Chapter

Mangrove Restoration under Different Disturbances Regime in the Niger Delta, Nigeria

Aroloye O. Numbere

Abstract

Mangroves of the Niger Delta are the largest in Africa and are the source of numerous ecosystem services such as firewood, seafood, building materials and medicinal herbs. Their sustainable use and protection are important for future generations. However, anthropogenic activities such as oil and gas exploration, urbanization, industrialization, dredging, overexploitation and sand mining are the major disturbances that have pushed the mangroves to the brink of extinction. Therefore, in other to restore lost areas of the mangroves natural and artificial means can be adopted to bring them to a restored state. More often than not emphasis of recovery had been placed on artificial remediation and restoration, where polluted sites are cleaned with chemicals and nursery seedlings transplanted to remediated such sites. Nevertheless, this chapter discusses the possibility of utilizing natural means of forest recovery through seedling recruitment and regeneration. This can be achieved by establishing the right environmental conditions such as setting up of a hydro-channel to ensure smooth inflow and out flow of river water carrying seeds, availability of parent mangrove trees to supply the seeds, and the availability of the right soil condition to enable seedling germination and growth. The use of dried and ground mangrove parts as a new way for restoring polluted soil is discussed; in addition, the unconventional proposition of using low key pollution to manage and increase forest resilience is highlighted in this work even though further studies are recommended. Future direction of mangrove restoration should be tilted towards the application of the force of nature, which has the potentials of reversing the adverse effect of anthropogenic activities in well managed and protected sites.

Keywords: ecology, hydrocarbon pollution, remediation, recruitment, succession, urbanization

1. Introduction

Mangroves of the Niger Delta are the most abundant and most productive forest in Africa [1]. It is also the third largest in the world. The significance of mangroves unlike other rain forest ecosystem e.g. Mahogany (*Khaya ivorensis*), obeche (*Triplochiton scleroxylon*) and iroko (*Malicia excelsa* is the kind of ecosystem services they provide [2]. This is because in addition to purifying the air, stabilizing the soil and being used as timber, mangroves play special role in the environment by serving as one of the biggest carbon sink in the world [3] based on the kind of terrain they occupy. They are the only tree species that grow within the swamps and at the fringes of the sea in highly saline environment [4]. They are adapted to one of the most gruesome environments for any tree to survive. For instance, apart from their salty environment, they grow in soft and muddy soil and are constantly bashed by violent tidal currents. In spite of all these environmental difficulties the mangroves had come out unscathed. Mangroves tend to survive very difficult environmental conditions. To deal with high salt, their system shuts off, sweats out or pumps out excessive salt to survive their environment. Their adventitious root system grows not only from the bottom of the tree but also grow out from the branches in an octopus-like manner to be rooted in the swamp, which provide additional support from the ground-based roots. These roots system if not carefully identified can easily be mistaken for mature stems. Excess salt that will easily kill off other trees act as nutrients for their rapid growth. The survival of mangrove in its difficult environment can be a lesson on resiliency for humans.

1.1 Natural mangrove recruitment

Seedling recruitment in mangroves occurs when juvenile organisms survive to be added to a population, by birth or immigration, usually a stage whereby the organisms are settled and are able to be detected by an observer in natural mangroves forest [5]. The Nigerian landscape has significantly changed over the last few decades and anthropogenic activities by man such as sand mining practices is one of the most important causes of this change. Rapid re-establishment of native vegetation, particularly after a large-scale disturbance, can be critical in preventing soil erosion, invasion by exotics, and other unwanted species such as *Nypa fruticans*. Re-colonization of disturbed sites may be slow and unpredictable, especially if seed sources are remote. Ecological restoration may involve not only artificial reintroduction of the original community dominants, but also nurse species that improve seed trapping and establishment [6], attract seed carriers, enhance soil conditions through organic matter or nutrient accumulation [7, 8], or provide protection of sensitive seedlings [9]. Ecological restoration approaches, however, must be based on a thorough understanding of the natural successional dynamics of the system as well as the growth requirements of the dominant plant species. The current challenge in ecological restoration is to manipulate development so that recovery of the entire suite of structural and functional features is achieved as quickly as possible [10]. Few studies have experimentally examined facilitation in the context of restoration [11, 12]. Facilitation may not only involve amelioration of environmental conditions that promote growth of a beneficiary species, but can also arise from effects of dispersal and establishment, e.g., trapping of seeds. Facilitation has been studied in extreme environments such as salt marshes [13, 14] where plants must cope with stresses such as salinity, flooding, and variable sediment and nutrient supplies such as mangroves. Mangroves are the tropical equivalent of temperate salt marshes, but in contrast to marsh grasses that can propagate vegetatively, these tidal forests are dominated by tree species dependent upon seedling recruitment for regeneration. Mangroves are frequently disturbed by hurricanes and human activities, which severely damage or eliminate the forest community [15]. Mangrove plant communities often contain herbaceous species, which are common components of the tropical beach habitat, salt marshes, or other wet coastal communities [16]. Although factors influencing mangrove recruitment such as seed and seedling predators [17, 18], flooding and salinity [19, 20], and sedimentation [21] had been studied in neotropical forests. Mangroves may be extremely slow to recolonize and grow, especially in harsh (e.g., arid, hypersaline) environments [22]. Mangrove ecosystems thus constitute not only a critical habitat with important ecological and societal benefits, but are systems in which facilitative interactions might be applied to improve restoration techniques.

1.2 Ecological restoration

Ecological restoration is defined as the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystem [23]. Ecological restoration includes a wide scope of projects including erosion control, reforestation, removal of non-native species (e.g. *N fruticans*) and weeds, revegetation of disturbed areas, day lighting streams, reintroduction of native species, and habitat and range improvement for targeted species. Hydrological connections to natural restoration site are also very important to allow in inflow of saline water and mangrove seeds [24]. Inflow of water will also clean the site from pollutants such as oil spillage [25].

Factors that affect ecological restoration include the following:

1. **Disturbance:** is a change in environmental conditions that disrupts the functioning of an ecosystem [26]. Disturbance can occur at a variety of spatial and temporal scales, and is a natural component of many communities. For instance, sand mining and oiling activities urban development are disturbances. Differentiating between human-caused and naturally occurring disturbances is important in restoration and minimization of anthropogenic impacts.

