Spatial Assessment of Earthworm Abundance, Biomass and Density in the Ecological Belts of Western Niger Delta, Nigeria

Charles Obiechina Olisa, Charles Uwadiae Oyegun, Olatunde Sunday Eludoyin

Department of Geography and Environmental Management, University of Port Harcourt, Port Harcourt, Nigeria
charlesobiechinaolisa@gmail.com

Abstract: The study examined the density, biomass and abundance of earthworm across different ecological belts of Western Niger Delta, Nigeria. Eight 20m x 20m quadrat were delimited in the natural vegetation in each of the rainforest (RF), mangrove (M), fresh water swamp (FWS) and guinea savanna (GS) within which three quadrats of 1m x 1m were delineated to collect earthworm species. Earthworm species were collected from the topsoil (0-15cm) and subsoil (15-30cm) and were taken to laboratory for further analysis. Descriptive statistics and inferential statistics were used for data analysis. Findings showed that a total of 19 earthworm species were found with 58.5% individual species recorded in the topsoil and 41.5% recorded in the subsoil. The total population of *Eudrilius eugeniae* was predominantly highest in both topsoil (38.4%) and subsoil (27.1%). The total population of individual species of earthworm was least in GS in the topsoil (11.9%) and subsoil (8.4%). The mean biomass of earthworm was significantly highest in the FS in the topsoil (1.04±0.3 g/ha) and subsoil (0.44±0.3 g/ha). The total density of earthworm was highest in FS in the topsoil (8.68 ha) and RF recorded the highest in the subsoil (4.16 ha). Soil impact index was below the threshold of 0.2 in M and GS. The study recommended that the earthworms' functions in M and GS are needed to be improved to accomplish significant leaf-litter breakdown and recycling to increase the soil nutrients for optimum food production.

Keywords: Abundance, Earthworm, Density, Biomass, Ecological belts, Nigeria

1. Introduction

The role of earthworms as one of the most critical groups of ecosystem engineers in human-modified and natural environments has been progressively more acknowledged only during the last 30 years. Earthworms and humans have been acting together in building landscapes for millennia (Cunha, et al., 2016). Earthworm populations are important decomposers contributing to aggregate formation and nutrient cycling processes involving nitrogen cycles, phosphorus and carbon (Lemtiri, et al., 2014). Thus, soil organisms in which earthworm is inclusive play key roles in several ecosystem functions, i.e. enhancing plant productivity, improving water relations, regulating nutrient mineralisation, permitting decomposition, and acting as an environmental buffer (Neher, 1999). The processes of carbon (C) and nitrogen (N) mineralization carried out by microorganisms are affected directly and indirectly by invertebrates over a wide range of spatial and temporal scales (Anderson, 1988). Earthworm affects pedogenesis in two major ways: first by modifying soil profile through bioturbation and second by their effects on decomposition and nutrient cycling (Lee, 1985). The effects of earthworm community on soil properties, processes and pedogenesis are largely dependent on the species composition, abundance,

human management, climate, soil and vegetation types (Lavelle, et al., 2004). The pedoturbation effects of earthworms on soil processes and the populations of other organisms (including plants) are often intense and may lead to significant permanent changes in the soil. In agricultural areas, these changes are generally beneficial to soil fertility and plant production (Baker, et al., 2007), but in native forests, they may be damaging to the soil/litter layer and associated fauna and flora (Bohlen et al., 2004a).

However, in areas dominated by geophagous endogeic species, the role of earthworms in surface-litter decomposition and incorporation is mostly indirect, through the deposition of casts on litter and the increase of rate of microbial activity (Brown et al., 2000). Therefore, determination of the earthworm community present in a particular site is an important step toward understanding their role in pedogenesis. In low-fertility, tropical soils poor in organic matter, such as some tropical pastures and savannas, earthworms may reach high biomass (Decaens, et al., 2004) and produce large amounts of castings (up to >1,000 Mg ha^{-1}), resulting in major effects on soil structure and nutrient cycling (Lavelle, 1997). In fact, the selection and transport of finer particles by these animals can affect soil surface horizon texture, altering contents of

clay and coarse sand in the soil profile (Nooren, et al., 1995).

