Factors affecting abundance and distribution of submerged and floating macrophytes in Lake Naivasha, Kenya

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Abstract

Macrophytes have been shown to perform important ecological roles in Lake Naivasha. Consequently, various studies regarding the impact of biotic factors on the macrophytes have been advanced but related studies on environmental parameters have lagged behind. In an attempt to address this gap, sampling on floating species and submergents was carried out in eight sampling sites in 2003 to investigate how they were influenced by a set of environmental factors. Soil texture (sandy sediments; $P < 0.05$, regression coefficient = −0.749) and wind were the most important environmental parameters influencing the distribution and abundance of floating macrophytes. Combination of soil texture and lake-bed slope explained the most (86.3%) variation encountered in the submergents. Continuous translocation of the floating dominant water hyacinth to the western parts by wind has led to displacement of the submergents from those areas. In view of these findings, the maintenance and preservation of the steep Crescent Lake basin whose substratum is dominated by sand thus hosting most submergents remain important, if the whole functional purpose of the macrophytes is to be sustained.

Key words: Kenya, Lake Naivasha, macrophytes, nutrients, soil

Résumé

On a montré que les macrophytes jouent un rôle économique important dans le lac Naivasha. Par conséquent, diverses études ont été réalisées sur l'impact des facteurs biotiques sur les macrophytes, mais les études correspondantes sur les paramètres environnementaux sont à la traîne. Pour essayer de compenser cette lacune, en 2003, on a réalisé un échantillonnage des espèces flottantes et submergées sur huit sites d'échantillonnage pour étudier comment elles étaient influencées par un ensemble de facteurs environnementaux. La texture du sol (sédiments sableux, $P < 0,05$, coefficient de régression = 0,749) et le vent étaient les paramètres environnementaux les plus important quant à l'influence sur la distribution et l'abondance des macrophytes flottants. La combinaison de la texture du sol et de la pente du fond du lac expliquait la plus grande partie (86,3%) de la variation rencontrée chez les espèces submergées. Le déplacement continuel des jacinthes d'eau, qui est la plante flottante dominante, vers la partie ouest par le vent a entraîné le déménagement des espèces submergées hors de cette partie du lac. Au vu de ces résultats, il est important d'assurer l'entretien et la préservation de la pente raide du bassin du lac en forme de croissant si l'on peut conserver l'ensemble de la fonction des macrophytes.

Introduction

The first scientific description of aquatic vegetation of Lake Naivasha was by Beadle (1930) who carried out studies of species zonation across a fringing papyrus swamp on the eastern shore opposite Crescent Island. Subsequent studies have demonstrated the importance of, for example, floating species, which range from hosting other plants to acting as a shelter to a myriad of micro- and macro-invertebrates. The floating mats act as feeding platforms of various bird species (Adams *et al.*, 2002).

Submerged aquatic vegetation, on the other hand, performs a number of irreplaceable ecological functions, which range from chemical recycling to physical

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modification of the water column and sediments to providing food and shelter for commercial, recreational, as well as ecologically important organisms (Balirwa, 1995; Thayer, Fonseca & Kentworthy, 1997). Many bird species such as coots, waterfowl and small mammals, e.g. beavers and muskrats feed on submerged vegetation. Diverse invertebrate communities exist among the submerged vegetation. For example, between 1992 and 1994, the average number of micronectans recorded on submergents of Lake Naivasha, ranged between 170 and 280 g per 100 g of air-dried macrophytes. A total of 200 flatworms were recorded from *Potamogeton schweinfurthii* A. alone.

The occurrence and subsequent abundance of aquatic plants in a habitat are governed by many underlying abiotic or/and biotic factors. The nature of substratum on which plants are anchored, influences the types and amount of vegetation found in a particular locality. Soil texture determines the stability of substratum, which harbours the plants and is also closely related to the chemical constituents of soil. Hence, clayey and/or silty soils are more fertile than sandy soils (Barko & Smart, 1986). The soils of Lake Naivasha are varied as a result of different underlying geographic processes resulting in silty/clayey soils, rocky and sandy sediments, which dominate some areas of the lake. Given this heterogeneous nature of the lake-bed sediments, Lake Naivasha soils could be an important factor influencing distribution and abundance of macrophytes.

