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Pteropus voeltzkowi and the Understory: A Study of the Behavioral Impacts of the Pemba Flying Fox on the Vegetation and Soil Quality of Pemba Island

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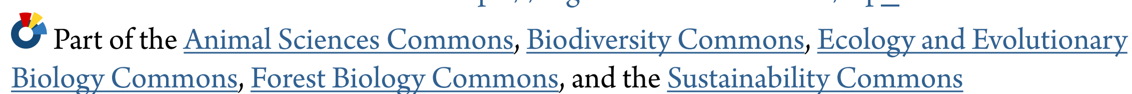
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Pteropus voeltzkowi and the Understory: A Study of the Behavioral Impacts of the Pemba Flying Fox on the Vegetation and Soil Quality of Pemba Island

Lea Davidson

SIT Tanzania- Zanzibar Spring 2017
Macalester College
Advisor- Said Juma

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1.0 Acknowledgments

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2.0 Abstract

This study examines the impact of *Pteropus voeltzkowi*, colloquially known as the Pemba Flying Fox, on biodiversity and health of the forest ground layer. Known to serve as reforesters, high concentrations of both fruit seeds and nutrient dense guano are introduced into specific environmental locations due to the bat's behavioral patterns. Working around two roost locations, one in Ngezi Forest and the other at the Kidike conservation site near Mjini Ole, diversity of juvenile vegetation was measured and quantified. In a laboratory setting, soil samples from both sites were analyzed for impacts of guano concentration on soil chemical properties. Results found trends at the Kidike roost site of increased vegetation diversity with roost proximity, while soil analysis indicated a correlation between increased guano concentration and increased soil fertility.

3.0 Introduction

Subsistence or economic use of natural resources is a staple in the livelihoods of many Pembans', with prevalent charcoal production, rubber tapping, clove plantations, commercial timber cutting, and small-scale farming. These practices, many introduced by or developed as a coping method for colonial pressures, all in some way take from the land, carving the island's once blanket of primary forest into a distinct patchwork across the landscape. As populations and levels of individual consumption have grown with time, what once were tenable land use strategies developed into rates of unsustainable use. A variety of efforts have been employed to mitigate the effect of deforestation on the island of Pemba by local and foreign actors, yet I believe that other effective conservation strategies already exist, incorporated within the ecosystem to manage temporal variation.

This study will assess the effect of *Pteropus voeltzkowi*, the Pemba Flying Fox, on the forest ground layer, defined in this paper as encompassing all vegetation less than 1 m and the composition of the soil A horizon.

4.0 Background

The island of Pemba lies at the northernmost tip of the Zanzibar Archipelago in the Western Indian Ocean (WIO), 6 degrees south of the equator and off of the east African and Tanzanian coast. Pemba is home to a tropical, sub-humid climate, with a temperature fluctuation between 23 and 30 degrees celsius and up to 200 cm of rainfall annually. Two primary rain patterns distinguish the island's seasons, with the 'masika' heavy from March to May in which the

island obtains half of its total annual rainfall, and the lighter 'vuli' rainy season from October through December (FAO U.N., 1990).

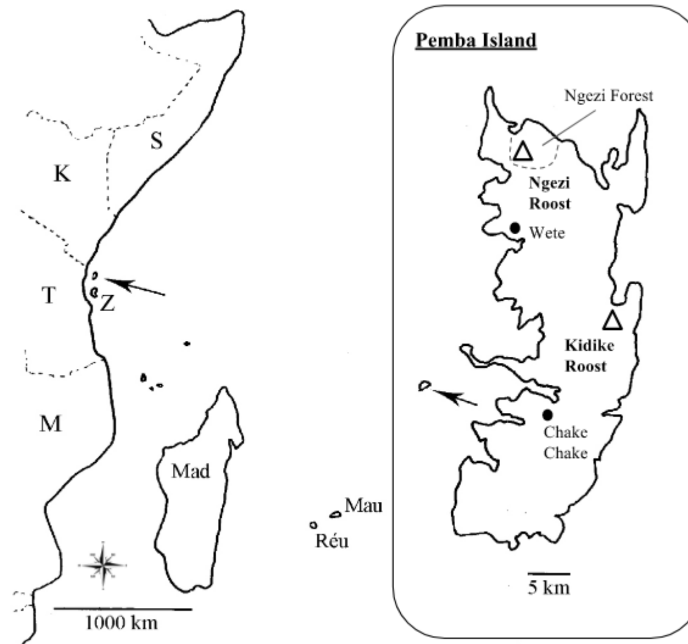

Figure I. Map of east African coast, with inset of Pemba Island. Triangles mark study locations on the island.

With a relatively low population density, Pemba is largely rural, with undulating hills broken only by small agricultural plots of common subsistence crops such as cassava, rice, and bananas. In total, 74% of the island's land use is for cultivation of both subsistence, but also commercial crops, such as cloves or coconuts. Pemban soil is relatively fertile, formed under the deposition of deltaic sediment during the late Miocene, today a mix of eroded silts, clay, and sand (FAO U.N., 1990).

Nine-hundred and eighty-eight square kilometers, this island is separated from the coast of mainland Tanzania and Unguja island by approximately 50 km and deep channels. Believed to

have separated due to faulting during the early Pliocene, approximately 6 Ma years ago, as a result the island is home to only 27 mammalian species (Rowson, 2010). Of these, 13 are species of bat, yet *Pteropus voeltzkowi* remains the only endemic mammalian species on the island. It is not uncommon for subspecies of the order Megachiroptera, commonly known as Old World fruit bats, to develop endemism on islands, with dispersal across the WIO region of Australia, Southeast Asia, and Eastern Africa (Mickleburgh, Hutson & Racey, 1992). *P. voeltzkowi* are especially suited to the highly vegetated island of Pemba, as their diet staples include fruit in the form of mangos, breadfruit, figs, and papaya, and additionally nectar and pollen. Settlement of the island by humans and the subsequent cultivation of fruit trees has further supported their survival, as *P. voeltzkowi* remains the largest frugivorous flying species on Pemba (Entwistle, 1997)[b].

Though historic roosts have been identified throughout the island, a 1989 survey yielded a population of only 10 recorded individuals, marking the bats at critically endangered under the IUCN. Pembans' relations to *P. voeltzkowi* are generally that of relative indifference, as bat impact on commercial fruits is generally minimal, as they prefer over ripe fruit unfit for sale. Overhunting though was attributed as a factor of this decline, as fruit bat is a traditional food (Entwistle, 1997)[a]. Large scale deforestation however, resulting in habitat loss, was likely the main cause of this decline, and community education and protection efforts were rapidly implemented (Leary, 1998). A subsequent survey in 1992 indicated the existing population had returned to upwards of 3,600, yet persistent pressure on land and forest resources continues to threaten their existence (Entwistle, 1997)[a].

In recent years, researchers have hypothesized that fruit bats potentially play a less passive role in maintenance of forest habitat. Fruit bats are known to not only consume fruit, but in the process carry it long distances, releasing undesired products such as seeds into their immediate environment in the forms of both scat (guano) and ejecta (pellet of pulp, fibers, and seeds spit out) (Entwistle, 1997)[b]. Further studies indicate that passage of seeds through the short digestive tract of fruit bats is correlated to significantly faster rates of germination, as the pericarp is compromised (Fleming & Heithaus, 1981). *P. voeltzkowi*'s coating of fine brown hair additionally plays a role in pollination. In the instance of the Kapok tree, it is believed that *P. voeltzkowi* serves as the only seed dispersal agent on the island (Elmqvist et al., 1992). The flight patterns of the Pemba Flying Fox make their behavior as agents of seed dispersal critically important to Pemba, both for reforestation and conservation efforts of primary and secondary forest, and for the maintenance of economically valuable plant species across the island. Because they fly multiple kilometers each night, bats have the ability to access and connect these isolated patches of forest.