The biochemical decomposition of organic matter (OM) is primarily accomplished by microorganisms, but earthworms are crucial drivers of the process as they may affect microbial decomposer activity by grazing directly on microorganisms (Gómez-Brandón, et al., 2011); and by increasing the surface area available for microbial attack after diminution of OM (Domínguez et al., 2012). Earthworms directly affect the decomposition of soil through gut-associated processes, via the effects of ingestion, digestion, and stimulation of the OM breakdown and microorganisms (Monroy, et al., 2008; Aira, et al, 2009). Several factors may contribute to the mineral weathering mediated by earthworms, such as low pH and a bacteria-rich microenvironment in the gut of earthworms. Rizhiya (2007) indicated that earthworms increased N_2O fluxes when grass residue was applied to the soil. The formation and production of N_2O in soils is determined by microbial processes: nitrification, denitrification, and nitrifier denitrification (Wrage, et al., 2001). The beneficial effects of soil organic matter on soil productivity through the supply of plant nutrient, enhancement of cation exchange capacities and improvement in soil and water retention have been established (Lemtiri, et al., 2014). Thus, earthworms play a role in both acceleration of decomposition and mineralization processes (C loss) and in carbon storage or protection from decomposition (C accumulation) in stable aggregates (Brown et al., 2000). Aggregate stability is a key factor for physical soil fertility and it also affects SOM dynamics (Abiven, et al., 2009). Aggregates are formed through the combination of clay, silt, and sand, with organic and inorganic compounds. Their stability is used as an indicator of soil structure (Six, et al., 2000). Edwards and Bohlen (1996) revealed that agricultural practices such as tillage, drainage, irrigation, lime application, pesticide use, fertilization and crop rotation can influence significantly earthworm biomass and activity. In case of tillage and earthworm biomass, no-till management systems promoted earthworm abundance (Johnson-Maynard, et al., 2007); while deep ploughing and intensive tilling reduced earthworm populations (Edwards and Bohlen, 1996). Mechanical weeding was found to be responsible for habitat disturbance, physical damage to earthworms and disturbance in reproduction functions among other factors (Ernst and Emmerling, 2009).

Knowledge of different physical, chemical and management factors that affect the biomass, distribution and abundance of earthworm population is important to identify their ecological appropriateness in order to quantify the impact of earthworm on the soil properties in different landuse like agricultural land (Mele and Carter, 1999; Kalu, et al., 2015). Also, understanding the influence of the earthworm abundance and tree species diversity and richness is highly required because of the ability of the duo to conserve soil. Having known that the presence of earthworms modifies the environment (soil quality) due to their various activities like burrowing and casting which affect the activities of other organisms (Kalu et al., 2015), yet the distribution of earthworm across different major ecological zones in Nigeria remains poorly studied and scanty in the literature. Thus, the present study assessed the density, biomass and abundance of earthworm in the Western Niger Delta, Nigeria.

2. Materials and Methods

The study area is the Western Niger Delta Region of Nigeria. It is located between longitude 4° 15' 0"E and 7° 0' 0"E and latitude 5° 0' 0"N and 7° 30' 0"N. The Western Niger Delta Region comprises Ondo, Edo and Delta States (Figure 1). The study area involved the four ecological zones namely guinea savanna, rainforest, fresh water swamp and mangrove in the Western Niger Delta Region. The study area is located in the tropics and therefore experiences humid tropical climate (Adejuwon, 2012). It has distinct dry and wet seasons. Between 8 and 10 months in the year, the climate of the region is dominated by tropical maritime (mT) air mass while the remaining 2 to 4 months of the year are under the influence of the dry tropical continental (cT) air mass (Adejuwon, 2012). The annual temperature range is small as low as 3^0C. Mean monthly temperature is $26\text{-}28^0C$ (Adejuwon, 2012). Rainfall is between 1800mm and 3000mm per year (Ologunorisa and Adejuwon, 2003; Emaziye, et al., 2012). Relative humidity is about 85% (Adejuwon, 2012). The relief of study area comprises of coastal plain (Adejuwon, 2012). It is generally low lying without remarkable hills, consisting of unconsolidated sediments of quaternary age. Some hills can be found northwards within the Aniocha LGA in Delta State and northern parts of Ondo State. Thus, the relief of the region includes coastal lowland, the Esan Plateau, Orle valley, the dissected uplands of Akoko-Edo and Akure-Owo axis (Adejuwon, 2012). The soil types are made up of ferrosols predominantly dominated by sandy and little clay composition (Imoroa, 2000; Okoh, 2013). Geologically, the study area is underlain by the Coastal Plain sands having its place from the Pleistocenic Formation (Nwakoala and Warmate, 2014). The drainage of the study area is made up of River Niger that discharges into the sea through its several distributaries such as the Forcados, Escravos and Warri rivers and creeks such as the Bomadi Creeks, amongst others (Aweto, 2001; Okoh, 2013). Rivers Jamieson and Ethiope rise from the north and

