure 3: Tree height class distribution at the two restored mangrove sites. (Source: adapted from Tandia, 2011).

Figure 3

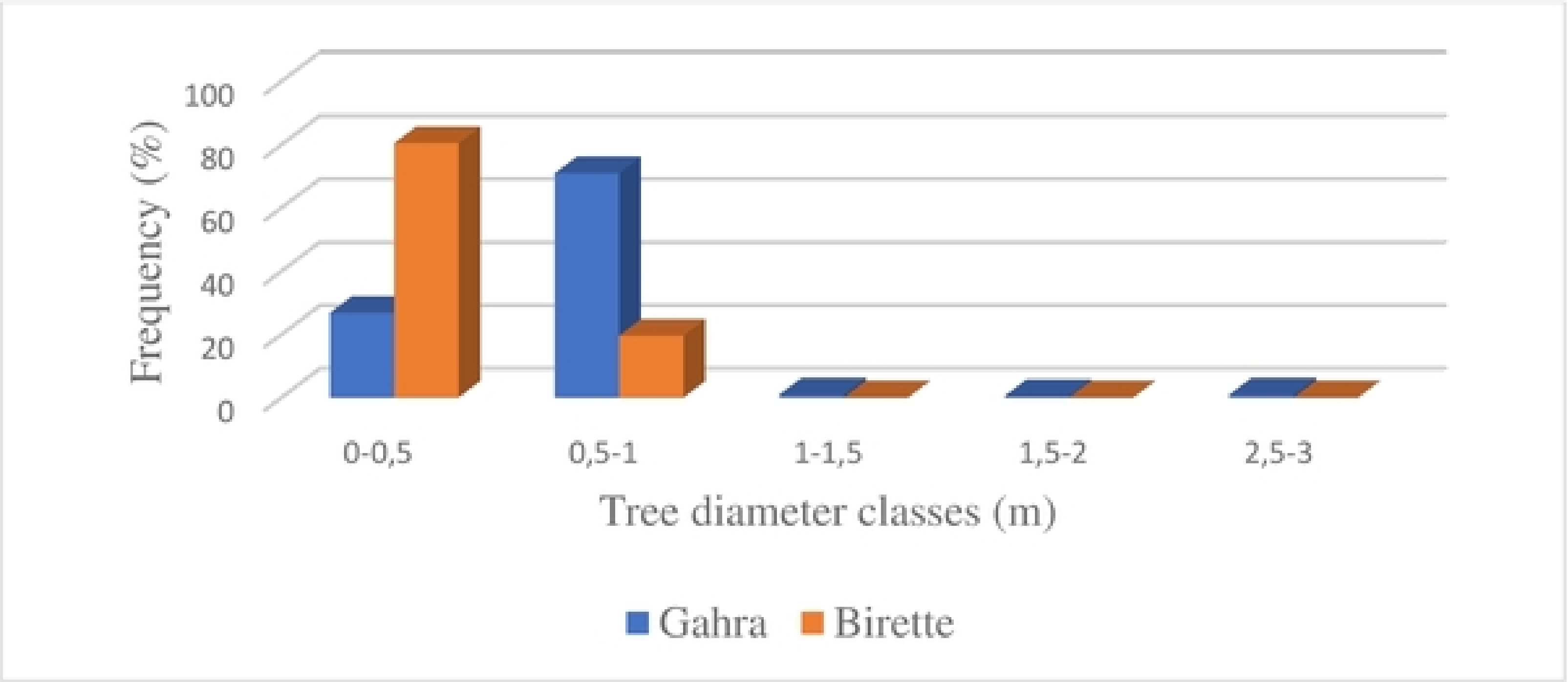
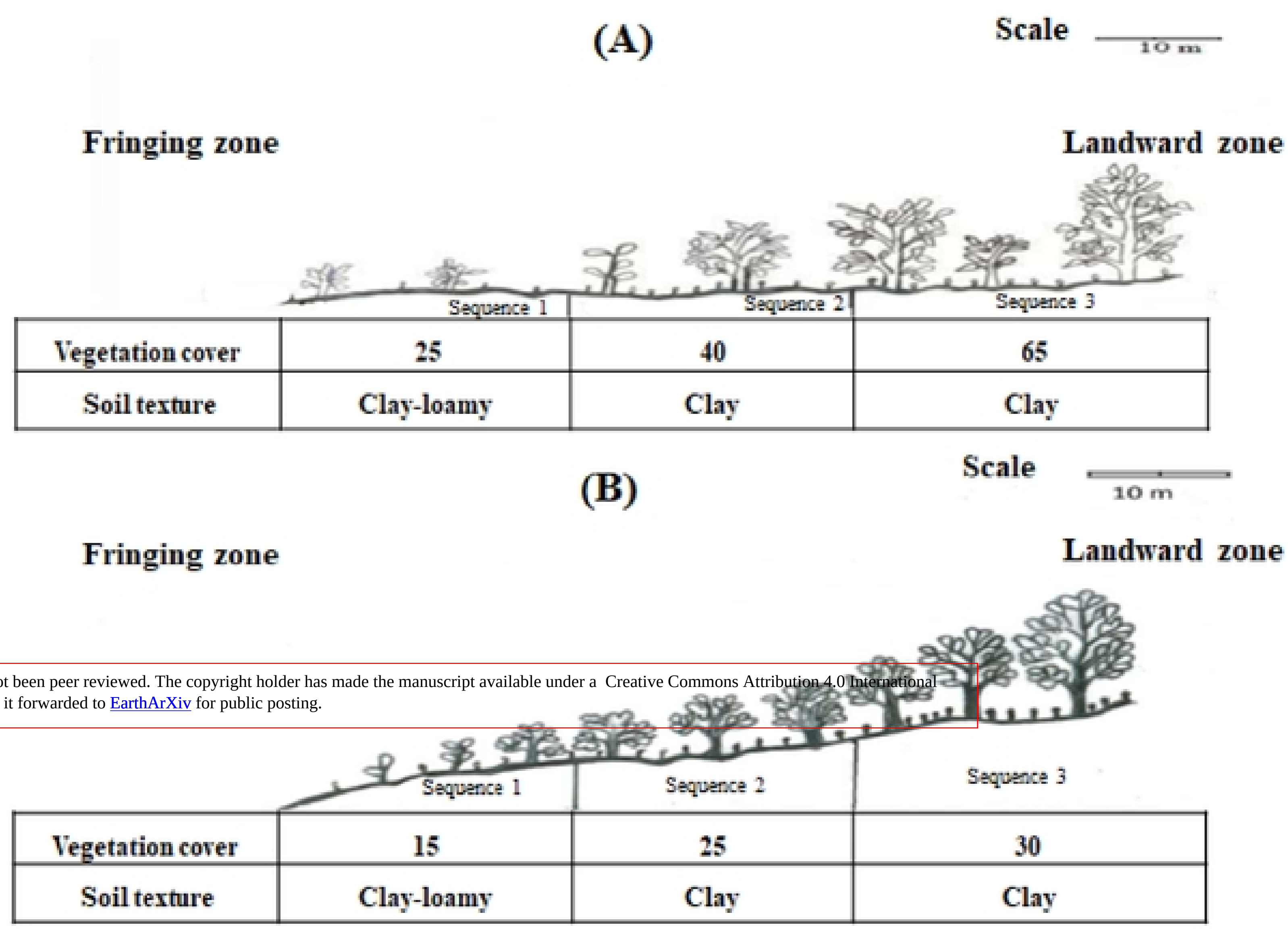


