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Carbon Stock in Different Pools across Different Vegetation Structures in a Tropical Rainforest in Ile-Ife, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OOA designed the study, wrote the protocol and wrote the first draft of the manuscript. Author OOA managed the literature searches, analyses the study performed the spectroscopy analysis and managed the experimental process. Authors OOA and AIO identified the species of plant. Author AIO supervised the write-up. Both authors read and approved the final manuscript.

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ABSTRACT

Carbon stock in the soil pool, shrubs, herbaceous plants and standing floor litters across different vegetation structures were investigated in a tropical rainforest with the aim of providing information on the carbon stock in these pools across these physiognomies. Two plots, each of 20x20 cm were marked out at each site, five lines transects were systematically laid in each plot and a quadrat of 1×1 m was established at every 2 m point where the above ground biomass of shrubs and herbs were collected by clipping at 2 cm above the ground, oven dried at 70℃ to a constant weight and weighed. Standing floor litters were randomly collected at every three month intervals for a period of one year at five points using a quadrat size of 50×50 cm for a period of one year; sorted out into leaves and wood, oven dried at 70℃ to a constant weig ht. Five soil samples were also randomly collected from each plot at 0-15 cm depth, air dried, sieved and analyzed for total organic carbon. Carbon stock ranged from 0.27-0.74 Mg C ha^{-1} in the herbs, 1.86-3.51 Mg C ha^{-1} in shrubs in the study sites. Carbon stock in standing floor litters ranged from 5.83-25.44 Mg C ha^{-1}. Soil carbon stock was significantly higher ($F_{2, 27 (0.05)}$ = 295.61; P = $4.39×10^{-19}$) in the *Tectona grandis* plantation

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compared to other vegetations. Contributions of C stock is in the order of soil > standing floor litter > Shrubs >herbs.

Keywords: Aboveground; floor litters; herbs; organic matter; riparian; shrub, soil.

1. INTRODUCTION

Forest soil contain a significant amount of carbon and soil carbon in the forest is a major component of the global C cycle that contributes to the carbon sequestration [1-3], and is equally important for sustaining forest productivity [4]. The soil organic carbon sources include plant, animal and microbial residues in all stages of decomposition [5] and a major input of vegetative carbon to forest soil is represented by litter [6]. Soil organic carbon is a soil property subject to change and highly variable in space and time [7]. Soil organic carbon is a large and active pool, containing roughly twice as much carbon as the atmosphere and 2.5 times as much as the biota; it enters the soil as roots, litter and harvest residues and is primarily stored as soil organic matter [8]. Soils are the largest carbon reservoir of the terrestrial carbon; this is because about three times more carbon is contained in soils than in the world's vegetation [9].

Sheikh [10] also pointed out that soils hold double the amount of carbon that is present in the atmosphere and that organic carbon in the soil plays a very important role in the global carbon balance [11]. It is an essential component of the earth's ecosystem due to its importance in maintaining life-balance [12]. Depending on the changes in the level of soil organic matter, soil can act as sinks of carbon concentration in the atmosphere, thereby increasing the concentration of carbon in the soil [13] or as a source of atmospheric CO_2 [14].

Severe depletion of the soil organic pool degrades soil quality, reduces biomass productivity, and adversely impacts water quality, and the depletion may be exacerbated by projected global warming [9]. Since soil C is a principal source of energy for the nutrient-recycling activities of heterotrophic soil organisms, the maintenance of soil C stocks is vital for sustaining forest productivity [15-16]. It had been concluded that an increase in the stock of soil organic carbon will positively impact on nutrient availability, improve soil structure by holding soil particles together thereby improving water holding capacity, root growth and water infiltration [12].

Understorey plants have also been pointed to contribute to carbon stock in the forest ecosystems though the contribution is small compared to soil and trees above ground biomass. [17] reported that carbon stock in understorey vegetation from *Vochysia guatemalensis* and *Hyeronima alchorneoides* plantations was 38.5 and 42.8 Mg C ha^{-1} in Costa Rica respectively. A total aboveground biomass amounts to be 5.95 Mg ha^{-1} and 1.32 Mg ha^{-1} in shrubs in a primary mixed deciduous forest and secondary mixed deciduous forest in Thailand [18]. Also, herbaceous plant biomass in an artificially regenerated riparian forest was reported to be significantly greater than herbaceous plant biomass in a naturally regenerated, highly disturbed and minimally disturbed riparian forest in USA [19].