Water clarity is another physical factor that directly influences submergents. The quantity and quality of light reaching the bottom are a function of the amount and nature of particles suspended in the water column. Normally, enhanced light abstraction by the suspended matter will negatively impact the submergents. Lake Naivasha has, over the years, experienced tremendous changes in water transparency. Secchi depth measurements as high as 3.7–5.7 m were recorded in 1979 (Burgis & Symoens, 1987); however, this has reduced since 1983 with measurements reaching 0.5–1.64 m (Harper, 1987). Christine (1995) observed Secchi depth measurements as low as 0.2–0.8 m in the Main Lake. Whereas this study did not attempt to find out the changes in macrophytes in relation to changes in water clarity over time, detecting a species that could be particularly sensitive to local spatial water transparency variations is of major importance in lake management. This would be useful in predicting the groups of plants that are likely to suffer most with continued deterioration in water transparency.

Changes in water level have impact on both floating and submerged vegetation and are better understood when explained in relation to the lake bathymetry. Lake Naivasha has varied lake-bed topography and experiences profound water level changes. A proportion of 28% of *Eichhornia crassipes* have been reported to die because of decrease in Lake Naivasha water level (Kariuki, 1992).

Nutrient status of various habitats offers a wide range of assemblages of plants. Plants in fresh water are often limited by the availability of essential nutrients especially nitrogen and phosphorus during a period of optimal growth in the tropics (Mitchell, 1969; Denny, 1985). Baruah (1981) reported that low concentration of phosphorus and nitrogen tends to reduce plant population as well as biomass in aquatic systems. In Lake Naivasha, seasonal variation in productivity of water hyacinth has been reported to be as a result of variation in concentration of both nitrogen and phosphorus (Kariuki, 1992). On the other hand, eutrophication of water systems leads to higher primary productivity with possibilities of depressed water clarity. Algal blooms, which can at times be lethal, are likely to occur and hence affect other aquatic life including fisheries. Increased amounts of nutrients may also lead to uncontrolled proliferation of submergents resulting in weedy scenarios or even enhanced epiphytic growth, which would impede the growth of submergents.

Other examples of factors influencing the spatial dispersal of aquatic plants are herbivory, human activities in the water body and riparian land, presence of pollutants, climatic factors and competition between and within species.

Unlike previous studies in Lake Naivasha (Christine, 1995; Harper & Zalewski, 2001), which concentrated on assessing the biotic, this study addressed the abiotic influences on the macrophytes of Lake Naivasha. To achieve this, two working objectives were set: (i) to determine the important physical and chemical environmental factors influencing the distribution and abundance of floating and submerged plants in Lake Naivasha; and (ii) to determine the abundance and distribution of the macrophytes.

Materials and methods

The study area

This study was carried out in Lake Naivasha (0°45′S, 36°20′E), a fresh water lake with a relatively small area of 100 km^2 (Harper & Zalewski, 2001) (Fig. 1). The lake surface area has, however, fluctuated depending on the

