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Geospatial Variability and Ecological Amplitudes of Plants along Nutrient Gradients in Imo River Wetland

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Authors' contributions

This work was carried out in collaboration with all the authors. Author FOO designed the study, supported for the equipment, coordinated the whole work and participated in the correction of the manuscript. Author REI performed the statistical analysis, wrote the protocol, developed the experimental study and wrote the manuscript. Author TEP supported for the equipment and paid for the analysis of the samples. All the authors read and approved the final manuscript.

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ABSTRACT

This study assessed the geospatial variability and ecological amplitudes of plants along nutrient gradients in Imo River Wetland. Systematic sampling was employed for the vegetation and soil using ten 10 m x 10 m quadrat spaced at 20 m interval along established belt transects. Soil samples were obtained using a soil auger at two rooting depths (0 – 15 cm and 15 – 30 cm) and were analyzed using standardized methods. Eight (8) species belonging to six (6) families were found. *Nypa fruticans* was the most dominant (541.78±155.90 st/ha) and frequent (75%) species while *Phoenix reclinata*, *Rhizophora mangle*, *Laguncularia racemosa* and *Pandanus candelabrum* were the species with the least frequency of 25%, respectively. *Laguncularia racemosa* also had the least density value of 25.00±0.00 st/ha. The ecological amplitudes showed that species responded differently to nutrients and environmental gradients. *Nypa fruticans* showed peak density values at

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pH and available phosphorus values of log 1.64 and log 0.77 mg/kg respectively. *Phoenix reclinata* and *Rhizophora mangle* showed a strong affinity for organic carbon and total nitrogen reaching peak density values at log 2.69% and log – 0.99%, respectively. *Nypa fruticans* recorded wide adaptability with increasing Ca concentration reaching a peak density value at log 2.44 cmol/kg. Generally, *Nypa fruticans* was the most successful of all species having recorded the highest density values at different nutrient gradients. By and large, this study showed overlapping occurrences of species in response to varying levels of nutrients across the plots and lends credence to wetland conservation and appropriate environmental monitoring against invasive species.

Keywords: Geospatial variability; ecological amplitudes; nutrient gradients; Imo River Wetland; mangrove vegetation; soil.

1. INTRODUCTION

Wetlands according to [1] are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salty including areas of marine water, the depth of which at low tide does not exceed 6 meters. This definition incorporates an extensive range of landscapes such as lakes, rivers, swamps, marshes, wet grasslands, estuaries, deltas and peatland, where three integral components are accentuated. These include hydrology (water), pedology (soil) and vegetation (plants). Aquatic plants also referred to as hydrophytes occupying a different ecological niche in wetlands. The distributional patterns of these flora are not only a function of anthropogenic upheavals, but also a reflection of their responses to varying environmental gradients. These environmental gradients are measures of the physical environment that explain the distribution of species in terms of tolerances. The tolerances of species to ecological factors may vary among species depending on if the species is growing in a monoculture or a mixture with other species [2 - 6]. Commonly used ecological gradients include pH, salinity, temperature, precipitation, nutrients, moisture regime and frequency of natural disturbances (fire, wind, or infestations). For this study, emphasis will be laid on the nutrient gradient.

Nutrient availability is an important abiotic factor which plant species depend on for their growth and massive proliferation in various ecosystem. Nutrients are distributed in varying quantities in diverse landscapes and as a result, spatial heterogeneity abounds when the quantity of nutrients that is measured at different locations within a particular ecosystem exhibit values that differ across the ecosystem [7]. Due to this variation, species within that ecosystem will react differently to the environmental factors present. This phenomenon referred to as ecological amplitude shows the various limits of environmental conditions within which an organism can live and function. No matter how rich an ecosystem may be, the species within that habitat have differential responses and adaptations to prevailing ecological factors creating a close association between spatial variability in environmental variables and ecological amplitudes of plant.

However, the ecological amplitudes of species vary and are dependent on certain traits which may be advantageous and disadvantageous in certain environments [8]. Some species possess traits that expedite rapid growth proliferation under conditions of ample light, moisture, and nutrients, allowing successful competition against other plants [8]. Others, with different traits, are able to grow and reproduce under environmentally stressful circumstances, such as low moisture or poor nutrient conditions, dense shade, or high salinity. Some species have wide ecological amplitudes while others are restricted to narrow ecological amplitudes [8]. However, there are no species that can adapt and thrive under all conditions [8]. Thus, both within and among plant communities, one finds a variety of traits, resulting in a range of possible responses to environmental changes, both along environmental gradients and over time. Understanding plant segregation along soil environmental gradients is not simply a major gap in our knowledge of tidal wetlands; it is also crucial for both the conservation and restoration of wetland ecosystems.