Thriving *P. voeltzkowi* communities additionally have positive implications for the agricultural sector. Recent experimentation has indicated that bat guano is especially high in the nutrients of phosphorous and nitrogen, and work is beginning for its implementation as a method of organic fertilizer. Studies involving plant germination and guano input have found significant impacts, with a positive correlation of application to overall biomass, expediting early stage plant growth (Shetty, 2013). The soil of Pemba has historically suffered from lovel levels of phosphorous, and Pemban use of already available guano as fertilizer would not only improve

yields, but strengthen further justification for the preservation of *P. voeltzkowi* roosts on the island.

5.0 Study Area

5.1 Ngezi Forest Roost Site

In Ngezi forest, patterns of movement, roosting, and migration by *P. voeltzkowi* are relatively fluid. Though local oral history and ranger knowledge asserts the presence of between three and four distinct roosting locations within Ngezi, occupation of these locations occurs with seasonal and daily variation. Indeed when initially evaluating which roost in which to focus the study, park officials led me to a roost area near the eastern perimeter bordering farmland, and a large roost relatively near the park entrance off of the main road. This first area was visited only one day, proving difficult to locate and relatively deserted, with only two bats visible. Park officials noted however that this site is a historic roosting location, and on this day the bats likely chose a different area of the forest, possibly due to disturbance, but likely random choice. Visiting the second roost on multiple days, numbers of *P. voeltzkowi* varied widely, with accurate counting difficult due to a thick canopy. Population numbers ranged from approximately 40 to 150 individuals across multiple days. Here the bats were known to reside in an approximate area, with several large trees for which they indicated preference, yet their specific location fluctuated. This location was ultimately the selected research site within Ngezi forest.

The soil at this location is relatively acidic, with a pH level slightly higher than 5.5. Distinguished as a humic cambisol, this is a soil of poorly defined structure with organic

material. Soil is dark brown and sandy, with silica acting as a cementing material. Like most tropical forests, overall organic matter content is low (FAO U.N., 1990).

5.2 Kidike Roost Site

The second location was at the Kidike roost site, near the village of Mjini Ole. Oral history and oversight by the Kidike Conservation Club indicates that the roost has been in operation for upwards of 50 years. This is partially due to cultural taboos protecting the roost area, a local graveyard. This patch of forest is surrounded by farm land, consisting of an average of 29 trees joined by patches of thick overgrowth. Here, *P. voeltzkowi* permanently reside in large numbers, ranging from to 1,352 to 1,689 individuals during the observation period. This permanence is partially attributed to the isolation of this forest segment, but also to historic preference. This site experiences increased levels of surrounding disturbance, as it borders the village and bats are frequently exposed to humans.

Soil at this location is classified as a vertic and gleyic cambisol, meaning a soil lacking defined horizons with clay content and saturation of water. This is likely a result of some of the erosion products of Miocene clays. pH of this soil typically ranges from 6.8-8.8, considered a part of the island's 'lowland soil'. Soil is a dark brown clay, though samples collected appeared relatively sandy (Land Evaluation, Pemba, 1990).

6.0 Methodology

This study incorporated both field and laboratory components for the analysis of two varying *P. voeltzkowi* roosting locations on Pemba island. Quantitative methods were employed to analyze vegetation diversity and density in proximity to *P. voeltzkowi* roosting sites in situ,

while additional analysis of soil quality was carried out through sampling and assessment in laboratory.

Roosts selected for study were chosen based on quantity and consistency of *P. voeltkowi* presence. Using the patch count method, where groups of bats are counted by estimates of ten with binoculars. *P. voeltzkowi* were counted and recorded at the roosting locations at approximately identical time stamps across multiple days.

6.1 Vegetation Survey

Vegetation surrounding roosts was surveyed to quantify the biodiversity of juvenile and newly established plants within short and long range proximity to the roosting location, as well as assess relative density. Here the surrounding area was designated as two distinct zones, A and B. The area was surveyed using 1 m by 1 m quadrats. All area was demarcated utilizing a measuring tape and string. Within each quadrat, only plants beneath 1 m were recorded, using a measuring tape.

At the Ngezi roost, due to the transience of this specific *P. voeltzkowi* population, three trees in close proximity were selected after observation of roosting habits after several days. These trees being relatively equidistant, were connected in a triangle, with zone A demarcated on the outside. Quadrats were randomly sampled within a 5 m zone, at every meter between the trees (see appendix A).

In the sampling of zone B, frequent *P. voeltzkowi* movement within a proximate area made sampling further from the trees necessary. Zone B was surveyed 10 m off of a ranger trail which is used to reach the roost area, but exists away from the area inhabited. Quadrats were

surveyed approximately every 30 m along the trail, at a distance of 10 m away to reduce disturbance factors.

At the Kidike roost, *P. voeltzkowi* concentration allowed for surveying of zone A to encompass all area within a 5 m radius of a roosting tree, while zone B consisted of the area 5 m to 20 m from the tree (a total of 25 m from the roost). The surveying of zone A occurred at four separate trees, with approximately 5 quadrats surveyed around each, and in zone B at four separate locations with 5 quadrats in each. Quadrats were randomly sampled within these zones (see appendix B).

Plant species, overall richness, and density were recorded for each quadrat, both in situ with help from park rangers and local experts, but additionally through photographs and leaf sampling. Vegetation results were assessed using both the Shannon-Weiner and Simpson indices of diversity, as well as relative abundance and species richness.

6.2 Soil Analysis

Soil samples collected at a depth of 10 cm were obtained at both roosting sites in zone A, with three replicates per zone. Soil collected from a fallow field untreated by organic and inorganic inputs for one growing season served as a control variable, while soil from a field currently growing crops and treated with inorganic fertilizer and manure was collected for a negative control. This soil was obtained from a local farm in northern Pemba between the two roosting locations. Soil was collected during vegetation surveys. Samples were tested in laboratory at the Kizimbani Agricultural Institute for pH using the 1:2.5 soil-water suspension with a pH probe, total organic carbon via the Walkley-Black method, total phosphorus via the Bray and Kurtz No. 1 method, and total nitrogen content via semi-micro Kjeldahl block

digestion. For detailed methodology regarding laboratory procedures, see appendix C. Testing the impact of guano on a variety of soil factors in a laboratory setting allowed for the control of external variables for quantification of guano impact on Pemban soil. To analyze the results of these tests, data was ordered and calculated in excel, and evaluated for statistical significance using the ANOVA test model.

7.0 Results

7.1 Vegetation

Across all zones at both roosts, 72 species of vegetation were identified through 1,864 individuals. Relatively little species overlap occurred across locations, while zones of the same location yielded similar, yet non identical vegetation communities.

7.1.1 *Ngezi roost site*

At the Ngezi forest roost site, a total of 41 species were assessed across 65 quadrats. In total, 1,023 individuals were recorded.

Zone A, in closest proximity to the roost, yielded 26 species from 35 surveyed quadrats, resulting in an average species richness of .72 per m^2 and density of 14.4 individuals per m^2 . *Blighia unijugata*, *Zamioculcas boivinii*, and *Landolphia kirkii* were the most prominent species of this location, with *Blighia unijugata* notably dominant. Together, these species encompassed 72% of the zone's total population. This lack of species evenness resulted in low overall diversity within the zone, further quantified through a Shannon index value of 1.55, and a Simpson index of diversity of .72. At the quadrat level, each quadrat averaged a density of 14.4 individual plants and 3.8 distinct species per m^2.

