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Distribution and regeneration status of *Vitex payos* (Lour.) Merr. in Kenyan drylands

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We investigated the population structure and regeneration status of *Vitex payos* (Lour.) Merr. in Kenyan drylands. The study quantified the spatial distribution pattern of *V. payos* tree populations in their natural range; and assessed their regeneration status to determine the stability of the populations Woodlands and farm inventories were conducted in Mbeere, Mwingi and Kitui districts of the Eastern Province of Kenya. The nearest-neighbour sampling method was used to determine tree density and distribution of *V. payos* in the study sites. The number of seedlings and saplings were counted. The diameters, crown diameter, and tree heights of sampled trees were measured. These morphological parameters were summarized on per hectare basis. The patterns of distribution of *V. payos* trees showed an aggregation of trees on farms and bushes. Tree densities ranged from 1.6 on farmlands to 20.3 trees per ha in the woodlands. The expected mean distances between nearest neighbouring trees were higher than the observed values on all sites, confirming that *V. payos* trees were more aggregated than randomly dispersed. The mean tree heights varied from < 5 m to > 9 m cross study sites. The sampled populations were dominated by trees (55%) within the range of 10 to 20 cm dbh. Highest numbers of seedlings from all origins were recorded in the bushes in Kitui and Mbeere districts 101 and 78 seedlings per hectare, respectively. Sapling population densities were generally low.

Key words: Edible wild plants, dryland resources, indigenous fruit trees, Vitex payos, wild fruit trees, Kenya.

INTRODUCTION

Past agricultural activities are some of the major factors that have influenced the present day species composition among the various natural vegetation types in Kenya(Turner et al., 1998). These activities include

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cultivation of food crops, planting of exotic tree species and overstocking of livestock that interfere with the regeneration of natural vegetation through continuous trampling and/or browsing of young plants as well as the reproductive parts of adult plants - flowers and fruits (Turner et al., 1998). In particular, the planting of exotic species for different end-use products including fruits currently poses a major threat to indigenous species such as *Vitex payos*, yet many of these indigenous species are considered slow growers and therefore, often not preferred by farmers for on-farm planting (Dunn, 1991). The increasing human population exploiting a given environment, land fragmentation and climate change also contribute to the overall decline in indigenous vegetation (Wanyonyi, 2012; Oroda, 2011; Morris, 2010).

V. payos like other indigenous fruit trees are commonly found scattered on farms in Kenya (Jama et al., 2008; Ekesa et al., 2009). Small scale farmers retain naturally regenerated *V. payos* trees on arable fields, grazing lands, homesteads and along farm boundaries for various purposes such as fruits, apiculture, timber, shade, soil amelioration, firewood among others (Jama et al., 2008). The species regenerates naturally by seed, root suckers and coppicing (Maundu et al., 1999; Mbora et al., 2008). Root suckers often develop from injured roots especially during land preparation for agricultural purposes (Mbora et al., 2008) or construction of soil conservation structures such as terraces. Due to heavy browsing of the regenerates, especially during the dry season, majority of them remain stunted for long periods. Regenerates established from seeds often suffer heavy mortality because of combined effects of browsing and drought before their root systems are fully developed (Luoga et al., 2004). On the contrary, regenerates that grow from root suckers and stumps benefit from already established root systems and therefore tolerate the extreme environmental vagaries with less threat of mortality (Kauter et al., 2003). Trees in woodlands are often small and suffer from the dry weather due to excess competition. This is unlike on the farms where trees are properly protected through weeding thereby reducing competition for both nutrients and water resulting in bigger trees. However, due to the principal purpose of the land is agricultural, only a few trees are retained. These trees also maintain their leaves for a longer period even after the on-set of the dry season.

The objectives of this study were therefore to: quantify the spatial distribution pattern of *V. payos* tree populations in their natural range; analyze the size distribution pattern of *V. payos* trees under different land uses; and assess the regeneration status of the species in order to determine the stability of the populations. It was hypothesized that the tree spatial distribution in the natural range of the species is not different among locations and land uses. Secondly, that the density of seedling, sapling and mature trees are each randomly distributed on farms and bushlands with their populations decreasing with increasing age, a J-inverse distribution, indicating stable regenerating populations.

MATERIALS AND METHODS

Study area

The study was conducted in Mbeere, Mwingi and Kitui Districts which are located in the arid and semi-arid (ASAL) parts of Kenya. Mbeere is situated at between latitude 00°20' and 00° 50' S and longitude 37°16' and 37° 56' E with a mean annual rainfall of between 640 and 1100 mm, while Mwingi is situated at between 00°03' and 01° 12' S and 37°47' to 38°57' E and receives 600 to 1100 mm mean annual rainfall. Kitui District lies between 00°04' and 03°00' S and 37°45' to 39°00' E and receives a mean annual rainfall of between 500 and 1000 mm. The rains have bimodal distribution from March to May (long rains) and October to December (short rains) with peaks in April and November, respectively. Minimum and maximum temperatures in the study districts are fairly constant with values of 21.6 and 34.8°C in Mbeere, 22.8 and 37.2°C in Mwingi, 21.9 and 36.6°C in Kitui, respectively. These areas are predominantly under subsistence crop production practiced by low resourced farmers, who also rear large herds of livestock under free range grazing system. These areas are also characterized by low soil fertility and experience frequent droughts and famine.

Data collection

Nearest-neighbour sampling method, in which the distance and direction of the 100 sampled trees were measured from a randomly selected individual tree to its nearest neighbour, was used to determine tree density and distribution of *V. payos* in the three study sites (Sparks et al., 2002). However, several trees were found to be each other's nearest neighbour and use of these distances twice could decrease sample variance (Donnelly, 1978). Furthermore, the trees at the edge of the imaginary plot could not have trees outside the fixed number as their nearest neighbours. To overcome the bias as a result of these two conditions, Donnelly's correction factor was used (Donnelly, 1978). Tree densities in circular plots could be estimated as $\rho = n/\pi r_d^2$, where ρ is tree density (trees m^{-2}), n is the sample size and r_d is the distance (m) of the uttermost tree from plot centre, assuming the area occupied by the n trees was circular. In each of the three study areas, two major types of land use, woodlands and on farm, were randomly selected for the survey of tree density, size class distribution and regeneration status of *V. payos*.