northeast respectively and subsequently join and form the Benin River, which eventually discharges into the sea in the West (Emaziye et al., 2012). Also importantly, River Osse in Ondo State which also discharges into the Atlantic Ocean. The study area comprises natural vegetation of lowland rainforest with patches of swamp vegetation. The forest was a

major source of timber and the notable timber producing species include *Antiaris toxicaria*, *Milicia excelsa*, *Ceiba pentandra*, *Piptadeniastrum africanum*, *Pentaclethra macrophylla*, *Chrysophyllum albidum* and *Irvingia gabonenesi*s (Okoh, 2013). The types of occupation of the residents in the study locations include farming, fishing and industrial jobs.
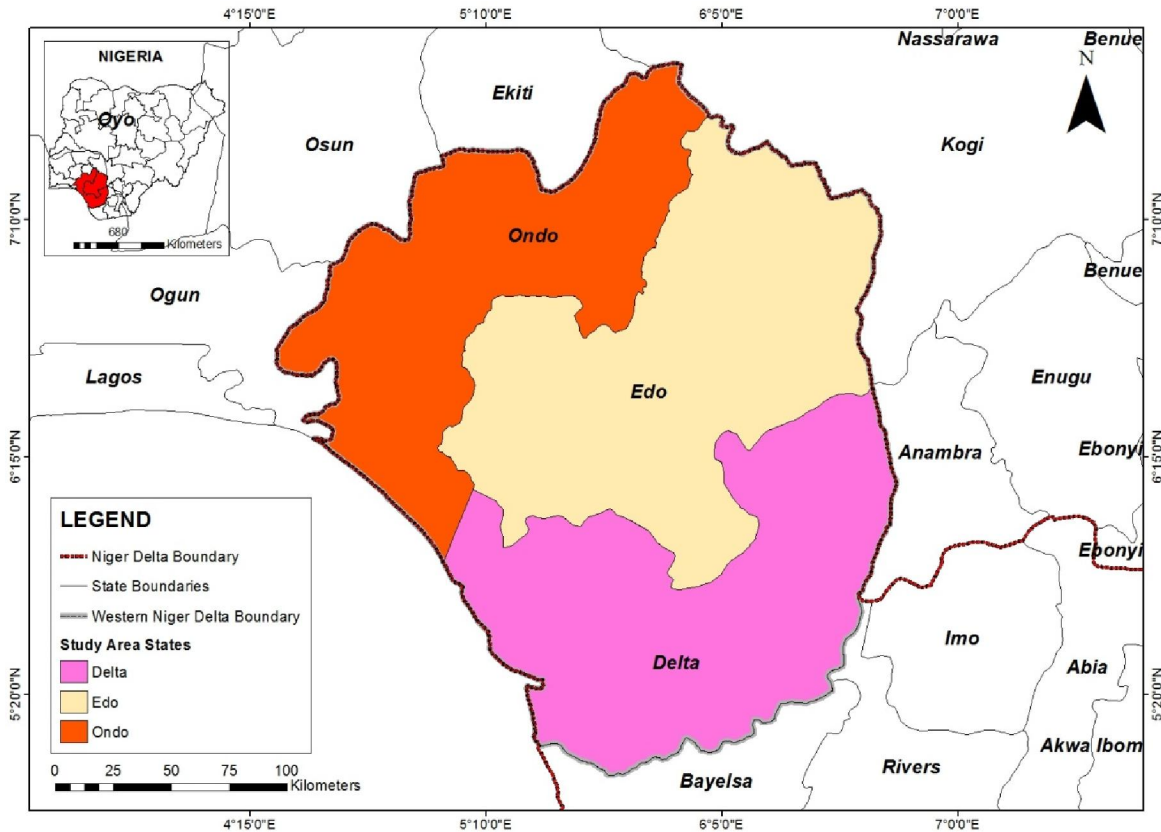

