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Research Article

Assessment of Germination Rates for *Cyperus papyrus* L. in Shore Soils of Lake Naivasha under Varying Chronosequence and Land Use

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Abstract: Water level fluctuation in Lake Naivasha has resulted in loss of papyrus cover. Land exposed after receding of the lake has been put under grazing and cultivation. A 3 months study was conducted to establish whether the varying number in years of land exposure (chronosequence) and differences in land use had affected the ability of papyrus seeds to germinate and thrive in these soils. Soil samples were collected at areas of different chronosequence and land use. They were put under water saturation conditions; germination and biomass accumulation rates of papyrus were observed. ANOVA was used to test for any significant differences in the measured variables amongst sites. Data not meeting normality assumptions was analyzed using Kruskal-Wallis test. With treatment one (over seeded sterilized soils), germination results revealed a significant influence of predictor variables; land use ($\chi^2 = 28.7$; df = 2; $p<0.001$) and duration ($\chi^2 = 94.1$; df = 3; $p<0.001$). Germination results for treatment two (seed bank soils), also revealed a significant impact of duration ($\chi^2 = 94$; df = 3; $p<0.001$) and land use ($\chi^2 = 34.7$; df = 2; $p<0.001$). This study provides vital information on areas where viable diaspores are still present. It also helps in identifying areas where viable papyrus seeds no longer exist, thus necessitating human intervention by way of seed re-introduction. With over seeding, papyrus restoration was found to be possible even in areas with no viable diaspores. Further research is necessary to establish if there are viable vegetative parts left in these soils as their regeneration could speed up papyrus restoration efforts.

Keywords: Chronosequence, germination rate, papyrus, seed bank, viable diaspores

INTRODUCTION

Cyperus papyrus is an aquatic sedge found in wetlands in the subtropical and tropical zones worldwide that provides numerous ecological and socio-economic benefits. Ecologically, it aids in regulating the hydrological regime, acts as habitat for wildlife (including numerous bird species), acts as a water filter and enhances retention of nutrients and sediment coming from upstream (Gaudet and Muthuri, 1981), thus reducing eutrophication and silting-up and additionally reducing water loss by 15 to 20% (Howard and Harley, 1998). Socio-economic benefits include its use in making mats; its culms are used as building material and together with the starchy rhizomes that culms serve as food for humans and livestock.

Lake Naivasha (0°45` S, 36°20` E) lies in the Eastern Rift Valley in Kenya (Mavuti and Harper, 2005), approximately 80 km northwest of Nairobi and at 1,890 m.a.s.l with a fluctuating surface area of about 100 km^2 (Harper and Mavuti, 2004). The water levels have been varying over time, being low when there is over-abstraction and high when there are sudden rains, such as the El Niño of 1997 and the recent heavy rains between 2012 and 2013. The surface area of Lake Naivasha in Kenya now fluctuates by 30% between periods of high (939 mm) and low (442 mm) annual rainfall (Becht and Harper, 2002). Water recession in Lake Naivasha has not only resulted in an absolute reduction of papyrus cover, but also in a spatial shift of the littoral papyrus fringe by several hundred meters, following the immense water fluctuations, particularly over the last three decades. Excessive water abstraction for domestic use (Naivasha and Nakuru towns) and agro-industrial purposes (flower and vegetable farms) in combination with larger seasonal and inter-annual rainfall anomalies have contributed to reduction of lake water levels as well as papyrus cover. Additional contributing factors to the reduction in papyrus cover include cultivation on the lake shores, water pollution and excessive grazing by wild animals and domestic livestock.

Papyrus is the world's largest sedge (Cyperaceae) and is an important plant in Lake Naivasha, due to its water purification and sediment/nutrient retention capacity (IUCN Eastern Africa Regional Programme,