Zone B surveyed in an area nearby, yet removed from *P. voeltzkowi* roosting, encompassed 19 species and 30 quadrats with an overall species richness of .63 species per m^2, indicating the zone had marginally less variation of species. Evenness within the zone however was greater, with the dominant species *Piper nigrum*, *Landolphia kirkii*, and *Zamioculcas boivinii* making up only 64% of the flora. This was further corroborated in a Shannon index of 2.01, and Simpson index of diversity of .88 . On average, quadrat density was 17.3 individuals and 4.3 species per m^2, with an overall zone density of 17.3 individuals per m^2. For figures illustrating species composition by zone, see appendix D.

7.1.2 Kidike Roost site

In the culturally protected forest patch of Kidike, a total of 38 quadrats were sampled containing 37 species and 841 individuals.

Beneath *P. voeltzkowi* roosts, zone A yielded 25 species from 18 quadrats, with an average species richness of 1.39 species per m^2 within the zone. Besides *Pogostemon cablin* and *Commelina benghalensis*, the two species in majority, species evenness was relatively high. This was expressed through a Shannon index value of 2.68 and Simpson diversity index of .90 . Per quadrat, zone A averaged 21.8 individuals and 4.4 species per m^2, indicating the foliage in this area was relatively dense. For the entire zone individual density was 21.8 per m^2.

Zone B, within 25 m of the roost, contained 20 species found across 20 quadrats. Species richness was 1.0 per m^2, lower than that of zone A. Not only did this zone have fewer species, but less overall species evenness, with dominance primarily by *Tamarindus indica*, as well as *Ocimum canum* and *Mitracarpus scaber*. This was expressed in a Shannon index value of 2.30 and a Simpson diversity index of 0.88. Both index values are lower than that of zone A,

indicating lower vegetation diversity, and evenness across species. Further corroborating this, each quadrat averaged 22.5 individuals and 4.35 species per m^2, indicating a denser yet less diverse study area. Overall individual density for this zone was 22.5 per m^2. For figures illustrating species composition by zone, see appendix E.

7.2 Soil Analysis

7.2.1 pH

Analysis of replicates collected from the Ngezi roost site, yielded pH values of 6.61, 6.41, and 6.52, with an average of 6.51. Samples from the Kidike roost yielded pH values of 7.33, 7.42, and 7.74 respectively, with an average of 7.50. Soil samples from a fallow agricultural field on Pemba serving as a positive control yielded pH values of 7.29, 7.42, and 7.35, with an average of 7.35. Soil samples from a field treated with inorganic fertilizer and manure acted as a negative control, producing pH values of 7.21, 7.47, and 7.39, an average of 7.36. The nature of the pH reading via probe resulted in potential error, with a deviation of the reading +/- .22.

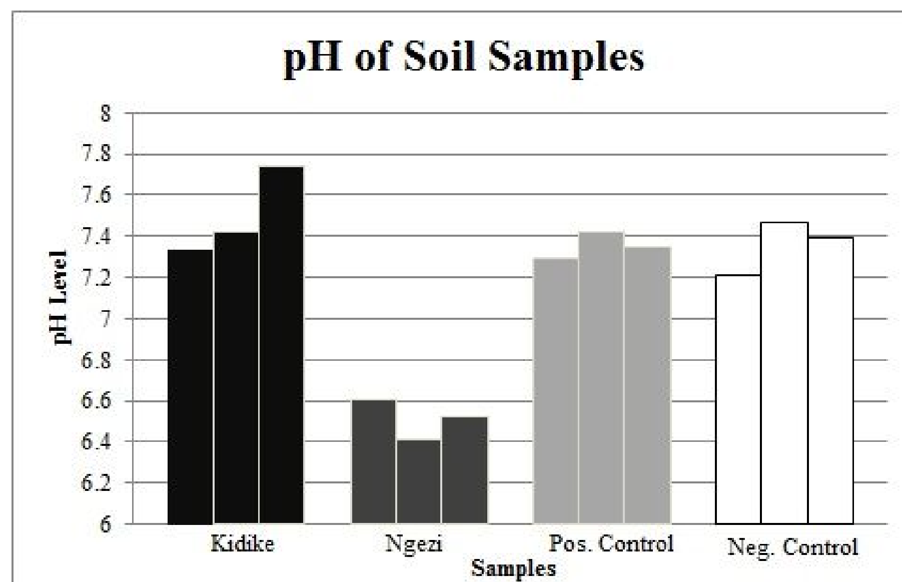

Figure II. pH of soil samples by replicate.

7.2.2 Total Organic Carbon and Total Organic Matter

Soil Samples from the Ngezi roost possessed 0.58%, 0.10%, and 0.07% total organic carbon, translated to measurements of total organic matter of 1.00%, 0.17%, and 0.68% respectively. Kidike roost yielded the highest percentages, with 3.28%, 3.24%, 2.25%, and total organic matter of 5.65%, 5.57%, and 3.86%. The positive control yielded values of 0.072%, 0.652%, and 0.097% for total organic carbon, and 0.125%, 1.12%, 0.166% for total organic matter. The negative control samples had total organic carbon percentages of 0.053%, 1.55%, and 1.16%, and total organic matter percentages of 0.914%, 2.66%, and 1.99%. The results of both controls reinforce a logical trend of higher total organic carbon percentages with organic inputs, indicating effectiveness of methods.

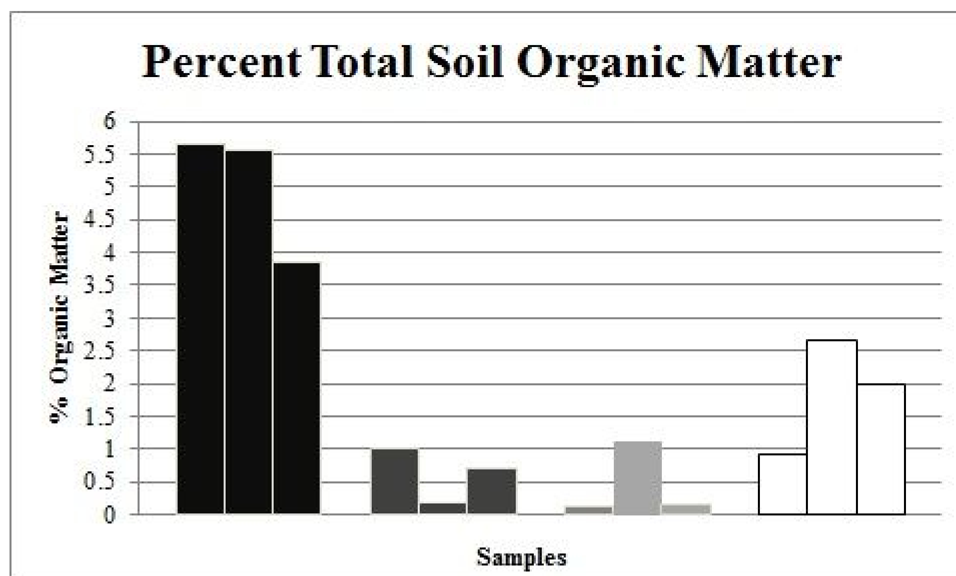

Figure III. Percent total organic matter of soil samples by replicate.

7.2.3 Total Phosphorous

Ngezi roost samples indicated total phosphorous of 60.46, 53.92, and 50.66 in parts per million (ppm). Kidike roost soil produced 94.81, 125.88, and 94.81 ppm. The soil samples of the

positive control indicated 37.57, 45.75, and 34.30 ppm. Negative control samples resulted in 73.55, 137.34, and 101.36 ppm.