In each land use type, one mature *V. payos* tree (≥ 10 cm dbh) was randomly selected and used as the starting tree in all the three sites. Moving in a circular manner around the first tree and while increasing the radius, other 99 neighbour trees were identified, located and marked, keeping the area compact. All the tree positions were recorded using a GPS (GPS 12XL Garmin Olathe KS, USA). Bearings and horizontal distance to the nearest neighbour were also recorded between all trees in a plot using compass and meter tape. These recorded distances and bearings from the starting tree and from one tree to the others were used to estimate the spatial distribution and tree population density in each study site.

The diameters at breast height (DBH), tree heights and crown diameters of all the 100 sampled trees were measured. DBH was measured with a diameter tape, height with a telescopic pole and crown diameter was derived as the average of two perpendicular crown diameters through the crown vertical projection.The area occupied by the 100 sampled trees was mapped graphically on a grid scaled at 50 × 50 m for the study of species regeneration. All the 0.25 hectare grids were allocated a number to allow random selection of plots to sample for seedlings and saplings. Ten percent of these 0.25 ha plots were randomly selected. Within these plots, the seedlings (≤ 1 m height) and saplings (> 1 m height but dbh ≤ 10 cm) were counted. Seedlings and saplings were classified as originating from seed, root suckers or stump coppices. They were distinguished as follows: those from seed generally had one stem at the ground level, those from root suckers were characterized by multiple stems at the base while those from stump coppice had visible stumps. When there were doubts regarding the origin of an individual seedling, root system was partially excavated to reveal the stump or the old root. The number of regenerates of each origin was used to calculate the density (stems ha^{-1}).

Data analysis

The area occupied by the sample trees was more of a polygon with many sides as prescribed by outer trees. Consequently, the area of the plot, A in m^2, was obtained by tracing the coordinates of the outer edge trees and calculating the area of the triangles and rectangles. The lengths of the sides of the polygon prescribed by the outer trees were summed to give the perimeter *L* of the plot. The tree density was therefore computed as $\rho = n/A$. The mean distance between nearest neighbours was computed as $r_A = (\sum r_i)/n$, where r_i is distance of the i^{th} tree from its nearest neighbour. The mean distances that would be expected, r_E, for each plot if the trees were randomly distributed and with the same tree density as the computed value and the variance, σ_r^2 were calculated using the Clark and Evans (1954) formula, $r_E = 1/2\sqrt{(\rho)}$ and $\sigma_r^2 = 0.0683/\rho$, where r_E is the expected mean distance to the nearest neighbour in an infinitely large population with a random distribution of density ρ - (where the unit of measurement used in the calculation of ρ must be the same as that used in measuring *r* – in this case m and m^2).

However, with Donnelly (1978) correction factor, the corrected mean nearest neighbour distance (r_c) and the variance (σ_c^2) are,

$$r_c = r_E + (0.0514 + 0.041/\sqrt{n})*(L/n) \text{ and } \sigma_c^2 = \sigma_r^2 + 0.037\sqrt{(1/\rho)}*(L/n),$$

Where L is the sample plot boundary length (as a polygon) and other variables as defined earlier.

Assuming spatial randomness of the trees, the standard error of the corrected expected mean nearest neighbour distance (s_r),

$$s_r = \sqrt{(\sigma_r^2/n)}$$

such that the *p* value of deviation from the expected mean distance is obtained as (Campbell, 1996):

$$c = (r_A - r_c)/s_r$$

The ratio *R* of r_A/r_c was used as a measure of the extent to which the sampled populations deviated from a randomly distributed population of the same density. Where the trees are heavily aggregated, the *R* ratio tends to 0 as the distances between most neighbouring trees are close to or equal to 0 (Clark and Evans, 1954). At the other extreme, where trees are regularly and uniformly distributed, the *R* ratio is greater than 1 (Clark and Evans, 1954). Besides comparing the spatial distribution of trees between plots, descriptive statistics, non-parametric analyses and t-tests were calculated using SPSS for windows Version 16 to make comparisons between study sites (districts) and land uses (bush and farm). To compare individual districts where significant differences were found, Tukey's post hoc test was applied (Kleinbaum and Kupper, 1978; Dancey and Reidy, 2007).

The tree morphological parameters of height, diameter at breast height and crown diameter were summarized on per hectare basis and checked for normality using Levene test (Dancey and Leidy, 2007). Trees were assigned into dbh classes (10 ≤ 19.9 cm, 20.0 ≤ 29.9 cm, 30.0 ≤ 39.9 cm, 40.0 cm and above); height classes (≤ 5.00 m, 5.01 ≤ 7.00 m, 7.01 ≤ 9.00 m, and 9.01 m and above), and crown diameter classes (≤ 3 m, 3 - 5 m, 5 - 7 m, 7 - 9 m, and 9 m and above). Populations were compared using analysis of variance (ANOVA) at 95% confidence interval. Tukey's post hoc test allowed pair wise comparison of the mean heights, dbh and crown diameters of individual populations. To determine those populations that were actually different, a Mann Whitney U test was used to compare the two land uses while a Kruskal Wallis test was used to compare the districts. Seedlings and saplings were summarized on a per hectare basis from the 0.25 ha plots and ANOVA done to compare the different seedling origins while the land uses were compared using Student t test. Histograms were presented to show the regeneration trend among seedlings, saplings and trees for each population.

