Assessment of Asymmetric Mangrove Restoration Trials in Ogoniland, Niger Delta, Nigeria: Lessons for Future Intervention

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ABSTRACT

Mangrove restoration has been undertaken with varying degrees of success in many tropical and subtropical marine shorelines around the globe. However, mangrove reforestation in the Niger Delta, Africa's largest delta and mangrove belt is, at best, rudimentary. Here, we present floristic results on two opportunistic artificial mangrove regeneration case studies aimed at restoring mangrove swamps damaged by oil pollution (Bodo Creek) and colonized by invasive *Nypa fruticans* (nypa palm) (Kono Creek) in Ogoniland, eastern Niger Delta, Nigeria. Nursery raised seedlings of the delta's dominant *Rhizophora racemosa* were planted 1 m apart in zigzag fashion at both locations. Planting at the oil-polluted site was preceded by soil quality investigation and bio-stimulation with fertilizer, whereas at Kono Creek, there was no addition of fertilizer before and after planting. A 3-year post planting evaluation of survival rate, growth, and girth parameters showed better performance of mangroves at the Bodo Creek restoration than at the Kono Creek restoration, with survival rates of 72% and 12%, respectively. In sharp contrast to the Bodo Creek restoration, few stands of the planted mangroves at the Kono Creek restoration had started producing propagules. Investigations of soil quality, and where necessary, followed by remedial treatment, particularly augmenting key nutrients, are critical precursors of successful artificial mangrove regeneration.

Keywords: ecosystem services, mangrove revegetation, nypa palm, predation

Restoration Recap

- Mangrove restoration is just emerging in the Niger Delta, despite being Africa's largest and most degraded mangrove hub.
- This paper presents two contrasting case studies of mangrove planting to restore crude oil killed and *Nypa fruticans* (nypa palm) invaded swamps in Bodo and Kono Creek, respectively.
- Nursery raised Niger Delta dominant red mangrove (*Rhizophora racemosa*) seedlings were transplanted after soil enrichment and clear-cutting of *N. fruticans* at Bodo and Kono Creek, respectively.
- Third year post-planting evaluation of mangrove survival, height and stem diameter showed significant differences in all the parameters between Bodo and Kono planted mangroves, having 72% and 12% survival rates, respectively.
- Reduced transplanting time-stress and soil quality enhancement, particularly augmenting limiting nutrients and reducing contaminant concentration to seedlings tolerant levels, are recommended critical drivers for successful mangrove restoration in degraded wetlands.

Mangrove forests occur between approximately 30° N and 30° S latitude on low energy, sedimentary intertidal shores of the tropics and subtropical areas (Giri et al. 2011). These aquatic forest communities are semi-diurnally and diurnally inundated by tides, with seasonal and continuous inputs of freshwater (Mazda et al. 2005). Mangrove trees are physiologically and morphologically adapted to

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Ecological Restoration Vol. 34, No. 3, 2016
ISSN 1522-4740 E-ISSN 1543-4079

environmental challenges of the intertidal habitat, such as high and variable salinity, low oxygen, poor nutrient availability and substrate mobility (Ellison et al. 2012). The area occupied by world mangroves has been recently mapped as 152,000 km² (Spalding et al. 2010).

In Africa, mangroves cover an estimated 32,000 km², constituting about 19% of global coverage (FAO and UNEP 1981). The extent of the Niger Delta mangrove ecosystem is approximately 35% of all West African mangroves (FAO 2003). There are 69 species of mangrove plants in the world (Duke 1992), but there is controversy about the definite number of mangrove species in Nigeria (Jackson and Lewis 2000). However, Kinako (1989) listed three families represented by six species. These are: Rhizophoraceae *(Rhizophora racemosa, R. harrisonii,* and *R. mangle)*, Avicenniaceae *(Avicennia germinans),* Combretacceae *(Conocarpus erectus* and *Laguncularia racemosa).*

Mangroves provide numerous ecosystem services. These benefits have been broadly grouped under economic, ecological, cultural, and social functions (reviewed in Ronnback 1999, Moberg and Ronnback 2003). At least 24 mangrove goods have been identified (Ronnback et al. 2007), including but not limited to firewood, wood for construction, yam staking, scaffolds, manufacture of local dye, honey production, boat building material, furniture, traditional medicine, handles for traditional fans, axes and spades, net mending sticks, drum sticks, and carving of drums (gongs). Other ecosystem services provided by mangrove wetlands include protection against floods and storms**,** reduction of riverbank and coastal erosion**,** and maintenance of water quality. Additionally, mangroves sustain rich food webs within the mangrove habitat and tidal export of mangrove material supports offshore food webs. Many species of fish, crustaceans, molluscs, amphibians, reptiles, and birds are found in mangroves, having high potential values as scientific, educational resources and for ecotourism (Hoff 2010, Ronnback 1999, Vance et al. 1996, Robertson and Duke 1990).