The population of human beings has increased unprecedentedly and so has human activities. Industrial revolution, particularly in this epoch, has given rise to the deterioration of the environment and depletion of the available plant resources leading to flora extinctions. Also, over exploitation, habitat disturbance and destruction, pollution increase and the introduction of the exotic species have accelerated the loss of species and have altered the floristic patterns of indigenous wetland ecosystems. This problem is aggravated by the dearth in available information on the flora of indigenous wetlands of Akwa Ibom State, and in order to bridge this gap, this study aims at documenting the flora diversity and ecological responses of different plant resources found in these wetlands.

2. MATERIALS AND METHODS

2.1 Study Area

This study was carried out in a mangrove swamp forest of Utaewa Village in Ikot Abasi L.G.A of Akwa Ibom State, Nigeria. The swamp serves as an intertidal zone separating the riparian communities with the Sea. The surrounding vegetation is typically a mangrove with huge evidences of *Nypa* incursions. The coordinates of the sampled stations are shown in Table 1

Table 1. Specific co-ordinates of the sampled stations

Stations	Longitude	Latitude
Station 1	7° 31' 39.85" E	4° 35' 52.47"
Station 2	7° 31' 39.24" E	4° 35' 54.07"
Station 3	7° 31' 29.97" E	4° 35' 54.17"
Station 4	7° 31' 31.18" E	4° 35' 54.08"

2.2 Vegetation and Soil Sampling

The systematic sampling method was used in sampling the soil and vegetation using a ten 10 m x 10 m quadrat spaced at 20 m intervals along established belt transects [9]. In each quadrat, vegetation components (plants) were identified to species level and their frequency and density were obtained by enumeration. Unknown plant species specimens were collected for identification and confirmation from voucher specimens in Botany and Ecological Studies Departmental Herbarium. The parameters of the vegetation measured were the frequency of plant species, height, density, basal area, and crown cover. Using a soil auger in each of the quadrats, soil samples were obtained at two depths; 0-15cm and 15-30cm. Two soil samples were collected at opposite ends of each quadrat, stored in labeled Ziploc bags and taken to the laboratory for physicochemical analyses.

2.2.1 Determination of vegetation parameters

2.2.1.1 Density

This was determined using the method of [10]

2.2.1.2 Frequency

The frequency of each species occurrence was calculated thus:

$$\text{Frequency} = \frac{\text{Number of occupied quadrat for a species}}{\text{total number of quadrats thrown}} \times 100$$

2.3 Physicochemical Analysis of Soil Samples

Standard methods were used in analyzing soil samples. Soil pH, electrical conductivity and exchangeable acidity were determined using Beckman's glass electrode pH meter [11], a conductivity meter (Jenway Pcm 128723 model) and titration with 1N KCL [12]. Organic carbon, total nitrogen and available phosphorus were determined using Walkey Black wet oxidation method, Micro-Kjeldahl method and Bray No 1 method [13]. Total Exchangeable Bases were determined by EDTA titration method while sodium and potassium were determined by photometry method. The Effective Cation Exchange Capacity (ECEC) was calculated by the summation method (that is summing up of the Exchangeable Bases and Exchange Acidity (EA). Base Saturation was calculated by dividing total Exchangeable Bases by ECEC multiplied by 100. Soil particle sizes were determined using the hydrometer method.

2.4 Statistical Data Analysis

Statistical Package for Social Sciences (SPSS, Version 18.0) was employed for computation of descriptive statistics and graphical illustrations of the species responses to nutrient gradients.

3. RESULTS

3.1 Floristic Inventory

The floristic inventory of Imo River wetland is presented in Table 2. Eight (8) species belonging to six (6) families were found. They include: *Avicennia africana*, *Rhizophora mangle*, *Nypa fruticans*, *Phoenix reclinata*, *Terminalia superba*, *Laguncularia racemosa*, *Acrostichum aureum* and *Pandanus candelabrum*. *Nypa fruticans* and

Acrostichum aureum recorded a higher frequency of 75%, respectively while species such as *Rhizophora mangle, Laguncularia racemosa, Phoenix reclinata* and *Pandanus candelabrum* had the least frequency of occurrence of 25%, each. *Nypa fruticans* was the most abundant species with a density of 541.78±155.90 st/ha while *Laguncularia racemosa* had the least density value of 25.00±0.00 st/ha.