RESULTS

V. payos tree population structure

Spatial distribution patterns of mature *V. payos* trees showed that they were not uniformly distributed across their natural range (Figure 1). Trees were aggregated both on cultivated farms as well as in bushlands. Tree densities in the study areas ranged from 1.6 trees per hectare on cultivated land in Mwingi District to 20.3 trees in bush/fallow land in Kitui District (Table 1). Tree densities were higher in bushlands than on cultivated land in all districts. The expected mean distances between nearest neighbouring trees were higher than the observed values on all sites under the two land uses, an indication that trees in these areas were more aggregated than randomly dispersed. This is further supported by the *R* ratio values of the three villages which are less than 1 and the negative standard variate of the normal curve (c) (Table 1). Distribution of trees was positively skewed as there were few isolated trees sampled that were far from the others (Figure 1 and Table 1).

Comparison of the six populations of *V. payos*, gave an *F* value of 5.97 indicating that the six populations were significantly different at $p = 0.05$. Seperation of the means revealed significant Chi-square values of 152.605 for districts and 156.799 for study plots both with an associated probability value of $p < 0.001$. Trees in Mbeere were relatively more dispersed while trees in Kitui were more aggregated (28.28 ± 1.60 m for Mbeere; 17.26 ± 1.74 m for Mwingi; and 6.29 ± 0.57 m for Kitui trees). In the study plots, the mean nearest neighbour distance ranged from 5.10 ± 0.7 m in on farm land in Kitui to 33.56 ± 2.47 m in farm lands in Mbeere District. There were no differences between combined data for each land use from the three districts with *Z* value of -0.505 and *p* value of 0.613.

At 95% confidence interval, the population structure

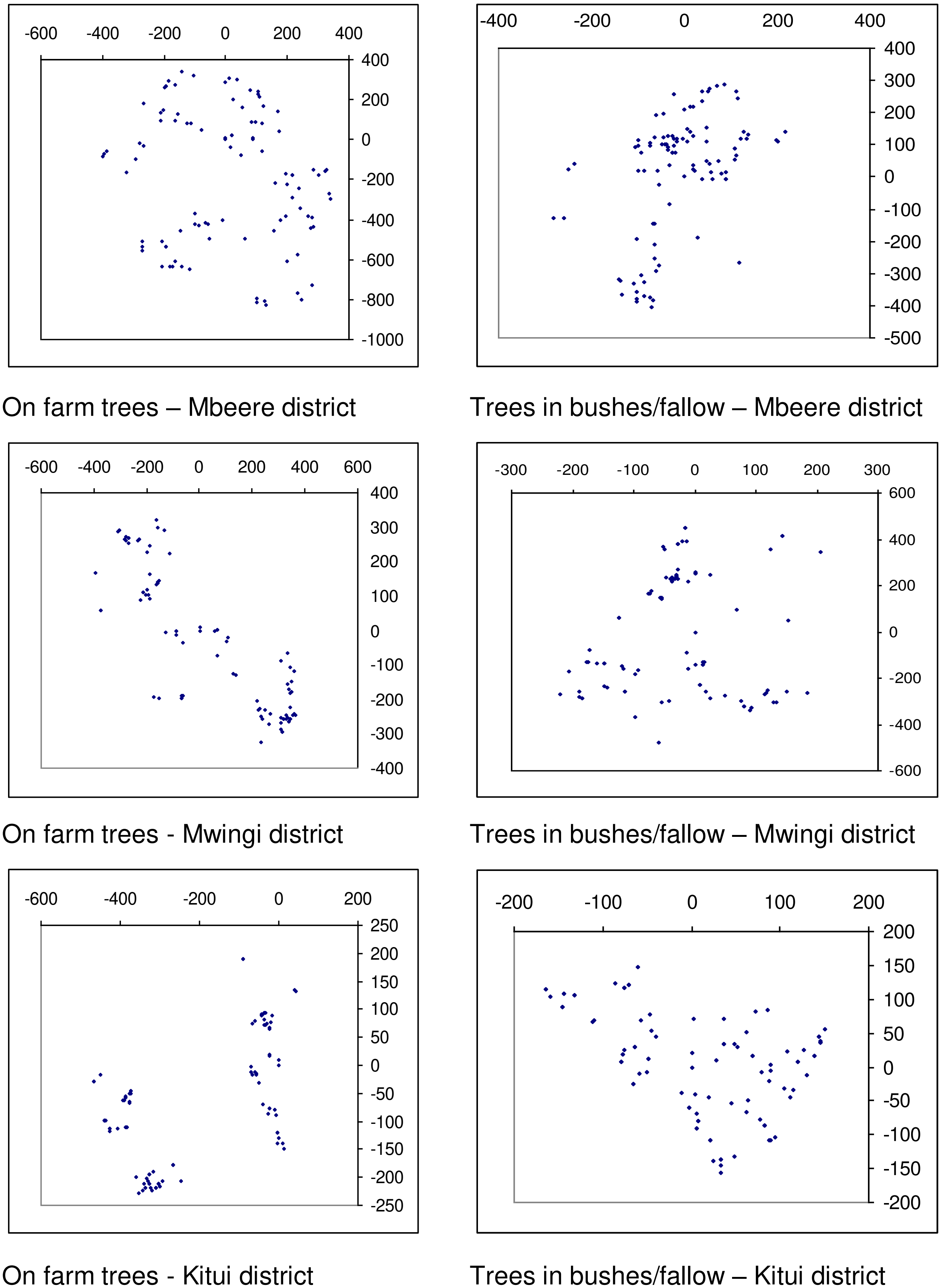

Figure 1. Spatial distribution pattern of mature *V. payos* trees on arable land and bushland in villages in Mbeere, Mwingi and Kitui Districts, Kenya (distances are in metres, 0,0 represents the center tree).