Figure 1: Western Niger Delta

A quadrat of 80m x 100m was delimited in natural (virgin) vegetation in the four ecological zones of the Western Niger Delta (Shen, 2011). This quadrat was sub-divided into quadrats of 20m x 20m from which eight (8) quadrats were randomly selected in each ecological zone. Thereafter, three quadrats of 1m x 1m were delineated in each sampled 20m x 20m quadrats and were bulked together to have a total composition of earthworm species in each quadrat (Owa, et al., 2003). The sample plots were delimited with pegs and tagged with red coloured ribbon for easy identification of the boundaries. The sampling methods adopted for this study were stratified and simple random sampling techniques. Earthworm samples were collected at the soil depth of 0-15cm and 15-30cm, Earthworm populations were collected by digging and hand-sorting (Oboh, et al., 2007; Salehi et al., 2013). Digging is the simplest, as it requires only a spade and perhaps a quadrat for density calculations to

detect both near surface (epigeic) earthworms and horizontal burrowing (endogeic) species (Butt and Grigoropoulou, 2010). Collected earthworm samples were identified adopting the methods of Segun (1998) and Owa *et al*. (2003). Earthworm composition was determined by counting the individual earthworm in the field and preserved in 4% formalin before bringing them to the laboratory (Julka, 1988). The earthworms were processed and separated according to species in the laboratory. In the laboratory, the earthworms were washed in the running water and drying them with a paper towel in the open air for three minutes (Baretta et al., 2007; Fonte, 2009). All the earthworms were then oven dried at 60°C for 24 hours. Earthworm biomass was computed as stated in Salehi et al. (2013).

LN (biomass) = [2.2853 x LN (length)] – 11.9047

Length of individual earthworm was measured to the nearest millimeter using a meter rule (Oboh *et al*.,

2007). Earthworm population density was computed by dividing the total number of individual earthworm in all quadrats by sampling area (0.0001 ha). Earthworm Soil Impact Index (SIINDEX) was computed using density and biomass of the earthworm. This is because SIINDEX is a function of density and biomass (Owa *et al*., 2003). SIINDEX is defined as the square root of the product of the earthworm density (in million worms/ha) and earthworm biomass (gm⁻²). SIINDEX helps to determine the rate at which leaf litter breaks down and re-injection into the soil (Owa *et al*., 2003). Forests with SIINDEX less than 0.2 should be regarded as endangered, because their earthworm functions are too low to accomplish significant leaf-litter breakdown

and recycling (Owa, et al; 2001). Descriptive statistics were used to describe the mean values of the earthworm parameters. Inferential statistics which include analysis of variance (ANOVA) was used to determine the significant variations in earthworm parameters across the ecological zones in the study area at 0.05 significant levels. Pairwise t-test was used to determine the significant variation in the earthworm parameters between the topsoil and subsoil at 0.05 significant levels.

3. Results

Earthworm species distribution across the ecological zones

Table 1. Earthworm population in topsoil and subsoil across ecological zones

| S/N | Earthworm Species | Topsoil | | | | Total | Subsoil | | | | Total | Overall Total |
		FS	MS	GS	RF		FS	MS	GS	RF		
1	*Eutoreutus abinsanus*	23	0	4	0	27	6	0	2	0	8	35
2	*Ephyriodrilus afroccidents*	26	0	0	5	31	13	0	0	8	21	52
3	*Eudrilius eugeniae*	105	12	10	9	136	0	12	6	10	28	164
4	*Hyperiodrilus africanus*	16	13	0	5	34	0	6	0	14	20	54
5	*Iridodrilus roseus*	16	0	0	3	19	0	0	0	10	10	29
6	*Ikennodrilus wurea*	15	0	0	0	15	0	0	0	0	0	15
7	*Parapolytoreutus obiensis*	16	0	0	0	16	0	0	0	0	0	16
8	*Hyperiodrilus oshogbensis*	0	3	0	0	3	16	0	0	0	16	19
9	*Keffia penetrabilis*	0	0	0	0	0	6	4	0	0	10	10
10	*Lumbricus terrestris*	0	0	18	10	28	36	4	3	30	73	101
11	*Heliodrilus lagossensis*	0	8	0	4	12	7	8	4	9	28	40
12	*Keffia proxipora*	0	0	0	8	8	8	0	0	11	19	27
13	*Iridodrilus tonyii*	0	3	0	0	3	0	0	0	0	0	3
14	*Libyodrilus mekoensis*	0	2	0	0	2	0	0	0	0	0	2
15	*Libyodrilus violaceus*	0	2	0	8	10	0	0	0	12	12	22
16	*Iridodrilus preussi*	0	0	2	0	2	0	0	2	0	2	4
17	*Iridodrilus vomiensis*	0	0	4	0	4	0	0	2	0	2	6
18	*Keffia variabillis*	0	0	4	0	4	0	0	2	0	2	6
19	*Total*	217	43	42	52	354	92	34	21	104	251	605
	Percentage (%)	61.3	12.1	11.9	14.7	100	36.7	13.5	8.4	41.4	100	