   Human disturbance: This is a kind of disturbance caused by humans e.g. urbanization and industrialization. Humans build bridges, shopping malls, roads, schools, hospitals etc. in cleared mangrove forests. These activities eliminate the natural wetland system and destroy numerous biodiversity that inhabit this environment (barnacles, mussel, periwinkles, crabs etc). During oil and gas exploration humans deliberately bulldoze and clear large acre of forest to make way for the establishment of booth camps, oil wells and crude oil pipelines. The pipelines conveys petroleum products from oil wells to the refinery while finished products are transported back via pipelines to tankers evacuating products at the port (**Figure 1A**). These pipelines are established by creating right of way passage (ROW) through deforestation (**Figure 1B**), furthermore, crude oil spills occur from these pipelines due to sabotage or mechanical failure leading to the destruction of vast amount of mangrove forest (**Figure 1C**).

   Natural disturbances: This is a disturbance that is caused by force of nature. This includes flood, erosion, hurricanes, tsunami and earthquake [27]. These disturbances are controlled by weather conditions and cause massive damage to mangrove forest, which changes the forest structure and composition (**Figure 2**).

2. **Ecological Succession**: is the process by which a community changes over time, especially following a disturbance [28]. In many instances, an ecosystem will change from a simple level of organization with a few dominant pioneer species to an increasingly complex community with many interdependent species. Restoration often consists of initiating, assisting, or accelerating ecological successional processes, depending on the severity of the disturbance. Following mild to moderate natural and anthropogenic disturbances, restoration in these systems involves hastening natural successional path.

3. **Habitat Fragmentation**: describes spatial discontinuities in a biological system, where ecosystems are broken up into smaller parts through land use changes (e.g. agriculture) and natural disturbance [29]. This reduces the size of the populations and increases the degree of isolation. Thus, the smaller and isolated populations are more vulnerable to extinction whereas fragmenting ecosystems decreases quality of the habitat.

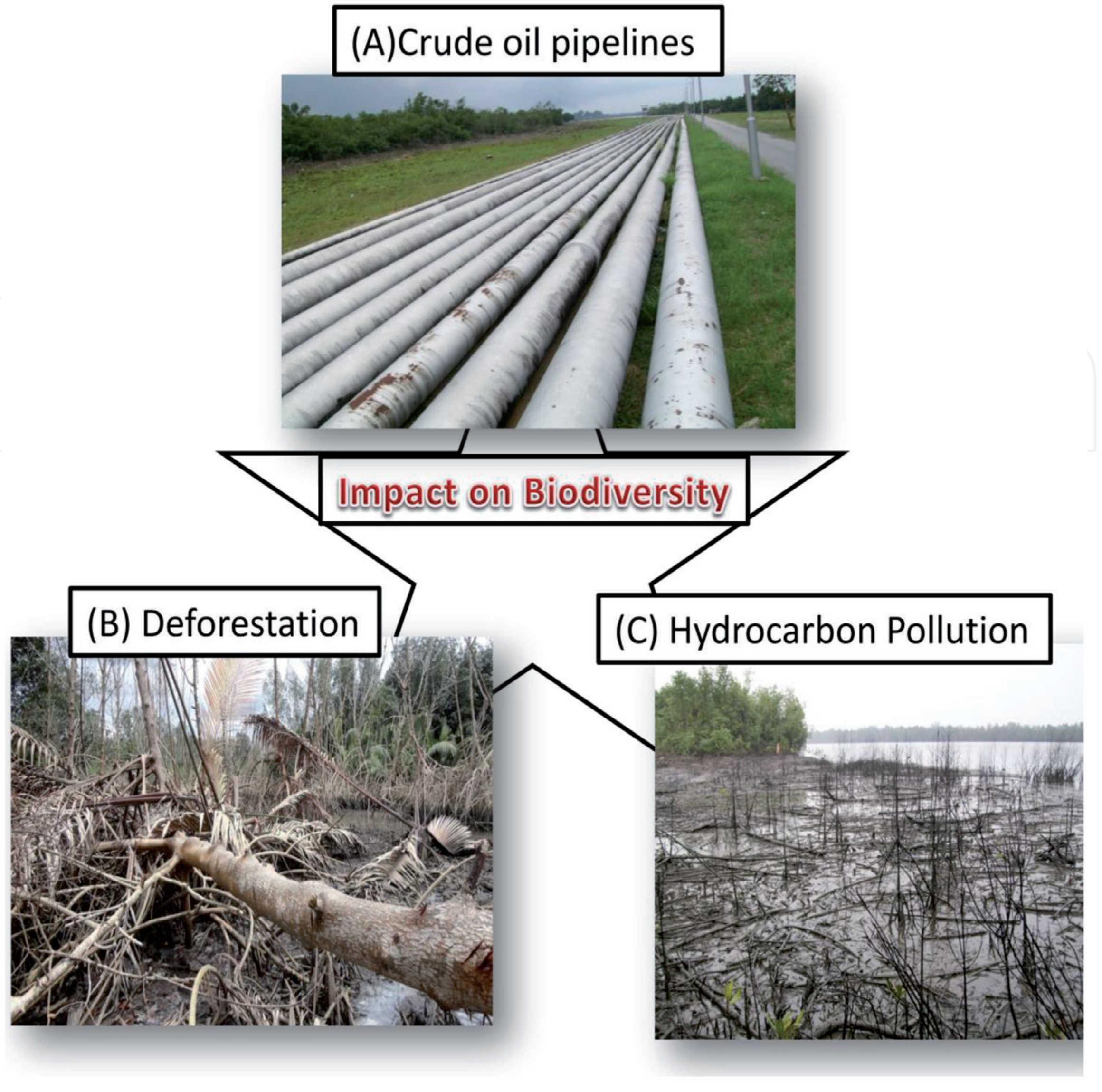

Figure 1.
Picture a: Pipelines' leading from Port Harcourt refinery to Okrika Jetty was taken in 2010. Spillages do occur, which affects neighboring mangrove forest. Picture B: Deforestation of mangrove forest at Okrika refinery Jetty to make way for pipelines right of way (ROW) taken in 2015. Picture C: Massive death of mangrove forest at Abbi Ama, Buguma Asari-Toru local government area of Rivers state following a major oil spillage. The picture was taken in 2010.