Many studies have coupled wild fish and invertebrate production to mangrove habitat nursery and protective functions (Lewis et al. 1985, Wolanski and Boto 1990, Thomas and Connolly 2001). It is estimated that each square kilometer of mangroves can support a fishery production of 90–280 tons annually (Ronnback 1999, Moberg and Ronnback 2003). One estimate puts the economic value of mangrove forests to local communities in the range of $27,000–$36,000 per hectare (Sathirathai and Barbiar 2001). Empirical data on fish reproduction function of mangroves in Nigeria are lacking, but a tentative estimate is that about 60% of commercial fishes in the Gulf of Guinea breed in the mangroves of the Niger Delta (Bassey 1999).

Globally, mangroves face serious threats, with increasing intensity in recent decades due to increasing human population pressures, need for land space, and new technologies (Moberg and Ronnback 2003). Mangrove wetlands are, therefore, amongst the most threatened natural ecosystems worldwide, with about 50% of the global area lost already (FAO 2003, Spalding et al. 2010); even at a faster rate than tropical rainforests (Field 1995). Human activities remain a major cause of degradation and loss of mangrove ecosystems in all parts of the world. Rubin et al. (1999) describe the destruction of the mangrove forests of the Volta River Estuary in Ghana due to two dams on the Volta River, and local timber harvesting. Zabbey (2008) and Zabbey et al. (2010) listed oil spillage, overexploitation for fuel wood, conversion to other forms of development, dredging and industrial discharges, and unhindered spread of *Nypa fruticans* (nypa palm) as major threats to mangroves in the Niger Delta. Oil spillage typically results in death of mangrove seedlings and trees; and many crabs and shellfishes as well as causing disruption of detritus-based food webs with consequent reduction in the fishery (Kio and Ola-Adams 1986, Kautsky et al. 2000). Natural recovery of oil damaged mangrove areas can occur through recolonization by floating mangrove seedlings in areas where oil concentration is lower than 30,000 ppm (Lewis 1983). Residual oil in sediment may persist for months and can take about 12 months to weather (Hoff 2010) and residual oil toxicity can result in mortality impact on mangrove seedlings as long as the residual concentration remains high (Getter et al. 1984).

Natural recovery of mangroves can be infrequent due to environmental impediments even though fecundity per mangrove tree can be enormous (reviewed in Hogarth 2007). Given the right hydrological conditions, mangrove propagules can naturally recolonize former mangrove areas and within a timeline of over a decade return to 'normal' mangrove forest. It is estimated that mangroves can recuperate successfully by secondary succession over a period of 10–15 years if there is normal hydrology and availability of propagules within the site (Field 1995). This depends on the right hydrologic conditions, the proximity of the restored site to propagule source, and the absences of propagule blockages (Lewis III 2005). Although, periods ranging from 10–50 years may be required for forest structure to return close to pre-impaired conditions but ecosystem function may take over a century to be fully reinstated (Moreno-Mateos et al. 2012, Rovai et al. 2012).

Mangrove restoration adopts different techniques, resulting in varying degrees of success in different hydrologic conditions and under different circumstances of human intervention. Ecological restoration is an all-embracing term, and according to the Society for Ecological Restoration (SER 2002), it is the "process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed". The goal of the process is to restore the structure, functioning, diversity, and dynamics of the degraded ecosystem using reference ecosystems as models (Lewis III 2005). Lewis and Marshall (1997) highlighted five critical steps that are necessary to achieve successful mangrove restoration, while Kinako (1989) emphasized the adoption of ecological mimicry, in order to maintain and preserve the structural and functional framework of the ecosystem. In other words, restoration should reflect the natural mangrove forest formation of irregular heights, stem diameter, and intermingling nature of mangrove stands, as well as species heterogeneity.

Despite several mangrove restoration initiatives around the globe (Ellison 2000, Lewis 2000, Lewis and Streever 2000, Saenger 2002) and increasing advocacy for mangrove restoration (Zabbey et al. 2010), there have been very few mangrove-planting attempts in Nigeria. Abere and Ekeke (2011) reported a failed attempt by the Mangrove Conservation Society of Nigeria (MCSN) to establish 9 hectares of mangrove restoration at Iwokiri in the Ogu/Boro local government area of Rivers State, Nigeria primarily, due to funding constraints. Isebor (2001) reported 60% loss of planted mangroves 2-year post planting at Igamu, near Lagos lagoon, Nigeria, attributing the heavy mortality to crab predation and severe reduction in rainfall. The purpose of this paper is to compare success rates (using survival and growth performance indices) of two mangrove planting case studies in Ogoniland, lower eastern Niger Delta, Nigeria. These were "opportunistic" pilot projects initiated by the Centre for Environment, Human Rights and Development (CEHRD) to demonstrate to local Ogoni communities that they can contribute to the recovery of degraded mangrove areas by low-tech planting endeavors. We highlight the strengths and weaknesses of the planting approaches adopted. Lessons learned from the mangrove planting trials presented herein may be useful to the anticipated restoration of the mangrove-dominated Bodo Creek, and similar environments in the Niger Delta region.