(FS-Freshwater swamp; M-Mangrove; GS-Guinea savanna; RF-Rainforest)

The earthworm species population in each ecological zone in the topsoil and subsoil are presented in Table 1 while Table 2 shows the total percentage of individual species of earthworm. A total of 19 species of earthworm were observed in the entire study area and a total of 605 individual species of earthworm of which 354 (58.5%) individual species were found in the topsoil and 251 (41.5%) were found in the subsoil. In the topsoil, of the total population, *Eudrilius eugeniae* was predominantly highest (38.4%), followed by *Hyperiodrilus africanus* (9.6%) and *Lumbricus terrestris* (7.9%) while the population of *Hyperiodrilus oshogbensis* (0.8%)*, Iridodrilus preussi* (0.6%) and *Libyodrilus mekoensis* (0.6%) were very low (Table 2). In subsoil, the population of

Eudrilius eugeniae was also highest (27.1%), followed by *Lumbricus terrestris* (16.7%) and *Ephyriodrilus afroccidents* (8.6%) and while the population of *Iridodrilus preussi* (0.7%), *Iridodrilus tonyii* (0.5%)*,* and *Libyodrilus mekoensis* (0.3%) were very low (Table 2). Of the total number of earthworm species found in the entire study area, 12 was found in freshwater swamp, 9 in mangrove, 7 in guinea savanna and 10 in rainforest. Comparing the earthworm population in each ecological soil with respect to the soil depth, it was revealed that in the topsoil *Eudrilius eugeniae* was highest (105) in the freshwater swamp, *Hyperiodrilus africanus* was highest (13) in the mangrove while, *Lumbricus terrestris* was the highest in the guinea savanna (18) and rainforest (10) (Table

1). It was also observed that in subsoil, *Lumbricus terrestris* was the highest (36) in the freshwater swamp, *Eudrilius eugeniae* was highest in both mangrove (12) and guinea savanna (6) while *Lumbricus terrestris* was highest in the rainforest. Generally, the total population of earthworm species was highest in the freshwater swamp in the topsoil (217 (61.3%)) while mangrove, guinea savanna and rainforest had 43(12.1%), 42 (11.9%) and 52 (14.7%) respectively (Table 1). In subsoil, rainforest had the highest population of earthworm species of 104(41.4%) and followed by freshwater swamp 92 (36.7%) and the lowest was recorded in guinea savanna (21(8.4%)) (Table 1). The mean abundance of earthworm was significantly varied among the ecological zones in topsoil (F=88.353; p<0.05) and subsoil (F=18.270; p<0.05). The mean density of earthworm was significantly varied between topsoil and subsoil (t=2.130; p<0.05) (Table 7).

Table 2. Total percentage of earthworm abundance in the topsoil and subsoil across ecological zones

S/N	Earthworm Species	Total Topsoil	Percentage (%)	Total Subsoil	Percentage (%)	Overall Total	Percentage (%)
1	*Eutoreutus abinsanus*	27	7.6	8	3.2	35	5.8
2	*Ephyriodrilus afroccidents*	31	8.8	21	8.4	52	8.6
3	*Eudrilius eugeniae*	136	38.4	28	11.2	164	27.1
4	*Hyperiodrilus africanus*	34	9.6	20	8.0	54	8.9
5	*Iridodrilus roseus*	19	5.4	10	4.0	29	4.8
6	*Ikennodrilus wurea*	15	4.2	0	0	15	2.5
7	*Parapolytoreutus obiensis*	16	4.5	0	0	16	2.6
8	*Hyperiodrilus oshogbensis*	3	0.8	16	6.4	19	3.1
9	*Keffia penetrabilis*	0	0	10	4.0	10	1.7
10	*Lumbricus terrestris*	28	7.9	73	29.1	101	16.7
11	*Heliodrilus lagossensis*	12	3.4	28	11.2	40	6.6
12	*Keffia proxipora*	8	2.3	19	7.6	27	4.5
13	*Iridodrilus tonyii*	3	0.8	0	0	3	0.5
14	*Libyodrilus mekoensis*	2	0.6	0	0	2	0.3
15	*Libyodrilus violaceus*	10	2.8	12	4.8	22	3.6
16	*Iridodrilus preussi*	2	0.6	2	0.8	4	0.7
17	*Iridodrilus vomiensis*	4	1.1	2	0.8	6	1.0
18	*Keffia variabillis*	4	1.1	2	0.8	6	1.0
19	*Total*	354	100	251	100	605	100