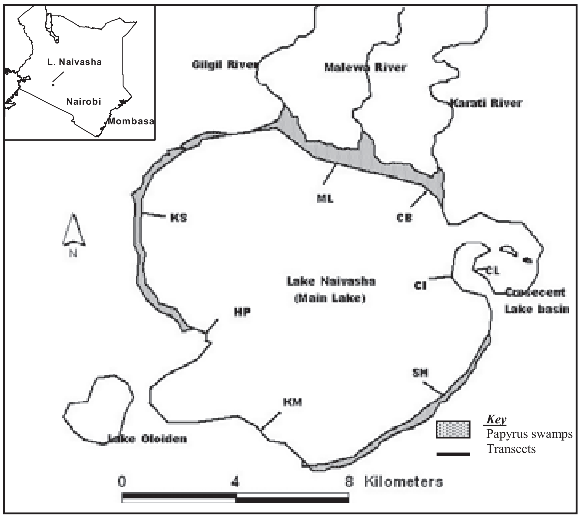

Fig 1 Map of Lake Naivasha showing sampling sites/transects (modified after Harper *et al.*, 2002) (CB, Central Landing Beach; MR, Malewa River Inlet; KS, Kasarani water Intake; HP, Hippo Point; KM, Kamere Landing Beach; SH, Sher Agencies; CI, Crescent Island; CL, Crescent Lake)

amount of precipitation, water inflow and loss in the catchment during a particular period of the year. Three rivers, the Malewa, Gilgil and Karati enter the lake in the northern part.

Sampling sites

Eight sampling sites and the same number of transects were established considering absence/presence of the target groups of macrophytes, while providing a range of sites presenting different local environmental characteristics. The *Central Landing Beach* provided a shallow area with low lake-bed topography occurring in the north eastern part of the lake; *Malewa River Inlet*: situated in the north, a turbid area where the principal rivers enter the lake; *Kasarani Water Intake Point*: a site to the northwest of the lake with minimal direct influence of both rivers and human activities such as farming; *Hippo point*: a site to the southwest of the lake with a steep lake bed; *Kamere*: a site to the south of the lake, a public entry point to the lake where washing and animal watering takes place; *Sher Agencies*: a site to the southwest of the lake, farming activities take place in the riparian land; *Crescent Island*: a site to the east of the lake, its riparian vegetation has been overgrazed by wild animals; *Crescent Lake*: an almost enclosed sub-basin with minimal interactions from the main lake. The sites were marked using hand-held Global Positioning System (GPS), Garmin 12XL.

Sampling methodology

Sampling was carried out during both dry and rainy seasons. A general collection of vegetation was carried out and identification was done using relevant keys (Agnew & Agnew, 1974) and herbarium facilities at University of Nairobi.

Sampling of floating vegetation was carried out using 1 by 1 m quadrat. The quadrat was thrown randomly six times within an area at the shoreline measuring 10 by 30 m, and the plant species present within the quadrat recorded. The abundance of each floating species was represented as percentage frequency, i.e.

$$\mathrm{Pf}_{\mathrm{sp}} = (R_{\mathrm{sp}}/R_{\mathrm{total}}) \times 100, \qquad (1)$$

where $\mathrm{Pf}_{\mathrm{sp}}$ is per cent frequency of a species; R_{sp} is number of quadrats with the species; and R_{total} is total number of quadrats.

Submergents were sampled by the rake method (Jessen & Lound, 1962) along transects, which were marked perpendicularly to the shoreline (Fig. 1) so as to reach 4.5-m depth. The plant species present on each rake sample were recorded. The abundance of each species was represented as percentage frequency, i.e.

$$\mathrm{Pf}_{\mathrm{sp}} = (R_{\mathrm{sp}}/R_{\mathrm{total}}) \times 100, \qquad (2)$$

where $\mathrm{Pf}_{\mathrm{sp}}$ is per cent frequency of a species; R_{sp} is number of rakes with the species; and R_{total} is total number of rakes.

The hydrometer method (Bouyoucous, 1962) was employed for soil texture analysis. A composite sample of sediments was collected using an Ekman grab from each site and put in separate plastic bags for analysis. Water transparency was determined by the extinction of 20-cm diameter Secchi disc.

To get the gradient of lake-bed along a transect line, the distance between a particular depth and the shore was determined using a hand-held GPS unit or a measuring tape. The depth of a sample point was measured using a graduated rope onto which weight was attached. The gradient was computed as follows:

$$G = (D/\mathrm{SH}), \qquad (3)$$

where G is gradient of lake bed; D is depth; and SH is distance from the shore.

Water samples for nutrients analyses were collected at 0.5 m by lowering acid washed polyethylene bottles.