Methods

Study Area

The mangrove restoration trials reported here were performed at Bodo Creek and Kono Creek in Ogoniland (Figure 1), Niger Delta, Nigeria. Bodo Creek is a network of mangrove tidal creeks on the upper reaches of the Andoni-Bonny estuarine system. Information on Bodo Creek configuration, hydrology, physico-chemistry of surface and interstitial water, and macrozoobenthos has been documented (Onwugbuta-Enyi et al. 2008, Zabbey et al. 2010, Zabbey and Hart 2011, Zabbey 2012, Zabbey and Malaquias 2013). Bodo Creek is approximately 9230 ha of a network of brackishwater creeks, with mangroves occupying about 60% of the total area (Pegg and Zabbey 2013). Bodo Creek was hit in 2008 and 2009 by two major oil spills with huge impact on the creek's mangroves, fisheries, and other biota (see details in Pegg and Zabbey 2013). Proposition of strategies for cleanup, remediation and 'restoration' of Bodo Creek is the central subject of ongoing (as at March 2015) mediation talks between the Bodo community and the Shell Petroleum Company of Nigeria, SPDC, a subsidiary of Royal Dutch Shell. The Netherlands Government through her embassy in Abuja, Nigeria, facilitates the cleanup mediation, with the assistance of the National Coalition for Gas Flaring and Oil spills in the Niger Delta (NACGOND).

Kono Creek, approximately 27.20 km from Bodo Creek, is a relatively small network of creeks, the main creek being a bypass of the Imo River. NEDECO (1961) described Kono Creek as a short creek entering the Imo River near Mile 8 on the west side. The high rate of freshwater discharge from the Imo River makes Kono Creek river-dominated with characteristically low salinity, less than 4 (N. Zabbey, University of Port Harcourt, Unpub. data). Save for the small stretch of the Nwenua protected mangrove swamp, Kono Creek marginal vegetation is predominantly *N. fruticans*, which NEDECO (1961) erroneously described as a type of 'raphia palm' typical of the Imo River sector.

Nypa fruticans is alien to West Africa. Historically, the palm seedlings were taken from Singapore Botanical Garden and firstly introduced to the coast of Calabar in Nigeria in 1906. A transplant followed it from the trial plantation in Calabar to Oron and Opobo in 1912 (Holland 1922). Subsequently, in 1946 additional 6000+ seedlings of *N. fruticans* were imported from Malaysia and planted in the Niger Delta (Zeven 1973). It is from the above entry points that the species spread rapidly and colonized the West African coast as far as the Cameroons (Sundaland and Morakinyo 2002).

Bodo Creek

The mangrove planting was done in an oil-killed mangrove swamp situated at Kiele waterfront of Bodo Creek (4°37′354″ N, 7°15′707″ E). A minor oil spillage happened in an adjoining community in 2003, and some of the spilled oil was tidally transported and deposited at the relatively low-lying swamp of the restoration site, killing the existing mangroves; while mangroves at the opposite and adjacent swamps were intact (Figure 2).

The restoration began in July 2005 with reconnaissance field investigations to ascertain the level of impact and assessment of physico-chemical characteristics of the environment. Protruding root stumps of the dead mangroves were clear-cut and removed from the site to avoid re-impact from clogged oil on root stumps and also to enhance the surface area for photo-oxidation and aeration. Nevertheless, established volunteer mangrove seedlings were retained (Figure 2). Dead stumps near the subtidal fringes of the swamp were also retained to prevent marginal erosion.

A preliminary pre-treatment survey was carried out in July 2005 to ascertain the concentration of oil in the sediment, status of priority nutrient and other soil physico-chemical parameters as well as microbial investigation for