3.2 Physical and Chemical Characteristics of Soil

Table 3 shows the physical and chemical characteristics of soil recorded in study stations within Imo River wetland. The result showed that pH concentration was highest in station 4 (5.50±0.40) and least in station 3 (3.90±0.60). Electrical conductivity ranged between 2.43 ds/m (station 3) and 3.34 ds/m (station 1). The organic carbon recorded the highest value of 14.80±2.01% in station 3 and the least value of 9.77±1.52% at station 4. Total nitrogen had the highest mean concentration of 0.37±0.07% in station 3 and the least value of 0.24±0.00 in station 4%. Station 2 had the highest value for available phosphorus (2.17±0.61 mg/kg) and Ca (11.49±2.41 cmol/kg) while station 3 had the least values for available phosphorus (1.66±0.40 mg/kg) and Ca (7.60±0.61 cmol/kg). Station 1 had the highest values for magnesium (3.62±1.14 cmol/kg) and Na (0.49±0.01 cmol/kg) while stations 4 and 3 recorded the least values for magnesium (2.11±0.01 cmol/kg) and Na (0.27±0.00 cmol/kg). For K, its highest and least mean values were recorded in stations 2 (0.46±0.01 cmol/kg) and 4 (0.26±0.00 cmol/kg). Exchangeable acidity had its highest value in station 1 (3.10±0.41 cmol/kg) and least value of 2.40±0.40 cmol/kg in station 4. Station 2 had the highest values for ECEC (19.13±3.4 cmol/kg) and base saturation (84.49±5.10%) while the least values for ECEC (13.47±1.23 cmol/kg) and base saturation (81.45±5.21%) were recorded in station 3. For the particle size classes, sand was highest in station 3 (79.20±2.21%) and least in station 4 (45.20±2.00%), silt and clay contents were highest in station 4 (22.820±0.60% and 31.98±10.98%) and least in station 3 (8.820±1.61% and 11.820±1.32%).

3.3 Ecological Amplitudes of Species to Environmental Gradients

The ecological amplitudes of four dominant species (*Avicennia africana, Rhizophora mangle, Phoenix reclinata and Nypa fruticans)* in four stations of Imo River wetland to environmental gradient (pH, total nitrogen, available phosphorus, organic carbon and calcium) are presented in Figs. 1 – 5. General density scores of species are 0 – 30 in *Nypa fruticans*, 0 – 10 in *Phoenix reclinata,* 0 – 6 in *Avicennia africana* and 0 – 5 in *Rhizophora mangle*.

Table 3. Physical and chemical characteristics of Soil in Imo River Wetland

Parameters	Station 1	Station 2	Station 3	Station 4
pH	4.65±0.02	5.20±1.07	3.90±0.60	5.50±0.40
Electrical Conductivity (ds/m)	3.34±0.62	2.82±0.45	2.43±0.12	3.31±0.13
Organic carbon (%)	12.83±2.31	12.43±1.71	14.80±2.01	9.77±1.52
Total Nitrogen (%)	0.33±0.001	0.29±0.13	0.37±0.07	0.24±0.00
Available Phosphorus (mg/kg)	1.99±0.01	2.17±0.61	1.66±0.40	1.67±0.21
Ca (cmol/kg)	11.00±2.0	11.49±2.41	7.60±0.61	8.88±0.62
Mg (cmol/kg)	3.62±1.14	3.38±1.02	2.80±0.02	2.11±0.01
Na (cmol/kg)	0.49±0.01	0.35±0.08	0.27±0.00	0.42±0.21
K (cmol/kg)	0.33±0.02	0.46±0.01	0.30±0.01	0.26±0.00
Exchangeable Acidity (cmol/kg)	3.10±0.41	2.90±0.0	2.50±0.30	2.40±0.40
ECEC (cmol/kg)	17.99±3.6	19.13±3.4	13.47±1.23	14.07±3.02
Base Saturation (%)	82.73±10.4	84.49±5.1	81.45±5.21	82.94±1.86
Sand (%)	56.20±2.3	58.20±2.1	79.20±2.21	45.20±2.00
Silt (%)	11.82±1.40	13.82±0.61	8.82±1.61	22.82±0.60
Clay (%)	31.89±5.81	27.78±3.41	11.82±1.32	31.98±10.98