Samples for dissolved nutrients were filtered immediately using acid washed syringe and a Swinnex filter holder with GF/C glass microfibre filter. Samples were transported in a cool box with ice cubes to the laboratory for analyses. Phenol-hypochlorite method (Wetzel & Likens, 1991) was adopted for analysis of ammonium. Nitrate was analysed on filtered water samples run through a reduction copper–cadmium column (Wood, Armstrong & Richards, 1967) and then the resultant nitrite measured by the sensitive diazotization method (Lenore, Arnold & Rodes, 1989). The biologically available form of phosphorus was analysed from a water sample filtered using Whatman GF/C glass-fibre filter paper and analysis followed the method (Mackereth, Heron & Talling, 1978). Total Phosphorus was determined by potassium-persulphate digestion of unfiltered water sample at 1.03×10^4 Nm^{-2} (1.5 p.s.i) for 1 h using an autoclave. The method (Mackereth *et al.*, 1978) was followed to analyse for phosphate in the digested sample. Water samples were analysed the same day of collection or were stored in a refrigerator for analysis the following day. Water pH and conductivity were measured using portable Jenway Model 3071 and 4070 (0–2000 μS) (Gransmore Green, UK) meters respectively. Wind direction was determined using a hand held wind vane.

Data analysis was performed using MINITAB (State College, PA, USA) for windows version 13.20-computer program.

Results

The abundance and distribution of vegetation

The floating macrophytes. *Eichhornia crassipes* (Mart.) Solms and *Salvinia molesta* Mitchell were the only free-floating species recorded in Lake Naivasha during the study period. However, *E. crassipes* was five times more frequent than *S. molesta*. Although *E. crassipes* was recorded in all sites, Central Landing Beach, Malewa River Inlet, Sher Agencies and Kasarani sites had the highest abundance of this species. The abundance of the two floating species varied from one site to another as shown in Fig. 2. No *S. molesta* was recorded at Central Landing Beach, Crescent Island and Crescent Lake.

The submergents. Of the six submergent species recorded during the study, *Potamogeton octandrus* Poir (15.2) was the most frequent. This was followed by *Potamogeton pectinatus* L. (12.2), *Najas horrida* Magn (12), *Potamogeton schweinfurthii* A. (3.2), *Ceratophyllum demersum* L. (1) and

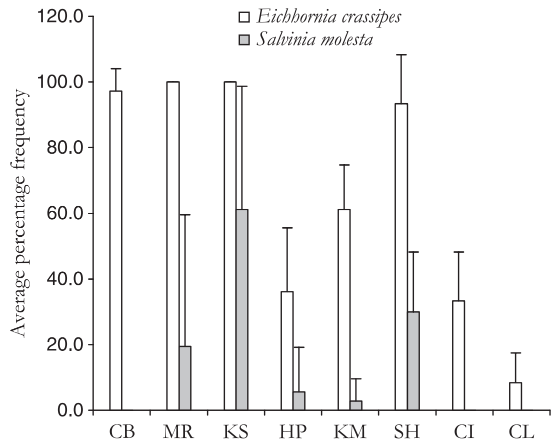

Fig 2 Spatial average percentage frequencies of floating species of Lake Naivasha (February–July, 2003). The vertical bars in all graphs indicate standard error of mean. CB, Central Landing Beach; MR, Malewa River Inlet; KS, Kasarani Water Intake Point; HP, Hippo point; KM, Kamere; SH, Sher Agencies; CI, Crescent Island; CL, Crescent Lake

Nitella sp (0.8) in descending order of percentage frequencies. *Nymphaea caerulae* Sav., which was found in very small quantities was the only floating-leaved plant encountered during the study. Submergents were found in the following sites: Crescent Lake, Crescent Island, Sher Agencies, Hippo point and Kamere.

The environmental factors

Sediments. The percentage composition of silt, sand and clay in sediments was significantly different among the sites. Highest proportions of sand were recorded at Hippo Point (93–97%) and Crescent Lake (89–91%) while Kasarani site had the lowest (10–27%).