A carbon stock of 3.6 Mg C ha^{-1} was also reported in understorey and herbaceous plants in a secondary tropical forest in Philippines [20], the contribution of woody lianas, shrub layer and the herb layer to carbon sequestration was found to be minimal. The combined carbon stock of these pools was 3.5 Mg C ha^{-1} representing 1.8 % of the tree layer in a study in southwestern China [21]. The combination of the decomposing leaves, woody materials, reproductive structures and other organic materials on the soil sum up the standing floor litters accumulated in the forest and plantation ecosystems and these constitute an active carbon pool in these ecosystems. A forest floor value of 5 Mg C ha^{-1} was reported for the tropical seasonal rain forest in Xishuangbanna [22] in Southwestern China. [23] reported that the surface litter carbon stock varied between 0.16 and 3.26 Mg C ha^{-1} in India. A value of 0.42 and 0.49 Mg C ha^{-1} was reported for dead wood and litter respectively in Japan [24]. [25] estimated carbon stock in dead wood to be 0.42-2.47 Mg C ha^{-1} in Japan.

Though, carbon stock in the soil pool have received considerable attention across the world, it should however be noted that little information is available in Nigeria, information on C stocks of other growth forms (shrubs and herbs) and standing floor litters across tropical rainforest in Nigeria have equally been ignored. This study, therefore determined the amount of carbon locked up in the soil pool, other growth forms (shrubs and herbs) as well as standing floor litters across three different physiognomies in a tropical rainforest ecosystem located within the Obafemi Awolowo University, Nigeria with the aim of providing information on the carbon stock in these pools across the different physiognomies.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted at the Obafemi Awolowo University Estate, Ile-Ife, Osun state, Nigeria. Ile-Ife is located on Latitude N 07° 31’ and Longitude E 04° 30’ and the elevation of Ife ranges from 215 m to 457 m above sea level [26]. The study sites lies between Latitude N 07° 032’ and Longitude E 04° 031’ while the elevation ranges from 243 m to 274 m above the sea level. The climate of the area is a tropical type with two prominent seasons, the rainy and the dry season. The dry season is short, usually lasting 4 months from November to March and the longer rainy season prevails during the remaining months. The annual rainfall average 1400 mm yr^{-1} [27] and it showed two peaks, one in July and the other in September, the mean annual temperature range from 27℃ to 34℃ [27].

The soil of the area is derived from material of old basement complex which is made up of granitic metamorphosed sedimentary rock [26]. Five major soil types have been recognized in this area: Inselberg soils, Hill creep soils, and sedimentary non-skeletal soils, drift soils, alluvial deposits [26]. The soil has been classified as lixisols and utisols [28]. The original vegetation of Ile-Ife is lowland rainforest as climax vegetation [29]. [30] described the vegetation as the Guinea-Congolian drier forest type. Most of the original lowland rain forests have been massively destroyed leaving remnant of secondary forest scattered around. Tree crops plantations like *Theobroma cacao*, *Cola nitida*, *Tectona grandis*, and *Elaeis guineensis* are now common around the area.

2.2 Sampling Procedure

Two samples plots, each of 20 × 20 m were marked out within the secondary forest, *Tectona grandis* plantation and riparian vegetation in the Obafemi Awolwo University community. The secondary forest is 29 years old having been last disturbed by ground fire that engulfed the forest in 1983. It is located within the Biological Garden and lies within latitude 07° 32' 23.11"N and longitude 04° 31' 23.09"E. Some of the dominant species present in the secondary forest includes: *Celtis zenkeri, Funtumia elastica, Newbouldia laevis* and *Trichilia prieuriana;* The *Tectona grandis* plantation is 38 years old going by the time of its establishment in the year 1967, it was last harvested in 1975. It is a monoculture of *Tectona grandis* trees lying within latitude 07° 32' 26.08"N and longitude 04° 31' 25.19"E and the Riparian vegetation whose age cannot be less than 40 years old, though the actual age cannot be ascertained due to unavailable statistics is located on latitude 07° 32' 30.06"N and longitude 04° 31' 31.11"E. Some of the dominant species encountered in the riparian vegetation includes: *Celtis mildbredii, Funtumia elastica, Pycnanthus angolensis* and *Sterculia tragacantha.*