Figure 4: Tree diameter class distribution at the two restored mangrove sites. (Source: adapted from Tandia, 2011)

Figure 4



(A)

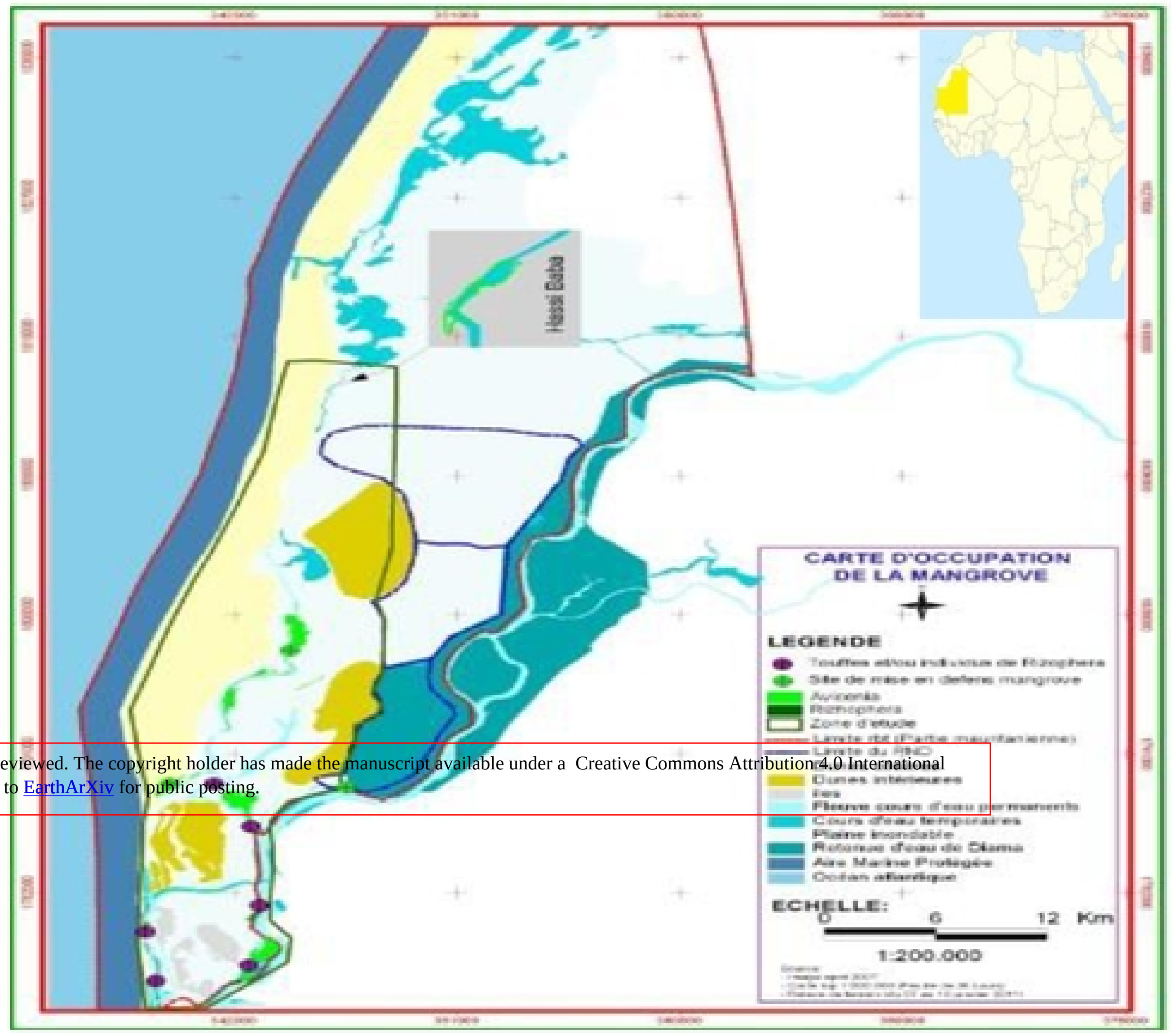
Vegetation cover	25	40	65
Soil texture	Clay-loamy	Clay	Clay

(B)