Table 1. Comparison of *V. payos* tree population densities and spatial distribution in arable and bushland in Mbeere, Mwingi and Kitui districts of Eastern province Kenya

Statistics	Mwingi		Kitui		Mbeere	
	On farm	Bushes/fallow	On farm	Bushes/fallow	On farm	Bushes/fallow
Area occupied by sample trees as a polygon (m2)	283119.5	267361.5	137157	49275.5	610279	210422.5
Number of trees sampled (n)	100	100	100	100	100	100
Sample population density (ρ)	0.000353	0.000374	0.000729	0.00203	0.000164	0.000475
Sample tree density per hectare (m)	3.53	3.74	7.29	20.29	1.64	4.75
Total distance between nearest neighbour (Σri)	1386.56	2045.43	509.86	728.11	3356.32	2279.46
Mean distance between nearest neighbours (rA) = (Σri)/n	13.86	20.45	5.10	7.28	33.56	22.79
Skewness of distribution of mean nearest neighbor	1.74	1.94	1.82	1.01	0.72	2.23
Expected mean distance between nearest neighbour in a large randomly distributed population of ρ density (rE =1/2√ρ)	26.61	25.85	18.52	11.10	39.04	22.94
Length of the sample plot boundary L	2132	2204	1470	925	2892	1799
Corrected expected mean nearest neighbour distance rc rc= rE+(0.0514+0.041/√n)*(L/n)	27.79	25.99	19.34	11.61	40.65	23.94
R ratio (measures the degree to which observed distribution deviates from a randomly distributed population of same density), [R = (ra/rc)]	0.50	0.79	0.26	0.63	0.86	0.99
σrE= 0.26136/√ (n. ρ): standard error of mean distance to nearest neighbour in a randomly distributed population of density ρ.	1.39	1.35	0.97	0.58	2.04	1.20
Variance of normally distributed distances in a random populations, $\sigma r^2 = 0.0683/\rho$	193.48	170.59	93.69	33.65	416.46	143.79
Variance of corrected mean nearest neighbour distances (σc2) [$\sigma c2=\sigma r^2+0.037\sqrt{(1/\rho)}*(L/n)$]	235.47	42.17	113.83	41.25	500.02	174.33
Standard error of the expected mean nearest neighbour distance sr = $\sqrt{(\sigma r^2/n)}$	1.39	1.31	0.97	0.58	2.04	1.20
Standard variate of the normal curve (c) = (rA – rE)/(σrE)	-10.02	-4.10	-14.68	-7.47	-3.48	-0.96

of the *V. payos* in Kitui District, irrespective of land use, were not significantly different.

The same was observed for sample plots in Mwingi District. However, trees on farms in Mbeere District were significantly more dispersed than those in bushes. Pair wise comparisons of the mean nearest neighbour distances between individual study plots using the Mann Whitney test showed all were significantly different (*Z* values -2.649 to -9.213, *p* values 0.01 to < 0.001) except between those in Mwingi; those in Kitui and the ones in bushes in Mwingi and Mbeere Districts.

Tree morphological characteristics

Tree height

Tree heights were not significantly different between the two land use practices across districts. Over 40% of trees from Kitui District were in the ≤ 5 m and 5 – 7 m height classes each, but 40% of those in Mbeere District were in the 5 – 7 m and 30% in the 7 – 9 m classes (Figure 2). Trees from Mwingi District were mainly in the intermediate height classes between these extremes. Mean heights differed significantly between individual study plots (Table 2). The trees in Kitui District were significantly shorter while trees in Mbeere were the tallest. In all districts, the trees on farms were taller than those in bushes (Table 2). Analysis of variance revealed that the tree heights in the three districts were significantly different from each other at 95% confidence interval (Table 2).

Diameter at breast height (dbh)