± = Standard error

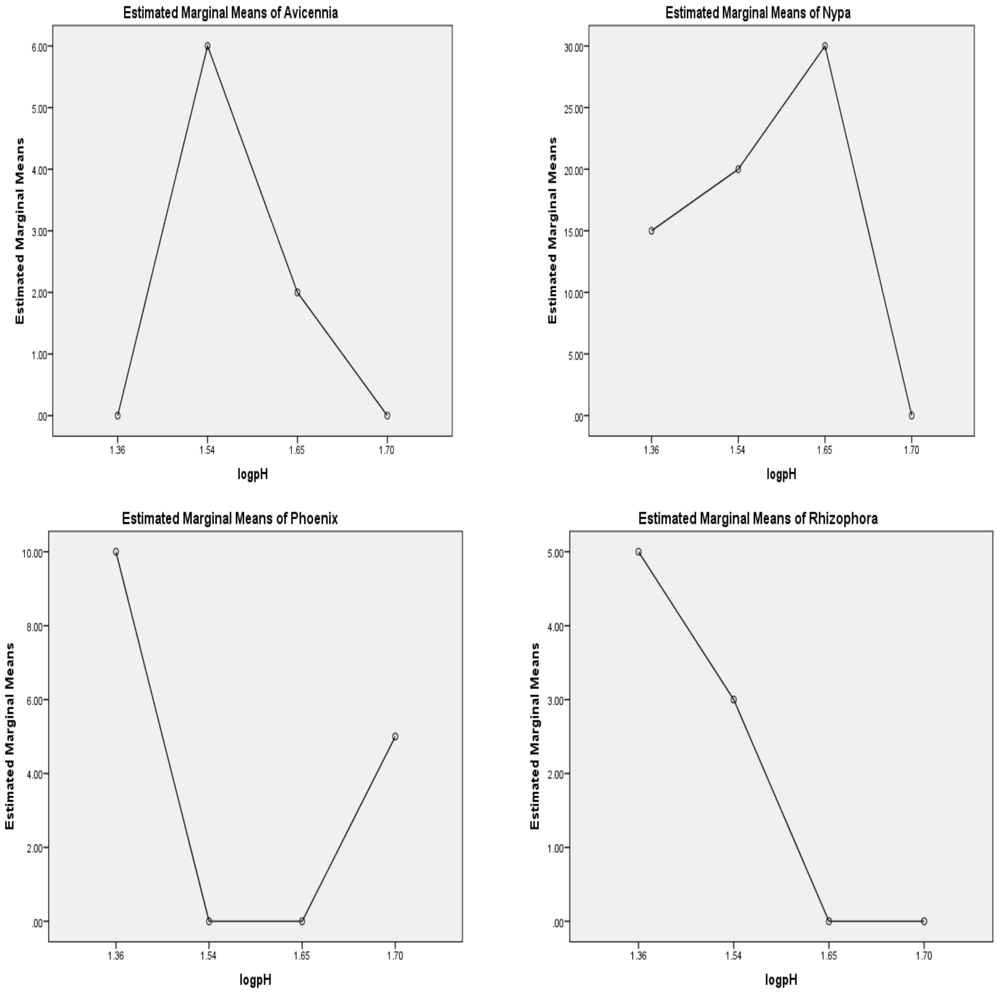
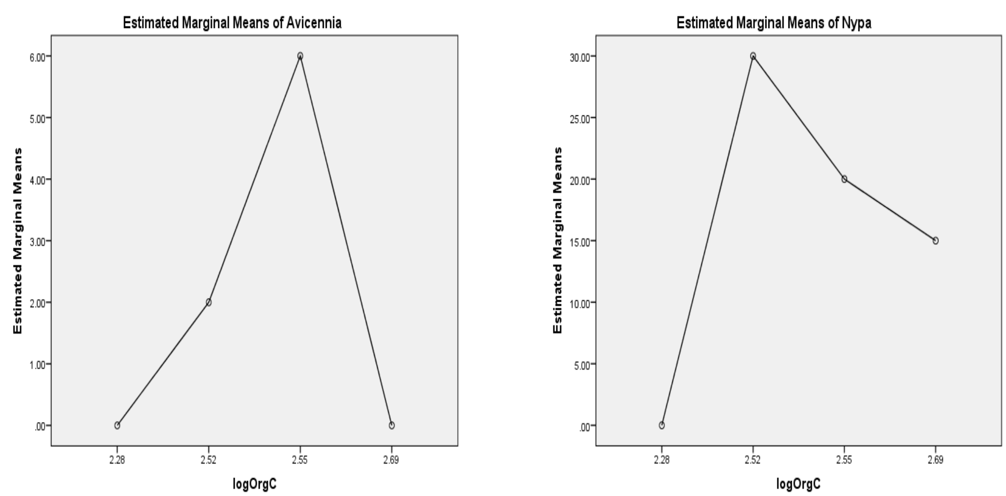