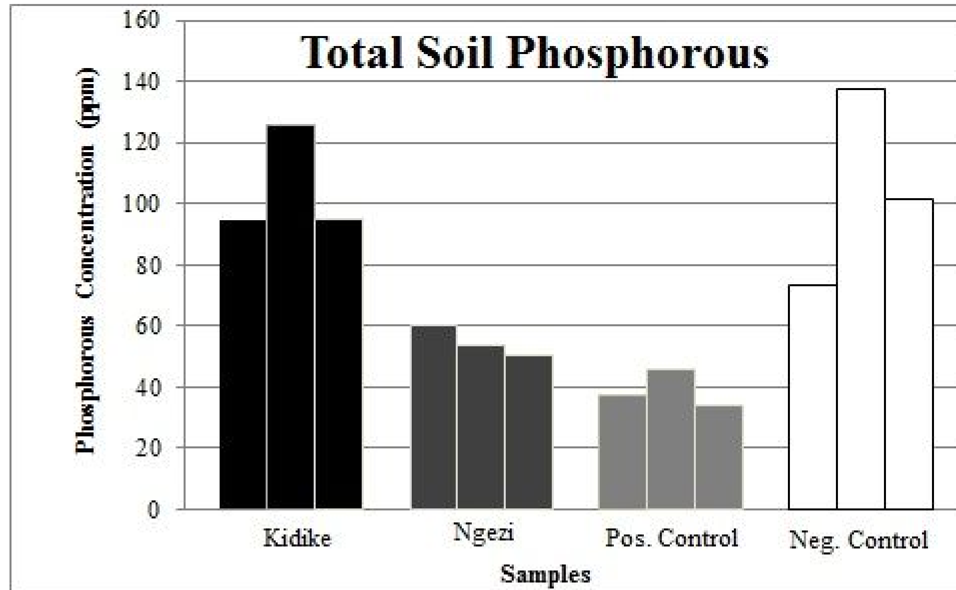

Figure IV. Phosphorous concentration of soil samples by replicate.

7.2.4 Total Nitrogen

Soil samples from the Ngezi roost site produced levels of total percent nitrogen of 5.5%, 4.6%, and 3.4%, with an average value of 4.5%. Kidike soil samples yielded percentages of 63%, 7.5%, and 4,2% 5.5%, 4.6%, and 3.4%, with an average of 24.9%. The positive control produced percentages of 23.4%, 8.4%, and 4.2% with an average of 12%. The negative control yielded samples of 17.6%, 7.3%, 3.7%, with an average of 9.5%.

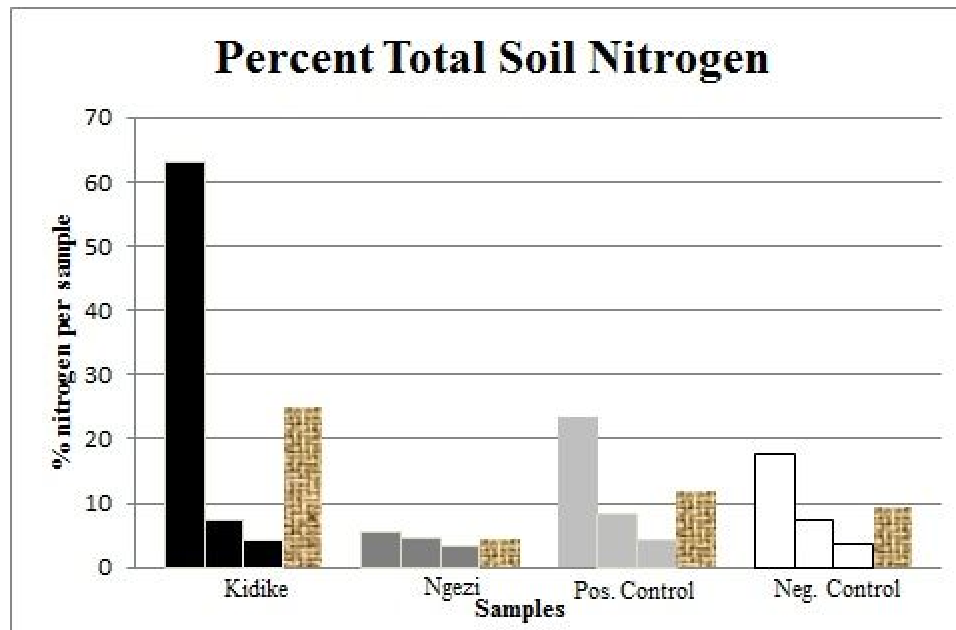

Figure V. Percent total nitrogen of soil samples by replicate, with the textured bar representing sample average. Results of Kidike sample 1, positive control 1, and negative control 1 were significantly higher than replicates of the same site, indicating potential laboratory error.

Analysis of all nutrient laboratory results when tested against a one-way anova produced an analysis of variance of $p < .05$, indicating statistical significance for all tests excluding percent nitrogen.

8.0 Discussion

8.1 Vegetation

Though the forest floor was carpeted with juvenile plants, the vegetation of surveyed quadrats lacked consistent, significant differences of species diversity and density with varying proximity to *P.voletzkowi* roosts.

At the Kidike roost, trends of higher biodiversity of vegetation were confirmed with roost adjacency. Zone A produced five more species than zone B, a species richness difference of .39

more species per m^2. Additionally, both diversity indices proved higher for zone A, indicating that along with a greater diversity of species, the zone displayed greater evenness, with less overgrowth of any one species. As frugivorous bats are known agents of reforestation, translocating the seeds of wild fruits they consume, it is logical that forest floor surrounding their roosts would be altered as a result of their debris, both dropped fruit, ejecta, and guano. Increased biodiversity with increased proximity could likely be attributed to the concentration of these waste materials, as the constant reintroduction of seeds of new species with various adaptations increases competition pressures on existing species. This competition pressure would help to prevent the overgrowth of any one particular species, as diversity of vegetation increases resilience and decreases invasibility of the entire community by any one species (Naeem et al., 2000). Though this study does not evaluate long term establishment of plant species, increased introduction is facilitated by *P.voeltzkowi* behavioral patterns. Additionally, evidence from further studies indicate that passage of seeds through the short digestive tract of fruit bats is correlated to significantly faster rates of germination, as the pericarp is compromised (Fleming & Heithaus, 1981). This passive alteration increases the likelihood of juvenile establishment of introduced seeds by *P. voeltzkowi*, providing translocated species an advantage in early establishment and niche partitioning over that of more naturally transported seeds.

Density of juvenile plants by zone did not match this trend, as zone B exhibited greater individual plant density by square meter: 22.5 individuals in zone B to 21.8 of zone A. A lower density per area indicates that zone A likely had lower overall niche saturation, meaning that introduced seeds in zone A would have less competition for resources and have a higher

likelihood of establishment. This further contributes to the greater establishment ability of introduced species within zone A.