V. payos populations sampled were dominated by

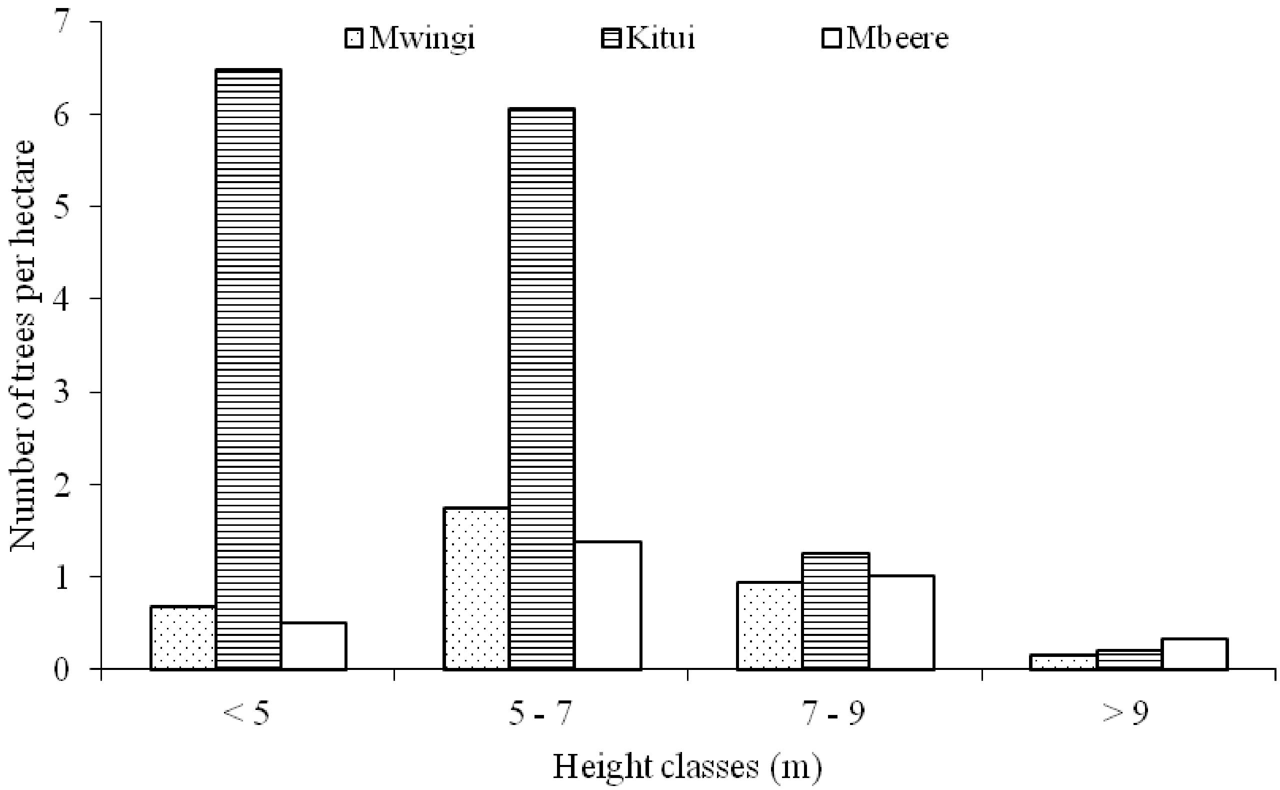

Figure 2. Height class distribution of *V. payos* trees in Mbeere, Mwingi and Kitui Districts in Eastern province, Kenya.

Table 2. Mean *Vitex payos* tree heights, dbh and crown diameter in three districts in Eastern province, Kenya.

District	Height mean (m)	Mean dbh (cm)	Mean crown diameter (m)
Kitui	5.25 ± 0.10^a	18.0 ± 0.4^a	4.86 ± 0.10^a
Mwingi	6.16 ± 0.11^b	18.1 ± 0.5^a	5.50 ± 0.12^b
Mbeere	6.80 ± 0.13^c	24.4 ± 0.6^b	5.81 ± 0.13^b

trees within the range of 10 to 20 cm diameter with over 55% of the trees (Figure 3). In Kitui and Mwingi Districts, the 10 - 20 cm diameter class contributed 60 and 76% of their population on farms and bushes, respectively. Trees with diameters above 30 cm made up to 8 and 7% of the trees in the two districts respectively. There was no clear difference in terms of tree diameters on farms and in bushes in the two districts. Trees in Mbeere in the 10 - 20 cm diameter class accounted for 25% of the population while trees with diameters higher than 30 cm were more on farms (36%) as compared to bushland (20%). Diameters differed significantly among plots in Mbeere with trees from this district differing significantly from those of the other two districts at p = 0.05 (Table 2). Mean diameters were higher in *V. payos* trees found in bushlands in Mwingi and Kitui Districts while the trees found on the farms in Mbeere had higher diameters than in those that were in the bushlands.

Tree crown diameter

Over 77% of trees in all populations were in 3 – 5 m and 5 – 7 m crown diameter classes. Among trees in bushland of Kitui District, 67% of the tree population had crown diameters of up to 5 m while those in cultivated sites had 51% of their population with crown diameters in the same range. The two study plots had 8% of the trees with crown diameters of more than 7 m. In Mwingi District, 38% of the trees had crowns with diameter of up to 5 m while 17% of the tree population had above 7 m crown diameters. There were more trees in the bushes with high crown diameters at 20% than on farms (15%). In Mbeere District, there were more trees with crown diameters less than 5 m (41%) and above 7 m (26%) on the farms than in the bushes (23%). Analysis of variance revealed significant differences between tree crown diameters in districts (Table 2). There were no significant

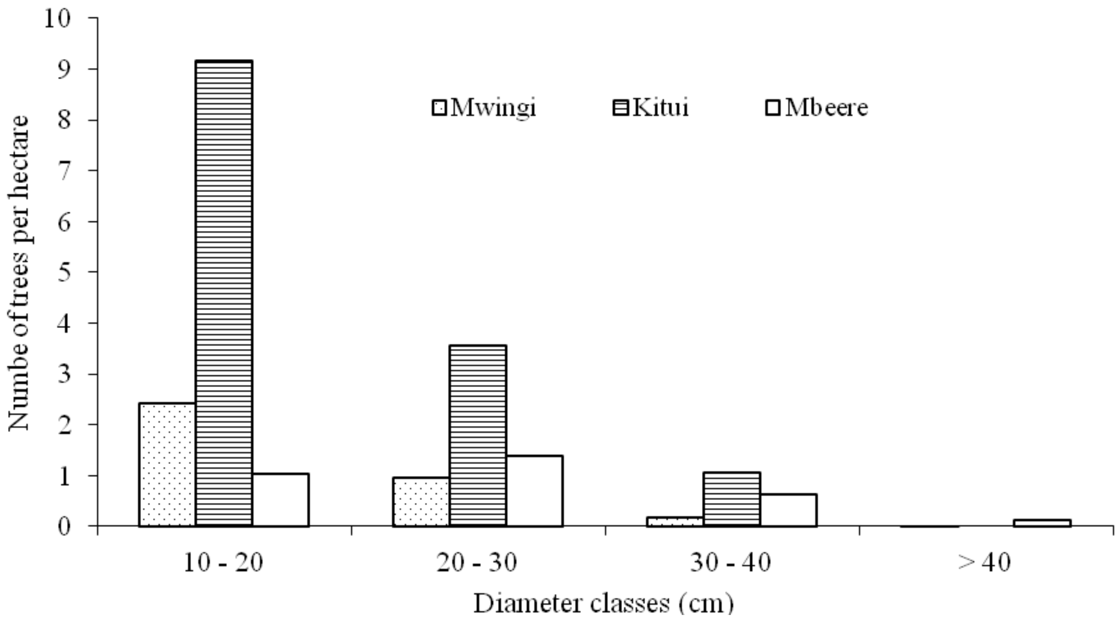

Figure 3. Diameter class distribution of *V. payos* trees in Mbeere, Mwingi and Kitui Districts, Kenya

Table 3. Mean number of *V. payos* seedlings per hectare from different land uses three districts in Eastern province, Kenya.