Vegetation cover	15	25	30
Soil texture	Clay-loamy	Clay	Clay

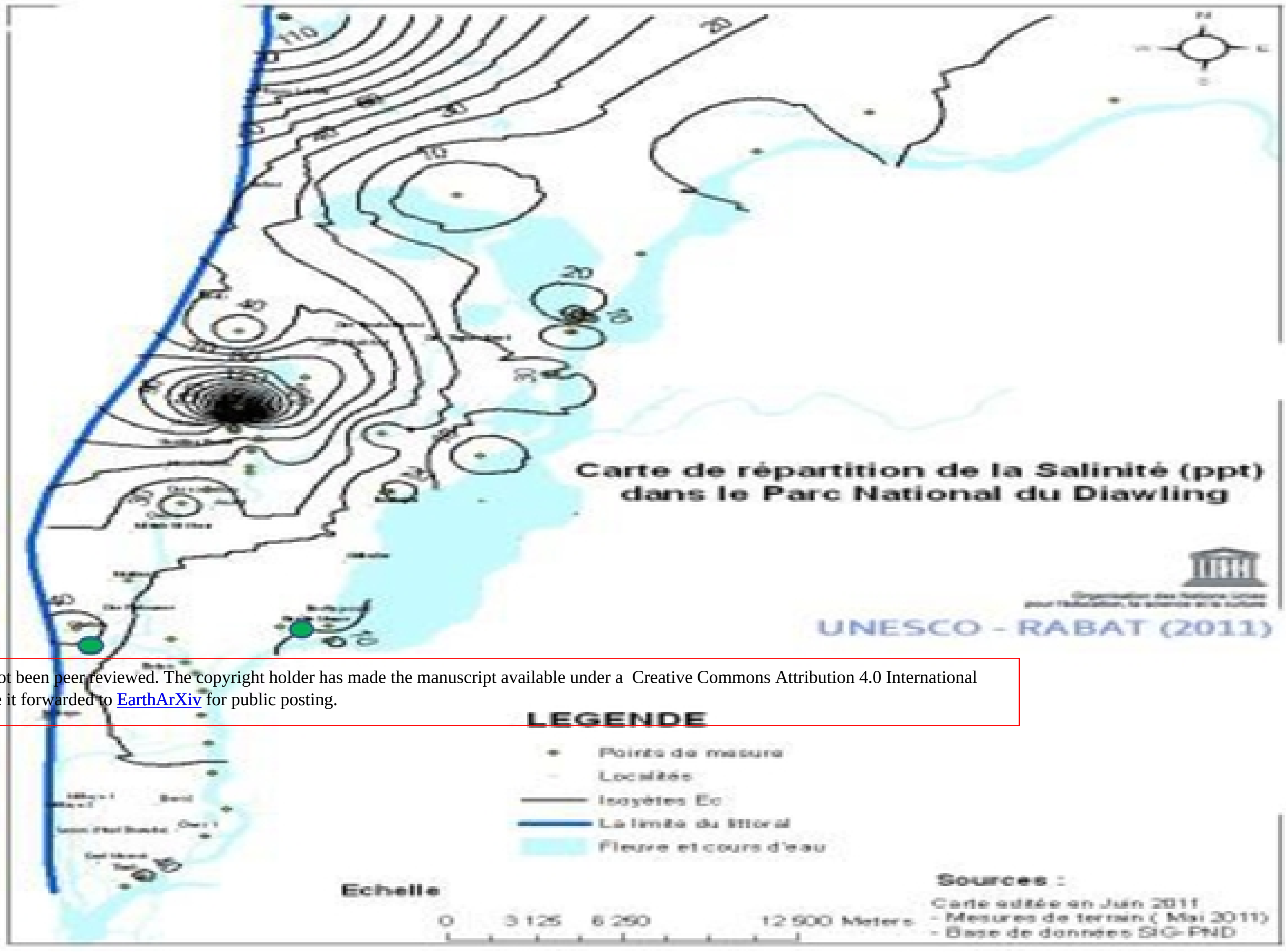
Figure 5: Mangrove (*Avicennia germinans*) phyto-ecological transect at Gahra (A), and Birette (B) reforested sites. (Source: adapted from Tandia, 2011).