Water transparency. Secchi depth measurements were below 1 m for sites in the Main Lake and did not exceed 1.5 m for Crescent sub basin. Crescent Lake site had the highest readings with a mean of 1.26 ± 0.21 m and the lowest was Central Landing Beach (0.22 ± 0.08 m). Spatial variation of water transparency at Crescent Lake differed significantly from others (one-way ANOVA: $F_{7,40} = 51.91$; $P < 0.05$).

Lake bed slope. Topography at all sites was determined and results were found to be in strong agreement with available bathymetric data. Of the eight sample sites, Crescent Lake had the highest substratum gradient followed by

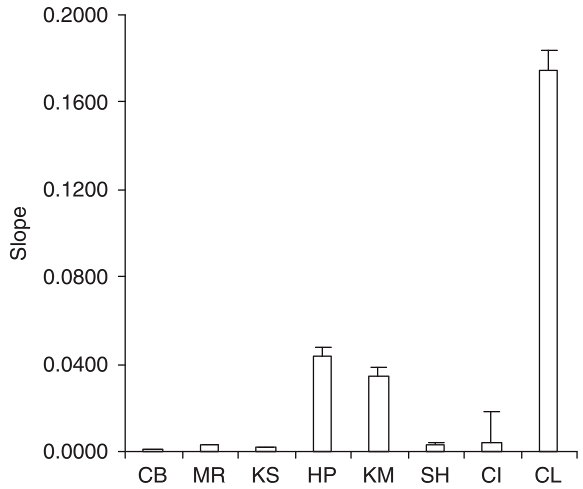

Fig 3 Slope of lake bed in relation to the sites in Lake Naivasha (February–July, 2003). CB, Central Landing Beach; MR, Malewa River Inlet; KS, Kasarani Water Intake Point; HP, Hippo point; KM, Kamere; SH, Sher Agencies; CI, Crescent Island; CL, Crescent Lake

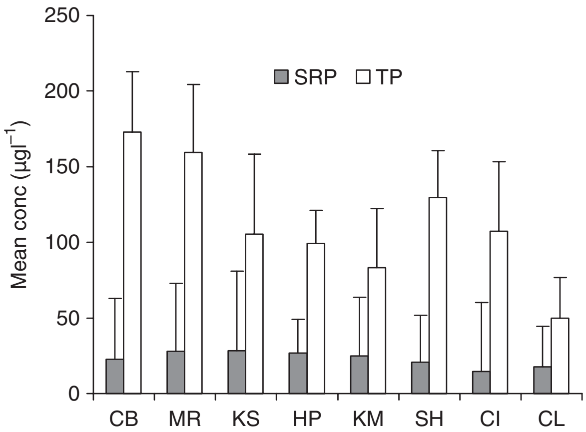

Fig 4 Mean spatial concentration of total phosphorus (TP) and soluble reactive phosphorus (SRP) in Lake Naivasha (March–July, 2003)

Hippo Point (Fig. 3). The lake bed slope differed significantly in the eight sites sampled.

Nutrients.

Nitrogen:. Mean concentration of ammonia was the highest at Hippo Point and the lowest at Central Landing Beach site while that of nitrites remained generally lower than ammonia or nitrates at all sites. However, there was no significant ($P > 0.05$) difference in concentration of the three forms of nitrogen among the sites. Malewa River Inlet site had the highest average concentration of nitrates (225 ± 102 μg l^{-1}) while Crescent Lake had the lowest (34 ± 12 μg l^{-1}). Significant temporal changes occurred with mean concentration of both nitrites and nitrates increasing from the month of May while that of ammonia was reduced.