Fig. 1. Ecological amplitudes of species along pH gradient



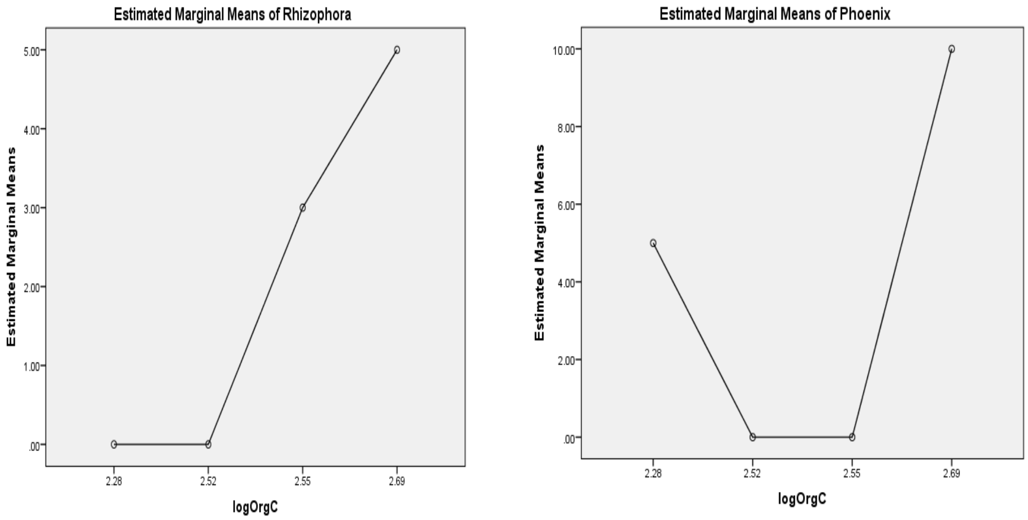


Fig. 2. Ecological amplitudes of species along organic carbon gradient

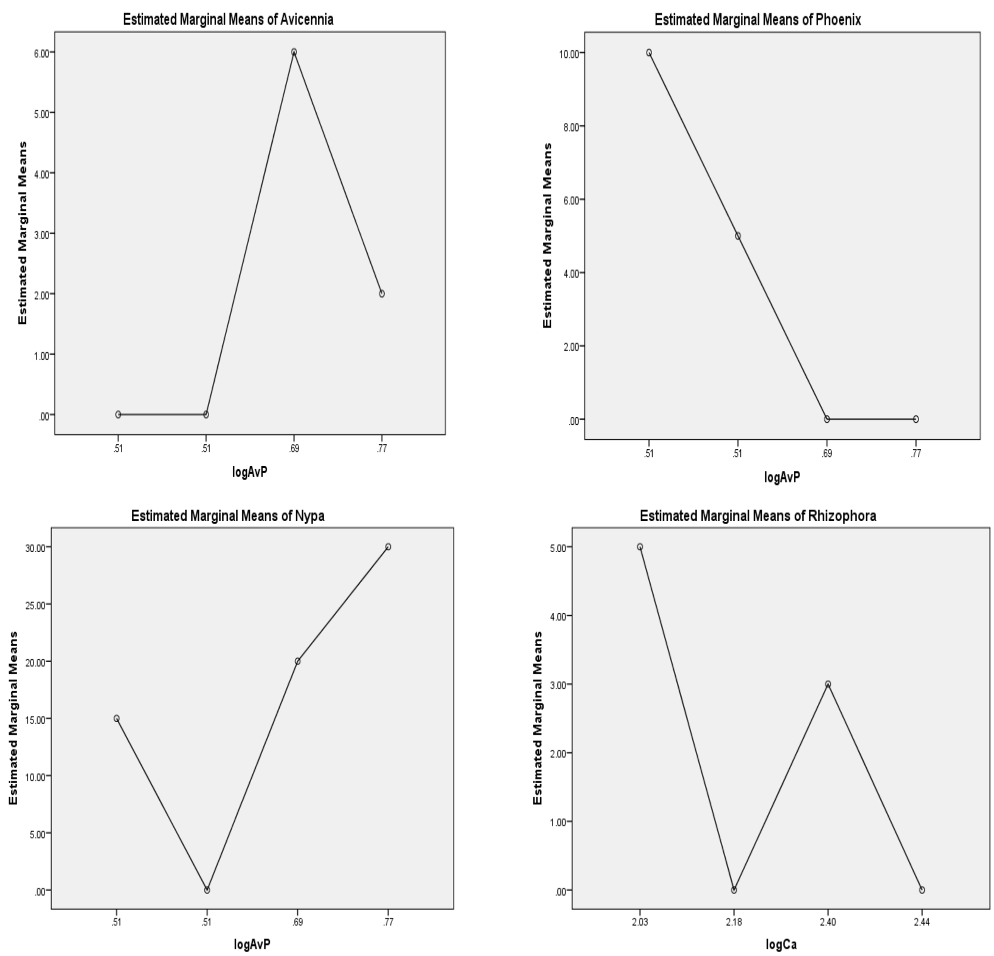