Figure 5



Map 1: Geographical distribution of the mangrove ecosystems in the Diawling National Park (Courtesy of DNP). Green color refers to *Avicennia germinans* stands.

Map 1

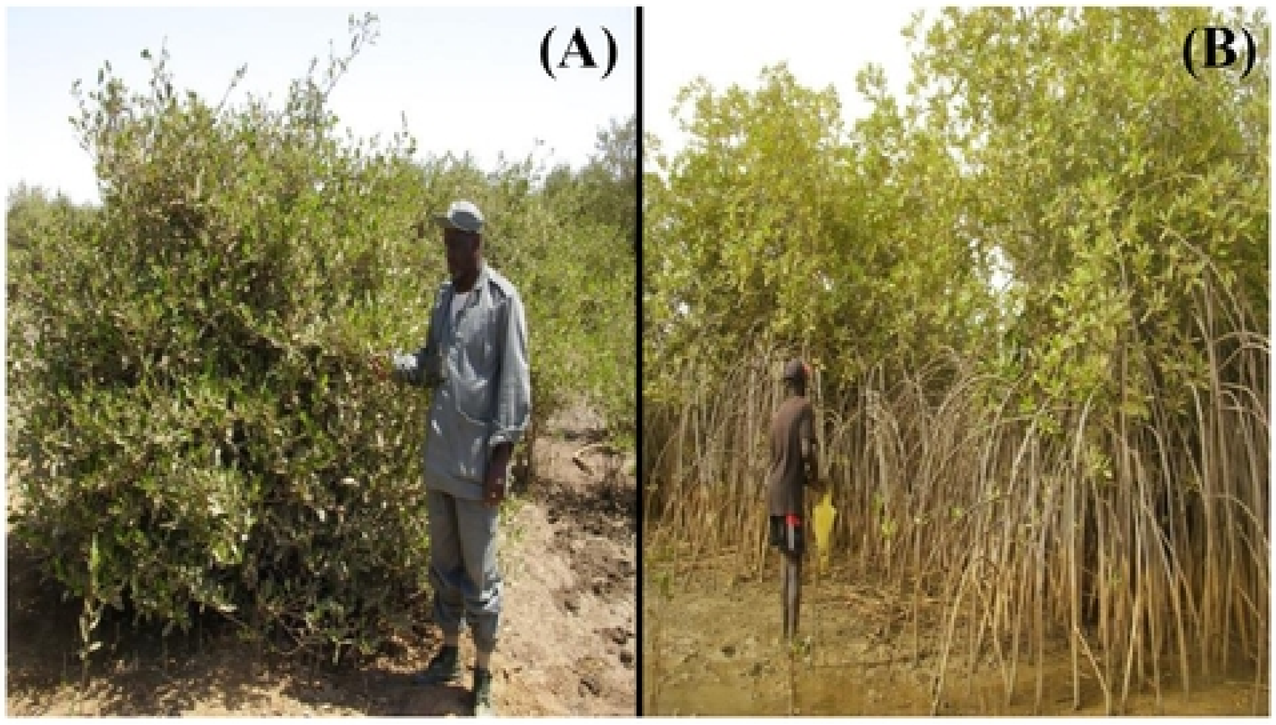


Map 2: Mapping of salinity at Diawling National Park area. Green circles refer to mangrove restoration sites (Gahra and Birette).