Phosphorus:. Highest mean concentration (29 ± 6.9 μg l^{-1}) of soluble reactive phosphorus was registered at Malewa River Inlet while Crescent Lake site had the lowest (15 ± 3.6 μg l^{-1}) as shown in Fig. 4. However, there was no significant ($P > 0.05$) difference in mean concentrations of soluble reactive phosphorus in the eight sites. Similarly, Malewa River Inlet (159 ± 74 μg l^{-1}) and Central Landing Beach (173 ± 88 μg l^{-1}) sites had the highest concentration of total phosphorus while the lowest concentrations (50 ± 27 μg l^{-1}) were recorded at Crescent Lake site.

Conductivity and pH. Conductivity in Lake Naivasha ranged from 80 to 390 μS cm^{-1}. Malewa River Inlet site had the lowest mean conductivity (168 ± 47 μS cm^{-1}) while Crescent Lake had the highest (317 ± 15 μS cm^{-1}) (Fig. 5). Conductivity was significantly ($P < 0.05$) different among the sites. Seasonal changes showed an increase in conductivity during dry period and a decrease during wet season. Peak values of conductivity were observed in April just before the onset of rains. pH values ranged from 6.8 to 10.2 (Fig. 6). The waters of Lake Naivasha are well buffered and, therefore, no marked variation in pH was observed throughout the study period. However, pH at Crescent Lake site was on average the highest (10.8 ± 1.1) and significantly ($P < 0.05$) different from the other sites. Malewa River Inlet site had the lowest mean pH (7.0 ± 0.1).

Prevailing ground level winds over Lake Naivasha. Overall, wind direction over the six months was observed to be mainly southeasterly (51%) and southerly (27%), with a proportion of 15% blowing to the west. The percentage value is equivalent to the frequency of wind to each direction. Prevailing winds over Lake Naivasha have been described as very important physical factor influencing lake's physical, chemical and biological functions (Tarras-

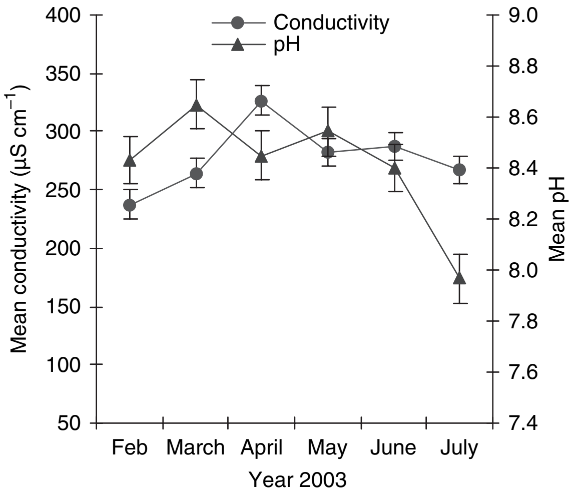

Fig 5 Mean monthly variations of pH and conductivity in Lake Naivasha (February–July, 2003)

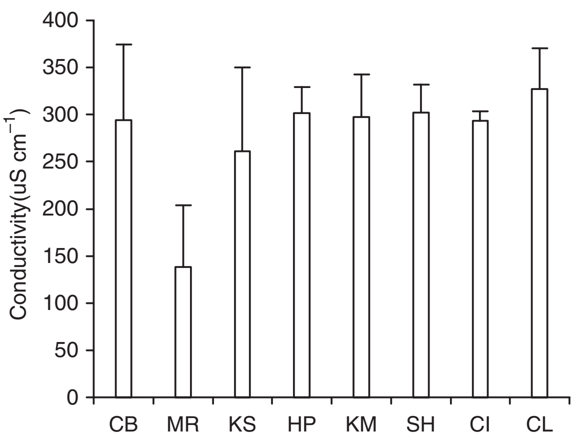

Fig 6 Spatial variations of conductivity in various sites in Lake Naivasha (February–July, 2003)

Wahlberg, 1975). In tropical lakes, circulation is usually a balance between wind induced mixing and stabilizing action of solar radiation.