Fig 3. Ecological amplitudes of species along the available phosphorus gradient

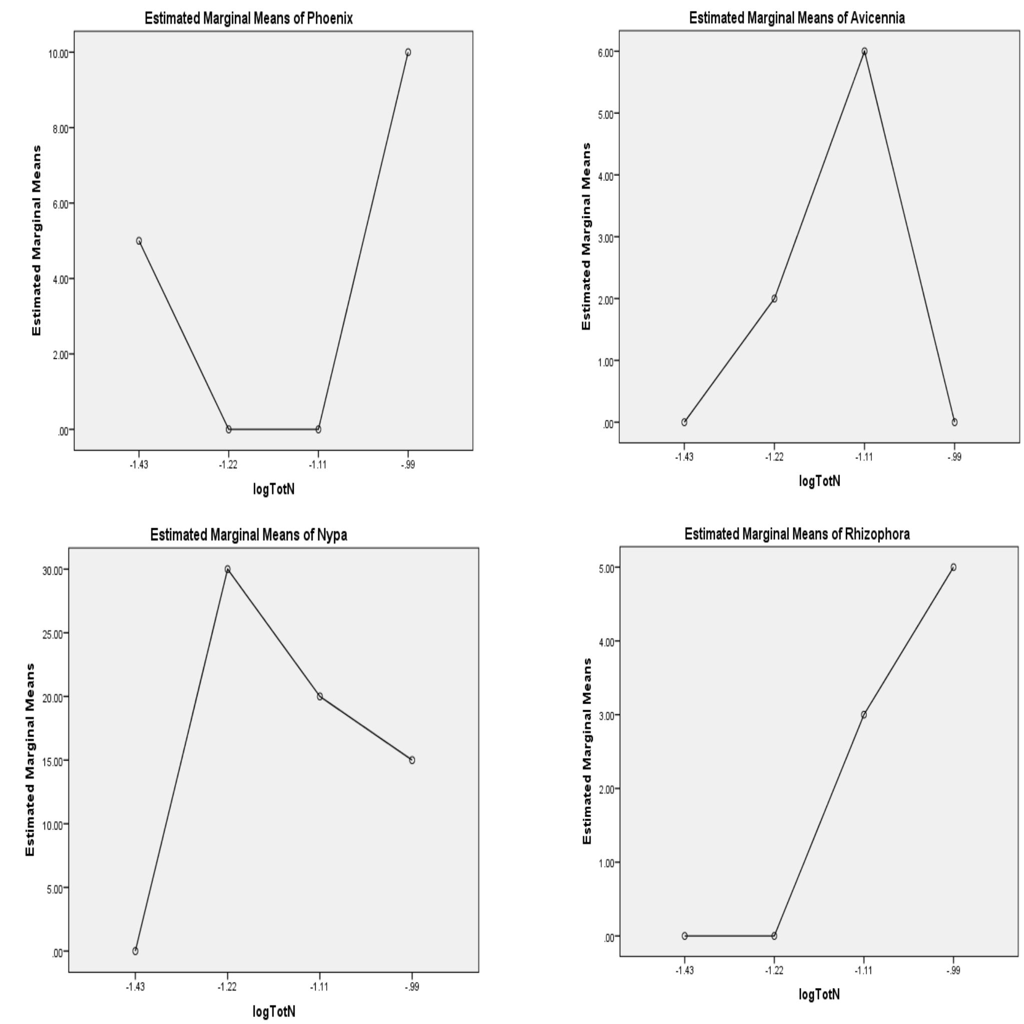
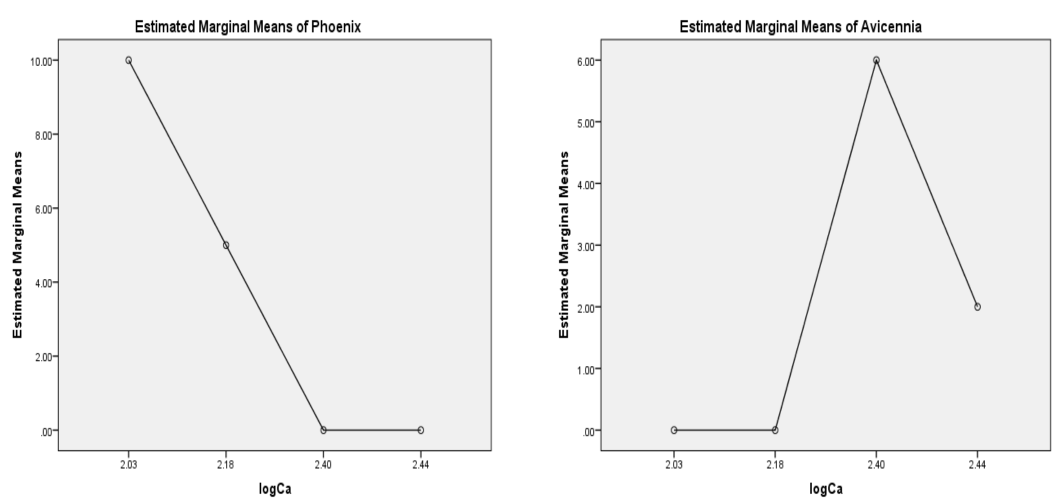
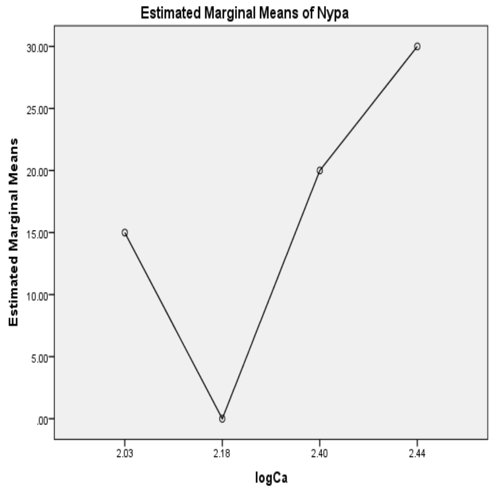