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2003). It fixes carbon along C-4 pathways and uses water efficiently (Boar *et al*., 1999). Its stands fix-nitrogen (Mwaura and Widdows, 1992), thus contributing immensely to the productivity of wetlands. Papyrus wetlands form land-water ecotones in the tropics that regulate the supply of dissolved and suspended material from land to open water (Pieczynska, 1990; Pinay *et al*., 1990). Papyrus also assimilates a large absolute mass of nutrients, minerals and carbon, which enters pathways of decomposition with a proportion of the dissolved or particulate products entering the open lake system (Boar, 2006). Together with other plant species in the land-water ecotone, papyrus regulates incoming materials, especially soluble and particulate nutrients (Gaudet, 1978a), according to classical eco-hydrological principles (Zalewski, 2002; Harper and Mavuti, 2004) and when intact, the papyrus stands can be thought of as "natural purifiers of water" (Kivaisi, 2001). The net primary production of a papyrusswamp at Lake Naivasha was calculated to be 6.28 kg dry weight/m^2/year which is amongst the highest recorded productivities for natural ecosystems (Jones and Muthuri, 1997) while the total net production of the former Lake Naivasha North Swamp was estimated to be 5.85 kg/m^2/year (Gaudet, 1978b).

Soils from land use areas of grazing and cultivation were sampled at four chronosequences; 5, 10, 15 and 20, respectively. Chronosequence refers to a sequence of related soils that differ in their degree of profile development because of differences in their age (Allaby, 1998). In this study, it has been used to refer to a sample strip of land used to monitor plant distribution along sites differing in the number of years that they have been out of water. A three month pot experiment was conducted to assess the viability of diaspores and the biomass accumulation rate of papyrus in water saturated soils. The aim of the study was to:

- Determine germination rate of papyrus seeds added in sterilized soils of different chronosequence and land use.
- Establish the germination rate of papyrus in soil seed bank under different land uses over varying periods of time.

MATERIALS AND METHODS

Study sites: The study was conducted along the shores of Lake Naivasha, Kenya, at the northern side of the lake, specifically those that have over the years been used for grazing and farming. Sites with soils that had been out of water for 5, 10, 15 and 20 years, respectively were investigated (Fig. 1). Each site was identified based on altitudes of former lake levels. Lake level data from November 1980 to May 2011 was the reference base. The three sites of land use from which the soil samples were collected included two grazing sites (that are within the KARI fields) and one cultivation site found in the Kihoto area. The two grazing sites at KARI were identified as the A site and the D site and were differentiated by their soil properties, with the A site having alluvial soil while D site has sediment soil. The third site, located at the Kihoto area has been put under cultivation of maize, kales, potatoes and other crops for both domestic and commercial use by local farmers. This site was labelled as K.

Sampling procedure: Soil samples were taken from each of the four chronosequences (5, 10, 15 and 20 year locations, respectively) in each of the three transects (A, D and K). A soil auger was used to collect the soil samples (10 cm depth excluding litter). At each point, the auger was used to collect ten random soil samples around the area. Soil from these ten points was then mixed thoroughly so as to geta homogeneous and representative sample from each sampling point. The soils were then air dried and sieved (mesh size 63 mm). There being two treatments, with the sterilized soils and with the non-sterilized soils, the soil samples were each divided into two. Each of the two soil samples was further divided into three replicates. All the experimental soil samples were weighed to measure 300 g. Half of the samples were subjected to the first treatment (t1) that involved sterilization of the soils at 105^{o}C for 48 h. These were the same samples where over-seeding with papyrus seeds was later conducted. The other half was subjected to the second treatment (t2) of seed bank, where they were observed over the three months period, on whether there were any viable papyrus seeds in them and how well they grew in these soils. Throughout the experiment, the soil samples were irrigated, maintaining the soil humidity at saturation point.

Germination rate assessment: The number of germinated plants on each pot was counted daily for the first three weeks. For the remaining period, germination was assessed on a weekly basis. Those plant species besides papyrus that germinated in the soil seed bank pots were counted as well. At the end of the third month, the final estimations were recorded and the seedlings were harvested and separated into groups according to the twelve sample locations and according to species type.

Data analysis: Kolmogorov-Smirnov test and Levene's test were used to test data for normality and homogeneity of variance, respectively. Data that met the assumptions of normality and homogeneity of variance was analyzed using Analysis of Variance