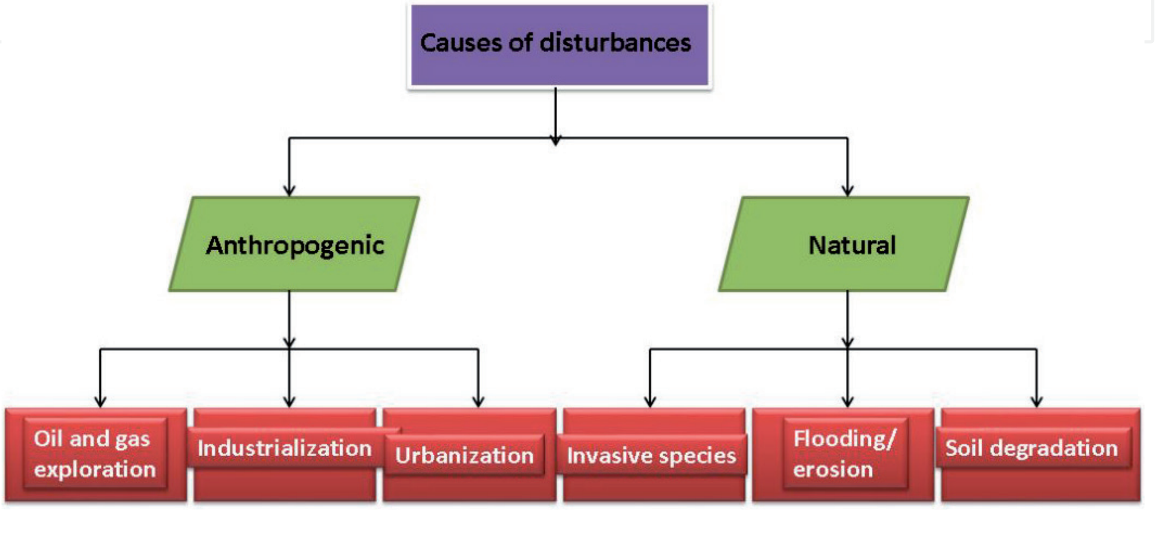

Figure 2.
Causes of disturbances in mangrove forest in the Niger Delta, Nigeria.

4. **Ecosystem function**: describes the most basic and essential foundational processes of any natural systems, including nutrient cycles and energy fluxes [30]. An understanding of ecosystem functions is necessary to address any ecological processes that may be degraded. Ecosystem functions are emergent properties of the system as a whole, thus monitoring and management are crucial for the long-term stability of ecosystems. Mangrove ecosystem functions include three major aspects namely: (1) good and services e.g. timber, fuel, food, medicine and dyes; (2) Environmental and ecological services such as (i) regulatory services e.g. coastal protection, climate regulation and (ii) supporting services e.g. nursery, biodiversity, nutrient cycling and soil formation; (3) Cultural services e.g. spiritual, esthetic, recreational and educational.

5. **Community assembly**: is a framework that can unify virtually all of community ecology under a single conceptual umbrella. Community assembly theory attempts to explain the existence of environmentally similar sites with differing assemblages of species [31]. It assumes that species have similar niche requirements, so that community formation is a product of random fluctuations from a common species pool.

6. **Population genetics**: Genetic diversity has shown to be as important as species diversity for restoring ecosystem processes [32]. Hence ecological restorations are increasingly factoring genetic processes into management practices. Such processes can predict whether or not a species successfully establishes at a restoration sit**e.**

7. **Pollution:** is the emission of toxic substances into the environment. Mangroves are impacted by hydrocarbon pollution [33], and this occurs during crude oil spillage from punctured pipelines at both offshore and onshore sites. The crude oil spilled into the water coat the roots of mangroves and suffocates them to death. Oil pollution in mangrove forest lead to the increase in heavy metal concentration, which creates toxic condition and lead to the death of immature mangroves [34].

1.3 Impact of pollution on mangrove restoration and ecosystem services

Pollution prevents propagule germination and growth, and causes mutation of mangrove which results to stunted growth and eventually death [35, 36]. Hydrocarbon pollution increases litter fall via defoliation, which increases the rate of productivity [37]. Pollution also slows, but do not stop the rate of decomposition [38]. Based on the action of pollution on mangrove structure it is as an impairing agent of its ecosystem functions. This is because it impedes the air purification role of mangrove trees because of increase in defoliation. Death of immature trees prevents their use as a source of firewood production, a major source of cooking energy by poor rural people already wallowing in poverty. The role of mangrove as a biodiversity hotspot is affected because of oil spill that kills other organisms that live on, within and around the mangrove forest.

1.4 Mangrove as a bio-remediation agent and pollution inhibitor

The ability of mangroves to survive in difficult terrain goes beyond the natural perturbations (sodium chloride, heat, waves etc) to anthropogenic activities (oil spillage, organic waste, pollutants etc.). This is because mangrove survive polluted environment by using similar means to survive a highly saline environment. This is because studies had revealed that mangroves growing in highly polluted sites have higher productivity than mangroves growing in lowly polluted sites [37]. The growth of mangroves in a polluted soil reduces the pollutant load by accelerating microbial action in the soil through decomposition of litter materials. Soil pollutants absorbed into mangrove parts are locked up and deactivated in guard cells which prevent the pollutants from becoming harmful to the internal organs of the plant just the same way salinity is controlled and eliminated in mangrove cells [39].

1.5 Mangrove resistance to pollution

Mangrove cope with pollution through the following means: (1) by acting as a sink for pollutants, this is because mangroves absorb heavy metals and prevent them from circulating in the ecosystem, (2) through defoliations of leaves that have absorbed pollutants. Here the leaves accumulate pollutants and later fall off to prevent the contamination of the tree [40]; (3) Tough giant root system, the adventitious root system of mangroves grow to a maximum height of above 5 meters from the ground and have only 25% of the root embedded in the swamp and 75% hanging in the atmosphere. This therefore makes oil spill or any pollutant to have limited focus of attack and thus less effect on the tree because of the low root-soil contact. (4) Mangrove root is tough and coated with algal growth, which further provides a layer of protection against external pollutants from the watery environment. This prevents the diffusion of crude oil into the root of mangroves and (5) Tidal flushing, is a process where the tides wipe away oil spills from the forest floor.