Map 2

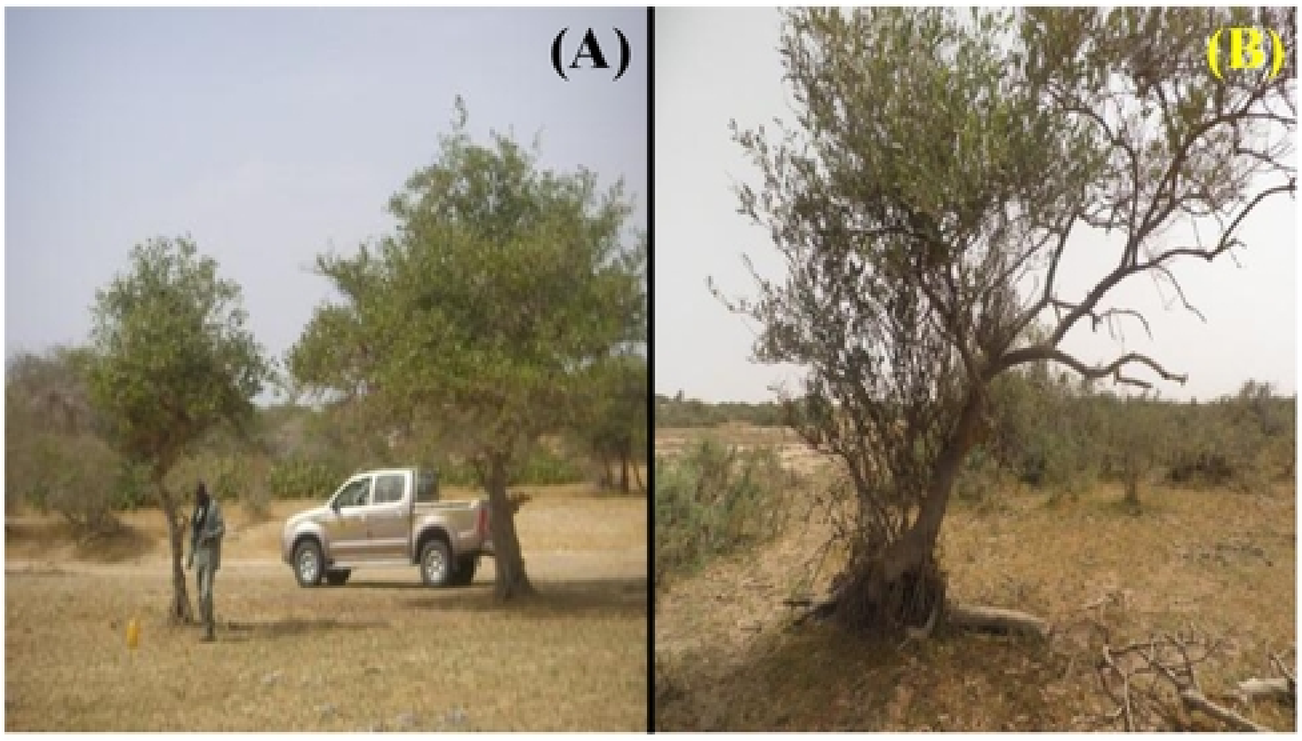
Picture 1: View of large bare and infertile areas around Ntiallakh basin in the Diawling National Park before start of the project.

Picture 1



Picture 2: Stunt Avicennia tree at Ntiallakh basin (A), and exuberant Rhizophora tree at M'boyo island

Picture 2



Picture 3: Dispersed Avicennia trees at Gahra (A), and Hassi Ba (B).