Species density (ha) of earthworm in the ecological zones

The species density of earthworm individual species is displayed in Table 3 whereby it was revealed that in topsoil *Eudrilius eugeniae* recorded the highest density of 4.2 ha and 0.36 ha in freshwater swamp and rainforest respectively, *Hyperiodrilus africanus* recorded 0.52 ha as the highest in mangrove, *Lumbricus terrestris* recorded 0.72 ha as the highest in guinea savanna. In subsoil, *Lumbricus terrestris* recorded the highest in freshwater swamp (1.44 ha) and rainforest (1.2 ha) while *Eudrilius eugeniae* recorded the highest in mangrove (0.48 ha) and guinea savanna (0.24 ha). In topsoil, the total density for earthworm was 8.68 ha, 1.72 ha, 1.68 ha and 2.08 ha in the freshwater swamp, mangrove, guinea savanna and rainforest respectively. However, in the subsoil, the rainforest had the highest total density of

earthworm species of 4.16 ha, followed by 3.68 ha in freshwater swamp. The total density of earthworm in the topsoil was 14.16 ha while in the subsoil, it was 10.04 ha.

Considering the mean total density of earthworm across ecological zones in both topsoil and subsoil as shown in Table 4, it was revealed that the mean total density in the topsoil in freshwater swamp was 1.09 ha, 0.22 ha in mangrove, 0.24 ha in guinea savanna and 0.26 ha in rainforest. However, in subsoil, the

mean total density was highest in the rainforest (0.52 ha) and followed by 0.46 ha in freshwater swamp and the least was observed in guinea savanna (0.11 ha). The mean density of earthworm was significantly varied among the ecological zones in topsoil (F=88.353; $p<0.05$) and subsoil (F=18.270; $p<0.05$). The mean density of earthworm was significantly varied between topsoil and subsoil (t=2.152; $p<0.05$) (Table 7).

Table 3. Earthworm density (ha)

Earthworm Species	Topsoil				Total Density	Subsoil				Total Density
	FS	MS	GS	RF		FS	MS	GS	RF	
Eutoreutus abinsanus	0.92	0	0.16	0	1.08	0.24	0	0.08	0	0.32
Ephyriodrilus afroccidents	1.04	0	0	0.2	1.24	0.52	0	0	0.32	0.84
Eudrilius eugeniae	4.2	0.48	0.4	0.36	5.44	0	0.48	0.24	0.4	1.12
Hyperiodrilus africanus	0.64	0.52	0	0.2	1.36	0	0.24	0	0.56	0.8
Iridodrilus roseus	0.64	0	0	0.12	0.76	0	0	0	0.4	0.4
Ikennodrilus wurea	0.6	0	0	0	0.6	0	0	0	0	0
Parapolytoreutus obiensis	0.64	0	0	0	0.64	0	0	0	0	0
Hyperiodrilus oshogbensis	0	0.12	0	0	0.12	0.64	0	0	0	0.64
Keffia penetrabilis	0	0	0	0	0	0.24	0.16	0	0	0.4
Lumbricus terrestris	0	0	0.72	0.4	1.12	1.44	0.16	0.12	1.2	2.92
Heliodrilus lagossensis	0	0.32	0	0.16	0.48	0.28	0.32	0.16	0.36	1.12
Keffia proxipora	0	0	0	0.32	0.32	0.32	0	0	0.44	0.76
Iridodrilus tonyii	0	0.12	0	0	0.12	0	0	0	0	0
Libyodrilus mekoensis	0	0.08	0	0	0.08	0	0	0	0	0
Libyodrilus violaceus	0	0.08	0	0.32	0.4	0	0	0	0.48	0.48
Iridodrilus preussi	0	0	0.08	0	0.08	0	0	0.08	0	0.08
Iridodrilus vomiensis	0	0	0.16	0	0.16	0	0	0.08	0	0.08
Keffia variabillis	0	0	0.16	0	0.16	0	0	0.08	0	0.08
Total	8.68	1.72	1.68	2.08	14.16	3.68	1.36	0.84	4.16	10.04

(FS-Freshwater swamp; M-Mangrove; GS-Guinea savanna; RF-Rainforest)