Nypa palm (*N fruticans*) is invasive in the Niger Delta because it is a foreign species brought in from Indonesia [41], and over the years they have driven away the mangroves and colonized their territory. *Nypa fruticans* are from the family palmae and have different bio-physical properties from the mangroves, which makes them to have an antagonistic relationship with the mangroves. Currently, nypa palms have limited ecosystem services as compared to the mangroves in the Niger Delta. This is the reason why they are removed from most location in favor of the mangrove forest. Although, there are ongoing research to manufacture manure and life buoy from the palms.

1.6 Mangroves (*Rhizophora* spp) parts as tools for bio-remediation of degraded forest

Mangrove parts (leaf, stem, root and seed) can be used in attenuating pollutants load in the soil. A recent study using ground mangrove parts on polluted soil shows a drastic reduction in oil pollution level (**Table 1**). The preliminary results shows that roots of mangrove and nypa palm performed better than other parts whereas the stem of mangrove had the least remediating effect (Numbere unpublished). Mangrove of the Niger Delta has one of the highest productivity levels in the world [29]. High litter fall causes high microbial activities, which in turn leads to high decomposition rate [38]. This has made the mangrove of the Niger Delta to survive a 50 year period of constant pollution from oil spillages. During major oil spillages (**Table 1**) hydrocarbon pollution suffocates the trees causing death and fragmentation of the forest. In addition mangrove response to stress includes the following (adapted from [42]):

1. Tree mortality
2. Defoliation of canopy
3. Root mortality
4. Bark fissuring/epithelial scarring
5. Development of abnormal adventitious root pneumatophores
6. Leaf deformities and chlorosis
7. Propagule shrinking
8. Alterations in the numbers of lenticels
9. Reduction in tree snail and crab mortality
10. Changes in in-faunal density

Mangrove survives pollution by shutting down pollutants from being absorbed into the root. It also survives by concentrating pollutants in the leaves which are later expelled from the tree via defoliation.

In addition, to pollution, construction or industrial activities carried out by government and private agencies lead to increased deforestation. It causes difficulty in the restoration of the mangrove forests. However, to recover such areas those structures have to be removed by bulldozing the buildings, excavating the soil and replacing them with mangrove swamp soil. Mangrove propagules should then be transferred from the nursery to the restoration sites after two years. The removal of invasive *N. fruticans*, which thrives in disturbed environment, is also important because they are the second most significant threat to mangrove forest after hydrocarbon pollution [33]. The palms grow mainly in fresh water but have adapted to salt water conditions having lived several years in this environment, where they compete effectively with mangroves [41].

Types of oil spills	Land	Swamp	Offshore	Total
Minor spills (1–249)				
Number of spills	457	446	130	1, 033
Quantity of spills (barrels)	7, 565	14, 317	21, 297	43, 179
Medium oil spills (250–2499 barrels)				
Number of spills	596	91	31	712
Quantity of spills (barrels)	17, 203	33, 139	49, 359	99, 701
Major oil spills (over 2500 barrels)				
Number of spills	206	32	16	256
Quantity of spills (barrels)	76, 996	44, 775	1, 379, 2423	1, 921, 013

Source: [43].

Table 1.
Size of spills with respect to ecological zones in Nigeria 1976–1985.

2. Methodology

2.1 Sample collection

1. **Plant parts**: Mangrove *Rhizophotra* (branch, leave, root, seed and stem) and nypa palm (leave, root and seed) parts were retrieved from the forest at Eagle Island (4°43'N and 7 °58′E). These parts were put in polyethylene bags and sent to the laboratory. They were oven-dried at 70 °C for 48 hours and then ground into fine powder by a hand grinding machine. The powdered form of the leaves were bagged and labeled (**Figure 3**).

2. **Soil**: soil samples were collected randomly at ten points with a soil augur 5 cm below the soil surface from a polluted site at Okrika. Some samples of the collected soil were bagged and sent to the laboratory for physicochemical analysis. The soil is then put in 27 (9 plant parts × 3 replicates) seedling containers for the remediation experiment.

Physicochemical analysis of the soil and ground parts were analyzed for Cadmium (Cd), Iron (Fe), Lead (Pb), total hydrocarbon content (THC) and Zinc (Zn).

Remediation experiment: the ground plant parts are applied to the soil surface and monitored for six months with monthly soil samples sent to the lab for physicochemical analysis.

Figure 3.
Remediation experiment using ground parts of mangrove (Rhizophora spp.) and Nypa palm (N. fruticans).

3. Results

The result (**Table 2**) shows that there was no significant difference in heavy metal concentration in the soil samples treated with the ground plant parts ($P > 0.05$).

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Metal				Mangrove parts				Nypa palm parts	
	Control	**M.branch**	**M.leaf**	**M.root**	**M.seed**	**M.stem**	**P.leaf**	**P.root**	**P.seed**
Cd	0.36 ± 0.01	0.94 ± 0.01	0.04 ± 0.01	0.06 ± 0.01	0.001 ± 0.00	0.4 ± 0.01	0.2 ± 0.01	0.001 ± 0.00	0.001 ± 0.00
Fe	2562.2 ± 0.25	454.2 ± 1.29	419.4 ± 0.46	431.9 ± 0.18	453.2 ± 0.61	436.8 ± 0.48	434.1 ± 0.48	457.6 ± 0.59	421.1 ± 0.45
Pb	12.02 ± 0.24	0.002 ± 0.001	0.001 ± 0.00	0.001 ± 0.00	0.001 ± 0.00	0.002 ± 0.001	0.001 ± 0.00	0.001 ± 0.00	0.001 ± 0.00
THC	607.9 ± 0.6	218.2 ± 2.15	118.3 ± 0.4	6.3 ± 0.11	224.1 ± 0.25	1137.9 ± 0.6	67.8 ± 0.65	15.3 ± 0.35	91.2 ± 0.39
Zn	14.18 ± 0.4	6.79 ± 0.02	6.9 ± 0.22	3.5 ± 0.01	12.2 ± 0.51	6.9 ± 0.15	8.0 ± 0.06	11.8 ± 0.46	5.3 ± 0.01

Where M refers to mangrove and P refers to Nypa palm species.

Table 2.
Concentration of total hydrocarbon content (THC) and heavy metals in soil samples after treatment with ground mangrove and nypa palm parts.

4. Discussion

Heavy metal concentration in mangrove versus nypa palm parts in soil.