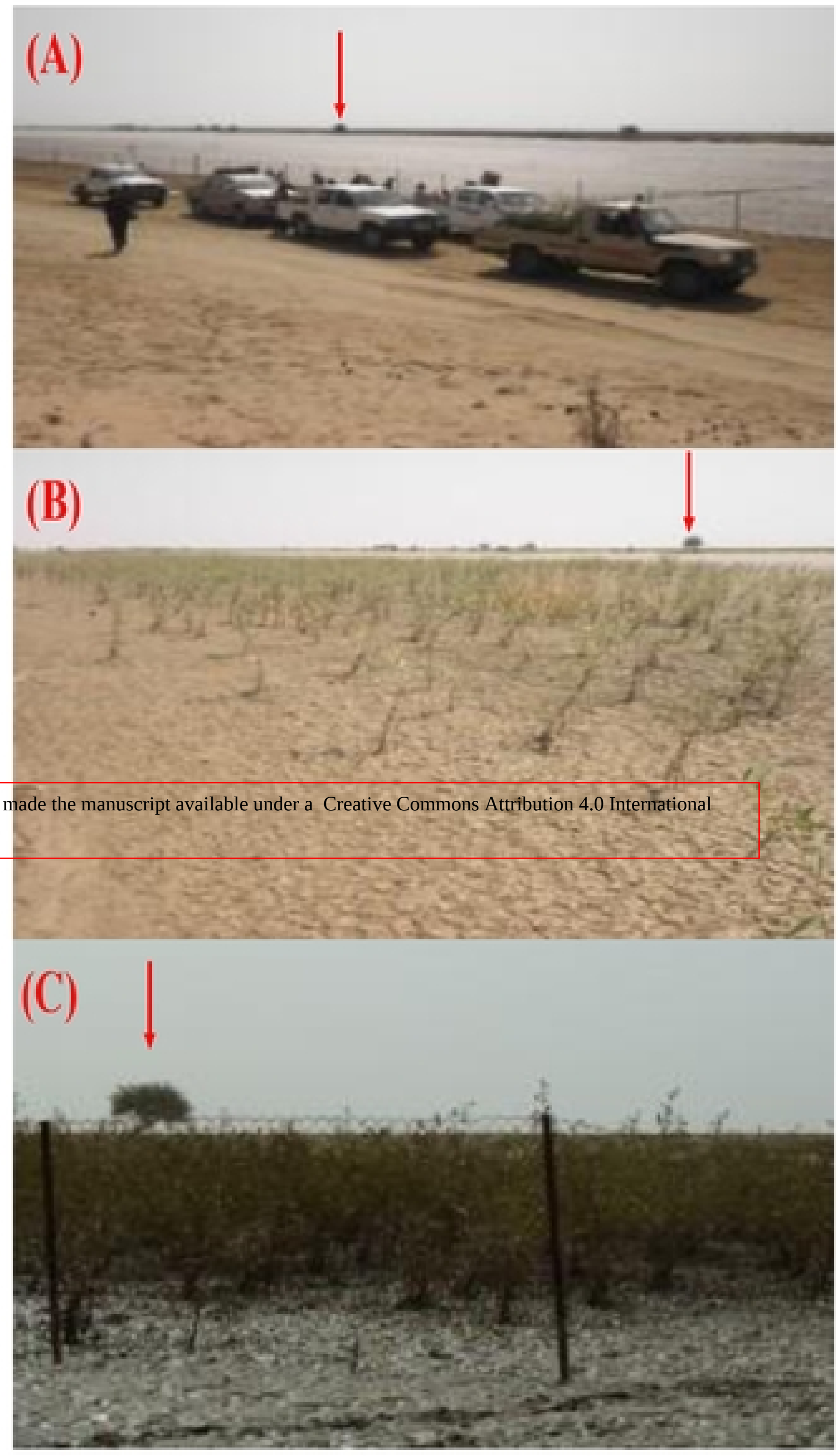
Picture 3

Picture 4: Animals breaking through the fence at Birette site.