2.3 Determination of Aboveground Biomass and Carbon Stock in other Growth Forms

To estimate the carbon stock in other growth forms (herbs and shrubs), five lines transects were systematically laid in each plot and a quadrat of 1 × 1 m was established at every 1 m point to identify the understorey plant species (shrubs, herbs) present in each plot. Their above ground biomass was collected by clipping at 2 cm above the ground. The collected shrubs and herbaceous plant species were transported to the laboratory, oven dried to a constant weight at 70℃ and weighed. The dried plant samples were ground and their carbon concentration was determined at the International Institute for Tropical Agriculture, Ibadan. Carbon stock was determined by multiplying the weight and percentage carbon concentration of the dried plant samples.

2.4 Estimation of Carbon Stock in Standing Floor Litters

To quantify standing floor mass, standing floor litter were randomly collected at five points using a 50 cm x 50 cm quadrat size, all the standing floor litter within the quadrat was collected and this was sampled at three month interval for a period of one year from February, 2012 to January, 2013. The collected litter samples were separated into leaves, woods, twigs and reproductive structures. The twigs and the reproductive structures were discarded because of their small quantity. The leaves and woods were oven dried at 70℃ to a constant weight, weighed and ground. The ground leaves and woods litter components were analyzed for organic carbon at the Department of Botany according to method described by [31]. Percentage organic carbon was calculated according to the equations below.

$$\text{Ash }\% = \frac{Wc - Wa}{Wb - Wa} \times 100 \quad (1)$$

$$C\ \% = (100 - \text{Ash }\%) \times 0.58 \quad (2)$$

Where: W_a = weight of crucible, W_b = weight of oven dried ground sample and crucible, W_c = weight of ash and crucible and C = organic carbon.

The dried weight of the standing floor litters and their percentage organic carbon were used to determine their carbon stock.

2.5 Estimation of Soil Organic Carbon and Bulk Density

Soil samples were collected randomly at five different points from each plot across the different physiognomy at a depth of 0-15 cm using a soil auger. Each soil sample was air-dried, passed through a 2-mm sieve and analyzed for total organic carbon at International Institute for Tropical Agriculture (IITA), Ibadan using [32]. Soil bulk density measurements are needed to convert soil carbon concentration i.e., mass carbon per unit mass soil into inventories or storage i.e., mass per unit area. Therefore, the bulk density was estimated by inserting a fixed-volume steel ring into the soil at five randomly located points in each plot at 0-15 cm. The rings were excavated; soil samples were removed from them, dried at 105℃ for 48 hours in a Gallenkamp model IH-150 oven and then weighed [33]. The calculated bulk densities; depth at which soil samples were collected and the concentration of carbon determined was used to estimate soil carbon stock at 0-15 cm in the various study plots.

2.6 Data Analysis

One way analysis of variance was employed to test for the significant difference between carbon stock in the soil pool, other growth forms and standing floor litters across the different physiognomies. Means of main effects were compared using Least Significant Difference (LSD) test, using SPSS 17.0 software package.

3. RESULTS

3.1 Aboveground Carbon Stock in Other Growth Forms across Different Vegetation Structures

The quantity of carbon stored in herbaceous plant species across the studied sites was small and it ranged from 0.27 in the secondary forest to 0.74 Mg C ha^{-1} in the *Tectona grandis* plantation (Table 1). Herbaceous plants carbon stock was found to be lower in the secondary forest compared to other physiognomies (Table 1). The amount of carbon stored in shrubs was not significantly different ($F_{2, 5\ (0.05)}$ = 0.73; P = 0.52) across the various physiognomies (Table 1). The value ranged from 1.86 Mg C ha^{-1} in the secondary forest to 3.51 Mg C ha^{-1} in the riparian vegetation. Carbon stock in shrubs was found to be greater than those in the herbaceous plant (Table 1).