The result reveals that there was significant difference in the heavy metal concentration between mangrove and nypa palm parts ($P < 0.05$). Soils treated with ground *N. fruticans* parts have lower concentration of THC and heavy metals as compared to *Rhizophora* species parts. This result revealed that *N. fruiticans* parts remediated the soil better than the *Rhizophora* species parts. *N. fruiticans* parts can therefore be used as a biological remediating agent to clean crude oil contaminated soil. This will be an advantage and a reason for protecting the palms in the long run because they have been seen as having no usefulness in this region.

4.1 Post-remediation of mangrove forest

After the remediation of polluted mangrove forest soils intensive re-planting can be done to recover the devastated forest [44]. This can come through natural or artificial process depending on the nature of the terrain. If it is an area that has the natural setting for recruitment, this strategy can be used. The set up that facilitates natural recruitment are an enclosed coastal channel, connection to an active river with good tidal pressure (i.e. fluctuation of high and low tides) or hydrology, swampy soil that contains soil nutrients such as Nitrates and Iron, nearby parent plants that supplies viable seeds, high litter fall, and high microbial activities. If these conditions are not already set up it can be deliberately established to accelerate the natural process of seedling recruitment as long as it is close to a river. Natural remediation can be facilitated by practically changing coastal structures to create a barrier to trap mangrove seedlings once they are brought in by tidal current to enable the seeds to settle down and grow. An example is the research at Eagle Island, which facilitated mangrove seedling recruitment and growth. But for a non-coastal area such as upland mangroves that are far away from the river natural recruitment will not be possible except artificial recruitment is done where seedlings are grown in nursery and transplanted to the field to facilitate growth. However if the disturbance type was sand mining activity the remediation, recruitment and regeneration methods will vary as given below.

Restoration of Mangrove Forest For a sand dump the sand on the surface has to be scooped away and replaced with swamp soil collected from nearby mangrove forest. After piling the area with mangrove swamp, it should be left for some weeks to settle and consolidate. River connection should be established if it does not exist already so that tidal water will flow in and out to deposit seeds and seedlings from parent trees in the catchment area. In flow of estuarine water will also change the soil chemistry through increase in salinity level. In addition, seedlings can be brought in from the nursery to supplement the ones recruited naturally. Details of the different regeneration methods that can be adopted are given below.

4.2 Mangrove forest regeneration

Forest regeneration is a process by which forest is renewed, and mangrove forest can be regenerated in two ways: (1) Natural and (2) Artificial (**Figure 4**).

1. **Natural regeneration**: This occurs when seedlings of mangroves sprout naturally without human intervention. It involves the provision of suitable environment for the growth and development of volunteer tree species, which are growing in the area. Mangrove forests require suitable environmental condition for them to grow such as high temperature to enhance productivity, precipitation and saline water. Natural regeneration usually occur after

disturbance such as deforestation, dredging, urbanization, clearing of forest to create right of way (ROW) passage for oil and gas pipelines [45]. The success of natural regeneration in mangroves is dependent on some factors, which are:

1. Presence of sufficient numbers of parent trees that would supply enough seeds that would be carried by tides to the regeneration sites.

2. Connecting hydrology that would bring in the seeds

3. Presence of an enclosure containing wire gauze to filter debris, but allow water to flow. Similarly, litter materials in the enclosure trap seeds and prevent them from being flushed away into the open river by tidal currents.

4. The right soil type (swamp locally called "chikoko") and chemistry that would accelerate the growth of the seeds

5. Production of viable seeds by the parent plant that would germinate fast within short period of time.

6. Low population of fiddler crab (*Uca tangeri*) that feed on the seeds

7. Reduction in anthropogenic disturbances in mangrove wetland can lead to the proliferation of fiddler crabs. The action of *U. tangeri* consuming seeds do not entirely affect seed growth negatively, but also helps to redistribute and bury mangrove seeds around the forest, which causes zonation and rapid growth of seeds [46].

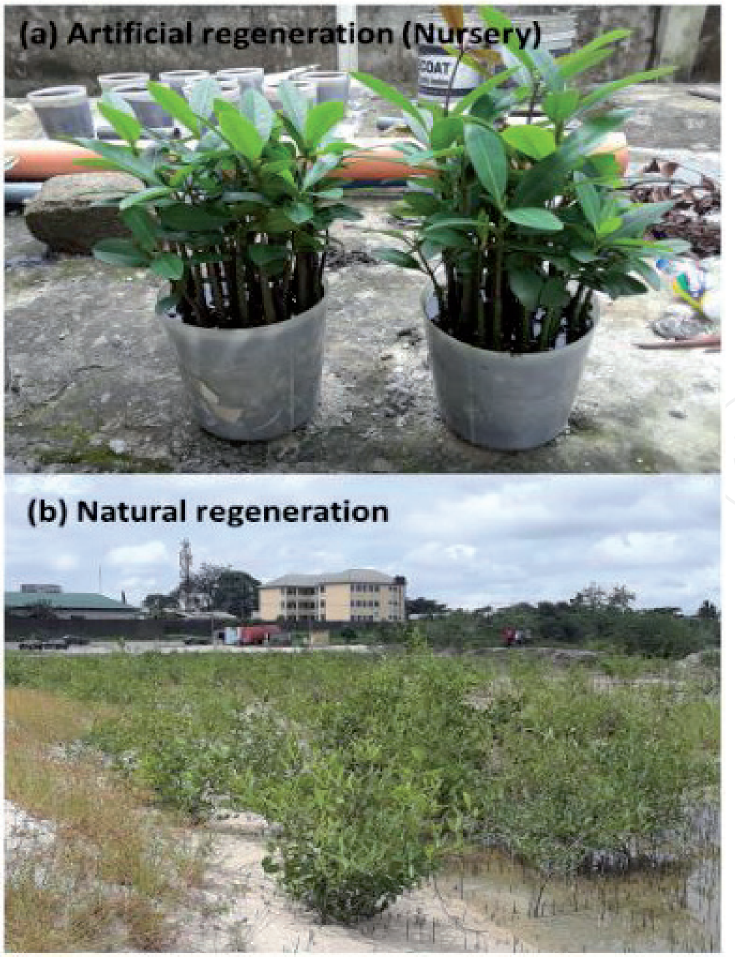

Figure 4.
The growth of mangrove seedling can occur through (a) artificial and (b) natural means of regeneration. The natural regeneration is occurring at Eagle Island, Niger Delta, Nigeria.