Picture 4

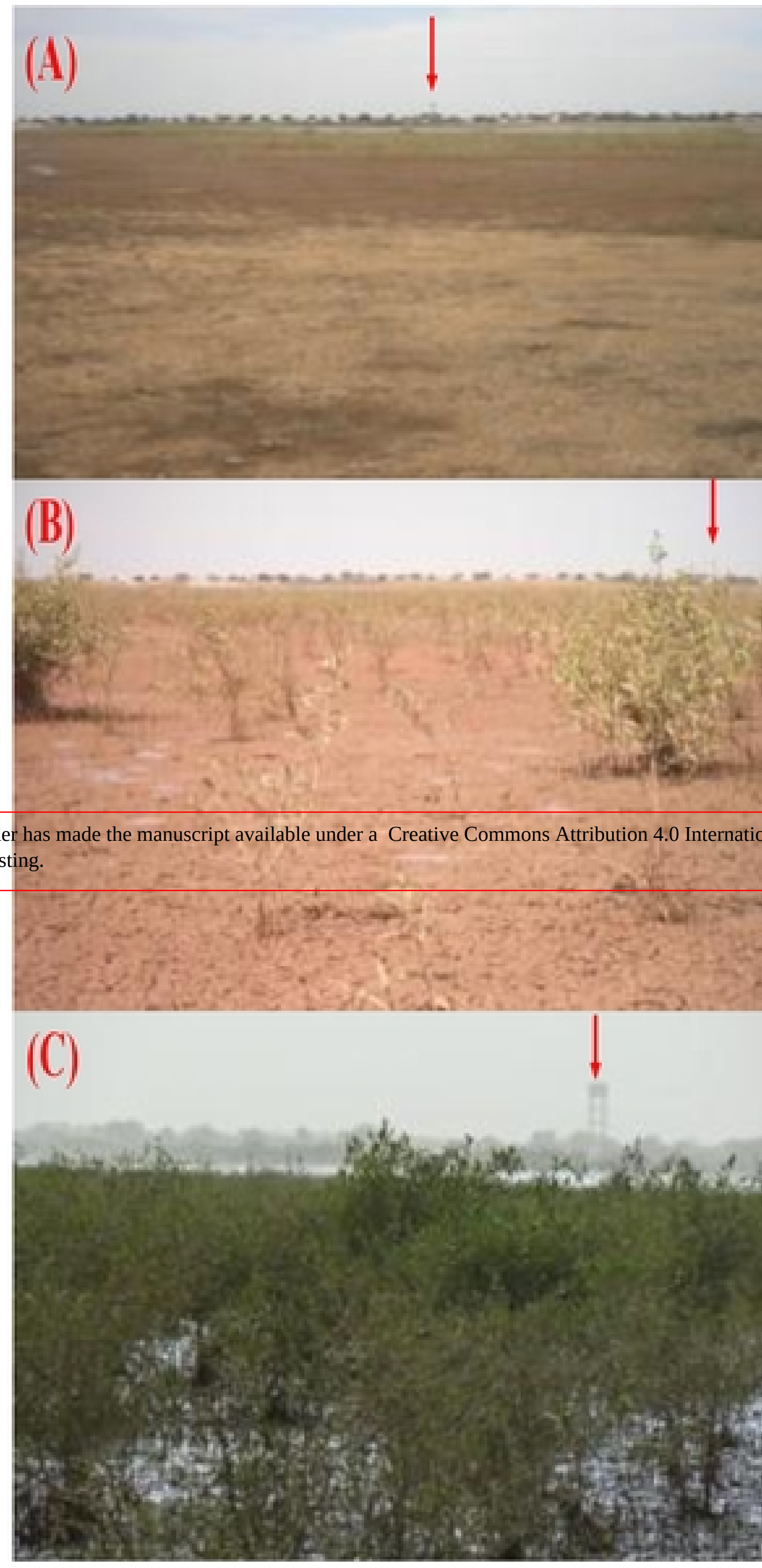
Picture 5: Extensive root development at the nursery is important for mangrove seedlings survival in the field.

Picture 5



Picture 6: A two-year evolution of mangrove reforested site at Gahra: on 04/12/2010 (day of planting); on 05/18/2011 (nearly one year after planting); and on 05/20/2012 (nearly two years after planting). Red arrow indicates a reference point, an Acacia tree).

Picture 6



Picture 7: A two-year evolution of mangrove reforested site at Birette: on 01/11/2010 (one day before planting); on 03/16/2011 (nearly one year after planting); and on 05/21/2012 (nearly two years after planting). Red arrow indicates a reference point, village water reservoir).

Picture 7