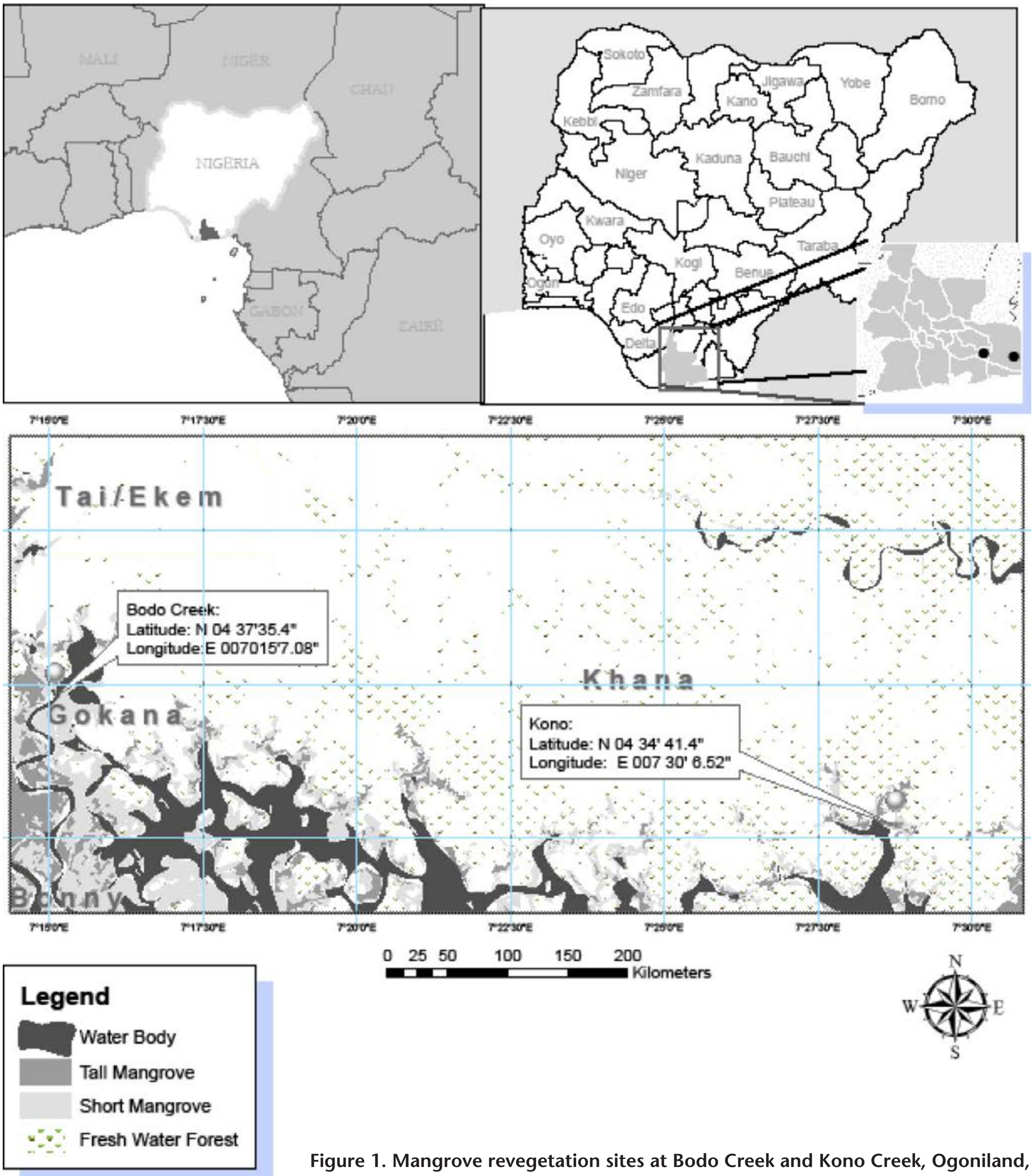

Figure 1. Mangrove revegetation sites at Bodo Creek and Kono Creek, Ogoniland, eastern Niger Delta, Nigeria.

presence of oil degraders. Initially four sampling stations were delineated for comparison. The restoration (i.e., the planted) swamp (38 m × 46 m) was marked Station 1, while seaward the swamp westward and adjacent to Station 1 was marked Station 2. The main creek fringing the swamps was tagged Station 3 while the unaffected dense mangrove swamp opposite the intervention plot was marked Station 4. Only sub-surface water samples were taken from Station 3. On the other hand both sediment and interstitial water samples were obtained from the other Stations (1, 2, and 4).

The preserved samples were taken to the University of Port Harcourt laboratory in ice-chests and analyzed for some priority parameters following standard methods (APHA1998). The physico-chemical parameters

Figure 2. Bodo Creek mangrove restoration plot situated at Kiele waterfront; mangroves on the opposite shores were intact.

investigated included Total Hydrocarbon Content (THC), Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and nutrients (nitrate-nitrogen and phosphate) (Table 1). Microbiological analyses were performed to know the status of microbial degraders, heterotrophic bacteria, and fungi present in the area (Table 2). These analyses were carried out to give insight into whether bio-stimulation (nutrient supplementation) or bio-augmentation (introducing microbial flora) was required.

The consolidated peaty sediments of the restoration plot (38 m × 46 m) were scarified by tillage at spots designated for planting. Since laboratory test revealed DO of pore water as zero in the degraded swamp, tilling the sediment increased the porosity and oxygenation of the sediment by increasing the surface area of the sediment

Table 1. Results of pre-treatment chemical analyses of subsurface creek and pore waters at the mangrove planted swamp in Bodo Creek, Ogoniland, Niger Delta, Nigeria. Station 1 = restoration site, Station 2 = swamp adjacent to Station 1, Station 3 = main creek adjacent to the mangrove swamp, Station 3 = unaffected mangrove swamp (reference). NM* = not measured, ND = not detected.

Parameter	Station			
	1	2	3	4
DO (mg/L)	—	—	4.3	—
BOD (mg/L)	NM*	NM	8.0	NM
THC (mg/L)	862	675	NM	105
Nitrate (mg/L)	0.5	0.5	1.5	0.4
Phosphate (mg/L)	0.4	0.4	0.02	0.3

Table 2. Results of pre-treatment microbiological load in water and sediment of mangrove restoration swamp in Bodo Creek, Ogoniland, Niger Delta, Nigeria. Station descriptions can be found in Table 1.