District	Land use	Origin of seedlings			
		Seed	Root	Stump/coppice	Combined
Mbeere	On farm	0.04[a]	0.04[a]	5.02[a]	6.00[a]
Mwingi	On farm	1.45[a]	6.55[bc]	2.91[a]	10.91[ab]
Mwingi	Bushland	4.08[ab]	1.06[ab]	1.06[a]	8.00[ab]
Kitui	Bushland	14.67[bc]	38.67[d]	47.33[c]	100.7[c]
Kitui	On farm	17.33[bc]	4.44[bc]	7.56[ab]	29.03[b]
Mbeere	Bushland	47.56[c]	16.44[cd]	13.78[b]	77.78[c]

Mean number of seedlings in a column followed by same letter are not significantly different at $p = 0.05$.

differences between tree crown diameters of trees on farms and in the bushlands. However, the trees on farms had slightly bigger crown diameters in Mwingi and Kitui Districts. Mbeere trees in bushes had bigger crowns than those on farms though the difference was minimal.

Regeneration of *V. payos*

Seedling populations

The highest numbers of seedlings from all origins were recorded in bushlands in Kitui and Mbeere Districts with combined 101 and 78 seedlings per hectare, respectively. The farm site in Kitui had 29 seedlings per hectare. Other study sites had fewer seedlings, with less than 10 individuals from all three sources, that is, seed, stumps and root sprouts. Sixty one percent of seedlings in bushlands in Mbeere were mainly from seed while 46.7% of those in bushlands in Kitui were from stumps and 38.5% from root suckers. The farm site in Kitui had a moderate population of seedlings (17 seedlings per hectare) of seed origin, which were more than those in bushlands (15 seedlings per hectare). On the farms in Mwingi, there were seedlings from root suckers that were protected by farmers. There were seven seedlings per hectare from stumps on farms compared to two seedlings from seed origin per hectare. In bushlands in Mwingi, regeneration was very low as was the case on farm in Mbeere District. In these study plots, regeneration was very low irrespective of the seedling origin with six and eight seedlings per hectare respectively (Table 3).

Analyses of variance revealed that there were significant differences between seedling numbers from individual origins and combined origins between the sample plots (Table 3). In the Mwingi bushlands, there

Table 4. Mean number of *V. payos* seedlings per hectare from Mwingi, Mbeere and Kitui districts in Eastern province, Kenya.

District / land use	Origin of seedlings			
	Seed	Root	Stump/coppice	Combined
Mwingi	3.05 ± 1.68[a]	4.19 ± 2.15[a]	2.29 ± 0.76[a]	9.52 ± 2.81[a]
Mbeere	22.74 ± 8.37[b]	8.00 ± 3.28[ab]	9.26 ± 2.27[b]	40.00 ± 11.22[b]
Kitui	16.27 ± 5.07[b]	18.13 ± 6.33[b]	23.47 ± 9.13[b]	57.87± 14.63[b]

Mean ± (sem) number of seedlings followed by same letter are not significantly different at p = 0.05.

Table 5. Mean number of saplings per hectare from different origins in three districts in Eastern province, Kenya (± sem).

District	Land use	Origin of saplings			
		Seed	Root	Stump/coppice	Combined
Kitui-	On farm	0	3.56 ± 2.05	7.56 ± 5.23	11.11 ± 6.79
Mbeere	On farm	0	0	1.2 ± 0.85	1.2 ± 0.85
Mwingi	On farm	0.36 ± 0.36	1.09 ± 1.09	2.18 ± 1.46	3.64 ± 2.50
Mbeere	Bushland	0.44 ± 0.44	1.78 ± 1.35	4.44 ± 2.62	6.67 ± 3.64
Mwingi	Bushland	2.8 ± 1.34	1.2 ± 0.85	2 ± 1.37	6 ± 2.40
Kitui	Bushland	3.33 ± 2.17	19.33 ± 12.33	12.67 ± 4.43	35.33 ± 18.17
p value		0.055	0.145	0.163	0.216

were high regeneration from seed while in Kitui bushlands, there were more seedlings regenerated from the root sprouts and coppices (Table 3). There were significant differences in seedling population from all origins among the three districts. Among seedlings of seed origin, Mwingi had the lowest population (6 seedlings per hectare) while Mbeere had the highest (48 seedlings per hectare) (Table 4). However, among seedlings from root sprouts and coppices, Mwingi had the lowest population (8 and 4 seedlings per hectare) while Kitui District had the highest number (43 and 55 seedlings per hectare respectively). Overall Kitui had highest seedling population though not significantly different from those in Mbeere. Combining all the districts, seedlings from all origins had significantly higher densities in bushes (55.36±11.35) than on farms (14.8±3.92).

Sapling populations

Sapling population densities were low, ranging from one sapling per hectare on farms in Mbeere District to 35 saplings per hectare in bushlands in Kitui. The saplings were generally few on farms with an overall mean of five saplings against a mean of 16 saplings in bushlands from the three study districts. In all locations, saplings of coppice origin dominated except in bushlands in Kitui where those from root suckers were dominant and in bushlands in Mbeere where saplings of seed origin were dominant (Table 5). On farms in Kitui and Mwingi Districts, there were no saplings of seed origin encountered, while on farm in Mbeere, only saplings of coppice were encountered. Analyses revealed no significant differences between saplings from all origins between the study sites (Table 5). Between the land uses, mean number of saplings of seed origin differed significantly (p = 0.009) while those from root suckers, coppices and all sources combined were not statistically different. Although there were no significant difference of sapling from root sprouts and stump coppices between on farm and bushlands, the number was higher in the bushlands in all cases. Comparison of the combined population of seedlings in the two land uses, saplings and trees, revealed a normal population trend though weak in bushlands (Figure 4). On cultivated sites, a reverse trend was observed: on farms in Mwingi District, there were more saplings than seedlings; while in Kitui and Mbeere Districts study sites, there were more trees than saplings (Figure 4).