3.2 Standing Floor Litter Carbon Stock across Different Vegetation Structures

The carbon stock recorded in leaf litter varied significantly ($F_{2, 19\ (0.05)}$ = 2.55.48; P = 1.85×10^{-14}) among the vegetations studied (Table 2). The amount of carbon recorded in the leaf litter was highest in the *Tectona grandis* plantation; it ranged from 1.22 to 1.58 Mg C ha^{-1} while the lowest value was recorded in the Riparian vegetation (Table 2).

There was significant different in the carbon stock recorded in the wood litter ($F_{2, 19\ (0.05)}$ = 17.35; P = 5.16×10^{-5}) across the studied sites (Table 2). The mean carbon stock value was higher in the *Tectona grandis* plantation compared to other vegetations. Total carbon stored in leaf and wood was almost equal in secondary forest 4.42 Mg C ha^{-1} and 4.45 Mg C ha^{-1} (Table 2), while riparian vegetation had the lowest total carbon stored in leaf and wood 2.82 Mg C ha^{-1} and 3.01 Mg C ha^{-1} (Table 2). Generally, there is distinct variation in the total carbon stock between leaf and wood litter observed in each of the three vegetations.

3.3 Soil Carbon Stock across Different Vegetation Structures

The amounts of soil carbon stock recorded across the studied sites are presented in Table 3. Carbon stock in the soil varied significantly

($F_{2, 27 (0.05)}$ = 295.61; P = 4.39×10^{-19}). Soil carbon stock was found to be higher in the *Tectona grandis* plantation compared to the secondary forest and Riparian vegetation (Table 3).

3.4 Total Carbon Storage in the Various Vegetations Studied

The summary of the carbon stock recorded in the different compartments in the ecosystem are presented in Table 4. The total carbon stock ranged from 70.49 in the secondary forest to 126.99.25 Mg C ha^{-1} in the *Tectona grandis* plantation (Table 4). The soil carbon stock contributed the highest, more than 75% to the total carbon stock across the different physiognomies. This is followed by the standing floor litters (leaf and wood litters) combined together, contributing 2.82-12.85% (Table 4), while the lowest contribution was recorded in other growth forms (shrubs and herbs), with a percentage of less than 1 in herbaceous plants and less than 5% in the shrubs across the different physiognomy.

4. DISCUSSION

4.1 Aboveground Carbon Stock in other Growth Forms (Shrubs and Herbs) across Different Vegetation Structures

Other growth forms (shrubs and herbs) have been reported to play an important role in the carbon sequestration of a forest and plantation ecosystems. The results obtained from this study showed that total carbon stock in herbaceous plants was higher in the *Tectona grandis*

Table 1. Distribution of carbon stock (Mg C ha^{-1}) in shrubs and herbaceous plants across the study sites

Name	Maximum	Minimum	Mean±std error	Total
Herbs				
Secondary forest	0.15	0.02	$0.09\pm0.03^{0.22}$	0.27
Tectona grandis plantation	0.37	0.04	$0.24\pm0.10^{0.22}$	0.74
Riparian vegetation	0.28	0.15	$0.22\pm0.04^{0.22}$	0.66
Shrubs				
Secondary forest	1.39	0.47	$0.93\pm0.46^{0.42}$	1.86
Tectona grandis plantation	0.96	0.71	$0.85\pm0.07^{0.42}$	2.56
Riparian vegetation	1.37	0.94	$1.16\pm0.12^{0.42}$	3.51

Value in superscript is the LSD value used in comparing the mean difference and mean difference is not significantly different across the column at p =.05

Table 2. Carbon stock (Mg C ha^{-1}) in the leaf and wood standing floor litter across the study sites, n=8

Name	Maximum	Minimum	Mean±std error	Total
Leaf				
Secondary forest	0.52	0.44	$0.48\pm0.01^{0.05}$	4.42
Tectona grandis plantation	1.58	1.22	$1.41\pm0.06^{0.05}$	12.85
Riparian vegetation	0.42	0.38	$0.39\pm0.01^{0.05}$	2.82
Wood				
Secondary forest	0.56	0.38	$0.48\pm0.02^{0.09}$	4.45
Tectona grandis plantation	1.66	0.86	$1.36\pm0.09^{0.09}$	12.59
Riparian vegetation	0.46	0.36	$0.42\pm0.02^{0.09}$	3.01