Advantages of natural regeneration: (i) The forest is established naturally and is not expensive when compared with artificial regeneration that involves finances; (ii) Natural regeneration of the forest do not require site recreation, a forest which naturally recreates will have much forest species; (iii) It brings about the establishment of natural ecosystem in an area of its choice. Natural regeneration does not permit the outbreak of pest and disease epidemic; (iv) It does not require management skill, it is rather based on experience. Mangrove forest restoration is mainly carried out using *Rhizophora* species (i.e. monospecific restoration). This is because of its ability to grow speedily in both nurseries and natural environment. However, in the natural environment many species (e.g. red, white and black mangroves and nypa palm) (See **Table 3**) are carried into restoration sites and grow at different pace depending on their ability to adapt to soil physico-chemical conditions, for instance natural mangrove recruitment site at Eagle Island, Niger Delta (**Figure 4**).

Disadvantage of natural regeneration: (i) It results in lack of uniformity of trees because there are differences in size classes; (ii) Lack of uniformity of stands, so that they cannot be used for suitable purpose such as logging that provides same size stems; (iii) It lacks uniform management e.g. rate of growth, and maturity of each tree is slow.

The development of forest via natural regeneration takes 10 to 20 years to grow to maturity and start fruiting. For the forest to develop quickly there need to be salt water that will facilitate growth, since most mangrove species are halophilic. Furthermore, there need to be adequate soil nutrients such as nitrate, phosphorus, calcium and zinc to aid growth. Mangrove forest is also facilitated by litter decomposition through microbial action that converts organic materials (leaves, seeds, and branches) to soil nutrients.

Artificial regeneration: This is the total replacement of old stand that has been cut down or affected by any form of disturbance with new seedlings, which are deliberately planted in nurseries and later transferred to the field. It involves deliberate establishment of forest trees in remediated polluted site. Direct planting of seedlings on the remediated site can also be done, especially if there is barrier created by swamp embankments to slow down tidal pressure to prevent erosion from carrying away the seeds. Artificial regeneration is used because there is adequate nurturing of seeds for 1 to 2 years to enable them to develop root system so that when planted in the field they will start to grow immediately to withstand environmental changes such as erosion, climate change and pollution. Similarly, during growth in nursery pest can easily be controlled and diseases prevented through the administration of chemicals to mitigate against future attack by

Species	Common name	Abundance	Proportion (p_i)	Ln (p_i)	P_i*Ln (p_i)	H	Rank
R. racemosa	Red mangrove	63	0.0334	−3.399	−0.114	−0.114	3rd
L. racemosa	Black mangrove	1079	0.5721	−0.558	−0.319	−0.319	2nd
A. germinans	White mangrove	709	0.3759	−0.978	−0.368	−0.368	1st
N. fruticans	Nypa palm	35	0.0186	−3.985	−0.074	−0.074	4th
Total		1886					

Table 3.
Abundance and diversity of different species of mangroves and nypa palms in a natural regeneration site at Eagle Island, Niger Delta.

disease-causing insects. Operations of artificial regeneration involve the following: (a) Site preparation such as clearing and removing of thorns, tree stems and other dirt (b) Seedling collection, which is very important in the establishment of a forest (c) nursery practice, i.e. raising the seeds in the nursery or seeds pots or bags. Nurseries are places where seedlings are raised before they are taken to the planting site. Its success lies in the production of adequate number of seedlings of the right quality and fast growing ability.

Two types of nurseries are permanent and temporary nurseries, permanent nursery is meant for large scale, continuous and sustained production of seedlings while temporary nursery is for a short term period of seedling growth.

Advantage of artificial regeneration: (i) There is a high rate of uniformity of the growth of the trees; (ii) Uniformity results in the production of trees very suitable for specific purposes e.g. red mangroves (*Rhizophora* spp) for firewood; (iii) The trees grow and mature faster than in natural regeneration.

Disadvantage of artificial regeneration: (i) It is very expensive and requires a lot of skills; (ii) Environmentally, it brings about change in existing ecosystem particularly in the area of its establishment; (iii) It may result into an outbreak of pest and diseases.

4.3 Species diversity

Species diversity describes the diversity of important ecological entities that span multiple spatial scales from genes to communities. This has to do with species richness and evenness in a specific area. In a second study of species abundance and diversity done at Eagle Island, which measures about 3900 m^2, it was found that black mangroves (*Laguncularia racemosa*) were the most abundant species (n = 1079) followed by white mangroves (*Avicennia germinans*) (n = 709), red mangroves (*Rhizophora racemosa*) (63) and nypa palm (*Nypa fruticans*) (35) (**Table 3**). *A. germinans* had the highest species diversity while *N. fruticans* had the least species diversity.

4.4 Mangrove reserve management

There are three aspects of mangrove management, the ecological, human and the ecosystem.

1. **Ecological management**: This occurs when there is a disturbance like hydrocarbon pollution, deforestation to establish urban areas and sand mining and shortly after these events take their courses through ecological succession. It involves a progressive change of plant growth through the replacement of destroyed mangrove with new mangrove community. An example is successional process of different species of mangrove seedlings including nypa palm colonization of an abandoned sand mining site at Eagle Island, Niger Delta (**Figure 5**).

The four stages of succession to be encountered in the above kind of environment include:

1. Pioneer species (P): This is the first species after a disturbance. It is common 1—5 years after a major disturbance had occurred such as earth quake, flood or volcano. An example of this species is annual plant such as weeds and grasses. Everything is killed leaving behind bare soil, but after a period of time there is a dramatic increase in weed,