At the Ngezi roost however, zone A experienced lower levels of biodiversity than zone B, primarily attributed to lack of species evenness throughout the zone, despite a species richness .11 greater than zone B. Zone A had significantly lower diversity index values, indicated lower overall diversity of vegetation. *Blighia unijugata* dominated zone A, specifically with high density and low diversity within quadrats between trees A and C. Encompassing 50% of the entire zone, this ratio was significantly skewed by quadrats almost entirely *Blighia unijugata*. *Blighia unijugata* possess a small, soft pink fruit which contain three large seeds (World Agroforestry, 2017). Conflicting reports fail to elucidate whether the fruit is toxic, with some reports indicating it is eaten by certain species of monkey. As a result, it is unlikely to be preferred and thus frequently translocated by *P. voeltzkowi*, and the high density at this location is likely due to factors unrelated to *P. voeltzkowi* behavior, such as a *Blighia unijugata* roosting tree. Indeed, Entwistle (1997) recorded the use of a *Blighia unijugata* roosting tree in the vicinity. High density of *Blighia unijugata* is thus considered a locational anomaly unrelated to the *P. voeltzkowi* behavior in question, rendering this specific tree of the Ngezi roost site poorly suited for this study. The impact of such an anomaly on the data however, does likely indicate that any existing vegetation trends related to *P. voeltzkowi* proximity at this site are weak. Lower species diversity of localized patches increases the vulnerability of such areas to invasion by introduced species, as higher stress is born by diverse niche competition (Chapin et al., 2000). With or without such close proximity to the *P. voeltzkowi* roost, this vegetation community would theoretically be highly subject to change over time. An additional explanation, is that

Blighia unijugata may more effectively compete for limited resources at this location, such as sunlight or water within a dense canopy, or nutrients from relatively depleted tropical soils. Ultimately however, this likely indicates that at the Ngezi roost, density and thus concentrated impact of *P. voeltzkowi* populations is too low to significantly alter the surrounding forest ground layer and vegetation.

Similarly to the Kidike roost, juvenile vegetation density at the Ngezi roost was lower in zone A in comparison to that found in zone B, with 14.4 individuals per m^2 versus 17.3 individuals per m^2. This trend is logical and likely due to extrinsic factors outside of *P. voeltzkowi* behavior, as the forest ground layer and quadrats surveyed within zone A were beneath large trees, with denser canopies which limited penetration of sunlight. Irregardless of individual species tolerance, light is considered one of the most critical limiting resource factors for the establishment and growth of juvenile plants (Denslow, et al., 1990). Such trees were required to support roosting *P. voletzkowi* populations, but likely reduced resource availability and increased competition of juvenile plants in the surrounding forest floor. As a response to such stressors, juvenile plant communities would likely exist in lower densities in this location. In zone B at both roosts, quadrats surveyed were outside of the zone of influence of the roosting tree and dense canopy, with less limitation of available sunlight, helping to explain the higher juvenile plant densities.

8.2 Soil Analysis

Soils of tropical forests are notoriously nutrient deficient, as hot, humid conditions coupled with heavy rainfall expedite physical and chemical weathering that leach out minerals, contributing to the formation of acidic soils. In particular, tropical soils lack phosphorus, but also

nitrogen and organic carbon. Tanzanian soil in general is particularly deficient in phosphorous (National Academy of Sciences, 1972). This is coupled with little organic matter, as tropical forests are generally not deciduous and any produced organic matter is rapidly broken down and stored in plants (L. Tropical Soils, 2017).

Soil analysis at the Kidike site yielded significantly higher rates of total nitrogen, and percent organic matter and organic carbon than both the positive and negative control, and the Ngezi roost site. Levels of total phosphorous for this site were additionally high, but slightly lower than that of the negative control. The negative control, farmland treated with inorganic inputs and manure, yielded the second highest rates of total organic carbon and total organic matter, with slightly higher but virtually identical rates of total nitrogen in the positive control. Soil from the Ngezi site had slightly higher rates of total phosphorous than the positive control of the fallow agricultural soil, but lowest rates of all other nutrients. This finding is believed to be accurate, as past reports have indicated that soil from Ngezi forest is historically low in organic matter, and a tropical soil leached of nutrients (FAO U.N., 1990).

Differences in nutrient composition between the two roost sites follow the trend of guano input, as the area with higher concentrations of guano displayed higher levels of nutrients necessary for fertile soil. Operating under the assumption that soils from both sites exhibited relatively similar nutrient breakdowns prior to guano addition by *P. voeltzkowi*, differing soil nutrient outcomes appear to be correlated to inputs of differing guano concentrations. The results of both positive and negative controls indicated the integrity of the methods, as manure and inorganic fertilizer have exceptionally high nutrient levels.

As the Kidike roost site has been occupied by high densities of *P. voeltzkowi* for generations, it is logical that the soil at this site would have experienced the greatest impact of guano inputs, as concentrations of excrement have been built up over time. Guano from frugivorous *Pteropus* species has been shown to have higher carbon to nitrogen ratios, as well as high levels of phosphorous (Emerson and Roark, 2007). Soil samples with the expected highest concentration of *Pteropus* guano mirrored these findings, with levels significantly elevated from that of Pemban soil non-altered with inputs. Soil samples from the Ngezi roost site displayed significantly lower levels of total phosphorus, total organic carbon, and total organic matter than the Kidike roost. The nitrogen levels for this site were the lowest of all samples, less than even that of the positive control.

Soil samples from the positive control produced average pH levels of 7.35, with the negative control samples averaging a pH of 7.36. The Ngezi roost yielding a more acidic average pH of 6.51, and the Kidike roost with a more basic average pH level of 7.50. On its own, guano is known to have a higher levels of pH, making it a more basic addition (Ferreira, 2007). Despite the lowest pH within the Ngezi site, these results still indicate increases in soil pH with additions of guano, as soil pH of Ngezi forest is historically low, with values slightly above 5.5. Results of ANOVA tests across all sample sites for each nutrient test (excluding nitrogen) confirmed significance of findings, indicating a positive correlation between the passive addition of guano and the increase of soil nutrients within Pemban soil. Though more sampling would be needed to more clearly elucidate a pattern, sampled soil currently enforces this trend.

8.3 Implications and Significance

The use of frugivorous *P. voeltzkowi* guano to improve soil quality for agricultural pursuits may soon be more important than ever, as the impact of global warming on existing climate systems has the potential to expedite rates of erosion, and thus weathering and leaching of soil minerals and nutrients in the coming years. Increased population pressure on subsistence agriculture will likely further strain Pemban soil, contributing to unsustainable land use practices and nutrient depletion. The application of guano is not only a reasonable solution for Pembans in the maintenance of soil health, but can serve to improve existing soil conditions, such as low phosphorous levels, increasing yields.

In addition to their role as agents of reforestation, *P. voeltzkowi* play a role in the maintenance of diversity of vegetation within the primary forest on Pemba island. Outside of localized diversity of plant species, critical for supporting diverse faunal populations, the translocation of plants across the island allows for the increased durability of plant populations across Pemba through the maintenance of genetic diversity.

Protection of *P. voeltzkowi* populations have additional implications for the environment with which they inhabit. Though locations like Ngezi forest reserve are already subject to protections, the expansion of *P. voeltzkowi* populations to new roosts have the ability to influence the preservation of remaining forest fragments across the island. More than simply trees, this can be critical in the protection of smaller plants and shrubs which reside within the forest understory. From observations of the Kidike roost, a forest fragment bordering a village, the understory of this roosting location was densely composed of plants with known medicinal uses. Here, local people explained that the majority of the village continues to rely on this vegetation as their main stock of medicinal plants and primary medical treatment. In poorer

areas, these medicinal plant stocks are critical for the health of communities. Maintenance additionally necessitates the retainment of traditional healing knowledge within the new generation. More than simply maintaining biodiversity for conservation concerns, protection of *P. voeltzkowi* populations can help to continue the longevity of local flora critical to the health of marginalized populations, a rationale that on its own is likely not great enough to trump economic interests on behalf of more powerful actors.

Ultimately, the quantification of the rationale for protection of *P. voeltzkowi* and roosting sites across the island is important for the longevity of such populations. Increasingly important is the understanding of *P. voeltzkowi* benefits outside of the sector of conservation, especially in regards to local farmers, a group with which they are sometimes pitted to be at odds. Improved understanding of the benefits of frugivorous bat populations to soil health can make the justification for their protection tangible, as well as encourage the growth of the island population, as individuals will want to encourage the establishment of roosting locations near farms. Use of guano as a local, renewable source of cheap and highly effective fertilizer could be the branding necessary to revive *P. voeltzkowi* populations in the remaining fragmented patches of primary forest across the island.