Fig. 4. Ecological amplitudes of species along total nitrogen gradient





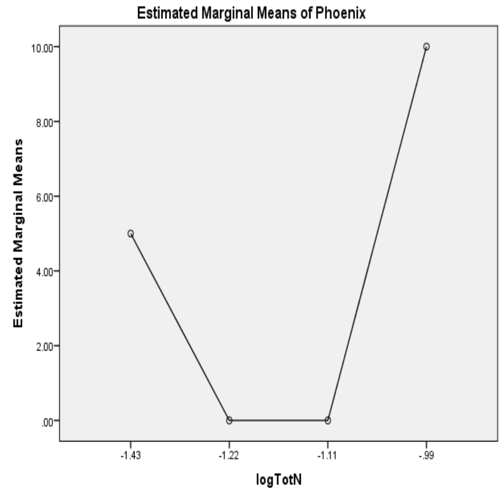


Fig. 5. Ecological amplitudes of species along Ca gradient

4. DISCUSSION

The vegetation attributes of Imo River wetland is well represented in this study. Marked variations in numerical abundance and distribution of species were observed. The river basin is rich in indigenous mangrove species. Noticeable variations in the frequency of occurrence and density of species were observed. This confirms that different species growing under similar environmental conditions respond and adapt differently to prevailing environmental (soil) factors. As such, species such as *Nypa fruticans* and *Phoenix reclinata* which recorded high density values may have possessed inherent abilities to adapt to prevailing pedological and hydrological conditions such as salinity, tidal flushing from the ocean and hypoxic and anoxic conditions. On the other hand, the low frequency of occurrence and density values associated with species such as *Rhizophora mangle, Laguncularia racemosa, Phoenix reclinata* and *Pandanus candelabrum* may depict their narrow ecological amplitudes in the wetland.