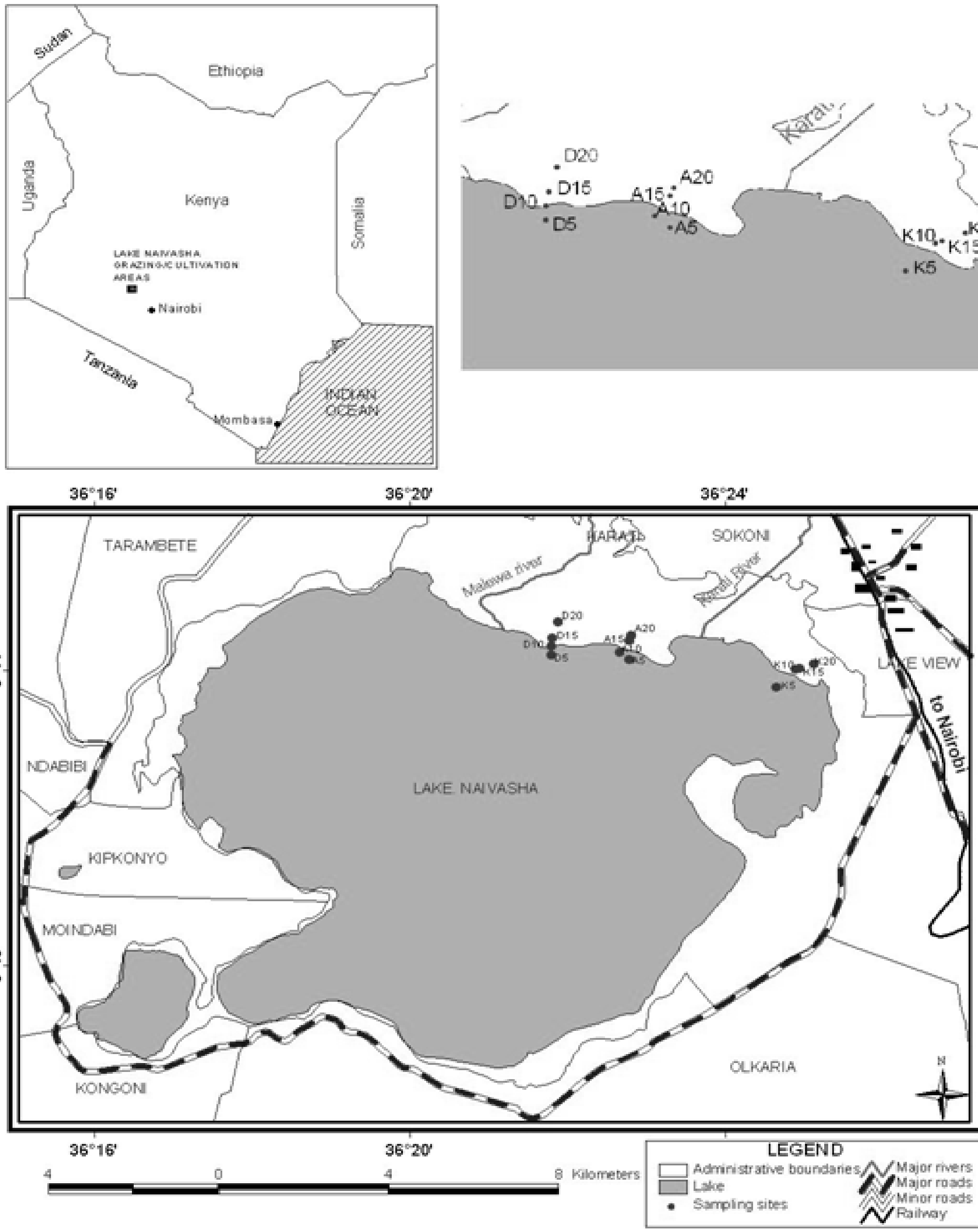

Fig. 1: Sampling sites on the study transects A, D, and K off the shores of Lake Naivasha, Kenya

(ANOVA) for any significant differences in the measured variables amongst sites. Data that did not meet the assumptions were analyzed using Kruskal-Wallis test.

RESULTS

Germination rate of papyrus seeds in sterilized soils: Germination rate was on the increase mainly for the first 6 weeks after which, most of the results revealed minor changes. This is because germination of papyrus occurs primarily within 28 days. Some of the seedlings died off soon after germination, leading to a decrease in the number of recorded germinated plants. With the first treatment, chronosequence 5 in the grazed sediment transect (D) had the highest number of germinated seeds in all transects, while chronosequence 15 in the cultivated transect had the lowest (Fig. 2 to 4).