9.0 Limitations

As with any ecological study, certain inherent limitations resulted from the study location in question and applied methods. Certain field conditions, such as the high density of vegetation and heavy rains, made quadrat sampling difficult, and the ability to have a consistent number of quadrats surveyed in each zone, at both sites, would strengthen findings. In floral identification,

because surveyed plants were juveniles, there was greater difficulty and likely greater error in effective species identification. Many species were identified in situ, though some were identified post situ through photographs and samples. Additionally, many plants were identified in Swahili and then translated to a scientific name, which introduced another potential source of error.

Increasing the number of roosts studied would strengthen the overall project and provide further replicates in varying contexts to confirm identified trends. Additional locations of soil sampling and replicates of soil samples would strengthen the findings of laboratory analysis. Notably, laboratory tests faced certain challenges due to equipment limitations, which had the potential to alter results or introduce contamination.

10.0 Future Directions

Future studies involving the behavioral impacts of *P. voletzkowi* populations on the various resources of Pemba island, be that flora or soil, are critical for long-term success of these mammals. To supplement this work, it would be beneficial to assess impact at different roosts in different areas of the island, in different types of forests, and of *P. voletzkowi* populations of varying densities.

Additionally, it would be interesting to study not only the physical differences in biodiversity with increasing proximity to roosting sites, but the genetic diversity of these plant communities, as *P. voletzkowi* theoretically allow for gene transfer across isolated and geographically distant sections of forest. Assessing the long-term establishment success of

juvenile plants within these two zones would additionally be interesting, as well as tracking the changes in make up of these plant communities over time.

11.0 Conclusion

Throughout the island, Pembans' lean heavily on their environments extractive, renewable, and spatial resources. The protection of *Pteropus voeltzkowi* roosts throughout the island benefits interests in both the conservation and agricultural sectors, through dispersal of seeds to areas disturbed by charcoal production, maintenance of genetic diversity between tree stands isolated by rubber and clove plantations, and the countering of soil degradation from continual agricultural production through high nutrient inputs. It is the quantification of importance, both for the ecosystem and economy of Pemba, that is key for securing long-term protections.

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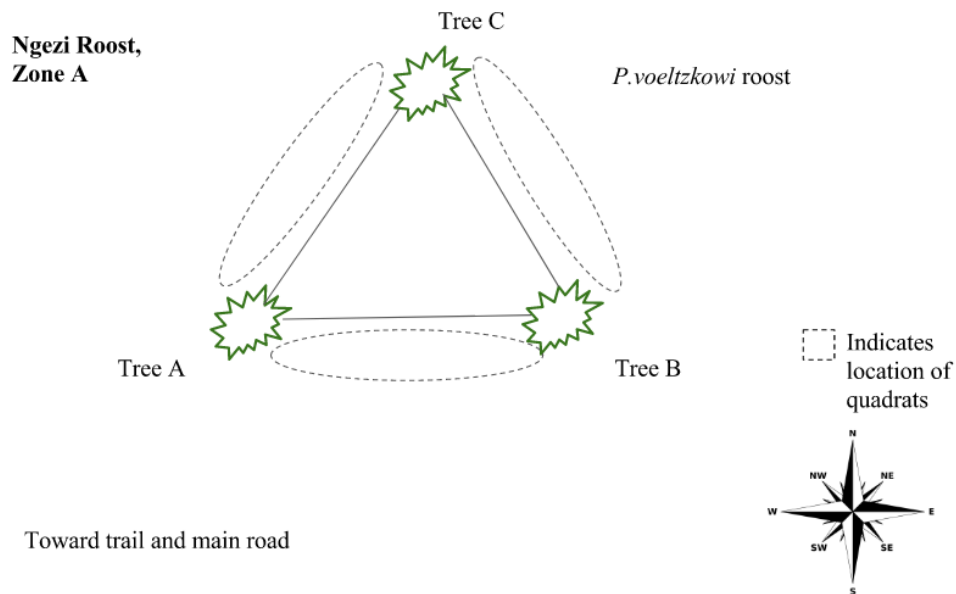
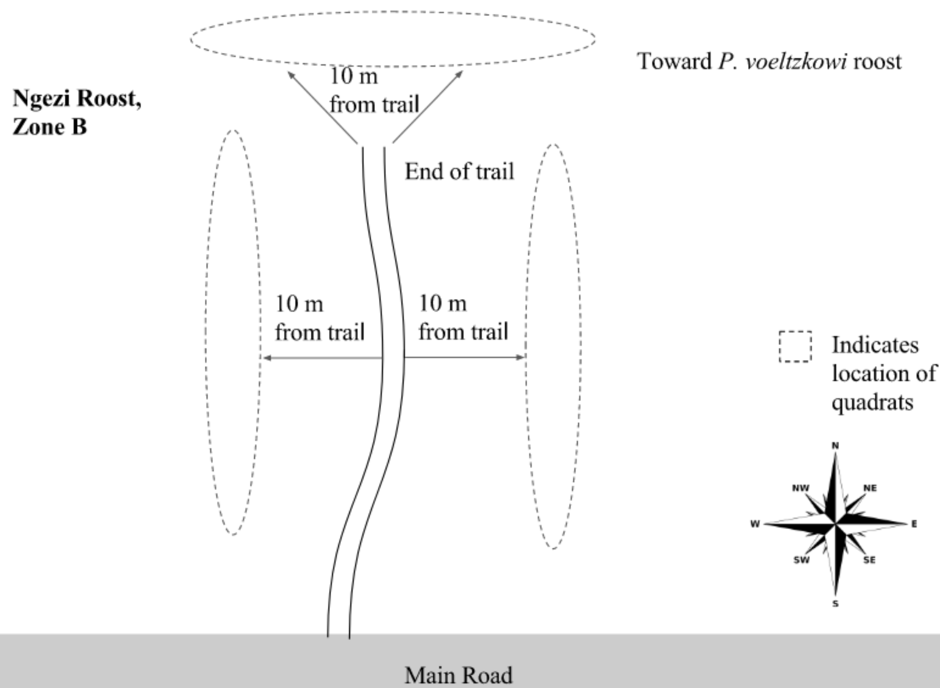
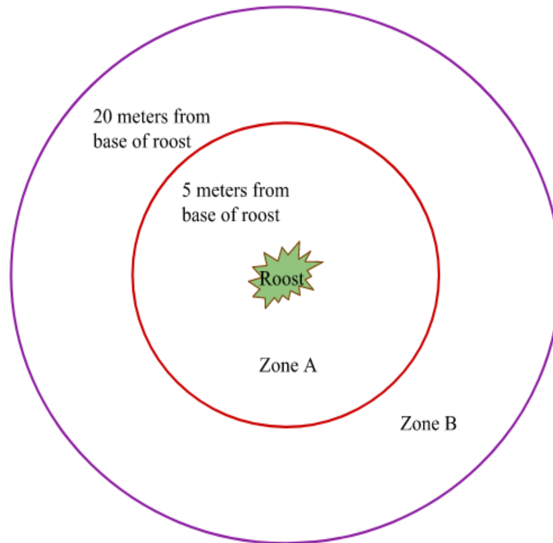
13.0 Appendices

Appendix A- Ngezi roosting site methodology, zones A and B





Appendix B- Kidike roosting site methodology, zones A and B



Appendix C- Soil Analysis Procedures; Directions were copied and annotated from a book of government issued soil analysis protocols at the Kizimbani Agricultural Training Institute.

pH in a 1:2.5 Soil- Water Suspension

1. Principle

The pH-H20 of the soil is potentiometrically measured in the supernatant solution of a 1:2.5 soil-water mixture.