Discussion

Prevailing ground level winds of Lake Naivasha was the most important factor that influenced spatial dispersal of the floating macrophytes. The wind readily drives the free-floating aquatic plants and the associated macrophytes from one point to another within the lake. The present wind direction results are in agreement with previous studies (Njuguna, 1982; Hubble, 2001), which showed that the direction of ground level wind is mostly southeasterly. Consequently, Central Landing Beach, Malewa River Inlet and Kasarani sample sites, which were all located in western–northeastern region, had the highest frequency of *E. crassipes*. *S. molesta* was correspondingly high in these stations except for Central Landing Beach site. Tall shoreline vegetation, however, tends to shield the floating plants from the impact of wind. The shielding effect by fringing *Sesbania sesban* (L) accompanied by favourable sediments texture enabled the presence of large mats *E. crassipes* at Sher Agencies.

Whereas the impact of wind on the floating plants may be viewed as direct, wind may be said to influence indirectly the distribution of submergents. The transportation of the floating plants to the same areas occupied by submergents disadvantages the latter mainly in two ways: the floating plants cut the supply of light and the decomposition of dead sinking floating plants impacts negatively on the submergents. Since the entry of the floating species in Lake Naivasha, the submergents have gradually been eliminated from the areas currently dominated by the floating species. Submergents are, therefore, concentrated in the eastern parts while floating plants are mainly found in the north-western parts of the lake.

Soil texture had also a significant (sand; $P < 0.05$, Regr. coeff. = −0.749) influence on distribution of water hyacinth and *Salvinia*. Soil texture is a key determinant in soil-water retention (Okalebo, Gathua & Woomer, 2002) and is poor in sandy compared to either silt or clay dominated soils. Although *E. crassipes* is free-floating, it survives dry conditions by attaching itself onto the moist ground (Gopal, 1987). Therefore, the sandy substratum in such areas like Crescent Lake and Hippo Point could not support high abundance of either *E. crassipes* or *S. molesta,* unlike Sher Agencies whose soils were dominantly silty or/and clayey.

Whereas low frequencies of *Salvinia* at Crescent Island could partly be attributed to location of the site in relation to wind direction, Central Landing Beach site should have recorded high amounts of *Salvinia* in this context. The low lake-bed gradient at Central Landing Beach implied that the site was left exposed and dry with receding lake-water, hence, dehydarting *Salvinia* plants which are, unlike *E. crassipes,* poorly adapted to drying conditions. The higher abundance of *Salvinia* observed at Malewa River Inlet site, which is also gently sloped, can partly be because of the fact that water from River Malewa moistened the exposed soils, hence, survival of

Salvinia. The highest frequency of *Salvinia* plants recorded at Kasarani site was attributable to several favourable factors. Apart from the effect of wind which blew in this direction, the steep lake bed ensured inundation at the site, hence, *Salvinia* plants were not subjected to dry soil conditions as was the case at Central Landing Beach, which had the lowest lake-bed gradient.

The lake-bed slope, soil texture and water transparency were the most important factors in determining the distribution and abundance of the major submerged species of Lake Naivasha. Lake-bed slope explained 32.4% of the total variation experienced in the distribution of *P. pectinatus* plant species whereas soil texture and lake-bed gradient could explain 86.3% of the variation encountered in *P. octandrus*. However, *P. schweinfurthii* showed preference to areas of low gradient as pure stands of this species could be found exposed with receding water. Lisowski *et al.* (1978) indicated that members of Potamogetonaceae show adaptation to adverse conditions by having tougher leaves when exposed, therefore, coping with exposure unlike other submergents.

Water transparency and soil texture could explain a total of 69.3% variation that occurred in abundance and distribution of *N. horrida* in Lake Naivasha. Areas with less sand and high water clarity apparently favoured establishment of the species making Sher Agencies the most favourable site for the species.

Sites with steep lake-bed slope, a firm substrata and high water transparency had the most submergents. As such, Crescent Lake, Crescent Island, Sher Agencies and Hippo Point are important for submergents and associated ecosystem services they provide. The maintenance of these sites and particularly Crescent Lake basin will remain important, if the ecological services offered by the submergents are to be sustained.

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