Value in superscript is the LSD value used in comparing the mean difference and mean difference is significantly different across the column at p =.05

Table 3. Total soil carbon stock (Mg C ha^{-1}) measured across the various study sites, n = 10

Name	Maximum	Minimum	Mean±std. error	Total
Secondary forest	6.64	5.39	$5.95\pm0.11^{0.37}$	59.48
Tectona grandis plantation	10.34	9.01	$9.82\pm0.15^{0.37}$	98.25
Riparian vegetation	6.78	5.72	$6.12\pm0.11^{0.37}$	61.23

Value in superscript is the LSD value used in comparing the mean difference and mean difference is significantly different across the column at p =.05

Table 4. Summary of carbon stock recorded in the different compartments across the different physiognomies

Parameters (t C ha^{-1})	Secondary forest	*T. grandis* plantation	Riparian vegetation
Herbaceous plants	0.27(0.38)	0.74(0.58)	0.65(0.91)
Shrubs	1.86(2.64)	2.56(2.02)	3.51(4.93)
Leaf litter	4.42(6.27)	12.85(10.12)	2.82(3.96)
Wood litter	4.46(6.33)	12.59(9.91)	3.01(4.22)
Soil	59.48(84.38)	98.25(77.37)	61.23(85.98)
Total	70.49	126.99	71.22

The percentage contributions of the various parameters to the total carbon storage are in parenthesis

plantation (0.74 Mg C ha^{-1}) than in the secondary forest and riparian vegetation but lower in the secondary forest (0.27 Mg C ha^{-1}) than in the riparian vegetation and plantation. This higher value of carbon stock in herbaceous plants in the plantation and the lower value in the secondary forest can be attributed to the fact that trees planted within the plantation were even spaced and gave rise to open canopy which might have influenced more herbaceous growth in the plantation compared to secondary forest with more closed canopy and lower herbaceous plants population.

The contribution of herbaceous plant to carbon stock across the different physiognomies in this study were lower compared to the reported value of (0.7 Mg C ha^{-1}) for Menglun forest and (1.2 Mg C ha^{-1}) Manyang forests in Southwestern China [21]. The combined results of 1.66 Mg C ha^{-1} for herbaceous carbon stock across the three vegetations was found to be lower than the combined result of 3.6 Mg C ha^{-1} reported in a secondary tropical forest in Philippines [20]. The higher total carbon stock estimated in shrubs in the riparian vegetation (3.51 Mg C ha^{-1}) than the plantation (2.56 Mg C ha^{-1}) and secondary forest (1.86 Mg C ha^{-1}). This can be attributed to the fact this vegetation is being disturbed thereby resulting into higher saplings growth while that of the plantation can be attributed to the open canopy structure. The results of carbon stock in shrubs estimated for the three vegetations in our study are comparable to the results obtained by [18] in Thailand where they recorded carbon stock for shrubs to be 5.95 Mg ha^{-1} in a primary mixed deciduous forest and 1.32 Mg ha^{-1} in a secondary mixed deciduous forest respectively.

4.2 Standing Floor Litter Carbon Stock across Different Vegetation Structures

The values of carbon stock estimated in this study (2.82-12.85 Mg C ha^{-1}) were generally higher than the carbon stock reported in a *Tectona grandis* plantation (0.36 Mg ha^{-1}) in Nigeria [34] for standing floor litters; value of 2.6-3.8 Mg C ha^{-1} in tropical forest in Asia [35]; 5 Mg C ha^{-1} in a tropical rain forest in India [22]. [23] also reported values that vary between 0.16 to 3.26 Mg ha^{-1} in India.

The significant variation among the three vegetations studied with the highest value been recorded in the plantation (12.85 Mg C ha^{-1}), followed by the secondary forest (4.42 Mg C ha^{-1}) and the least in the riparian vegetation (2.82 Mg C ha^{-1}). The significant variation and difference between the three vegetations might be as a result of high litter accumulation observed in the *Tectona grandis* plantation compared to the other sites. The higher litter accumulation might have contributed to the higher carbon stock recorded in the plantation since most carbon is still locked up in these litters. The flooding and leaching of the carbon as well as the flowing stream at the riparian vegetation could have resulted in the low carbon stock recorded in the riparian vegetation. Several other factors have been suggested to account for the variation in leaf litter carbon stock and this include climate, substrate quality and forest fragmentation [36-38].