2. Materials: Apparatus and Reagents

Electronic pH meter
Reciprocal shaker
Polythene bottles of 50 or 100 mL

Buffer solutions of pH 4.0, and 10.0, as well as deionized water used for such.

3. Procedure

- Weigh 10.0 g of air dry soil in a 50 or 100 mL polythene bottle.
- Add 25.0 mL distilled water, shake on shaker table for 30 minutes.

- Before opening bottle, shake by hand and allow suspension to settle.
- Calibrate pH meter against buffers to determine potential error.
-Immerse in supernatant, read pH upon stabilization. Record to one decimal place.

Total Nitrogen
Semi-micro Kjeldahl using a block digestion

1. Principle

The soil is digested with concentrated sulphuric acid in the presence of a selenium catalyst and the organic nitrogen is converted to ammonium sulphate. The solution is then made alkaline and NH_3 is distilled. The evolved ammonia is trapped in boric acid and titrated with any standard mineral acid. The procedure determines all soil nitrogen (including adsorbed NH_4), except that in nitrates.

2. Materials: Apparatus and Reagents

Block digestor with digestion tubes of 300 ml

(The digester should have an effective disposal of acid fumes, or be placed in a fume cupboard). [In this case, the block digestor was placed outside.]

Corresponding Kjeldahl distillation unit

Burette, 50 mL

Mortar and Pestle; sieve 0.5 mm

Measuring cylinder 25mL

Concentrated sulphuric acid, H_2SO_4, 95-97%

Catalyst mixture; mix by grinding in mortar approx. 100 g anhydrous Na_2SO_4, 10g $CuSO_4$ 5H20, and 1.55 g selenium powder. Instead of sodium sulphate, potassium sulphate may be used.

Sodium hydroxide, NaOH, 32%; dissolve 320 g NaOH in about 800 mL water in a 1 L heavy pyrex flask. Allow to cool with the flask stoppered to prevent absorption of atmospheric CO_2.

Mixed indicator solution; dissolve 0.150 g bromocresol green and 0.100 g methyl red in 200 mL 96% ethanol. Adjust the color to bluish purple with dilute sodium hydroxide or hydrochloric acid as required.

Boric acid indicator solution, 2%; dissolve 20.0 g boric acid in about 900 mL hot distilled water, cool and add 20 mL mixed indicator solution. Make to one liter with distilled water and mix thoroughly. Store in brown bottle.

Sulphuric acid, 0.01 M (0.02 N); dilute 5.5 mL concentrated sulphuric acid in about 900 mL distilled water and make up to 1 L (0.1 M). Mix thoroughly. Pipette 100.0 mL in about 900 mL distilled water and make up to 1 L. Mix again. Standardized against potassium iodate.

3. Procedure

I. Digestion

- Grind about 5 g air dry fine earth in mortar and pestle, sieve with 0.5 mm to get 1.00 g, measured on mass balance. [Here soil was dried in oven for 24 hrs.]

-Add the 1.00 g of soil to the digestion tube. Of soils high in OM (over 8%), use only 0.5 g. It is recommended to include one standard sample and two blanks for each series. [Here this was not done, as resources were finite.]

-Add about 1 g of catalyst mixture, mix well and rinse with a little DI water, just enough to moisten.

-Add 10 mL concentrated sulphuric acid and mix by swirling.

-Place tubes carefully in digestion block and heat until frothing stops. Increase heat and digest at about 360 degrees C until the digest is white or pale green; continue boiling for another 30 minutes, Swirl several times.

-Remove the tubes from the digester, allow to cool in the fume cupboard [outside] and add about 30 mL of DI water while swirling.

II. Distillation

-Add 20 mL boric acid indicator solution to conical flask (erlenmeyer) of 150 mL. PLace flask under condenser tube of the distillation apparatus so that the condenser tip is beneath the solution surface.

-Add 40 mL NaOH 32% to the digestion tube with a dispenser and distill immediately until approx. 70 mL distillate is collected.

-Remove the flask, rinse the condenser tip and titrate distillate with 0.02 N sulphuric acid until color changes from green to pink.

-For every set of determinations include one blank and one standard.

4. Calculation

%N= ((a-b)x N x 1.4 x Mc)/(W)

In which:

a= mL H2SO4 required to titrate the sample

b= mL H2SO4 required to titrate the blank

N= normality of the acid (H2SO4) [Here 0.02 N.]

1.4= 14 x 10-3 x 100% (14= atomic weight of nitrogen)

Mc= moisture correction factor

W= weight of air dry soil

The % nitrogen in the soil may be calculated to the nearest 0.0% (two decimals).

Available Phosphorous
Acc. to Bray and Kurtz No. 1\Suitable for acid soils ph<1

1. Principle

The easy acid-soluble forms of phosphorous are extracted by 0.025 M HCl and 0.03 M NH4F. Phosphate in the extract is determined colorimetrically with the blue ammonium molybdate method with ascorbic acid as a reducing agent.

2, Materials: Apparatus and Reagents

Spectrophotometer with cuvette of 10 mm path-length and a filter of adjustable for 882 nm (880-885 nm).

Polythene shaking bottles of 50 mL

Filters

Funnels

Hydrochloric Acid, HCl 0.5 M; dilute 32.5 mL of HCl 25% (or 21.5 mL HCl 37%) in distilled water and make to 500 mL.

Ammonium fluoride, NH4F, 1 M; dissolve 3.7 g NH4F in distilled water and make to 100 mL, store in polythene bottle.

Extracting solution Bray I; mix 30 ml NH4F 1 M with 50 mL HCl 0.5 M and make to 1 liter with distilled water, store in polythene bottle.

Sulphuric acid, H2SO4, 2.5 M; slowly and carefully add 35 mL concentrated sulphuric acid to 150 mL distilled water under constant stirring. Allow to cool and make to 250 mL with distilled water.

Ammonium molybdate solution, (NH4)6Mo7O24 4H2O; dissolve 4 g ammonium molybdate in 100 mL distilled water. Store in polythene or pyrex bottle and keep in refrigerator or in the dark.

Potassium antimony tartrate solution, KSbO C4H4O6 O 5H2O; dissolve 0.275 g potassium antimony tartrate in 100 mL distilled water (1000 ppm Sb).

Ascorbic acid solution; dissolve 1.75 g ascorbic acid in 100 mL distilled water. Prepare this solution fresh daily.

Mixed reagent; bring together in a 500 ml polythene or pyrex bottle the following solutions (in the sequence indicated) and homogenize after each addition: 50 mL 2.5 M H2SO4, 15 mL NH4-molybdate solution, 30 mL ascorbic acid solution, 5 mL KSb-tartrate solution, 200 mL distilled water. Prepare the mixed reagent fresh daily.

Boric acid, 1.65%; dissolve 16.5 g boric acid in a volumetric flask of 1000 mL in about 900 mL of distilled water. Make to volume and mix.

Standard phosphate solution, 100 mg/l (ppm) P; dissolve 0.4390 g pure, dry, potassium dihydrogen phosphate (KH_2PO_4) in distilled water in a volumetric flask of 1 L and make to volume. Mix thoroughly.
Diluted standard solution; pipette into a volumetric flask of 100 mL 5.0 mL of the 100 mg/1 standard phosphate solution and make up to volume with Bray I extracting solution.
Standard series; pipette into volumetric flasks of 50 mL respectively 0.0- 1.0- 2.0- 3.0- 4.0- 5.0- 6.0 -7.0 and 10.0 mL of the diluted standard solution. Make to volume with distilled water. The standard series is then 0.0- 0.1-0.2 -0.3 -0.4- 0.5-0.7 and 1.0 mg/L (ppm) P.