DISCUSSION

Population structure

V. payos trees on farms were normally clustered in aggregates based on the farmers' acceptance of the species, the past land use practices and the current level of utilization of the trees and their products. Some farmers have left some trees in clusters on the farm for commercial harvesting of the fruits while others spared

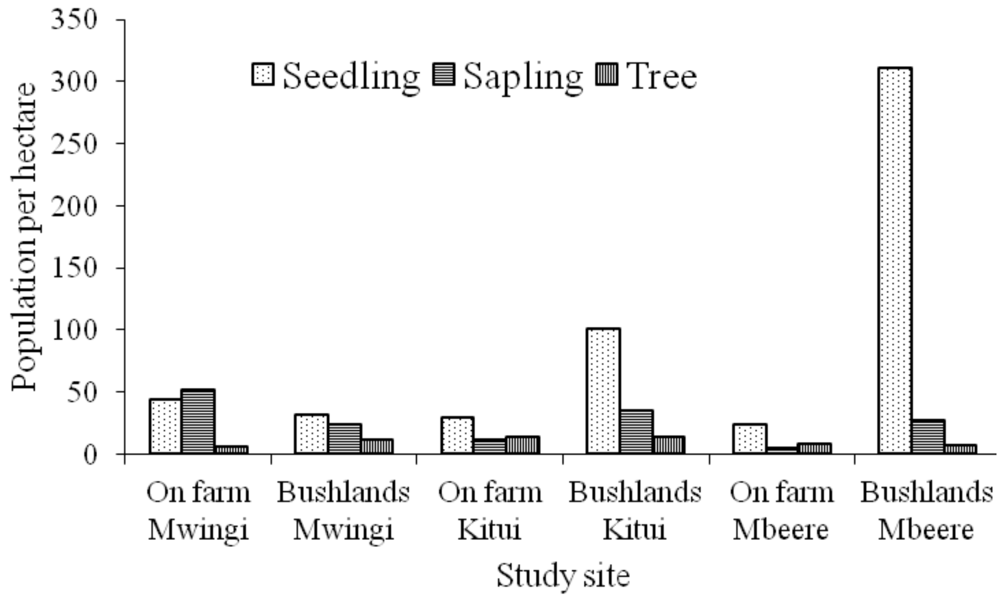

Figure 4. *V. payos* seedlings,saplings and trees in three districts in Eastern province, Kenya.

individual trees for provision of subsistence fruits to their households. Other trees were retained to provide sites for beehive keeping on the farms or shade for animals during dry season. Tree population densities expressed on a per hectare basis showed that there were fewer trees on farms than in bushes in all districts. In Mbeere, where the fruits are widely consumed with no sales, there were correspondingly fewer trees per hectare on farms than in bushlands. While in Mwingi District, where some farmers were involved in sale of fruits, the density of *V. payos* on the farm and in bushes were more or less equal. Farmers in this district were divided on the actual position of these fruits as commodity of trade. While some farmers left their fruits to waste on the ground, a few collected and took to markets. As a result, the maintenance and appreciation of the species was moderate, thus the low density of trees. In Kitui, the density of *V. payos* trees was higher than the other places; and higher in bushlands than on farms. Kitui study area was situated between two local markets, Ikanga and Mutomo, where these fruits are sold when in season. Thus traders frequented the area and many farmers were involved in on-farm sale of *V. payos* fruits.

The spatial distribution of the species did show aggregated clumps of trees scattered on farms. This indicated selective removal of trees and/or poor regeneration of the species. Among the six study populations, trees aggregation was high in Kitui and on farm sites in Mwingi with mean distances between nearest neighbouring trees being less than 15 m. The cause of this situation was retention of clumps of trees by individual farmers, rather than all sampled trees being close together on farms in the two districts. *V. payos* trees in Kitui District bushlands were scattered closely together as a stand in woodland whose farming activities were minimal and the owners were of advanced age. This clumped spatial distribution may be related to the past cutting for firewood and charcoal and the extensive coppicing and suckering ability of species.

In the villages with high mean distances between trees, several conserved trees were isolated on farms away from their nearest neighbouring trees (e.g. Mbeere District bushlands). While He et al. (1997) pointed out that the spatial distribution of a population shifts from highly aggregated to more random or uniform with succession, the tree population in the study areas was very low. Further, both abiotic (e.g. drought) and biotic factors (e.g. grazing, cutting, poor germination) may have greatly contributed to the current distribution pattern. According to Jama et al. (2008), the density of indigenous fruit trees often decreases with increasing human population pressure. Tree distribution in Mbeere was sparser than in the other two districts. The use level of the *V. payos* trees in Mbeere was low with only a few trees retained by individual farmers for provision of subsistence fruits and setting of beehives. Their crowns were said to be incompatible with both tobacco and ‘khat’ (*Catha edulis*) crops on farms, two cash crops extensively cultivated in Mbeere study area.

The height structure of *V. payos* showed that there is a consistent size class distribution trend in Mbeere and Mwingi Districts, which differed from that of Kitui. Stands in Kitui were predominantly in an area that experienced less precipitation than the other areas. The area formed the extreme edge of natural range of species to the south. It was therefore possible that the trees were not in their optimal conditions in terms of moisture, and thus the stunted growth. The diameter growth of the trees also followed the same trend, with tree sizes increasing as the environmental conditions (rainfall) improves from Kitui through Mwingi to Mbeere. Seedlings and saplings are by virtue of their size, greatly influenced by intensity, magnitude and frequency of disturbance they are subjected to (Khan et al., 1987; Duchok et al., 2005). In the present study, destruction of seedlings occurred mainly in the cultivated farmlands partly due to little appreciation of these trees by the farmers. During land preparation and weeding of crops, the seedlings and saplings of *V. payos* were normally uprooted together with other weeds. In the field, seedlings originating from seed could fail to grow due to soil compaction or destruction of seed before germination. Preliminary observations of the fruits of *V. payos* revealed that most of them contained few viable seed, either due to poor pollination or to fungal infection of embryo immediately after pollination (Kimondo, 2010).