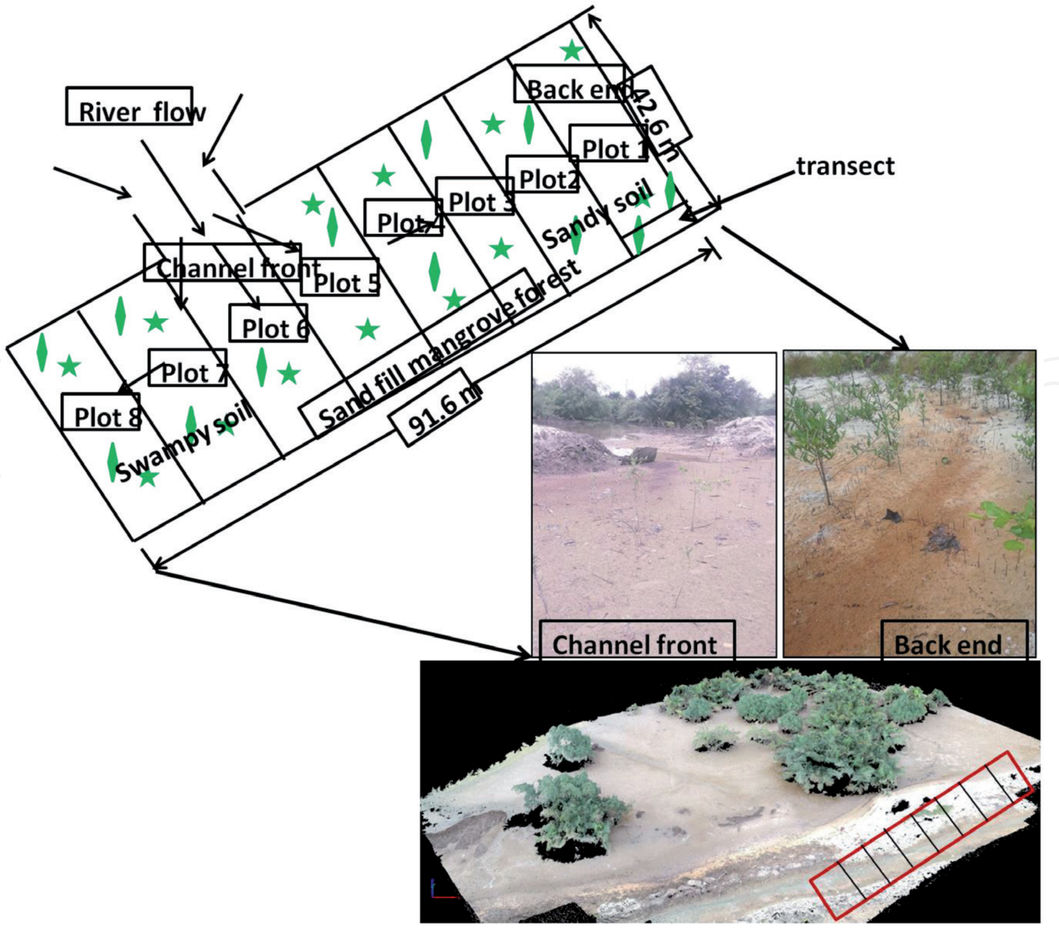

Figure 5.
Plant succession in deforested mangrove forest at Eagle Island, Niger Delta, Nigeria.

2. Early successional species (E): They are a group of species that replace pioneer species. They are dominant for 5–10 years e.g. woody shrub

3. Mid successional species (M): They are large shrubs or small trees that are dominant for 10–30 years. They basically replace their early successional species.

4. Late successional species (L): They are also called climax community. They are tall tree communities that exist in the absence of disturbance.

The cause of the regular progression of change in the mangrove community is seed dispersal, which is facilitated by water. Mangrove takes a long time to mature between i.e. 10–20 years. But the annuals like grasses grow faster and colonize the disturbed site few weeks after disturbance. The mangroves are the top species in the intertidal marine environment because of their ability to withstand the tough environmental conditions created by nature and humans.

4.5 Theoretical basis of succession as a means of restoration of mangrove forests

There is evidence to support the above successional pattern in marine intertidal system where progressive change in disturbed area lead to increase in diversity. One of such hypothesis is the intermediate disturbance hypothesis (IDH). It is an empirical relationship between the time a disturbance occurs and the time species diversity increases in a given location. This is because the climax no longer has the highest diversity. It explains why in some areas we have high diversity while in others we have low diversity. The cause of decline in diversity is competition. Low diversity is also caused by the suppression of early species. The implication for mangrove management is that classical pattern minimizes disturbance to maximize diversity whereas IDH pattern manages disturbance at an intermediate level. Therefore, to identify an IDH system the following should be noted: (a) there will be complete replacement during succession; (b) climax species need to competitively suppress all other successional species, (c) The climax species does not create a new species.

4.6 Regional versus local forest management

In mangrove forest restoration, regional management is better than local site management. This is because disturbance is managed to maximize diversity but make sure all successional stages exist within the management area. Secondly, at the regional level everything is reproducing. Moreover, disturbance does occur at different time and at different places so each one of four successional processes are often dominant. This is done by introducing disturbance in the system in other to maximize diversity. For example, after the Ozark forest is burnt down different species begin to sprout rapidly that were not originally present. This means humans can play a role in natural disturbance to maximize natural biodiversity. In the Niger Delta low level of hydrocarbon pollution i.e. minor crude oil spill (See **Table 1**) does not impact mangrove growth and development, even when deliberately added it will have little or no effect on plant growth. However, in major oil spill it may be harmful to growth by deforming the seedlings or killing them outright. Years of study mangrove forest in Niger Delta has shown that low level introduction of crude oil in mangrove forest could help facilitate the growth of seedling that has resilient qualities, and the elimination of weak species. However, further studies are needed to validate this field observation. This will ensure a long term positive feedback of rejuvenated growth, as recorded in previous findings, where it was discovered that highly polluted sites had higher productivity, species diversity and mangrove tree structure than less polluted site [29]. Although, this revelation has not been thoroughly studies to make a conclusive statement, there are some observations that point to the fact that crude oil pollution in low amount can facilitate mangrove growth in some areas in the Niger Delta. However, the implication is that there might be bioaccumulation of pollutant up the food chain. This suggestion is made because the mangroves of the Niger Delta had been growing in polluted environment for over fifty years without dying. Rather the major killer of mangroves is deforestation through urbanization and fire wood production. It is suspected but not proven that the DNA of this set of mangroves might have been imprinted with "pollution resisting genes" that has made them less vulnerable in the face of high pollution. The complete removal of a disturbance regime is a form of disturbance in itself because we are basically altering the order [47].

Human management: Humans are the ultimate problem of biodiversity especially the mangroves. This is because of their affinity for the mangroves due to the ecosystem services they render. All aspects of the mangroves are useful to humans such as the leaves, stem, root, leaves and seeds, which are used for producing medicinal herbs, fire wood, food etc. Hazardous climatic effect such as earthquake, tsunami, hurricane, cyclone and flood do not affect the mangroves of the Niger Delta rather humans are the greatest threat to the mangroves in this region. The aim of human management is to prevent negative anthropogenic effect on the mangroves by keeping people away from the forest. This is because human activities such as deforestation, logging, and oil and gas exploration are the major threats of mangroves. Since people cause problems for mangroves it is necessary to create zones of use, buffer and transition zones to protect forest resources. The purpose of this method is to allow plants and animals to be protected [32].