Station	Total Heterotrophic Bacteria (CFV/MI/CFV/G)	Hydrocarbon Utilizing Bacteria (CFV/MI/CFV/G)	Total Fungi Counts (CFV/MI/CFV/G)
1	1.60×10^6	4.00×10^5	< 3000
2	1.19×10^6	2.65×10^5	< 3000
3	9.25×10^3	9.50×10^3	3.00×10^2
4	1.56×10^6	3.20×10^5	< 3000

Figure 3. Nursery bed of *Rhizophora racemosa* established at Bomu Creek for transplanting.

for atmospheric oxygen uptake and released buried oil to the water-sediment interface. This enhanced tidal removal of the exposed oil during flooding and photo-oxidation when the mudflat is flooded and exposed during high and low tide, respectively.

To boost the nutrient status of the restoration plot, dry granular (slow-releasing) N/P/K fertilizers (25:10:5) were applied directly to the sediment surface at low tide. This method of fertilizer application is cost effective, and has been recommended for low energy beaches because washout due to tidal activity is relatively low (Venosa and Zhu 2005). During the first month of fertilizer application, about 1.2 kg of fertilizer was broadcasted on the surface of the plot every week. Subsequently, the same quantity of fertilizer mentioned above was applied every two weeks for one year. After five months of fertilizer application, porewater samples were taken from Station 1 (the restoration plot) for re-examination of the THC concentration.

Matured viable propagules of *Rhizophora racemosa* (red mangrove) were obtained from the wild to be raised in a nursery. The nursery plot was established approximately 1 km away from the contaminated swamp, to prevent chronic hydrocarbon-induced stress during sprouting. Nursery preparation was done concurrently at the time fertilization of the intervention plot began.

We adopted planting space of 1 m between plants, in zigzag fashion. Earlier, marked spots for planting were tilled and pegged. Nursery bred seedlings were carefully dug out and transported by canoe to the planting site. Caution was exercised not to damage seedling roots during transplanting, and to ensure that root-balls of the seedlings and embracing sediments were intact during digging, transportation, and planting. A total of 400 propagules were planted.

Planting took place in late November 2005, at which time the nursery-bred seedlings had six or more leaves on them. The height and girth diameter (at 0.5 m height) of the planted saplings were measured. Initial post planting evaluation was done one month after planting. Some seedlings, which might have had their root system damaged and had showed signs of wilting were replaced (replanted) with viable individuals. The overall growth performance was re-assessed in 2008. The height and diameter measurements were repeated, and the survival rate calculated by dividing the number of seedlings that survived up to the time of reassessment by the number that was planted, and multiplied by 100.

Kono Creek

The second restoration site was located at Kono Creek, Ogoniland (4°34′414″ N, 7°30′652″ E) (Figure 1). The mangrove restoration was necessitated by aggressive invasion of *N. fruticans* which had out competed native mangroves leading to a drastic reduction in the native mangrove cover. Kono Creek's marginal swamps are colonized by *N. fruticans* except a small stretch of the Nwenua mangrove protected area, the last standing intact mangrove vegetation swamp at Kono Creek.

An area of *N. fruticans* measuring 70 m × 40 m was marked and the palm jungle manually clear-cut with machetes followed by the removal of the palm rhizomes (stumps below-ground level). Since there was no visual sign of 'pollution', no remediation and nutrient addition was applied, as was done at Bodo creek, and baseline investigation of soil nutrient and other soil physico-chemical parameters was not undertaken. The mangrove nursery was set up five months before planting at Bomu Creek, 23 km away from the planted site, where matured propagules where plentiful and easily accessed. Approximately 500 *R. racemosa* propagules were raised in the nursery (Figure 3).

Four hundred nursery-bred seedlings were carefully dug out very early in the morning and transported by boat to the planting site. Caution was exercised to avoid damaging seedling roots during digging, and to ensure that root-balls of the nursery seedlings and sediments were intact during digging, transportation and planting. In addition, seedlings that showed signs of stress were discarded. Planting was done in 1 m intervals between plots in a zigzag pattern as at Bodo Creek to mimic natural mangrove forest structure. Each of the planting points were pre-marked and pegged. The seedlings were placed in wide, straight (vertical) holes and ensured that the roots did not curl upward. The hole containing the seedling or propagule was then covered with loose in situ soil to ensure proper aeration. The height and diameter of the planted seedlings were measured immediately after planting in April 2010. Performance evaluation was done to assess the condition and status (that is, survival and growth rate) of the planted mangroves three years post planting. Mean plant height and stem diameter between the initial and final assessment time were separated by t-test (excel version 10) at $p = 0.05$.

Results and Discussion

Percent vegetation cover, measured between 2–3 years is the main short-term parameter used in determining success of a mangrove restoration effort (Kaly and Jones 1998), but a much longer timeframe is needed to actually draw ecological conclusions in the light of population/community dynamics. In terms of number of planted seedlings that survived as at the time of evaluation, 360 (72%) and 48 (12%) seedlings were recorded at Bodo Creek and Kono Creek site, respectively (Figure 4). Other observable characteristics of superior performance at Bodo Creek compared to Kono Creek included higher branching and prop root densities (Figure 5 and 6). A plausible factor responsible for the differential growth and survival rate of the planted mangroves at Bodo Creek and Kono Creek is that at Bodo Creek, site-specific remedial treatment was performed. The long distance between Bomu nursery bed and the Kono restoration site (approximately 23 km) may have resulted in transportation stress during transplanting, which affected net survival.