Table 4. Mean total density (ha) of earthworm across ecological zones

Ecological Zone	Soil Depth	Minimum	Maximum	Mean±SD
Freshwater Swamp	Topsoil	0.88	1.36	1.09±0.2
	Subsoil	0.24	0.60	0.46±0.1
Mangrove	Topsoil	0.08	0.36	0.22±0.1
	Subsoil	0.08	0.24	0.17±0.1
Guinea Savanna	Topsoil	0.16	0.40	0.24±0.1
	Subsoil	0.04	0.24	0.11±0.1
Rainforest	Topsoil	0.16	0.40	0.26±0.1
	Subsoil	0.40	0.96	0.52±0.2

N=8

Biomass (g/ha) of earthworm across ecological zones

The biomass of earthworm in the topsoil and subsoil in the ecological zones is shown in Figure 1. It is displayed that at the topsoil, the mean biomass of earthworm was 1.04 g/ha in the freshwater swamp, 0.10 g/ha in mangrove, 0.08 g/ha in guinea savanna and 0.29 g/ha in the rainforest. It is also revealed that the mean biomass in the subsoil was 0.44 g/ha in

freshwater swamp, 0.08 g/ha in mangrove, 0.05 g/ha in guinea savanna and 0.28 g/ha in the rainforest. The mean biomass of earthworm in the topsoil was generally and slightly higher in the topsoil than that of the subsoil. The analysis also revealed that freshwater had the highest biomass in both topsoil and subsoil. The mean biomass of earthworm was significant varied among the ecological zones in topsoil (F=37.668 $p<0.05$) and subsoil (F=10.402; $p<0.05$).

The mean biomass of earthworm was significantly varied in the topsoil than subsoil (Table 7).
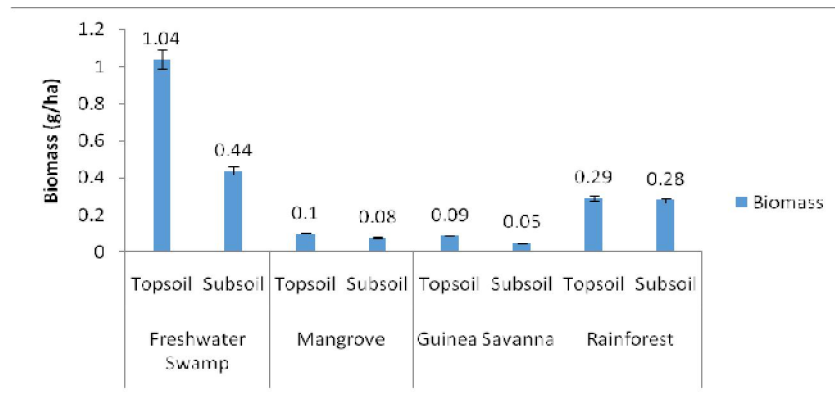

Figure 1: Earthworm Biomass (g/ha) across the ecological zones of Western Niger Delta

Length of earthworm across ecological zones

The mean length of earthworm presented in Table 5 revealed that the earthworm in the topsoil of rainforest had the highest mean length of 177.39mm followed by freshwater swamp (162.26mm) and the least was found in guinea savanna. In the subsoil, the mean length of the earthworm was the highest in the freshwater swamp (159.25mm) and the least was found in guinea savanna (130.35mm). In each of the ecological zones, there was slight variation in the mean length of earthworm between the topsoil and subsoil. The mean length of earthworm was significant varied among the ecological zones in topsoil (F=5.183; p<0.05) and subsoil (F=5.183; p<0.05). The length of earthworm was slightly varied in the topsoil than subsoil (Table 7).

Table 5. Mean length of earthworm (mm) in the topsoil and subsoil of ecological zones

Ecological Zone	Soil Depth	Minimum	Maximum	Mean±SD
Freshwater Swamp	Topsoil	135.01	177.21	162.26±12.5
	Subsoil	127.88	197.88	159.25±60.6
Mangrove	Topsoil	118.14	158.36	133.01±15.6
	Subsoil	119.31	138.60	131.37±6.9
Guinea Savanna	Topsoil	111.95	152.71	129.90±14.6
	Subsoil	118.28	147.35	130.35±10.0
Rainforest	Topsoil	135.10	271.17	177.39±51.6
	Subsoil	122.68	147.46	139.09±9.5

N=8

SIINDEX of earthworm across ecological zones

The soil impact index of ecological zones which incorporates earthworm biomass and density is presented in Table 6. It is shown that the SIINDEX of the freshwater swamp was the highest in the topsoil (1.06) and subsoil (0.43). The mean SIINDEX of rainforest in the topsoil was 0.27 while it was 0.38 in the subsoil. The mean SIINDEX of mangrove and guinea savanna in topsoil and subsoil were less than 0.2 threshold, thus the earthworms are endangered because their earthworm functions are too low to accomplish significant leaf-litter breakdown and recycling (Owa, et al., 2001). The mean SIINDEX was significant varied among the ecological zones in topsoil (F=66.665; p<0.05) and subsoil (F=14.961; p<0.05). The SIINDEX was significantly higher in the topsoil than subsoil (t=2.443; p<0.05) (Table 7).