The quantities of carbon stock (3.01-12.59 Mg C ha^{-1}) recorded in the wood litter across the three vegetations studied are comparable to the values reported for other tropical forests in other parts of the world (<1 to >30 Mg C ha^{-1}) [37-39,40-41], but greater than the estimate of [34] (0.06 Mg ha^{-1}) in Nigeria. The lower carbon stock in the *Tectona grandis* plantation reported by [34] might possibly be as a result of the fact that the site is degraded, younger and that it has just been reforested.

4.3 Soil Carbon Stock across Different Vegetation Structures

Soils in equilibrium with a natural forest ecosystem may have high carbon stock [9] and it has been suggested that the soil carbon stock may comprise as much as 50% of the terrestrial carbon stock in the tropical rainforest [42]. The carbon stored in the soil at 0-15 cm depth across the three vegetations studied (59.48-98.25 Mg C ha^{-1}) is consistent with the range estimated for the first 1 metre depth of soil (84-102 Mg C ha^{-1}) in Southwestern China [21]; and a 0-30 cm depth (79.06 - 95.10 t C ha^{-1}) in Nigeria [8] and are higher than the findings of 0-20 cm depth in Gabon (66 Mg C ha^{-1}) [43]; at 15 cm depth in USA (16.2 to 52 Mg C ha^{-1}) [44]. However, the result from this study was lower than what was reported for the first 1 metre depth of soil in Asia (130-160 Mg C ha^{-1}) [45].

The results in this study were higher than the results obtained for soil C stock at 0-20 cm depth in a 10 years *Tectona grandis* plantation (10.47 Mg C ha^{-1}) and in a disturbed forest (10.58 Mg C ha^{-1}) in Nigeria [34]. This might suggest that age is an important factor that influences the accumulation of carbon stock in the soil, showing that as the forest moves toward maturity, soil carbon stock increases. This assertion is however in contrast to the report of [17] who reported that as the forest move towards maturity, soil carbon stock decreases rapidly. The higher soil carbon stock in the plantation (98.25 Mg C ha^{-1}) and the lowest recorded in the secondary forest (59.48 Mg C ha^{-1}) in this study might be connected with the level of disturbance at the sites. It has been reported that fire, natural or managed is an important perturbation that affect soil carbon stock for a long period [9]. The lower carbon stock recorded in the secondary forest might be as a result of the fire that ravaged the site some 29 years ago. The higher carbon concentration and bulk density recorded in the plantation might have contributed to the increase in soil carbon storage in the plantation [46].

The contribution of soil carbon to total carbon storage was between 77.4-85.9% across the study sites. These values are in line with the findings of [17] who reported that the amount of carbon stored in soil amounted to 74.3% of the total carbon in forest in Costa Rica. Other studies in tropical areas of Costa Rica have shown that the amount of soil carbon was between 50% and 75% of the total forest carbon [47-49]. The findings of higher soil carbon stock recorded across the sites is similar to the findings of [9], who reported that soils are the largest carbon reservoir of terrestrial carbon. This high carbon content on the surface layer (0-15 cm) in these studied sites is a suggestion of the abounding inputs from litter falls, wood and fine roots.

5. CONCLUSION

Carbon stock varies among different physiognomies in the soil pool, other growth forms and standing floor litters. Carbon stock in the soil pool is the highest across the different physiognomies and its contribution to the total ecosystem carbon stock is more than 75%. Standing floor litters pool is the second largest pool and this pool contributed approximately 10% to the total carbon stock in the secondary forest and the *Tectona grandis* plantation except in the riparian vegetation where the contribution is 8%. Other growth forms contribution to the total ecosystem carbon stock was generally small across the different physiognomies. Their percentage contributions are 3%, 2% and 5% in the secondary forest, *Tectona grandis* plantation and riparian vegetation respectively. It was clear from this study that age and disturbance are the dominating factors affecting the different carbon storage at the different pools considered in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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