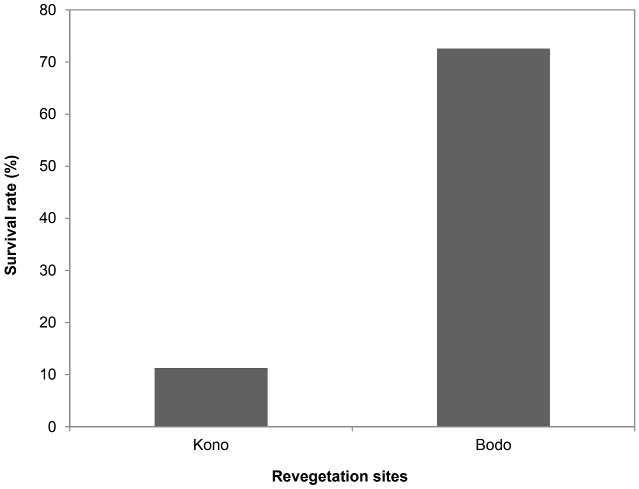

Figure 4. Final survival rate (%) of planted mangroves at Bodo Creek and Kono Creek.

Three months after planting, there was tremendous increase in aboveground height of the mangroves (Figure 7). At final assessment time, the mean plant height at Bodo Creek was significantly higher than that of Kono Creek (Figure 7). The mean stem diameter between initial and final time was also significantly different (Figure 8). The graph shows similar growth pattern at the initial stage between the seedlings of both sites; the difference set in as time progressed. Plausible hypotheses regarding eventual differences in nutrient concentration and the influence of this resource on the mangrove survival and growth performance across the sites could relate to: 1) The origin of organic matter and the resulting organic matter quality in the soil; and 2) The environmental setting where the sites are located. Cyclical nutrient uptake and regeneration occurs within mangroves due to sufficient leaf litter and decomposition (Robertson et al., 1992). Mangroves also have high capacity to store organic matter in their soils in comparison to other forested systems (Donato et al. 2011). Secondly, root systems of true mangrove species (sensu Tomlinson, 1986) and *N. fruticans* differ in their anatomy, production rates, and organic matter quality. So it would

Figure 5. Planted mangroves at Bodo Creek site three years post planting.

be expected that vegetation type (mangrove vs. *N. fruticans* which hitherto occupied Bodo Creek and Kono Creek, respectively) is an important driver of the concentration of nutrients and organic matter in the soil. *Nypa fruticans* rarely shed their leaves/fronds to recharge soil nutrients, even as the palm roots continue to remove nutrients from the sediment (Isebor 2003), causing mineral depletion. Notwithstanding biogeochemical advantages of mangrove over *N. fruticans* and anthropogenic nutrient fortification at Bodo Creek, Kono Creek being river-dominated, may have been nutrient sufficient. It has been shown that biogeochemical functions differ between restored mangrove stands due to variable hydrological and soil conditions (McKee and Faulker 2000). Generally, river-dominated systems receive larger nutrient inputs than tidal-dominated systems (Lugo and Snedaker 1974, Twilley, 1995).

Figure 6. Early propagule production by planted mangroves at Kono Creek, 3 years post planting; note luxuriant *Nypa fruticans* on the opposite shores.

However, considering the reasons above and the fact that nutrient concentration was not analyzed during planting at both sites, it is difficult to conclude or attribute variation in growth performance to differences in nutrient availability. Lastly, at Kono Creek, low salinity seems to be a natural factor (stressor sensu Lugo et al. 1981) impeding mangrove to re-colonize or constraining growth, as energy needs to be diverted towards other basal metabolic functions. It is, therefore, likely that planting (even followed by successive re-planting) might not "defeat" this environmental factor. Other factors that limit mangrove performances include less than 30% of tidal flooding (Hogarth 2007), older swamps which are naturally bereft of nutrients (Wolanski 2007), hypersaline water, sandy soils, or cracks in limestone substrates (Wolanski 2007). Cartaxana et al. (1999) noted that though coastal marshes are considered high nutrient wetlands, most of the nutrients and nitrogen in particular are present in the form of