Table 6. Mean SIINDEX in the topsoil and subsoil among the ecological zones

Ecological Zone	Soil Depth	Minimum	Maximum	Mean±SD
Freshwater Swamp	Topsoil	0.64	1.48	1.06±0.2
	Subsoil	0.18	0.67	0.43±0.2
Mangrove	Topsoil	0.07	0.25	0.15±0.1
	Subsoil	0.05	0.18	0.12±0.04
Guinea Savanna	Topsoil	0.09	0.25	0.14±0.1
	Subsoil	0.03	0.16	0.07±0.04
Rainforest	Topsoil	0.12	0.55	0.27±0.2
	Subsoil	0.25	0.72	0.38±0.2

N=8

Table 7. Variations of characteristics of earthworm in topsoil and subsoil across ecological zones

Earthworm Characteristics	Topsoil Mean±SD	Subsoil Mean±SD	Pairwise t-Test	F value Topsoil	F value Subsoil
Density (ha)	0.4488±0.4	.3138±0.2	2.125*	88.353**	18.270++
Biomass (g/ha)	0.3819±0.4	.2113±0.2	2.536*	37.668**	10.402++
SIINDEX	0.4025±0.5	.2513±0.2	2.443*	66.665**	14.961++
Abundance	11.2188±9.8	7.8438±5.5	2.125*	88.353**	18.270++
Length (mm)	150.6406±33.9	140.0153±20.1	1.690	5.183**	4.896++

N=32 *;**,++ Significant at $p<0.05$

4. Discussions

Eudrilius eugeniae was predominantly highest among the earthworm species. The result is similar to the findings of Owa et al (2003) whereby *Eudrilius eugeniae* was the highest in the study. The abundance and density of *Lumbricus terrestris* was higher in the subsoil than the topsoil. This may be attributed to their characters as anecic/endogeic species of earthworms that burrow deeply into soil horizon and forming persistent unbranching burrows and to migrate to deeper soil layers with which a state of aestivation to avoid desiccation can be maintained (Edwards and Lofty. 1977; Hale and Host, 2005). In subsoil, rainforest had the highest population of earthworm species and followed by freshwater swamp and the lowest was recorded in guinea savanna. The low abundance in guinea savanna could be attributed to the persistent bush burning activity because of the presence of grasses and this could be detrimental to the survival of invertebrates. This could as well affect the soil nutrient levels especially at the surface and root level. The reason being that the earthworms to move nutrients from soil surface to sub surface have been destroyed (Areola, 1982; Owa et al., 2003). Higher earthworm population recorded in the topsoil can be attributed to food substances that are being obtained easily in the topsoil. Kooch, et al. (2008) reported that earthworms are known to have a positive influence on the soil fabric and on the decomposition and mineralization of litter by breaking down organic matter and producing large amount of feaces, thereby mixing litter with the mineral soil. Thus, Thu (2017) reported that earthworm burrows provide not only the linkage between topsoil and subsoil for C and nutrients, but strongly increase microbial activities and accelerate soil organic matter turnover in subsoil, contributing to nutrient mobilization for roots and CO_2 emission increase as a greenhouse gas. The least abundance and density of earthworm observed in the guinea savanna may be attributed to losses in soil aggregate structure and reduction of soil organic matter content (Lee, 1985; Ashworth, et al., 2017).

5. Conclusion

The study can be concluded that the earthworm abundance, density, biomass significantly varied among the ecological belts of Western Niger Delta in both topsoil and subsoil. The total population of individual species of earthworm ranged from the least in guinea savanna to highest in the freshwater swamp in the topsoil and rainforest in the subsoil. The study recommended that the earthworms' functions in mangrove and guinea savanna are needed to be improved to accomplish significant leaf-litter breakdown and recycling. This will also increase the soil nutrients which can support agricultural production in the regions to ensure optimum food production that can support the growing population.

Corresponding Author:

Mr Charles Obiechina Olisa
Department of Geography and Environmental Management,
Faculty of Social Sciences,
University of Port Harcourt, Port Harcourt, Nigeria
E-mail: charlesobiechinaolisa@gmail.com

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