3. Procedure

-Weigh 5.0 g of air dry soil in a shaking bottle of 50 or 100 mL. Include one standard sample and two blanks for each sample.
-Add 35.0 mL extracting solution Bray I.
- Shake for 1 minute by hand, then immediately filter through filter paper. If filtrate is turbid filter again or add active charcoal.
-Pipette 10.0 mL of the sample extracts, standards, and blanks each into 50 mL volumetric flasks each containing 10 mL boric acid solution, 15 mL distilled water, 10 mL mixed reagent (in that order), mix well. Make up to volume and homogenize.
-Allow solution to stand 30-60 minutes for blue color to develop to maximum.
- Measure absorbance with a spectrometer with a 10 mm cuvette at 720 nm.

4. Calculation

Plot a calibration graph of absorbance against P concentration.
Mg P/kg soil (ppm)= (a-b) x 35 x Mc

In which:
a= mg/l P in sample extract
b= mg/l P in blank
35= dilution factor (35/5 x 50/10)
Mc= moisture correction factor [irrelevant because our soils were oven dried.]

Organic Carbon
Acc. to Walkley-Black

1. Principle

Soil organic matter is oxidized at a temperature of approximately 120 degrees C with a mixture of potassium dichromate and concentrated sulphuric acid (wet combustion). The excess potassium dichromate is titrated against ammonium ferrous sulphate with diphenylamine as an

indicator. Phosphoric acid is added to form a complex with iron (III), providing a sharper color change of the indicator.

2. Materials: Apparatus and Reagents

Burette, 0.1 mL graduation
Magnetic Stirrer
Erlenmeyer flasks, 500 mL
Mortar and pestle; sieve 500 mm
Dispenser, measuring cylinder 25 mL
Volumetric flasks, 1 liter
Wooden pads

Potassium dichromate. $K_2Cr_2O_7$, 0.1667 M (1N); dry about 50 g potassium dichromate (AR grade) for at least 2 hours at 105 degrees C. Let it cool in a desiccator for about one hour. Dissolve 49.035 g in water in a 1 liter volumetric flask and make to volume with distilled water.
Concentrated sulphuric acid, H_2SO_4, 95-97%
Concentrated O-phosphoric acid, H_3PO_4, 85%
Ammonium ferrous sulphate, 0.5 M $(NH_4)_2SO_4$ $FeSO_4$ $6H_2O$; dissolve 196 g ferrous ammonium sulphate in distilled water in a 1 liter volumetric flask and dilute to about 700 mL. Add very carefully, 20 mL concentrated sulphuric acid, mix and cool. Make to volume with distilled water and store in a brown bottle.
Diphenylamine (indicator); dissolve 1 g diphenylamine in 100 mL concentrated sulphuric acid. Under continuous swirling add very carefully and slowly 10 mL distilled water. Store in brown bottle.

3. Procedure

-Grind about 5 g air dry soil in mortar and pass over 0.5 mm sieve [Here it was oven dried for 24 hrs.]

-Weigh 1.0 g of the sieved soil into 500 mL erlenmeyer flask, include one standard sample and two blanks.

-Add 10.0 mL potassium dichromate solution with a burette or dispenser and swirl the flask gently to disperse the soil in the solution.

-In a fume cupboard carefully add 20 mL concentrated sulphuric acid with a measuring cylinder, swirl the flask gently or until the soil and reagents are mixed, then more vigorously (total 1 minute). Allow the flask to stand on a wooden pad for 30 minutes.

-Add 200 mL of distilled water and 10 mL phosphoric acid and allow to cool.

-Add 1 mL indicator solution and titrate the excess dichromate with ammonium ferrous sulfate while the mixture is being shaken to mix. At the end point the color will change from deep violet-blue; slow down the titration by adding the ammonium ferrous sulphate solution dropwise

while swirling. At the end point the color will change sharply to brilliant green [Here, dark emerald.] Mark the mL required for this change.
-Titrate blanks in the same way.

4. Calculation

The carbon content of the soil is:

$$\%C= ((((b-s)/(b)) \times 3)/W) \times Mc \times 1.32$$

In which:
b= mL ammonium ferrous sulphate required for blank
s= mL ammonium ferrous sulphate required for sample
W= weight of air dry sample in grams
3= equivalent weight of carbon
Mc= moisture correction factor [Here NA due to oven drying of soils.]
1.32= compensation factor for the incomplete combustion of the org anic carbon in this procedure. The factor is a compromise as the incompleteness of the combustion varies with the type of organic matter. Record results to one decimal place.

Appendix F- Species List, Ngezi and Kidike Sites

Several species at both sites were unable to be identified. Subsequent descriptions of these species are described below for future identification.

Ngezi Site

Alangium salvifolium
Antiaris toxicaria
Barrington racemosa
Blighia unijucata
Bombax rhodognaphalon
Calophyllom inophllum
Cordia alliodora
Costus sarmentosus
Cremaspora triflora
Dioscorea alata
Diospyros discolor
Dypsis pembana
Erythrophleum suaveolens
Flagellaria guineensis
Inhambanella henriquessi
'Ipo'
'Kirukia'
Landolphia kirkii
Persicaria perfoliata
Piper nigrum
Rawsonia lucinda
Saba comorensis
Saba florida
Sansevirea
Synsepalum brevipes
Tetracera litoralis
Unid. underground climber
Whitefield Elongata
Zamioculcas boivinii

Kidike Site

Alangium salvifolium
Boerharia diffusa

Canthium zanzibericum
Cassia spc.
Commelina benghalensis
Commifora spc.
Cordia verbenacea
Croton sylvaticus
Dioscorea alata
Erythrim abyssinica
Fluggea virosa
Haplocoelum inploem
'Kongwa'
Landolphia kirkii
Lobelis fervens
Milicia excelsa
Mimosa pudica
Mitracapus scaber
'Mkokwa'
Ocimum canum
Ocimum suave
Piper nigrum
Pogostemon cablin
Saba comorensis
Saba florida
Sclerocarya birrea sub. caffra
Sclerocarya birrea sub. carra
Sida acuta
Solanum melongena
Tamarindus indica
Trema orientalis
Urtica dioica

*11 unknown species from both sites were collected and unable to be identified.

Appendix G- Data for Soil Analysis Results

Site	pH	Total % C	Total % Org. Matter	Total P mg P/kg (ppm)	Total % N
Kidike 1	7.33	3.28	5.65	94.8	63
Kidike 2	7.42	3.24	5.57	125.9	7.5
Kidike 3	7.74	2.25	3.86	94.8	4.2
Ngezi 1	6.61	0.5814	1.00012	60.5	5.5
Ngezi 2	6.41	0.100253	0.1724	53.9	4.6
Ngezi 3	6.52	0.401	0.68974	50.7	3.4
P. Control 1	7.29	0.072	0.125	37.6	23.4
P. Control 2	7.42	0.652	1.12	45.7	8.4
P. Control 3	7.35	0.097	0.166	34.3	4.2
N. Control 1	7.21	0.053	0.914	73.6	17.6
N. Control 2	7.47	1.55	2.66	137.3	7.3
N. Control 3	7.39	1.16	1.99	101.4	3.7
p-value	0.000095	0.000866	0.000256	0.00469	0.563883**
sig. <.05					
	** test value not signifigant, likely due to Kidike 1, p. control 1, and n. control 1.				