Ecosystem management: It is a new way of managing reserve to benefit biodiversity and people. It is a strategy for protecting or restoring the function, structure and species composition of an ecosystem while providing for its sustainable socio-economic use. The tenets of ecosystem management of mangrove forest are as follows:

1. Ecosystems are dynamic- This means they change during succession because they are not static.

2. Ecosystems are subject to unpredictable events or disturbances such as fire, pest and insect attack, crab and animal herbivory, hydrocarbon pollution, earthquake and cyclone, so management need to be flexible in a process called adaptive management.

3. Humans are integral part of the ecosystem

4. Ecosystem requires constant monitoring of populations.

4.7 Sustainable management of mangrove forest

Sustainability means the ability to preserve an environmental resource to last for future generations. Therefore, sustainable management of mangrove forest is the process whereby mangrove forest is managed to last long for the benefit of incoming future generations. Studies have already shown that 5% of mangrove forest has already been lost in the Niger Delta due to oil and gas exploration, urbanization and invasive nypa palm species [48]. To manage mangrove sustainably, those aforementioned key factors that lead to their decimation need to be eliminated. Both onshore and offshore oil and gas exploration results to many cases of oil spillages recorded in the Niger Delta which has devastated large amount of mangrove forest for a period of over a sixty years (1956 to 2020). The rate of oil spillage has to be reduced drastically by the oil companies through the constant maintenance of old pipelines. In the same vein, sabotage of pipelines by local vandals has to be checked to prevent incessant oil spillages. Urbanization is a necessity to modernize the city, but the mangroves areas can be avoided or put into the city plan through urban ecology, where city and forest would exist side-by-side with each other, this will guarantee the survival of the forest. As for the *N. fruticans* they can be removed within the mangrove forest through the use of bulldozers so as to provide breathing space for the mangroves. When all these suggested changes are executed mangrove forest can last for centuries and become beneficial to future generations.

4.8 Mangrove restoration ecology

It is a process of intentionally altering a site to establish a given indigenous historic ecosystem. In this method we try to bring degraded location to what it was originally. There are four ways of accomplishing restoration; three are active method while one is passive method.

1. **Passive method**; It involves the stopping of degradation and allowing succession to occur. This method is good because it is predictable and attains climax. It involves natural succession. Here degraded land can be sealed off

and allowed to recuperate through natural seedling recruitment and regeneration. A classical example of this method is the natural mangrove seedling recruitment at an abandoned sand fill site at Eagle Island (**Figure 4**). Three year (2016—2019) monitoring of this area shows that seedlings that were carried into the site by tidal water had been growing naturally for the past 3 years without human intervention. This method holds great potentials in re-populating many polluted and destroyed sites in the Niger Delta. To achieve this method we need to create the right environmental condition such as establishing water channels, creating an enclosure to trap the seeds from escaping, improving soil chemistry and increasing microbial population of the soil. An example is the natural regeneration of mangroves at Sungei Api-Api, a man-made estuarine channel in Singapore [49]. Factors considered in this study include: the establishment of mangroves include: slope gradients, salinity and tidal inundation levels substrate type, tidal currents and propagule establishment.

2. **Active method**: This is required for areas that have been severely degraded. There are 3 active methods, and these include:

    a. **Replacement** – instead of going back to the original forest, which is impossible a new set of forest or plant community is established as a replacement. For instance, changing mangrove forest to another type of tropical forest (i.e. inter-species replacement) will not be the best option, this is because mangroves are habitat-specific and can only occupy swampy areas. Therefore to restore mangroves, the right soil condition need to be established. This method will work if nypa palm forest is replaced with mangrove forest and soil conditioning carried out. Why it would work out is because both species occupy nearly similar environment. Another kind of replacement that can be done is intra-species replacement where red mangroves (*Rhizophora* spp) are replaced by white (*Avicennia germinans*) or black mangroves (*Laguncularia racemosa*). This one is better than bringing in a completely different species. Mangrove fern (*Acrostichum aureum*) is a species that can grow in disturbed area. It can be planted as a pioneer species in remediated site.

    b. Rehabilitation- In this method an attempt is made to restore the original ecosystem, but it cannot be fully restored because most of the species had gone extinct. Mangrove forest can be rehabilitated after damage by carrying out artificial seedling regeneration or direct planting.

    c. Restoration- It is the attempt to fully restore the original ecosystem. Here the degraded mangrove forest can be restored through the provision of more species to enhance ecosystem structure and function. For instance, mangrove forest in Armacao dos Buzios Brazil was managed by establishing environmental protection unit, education and enlightenment campaigns to support active regeneration [50].

5. Conclusion and recommendation

Mangroves are unique species of plants that are useful to the environment therefore, their protection is important to prevent their extinction as a result of harmful practices such as sand mining, oiling activities, dredging, urbanization etc.

The resilience of mangroves in the face of pollution should not be overestimated because just like other species they have a threshold of resistance against environmental perturbation. And once this limit is surpassed they will become vulnerable to the slightest environmental change. There is therefore a need for repopulating lost mangroves to recover lost stands. Increase in population through natural and artificial means will ensure that mangroves become dominant again in their coastal habitat so as to withstand invasion by foreign species such as *N. fruticans*, which are the most dominant invasive species wreaking havoc to the mangroves. It is recommended that more emphasis should be placed on natural recovery of mangrove forest by deliberately facilitating this process. This can be achieved by the removal of foreign species, the establishment of connecting water channels, soil conditioning and seed transportation to sites of restoration. Finally to accelerate recovery process there can be a combination of natural and artificial seedling recruitment and regeneration methods.

Definition of terms

Replacement: This is to process of bringing in a new set of species in place of a destroyed system.

Rehabilitation: This is the process of fixing the damage caused by disturbance in other to take the system to look like the former system.

Restoration: This is to bring back a disturbed area to almost 100% similar to the previous system.

Author details

Aroloye O. Numbere
Department of Animal and Environmental Biology, University of Port Harcourt, Nigeria

*Address all correspondence to: aroloyene@yahoo.com

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