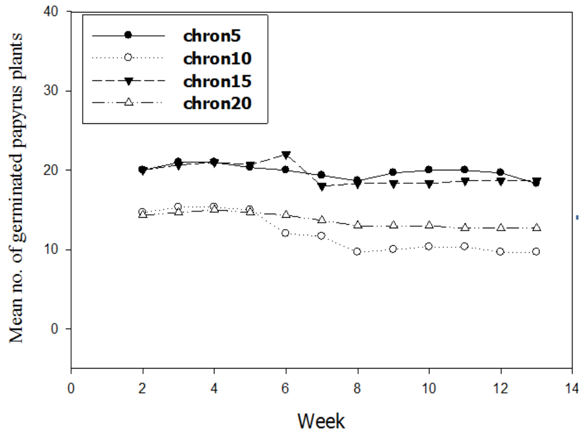

Fig. 2: Germination of papyrus seeds for sterilized soil samples from grazed Alluvial transect (A)

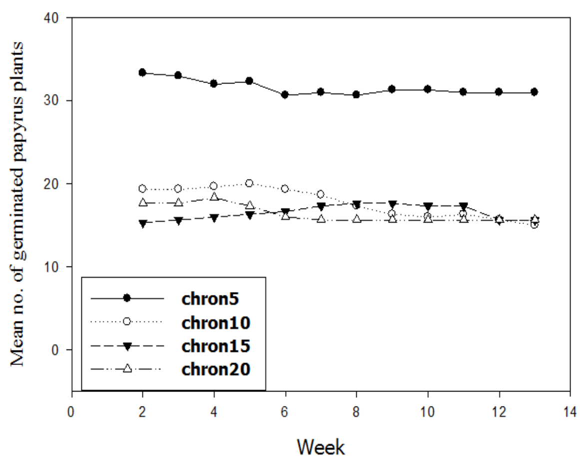

Fig. 3: Germination of papyrus seeds for sterilized soil samples from grazed sediment transect (D)

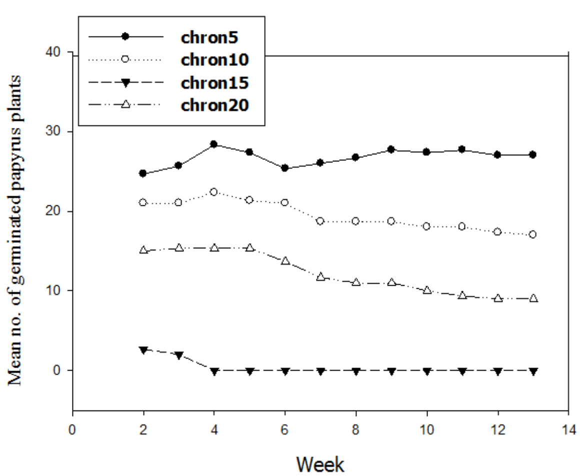

Fig. 4: Germination of papyrus seeds for sterilized soil samples from cultivated transect (K)

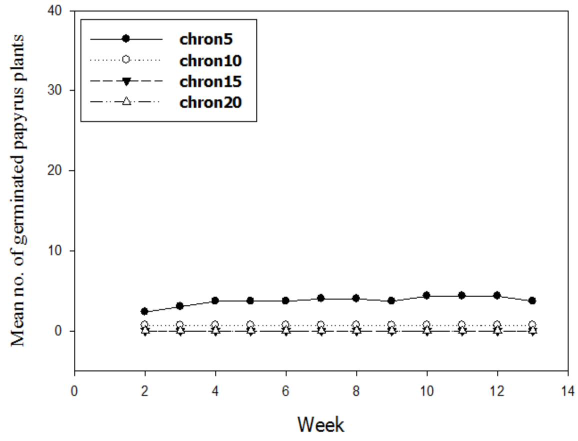

Fig. 5: Papyrus seeds germination for soil seed bank samples from grazed Alluvial (A) transect

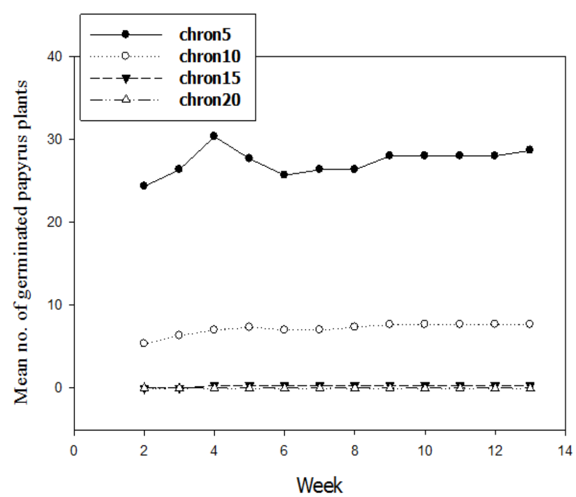

Fig. 6: Papyrus seeds germination for soil seed bank samples from grazed sediment (D) transect