Duchok et al. (2005) showed that germinated seedlings of *Illicium griffithii* were mainly found below fruiting trees. *V. payos* seedlings germinated below canopies of fruiting trees in bushes and cultivated areas. Nevertheless, in the bushes, these sites were normally the resting places for animals in the field especially during the dry hot season. Animals trampled upon the young seedlings causing heavy mortality. Kindeya (2003) quoted in Ogbazghi et al. (2006) reported that the seedlings in grazing fields often suffer as high as 90% mortality. Young seedlings were also prone to death due to effects of drought. In the present study, saplings on farms were frequently cut back to reduce the area they occupied thereby curtailing their development into mature trees. During the dry season, green foliage of *V. payos* saplings provided material for covering traditional earth kilns for charcoal production (Kimondo, 2010). In the fields, livestock also heavily browsed on crown of saplings while others were broken. Transition of saplings into trees was therefore very low. This seems to imply that there was generally poor natural regeneration status of *V. payos* in all the study areas, though the situation was more critical on the farms.

Variation of trees in size class distribution in natural stand should ideally follow a normal distribution. Many factors could cause some deviations in different locations. Ogbazghi et al. (2006) indicated that the deviation could be caused by the pattern of regeneration and anthropogenic factors assuming local environmental conditions are the same. In Mwingi, it was noted that *V. payos* trees compete for space on the farms with several introduced fruits such as citrus, mangoes, avocados and guava among others. The exotic fruits have ready market locally, and they fetch higher prices than the indigenous fruits. As such, indigenous fruit trees were cut to create space for agricultural crops and exotic fruit trees. The occurrence of burnt stumps of indigenous trees, including *V. payos* on farms near traditional earth charcoal kilns indicated the aim was to obtain charcoal and suppress the tree coppicing. There was marginal utilization of *V. payos* fruits in Mbeere mainly by children. The high income realized from both 'khat' and tobacco necessitated cutting of most *V. payos* and other indigenous trees to minimize competition of resources such as light, water and nutrients. High germination rate of *V. payos* seed in bushland in Mbeere occurred on land whose owners were absent (Kimondo, 2010). Fallen ripe fruits generally remained on the ground with minimal collection. After rains, these germinated directly below the tree. However, during the dry season, animals browsed and trampled the young seedlings resulting in minimal translation into saplings.

In a stable tree population, the number of seedlings should be higher than that of saplings and saplings numbers higher than that of trees (Duchok et al., 2005). The situation in Mbeere and Mwingi may without any efforts to plant or conserve the regenerates of *V. payos*, lead to the species becoming rare. The fact that most seedlings and saplings originated from root suckers and coppices is not healthy for the survival of *V. payos* in the study areas. It was therefore concluded that in such a situation, future planting stocks could be clones of existing trees as few seedlings from the seeds do mature into productive trees (Neke et al., 2006). The benefits associated with new genetic combinations shall thus be limited where regeneration through seed remains suppressed. This could also eventually result in regenerating trees close to parent trees, thus hindering exploitation of potentially new niches.

Crown diameter of *V. payos* ranged from 3 to 9 m though trees with greater diameters were observed especially on cultivated or fallow sites. This implied that with appropriate tending of trees and reduction of competition, it is possible to increase the crown volume and therefore fruit production. The large sized tree crowns in Mbeere could have been influenced by the higher rainfall received in the area. However, few big sized trees with large crowns still exist in areas experiencing harsh environmental conditions and sandy soils in Kitui and Mwingi. The production of fruits depends on an extensive crown of a vigorously growing tree. Identification of such trees growing in extreme marginal areas may provide future well adapted germplasm for planting.

CONCLUSIONS AND RECOMMENDATION

This study was aimed at investigating the population structure and regeneration status of *V. payos* in the drylands of Kenya. The spatial distribution pattern of mature *V. payos* trees showed an aggregation of trees both on farms and in bushes. Tree densities ranged from 1.6 trees per hectare on farmlands to 20.3 trees in the bushes. The expected mean distances between nearest neighbouring trees were higher than the observed values in all sites, confirming that *V. payos* trees were more aggregated than randomly dispersed. The mean heights of the trees varied from 5.19 to 7.05 m cross the three study districts. Tree heights in the three districts were significantly different from each other. The sampled populations were dominated by trees (55%) with a mean diameter ranging from 18.0 to 24.4 cm and mean crown diameter ranging from 4.86 to 5.8 m.

Highest densities of seedlings from all origins (seed, stumps and root sprouts) were recorded in the bushes in Kitui and Mbeere Districts with combined 101 and 78 seedlings per hectare respectively. Regeneration of seedlings was very low in Mwingi and some areas in Mbeere. Sapling densities were generally low with an overall mean of five saplings per hectare on the farmland against a mean of 16 per hectare in bushes from the three study areas. *V. payos* fruits are generally valued in some areas as a subsistence and commercial product. However, because of the high preferences of exotic fruits coupled with an increasing human population in the study areas, it was observed *V. payos* among other indigenous fruit trees continue to be cut down. Furthermore, natural regeneration was affected by livestock through browsing and trampling. Considering the adaptability and resilience of *V. payos* in these harsh environmental conditions in drylands, there is a need to promote its wide scale utilization and conservation. Superior trees in terms of tree size and the desired fruit traits should be sought to provide planting germplasm.

Conflict of Interest

The authors have not declared any conflict of interest.

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