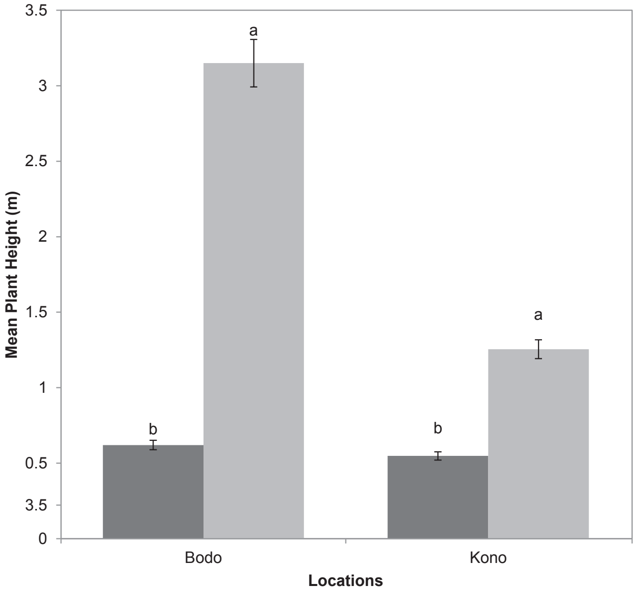

Figure 7. Mean height (m) of planted mangrove at the initial (dark gray bars) and final assessments (light gray bars) at Bodo Creek and Kono Creek restoration sites. Lowercase letters indicate significant differences between assessments within sites ($p < 0.05$).

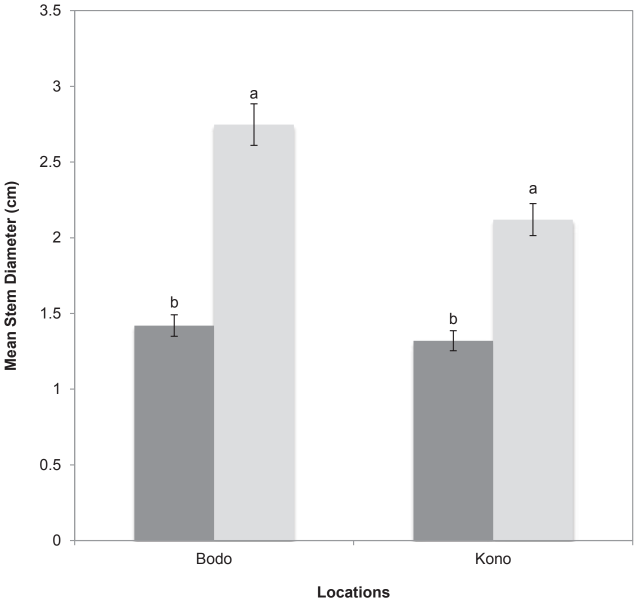

Figure 8. Mean stem diameter (cm) of planted mangrove at the initial (dark gray bars) and final (light gray bars) assessments at Bodo and Kono restoration sites (dark bars indicate initial diameter and light bars indicate final diameter). Lowercase letters indicate significant differences between assessments within sites ($p < 0.05$).

particulate organic matter and not readily available for microbial or plant uptake.

Pre-treatment results (Table 1) on the Bodo site had concentrations of nitrogen (nitrate) and phosphate of 2 mg/L and 0.43 mg/L, respectively. Zabbey et al. (2014) recorded a range of 0.088–3.53 mg/L and 0.004–1.38 mg/L of nitrate and phosphate in interstitial water of soft bottom intertidal flats at Bodo Creek, respectively. Based on field experiences on sandy beaches, the threshold concentration range for optimal hydrocarbon biodegradation on marine shorelines is around 2 to 10 mgN/L (Venosa et al. 1996). The initial THC was in the range of 675–865 mg/kg while DO was below detectable limit (Table 1). Tilling the sediment beneficially increased the surface area and porosity of the sediment for atmospheric oxygen uptake, which also enhanced biodegradation. More so, the addition of fertilizer improved the nutrient content of the substrate and reduced the THC (500–660 mg/kg) five months post treatment. Venosa et al. (1996) noted that when a major oil spill occurs in salt marshes, it is likely that nutrient availability would be the limiting factor for oil degradation, depending on the type of sediment, the season, and the quantity of oil spilled. In some cases, however, adding fertilizer does not significantly result in biodegradation of oil in mangrove sediment (Teas et al. 1993, Quilici et al. 1995). According to Jackson and Lewis (2000), mangrove propagules planted in sediments having hydrocarbon levels of up to 80 ppm have shown “good” growth.

It is plausible that the relatively higher survival rate of the Bodo Creek ‘restored’ mangroves was made possible by the slow-dissolving fertilizers applied, which enhanced rapid growth and fortified the plants to be able to withstand immediate and subsequent environmental vagaries. The reverse experience was the case at the Kono Creek restoration where fertilizer was not applied before, during, and after planting. Exported nutrient generated in neighboring mangroves may have been supportive of the Bodo mangrove growth. While majority of mangrove leaf litter is usually retained within the forest, a significant amount is also exported to near-shore and adjacent systems as organic carbon and nutrients (Ronnback 1999); water linkages between the swamps ensure inter-transference of these materials. It has been observed that nutrient supplementation could hasten vegetation recovery (A. Venosa, Director of Land Remediation and Pollution Control Division, US Environmental Protection Agency, Pers. Comm.). As noted earlier, *N. fruticans* swamps are presumably nutrient-deficient due to continuous nutrient removal from the soil by the palm without regeneration by leaf litter.