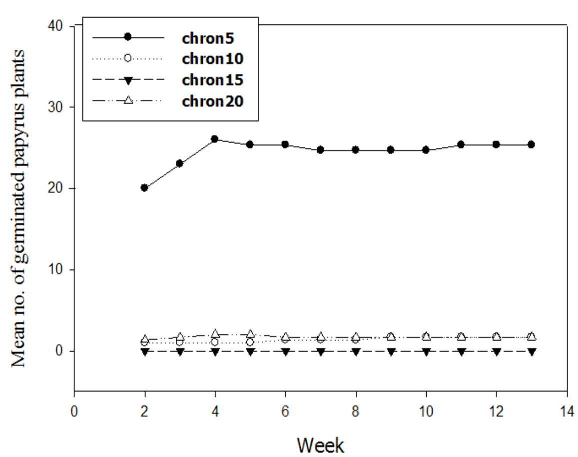

Fig. 7: Papyrus seeds germination for soil seed bank samples from cultivated (K) transect

Germination of viable diaspores in soil seed bank: Second treatment results portrayed that chronosequence 5 had the highest germination results at all the three transects (A, D and K), while chronosequence 15 and

20 remained very low throughout the experiment period (Fig. 5 to 7).

DISCUSSION

With the first treatment of sterilized soils, chronosequence 5, which was nearest to the lake was seen to be doing well at all the three transects, grazed Alluvial (A), grazed sediment (D) and cultivated site (K). This shows that soils at chronosequence 5 were higher in nutrients essential for papyrus germination, which might have been depleted or are lower in the other three chronosequences (10, 15 and 20) that had been out of water and under the different land uses for longer periods. According to Muthuri and Michael (1997), removal of large quantities of nutrients following papyrus harvesting may lead to reduced production rates in subsequent re-growth periods. This may explain why chronosequence 5 yielded the most number of germinated seedlings compared to the other chronosequences that had been under various land uses for longer periods. The other chronosequences (apart from 15 at transect K) also appeared to have a considerable number of germinated papyrus seedlings, meaning that there is high potential for papyrus to grow in these areas too if seeds are introduced.

According to DeBerry and Perry (2000) a preliminary understanding of the potential for vegetation development from the seed bank is essential for understanding plant community succession and future management considerations of created or restored wetland ecosystems. So, even though grazers may damage or remove all above ground biomass, regenerative capacity remains intact via seed bank and rhizome stock (Boar *et al*., 1999).

Germination results with seed bank revealed that the area closest to the lake, that is chronosequences 5 had more viable diaspores. One of the most important structural components of the wetland ecosystem, the seed bank, is of critical importance to the establishment and development of vegetation communities in wetlands (Van der Val, 1981). This means that the number of viable diaspores left in the soils after lake recession reduces with time, regardless of the prevailing land use, eventually dying off to almost zero as seen in chronosequences 10 and 15 which have been out of water for longer durations. With proper water conditions therefore, only the areas that have been exposed out of water for less than ten years are most likely to have papyrus regenerating naturally by way of seed germination. According to Van der Valk and Penderson (1989), the presence of viable seeds in the soil will direct the re vegetation sequence following grading or disturbance. This is mainly true for created and restored wetland systems that are graded or otherwise manipulated to implement or reintroduce a favorable hydrologic regime and are left to develop without planting or the addition of soil amendments.

Chronosequence 15 in transect K is an area whose soils were found to be very high in alkalinity; therefore, it does not support any vegetation growth and thus the almost zero germination results with both treatments throughout the experiment period (Fig. 3 and 7). According to Rahman and Ungar (1990), salinity inhibited the growth of seedlings and increasing salinity from 0 to 1.5% caused adecrease in the mean height of seedlings originating from collections made at low, medium and high salinity fieldsites. Papyrus germination and growth was therefore inhibited by high salinity in the K15 samples.

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