The low densities of quite a number of economically valuable tree species (*Avicennia africana, Rhizophora mangle*) could have been due to the selective exploitation of these species by humans for timber, firewood and boat construction which is prevalent in the area. Moreover, the death of viable seeds and poor nutrient status of microsites may have a contribution to low species density. The abundance or rarity of a timber species of high economic value in this area provides information on their intensity and pattern of exploitation. The rarity of such economic trees may underscore the gross inadequacy of seeds for regeneration, as a lot of mother trees must have been felled. [14] identified that the efficient reproductive strategies and good dispersal capabilities could also explain abundance and rarity of species in wetland ecosystems. This is quite true for invasive species such as *Nypa fruticians* and native mangrove species like *Rhizophora* sp. *and Avicennia* sp*.* For instance, while *Nypa fruticans* reproduces massively by means of the explosive mechanism, *Rhizophora mangle* relies more on vivaporosity. The closeness in frequency and density values of some species portrays high competition levels for environmental resources (nutrients, light and space) among taxa. This had been alluded to by earlier researchers [15].

For ecological studies, multivariate techniques are considered to be the best methods for the flora classification based on the abundance and species responses to environmental gradients [16]. [17] opined that one of the major goals of ecology is to explain the distribution and abundance of various species along spatial scales and that the diversity of a community can be assessed by the proportional species abundance data either by using statistical sampling theory or by a variety of non-parametric measures. This is evidenced in this study as the responses of species to different nutrient limits were presented (Figs. 1–5). In all graphical representations, there were overlapping occurrences of species along nutrient gradients and this may be ascribed to functional relationships between nutrients and vegetation components. *Nypa fruticans* seemed to be most successful species reaching ecological optima of 30 individuals (upper limits only). This may imply that this species had wide ecological amplitude to nutrient gradients over other species. Elsewhere, [18] showed that if the relative abundance of species in a particular plant group in a given community is somehow measured, there will be some common or dominant species, and some rare species with a varying degree of rareness. The dominance pattern here (as judged from the density values of *Nypa fruticans*) gives information as to the extent to which it has so invaded the ecosystem by exerting a powerful influence on the occurrence of other species. Dominance, which is an ecological manifestation arising from a number of exploitative mechanisms is well noted in the study area. [19] emphasized the asphyxiating and allelopathic effects of *Nypa fruticans* while studying the *Nypa* infested Stubbs creek Ecosystem. According to [20], *Nypa* spread is highly enhanced by the floating ability of the fruit and viability in the water over a long period of time. The seeds germinate in water while on transit to any readily available substrate to grow. On getting to a favorable substrate, they outgrow other plants growing in their colonies. Hence, this successful seed dispersal mechanism while displacing other mangrove species may have contributed to its high success in the wetland. Furthermore, the additional advantage for rapid colonization through the formation of rhizomes makes *Nypa* distribution a success. This synchronizes with the current findings.

The availability of nutrients is one of the most important abiotic factors which determines the plant species composition in ecosystems. For instance, nitrogen is the limiting nutrient for plant growth in most natural and semi-natural ecosystems, especially of oligotrophic and mesotrophic habitats. Most of the plant species from such conditions are adapted to nutrient-poor conditions, and can only survive and out-compete others successfully on soils with low nitrogen availability [21]. In confirming this, [22] had shown that the presence or absence of specific species could be an indication of nutrient availability or paucity in an ecosystem. Apart from nutrient availability, acidity tide and strong wind are imminent factors which could also affect plant community composition in this ecosystem.

5. CONCLUSION

The Imo River wetland is rich in indigenous mangrove species and showed overlapping occurrences of species to varying nutrient gradients. There were variations in frequency and density of species within this ecosystem which can be ascribed to their adaptation and response abilities to environmental factors as well as the overexploitation of available plant resources. *Nypa fruticans* was the most abundant plant species and this was due to its inherent abilities and wide ecological amplitudes which enhanced its successful invasion and colonization of the ecosystem. Apart from the fact that it adapts well to prevailing conditions and microsite variability in this wetland, its reproductive strategy of explosive mechanism gives it an edge over other species. In most areas within the ecosystem, the plant species are closely packed thereby leading to high competition levels between taxa within the wetland. This, therefore, depicts that though different species grow in the same environment or habitat, they exhibit differential responses and adaptations to soil nutrients.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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