Additionally, crabs can prey severely on mangrove propagules, saplings and pneumatophores (Hogarth 2007, Hoff 2010), leading to poor recovery rates (Dahdouh-Guebaset et al. 1998, Isebor 2001). However, crab predation was unlikely responsible for the massive mortality recorded at the Kono restoration site as *N. fruticans*, which hitherto occupied the planted swamp, and dominates adjacent swamps are poorly inhabited by crabs. Crab preference for mangrove swamps is linked to the huge quantity of daily mangrove leaf litter, which resident and vagrant crabs consume voraciously (Beever et al. 1979). In addition, immigrant crab herbivory on the planted mangrove seedlings during tidal flooding at Kono Creek (same for Bodo Creek) is also very unlikely as mangrove crabs retreat into burrows during high tide to avoid fish predators (Hogarth 2007).

Some stands of the planted mangroves at the Kono Creek restoration site had started to produce propagules three years post planting. This sharply contrasts the Bodo Creek situation where none of the relatively luxuriant and taller mangroves (with better root anchorage) had propagules on them (Figure 6). Naturally, *Rhizophora* mangroves may start to produce seeds as early as three years (R.R. Lewis, Lewis Environmental Services, pers. comm.), and keep reproducing year round (Odum et al. 1982, Clarke and Johns 2002). It is plausible that enhanced nutrients at the Bodo restoration site stimulated greater investment in foliage and stem growth (including branching), while mangroves planted at Kono responded to environmental limiting stress by investing in early reproduction. It is also known that nutrient-limited sites allocate more biomass in the belowground compartment, while nutrient-abundant sites invest most of it in the aboveground compartment (Castañeda-Moya et al. 2011, Castañeda-Moya et al. 2013).

Conclusions and Recommendations

The results indicate that the mangrove planting trial at Bodo Creek was "successful" because preliminary investigations and site-specific remedial treatments preceded planting. The reported success was merely planting success; at least two decades may be necessary to evaluate mangrove restoration success based on vegetation's structural features (Crewz and Lewis 1991, Luo and Xu 2010) and functionality. In contrast, though the Kono Creek restoration site shares similar tidal hydrology with the Bodo location, the 'gardening' approach (Stevenson et al. 1999) adopted at the former location failed to yield similar interim planting success, as was the case of the latter site. Being a bypass of the Imo River, Kono Creek is river-dominated and receives greater volumes of freshwater inputs than Bodo Creek. This shows that even when normal hydrology is assured, factors such site-specific nutrient levels and swamp elevation, oftentimes overlooked, can potentially undermine successful mangrove restoration. The "erroneous" presumption that Kono Creek, being visually "rich", having luxuriant marginal *N. fruticans* and having good freshwater hydrologic supply, did not require pre-planting investigation of basic soil physico-chemical parameters contributed largely to the failure recorded at the site. Preliminary soil quality assessment would have flagged off potential failure indicators, and would have warranted imperative remedial treatments.

Thus, in addition to Lewis and Marshall (1997) recommended five steps for successful mangrove restoration programs, it is important to investigate site-specific sediment needs of a would-be mangrove restoration site, particularly nutrient availability, followed by removing significant barriers to recovery. Furthermore, mangrove nursery should not be located too far from planting site in order to minimize transplanting-transportation stress. Intensive mangrove restoration schemes and the establishment of mangrove protected areas would, to a large extent, conserve mangroves of the Niger Delta and enhance the region's coastal and inland wild fisheries and biodiversity. Focused research is needed to understand the functional dynamics of Niger Delta mangroves. This would provide scientific basis for developing informed mangrove management and conservation strategies for the region. Restoration of degraded mangrove areas in the Niger Delta is strongly recommended, in order to reactivate and/or sustain the region's numerous mangrove-dependent economies.

Acknowledgements

We are grateful to the Centre for Environment, Human Rights and Development (CEHRD) for given us the opportunity to lead the technical components of both projects and, for granting us permission to disseminate the project data in this form. PADI Foundation, Global Green Grants and Rufford Small Grant provided funds for the first planting project. The second planting initiative was supported by Groundwork, sub-granted by Stakeholder Democracy Network (SDN) to CEHRD. Youth volunteers in both trial communities, to whom we are eternally grateful, supported the projects. The exceptional field assistance offered by John Gbei, Baribefe Bornu, Reuben Oku, Peter Nwinkiri, Michael Gbarabe, Friday Aalo, Elder Barisere Bia and the late Barisi Kpinanom Zabbey merits special commendation. The late Mr. Lekaaga Beta Baravil assisted in collecting propagules and in raising of seedling nursery at Bomu Creek. May the souls of Barisi and Lekaaga rest in peace! We sincerely thank Dr. Albert Venosa (former Director of Land Remediation and Pollution Control Division, US Environmental Protection Agency) for his technical guidance during the Bodo mangrove restoration project. He also gave the lead author insightful literature. We are profoundly thankful to Dr. David Little (Environmental Consultancy, Swavesey, Cambridge, UK) for his useful comments on the initial draft. We acknowledge with thanks the invaluable comments of two anonymous reviewers. The reference literatures they suggested were very helpful.

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