

LANDCOVER MAPPING AND MULTICRITERIA MODELING FOR EXPLAINING THE SPATIAL AND TEMPORAL DISTRIBUTION OF A PAPYRUS SWAMP AT LAKE NAIVASHA, KENYA

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ABSTRACT

This paper is an extract of a research (thesis) done on the distribution of the papyrus swamp at Lake Naivasha in 1998 by the same author. Based on *area per habitat* and *trends* as indicators, the distribution was derived from the temporal analysis of land cover maps. Remotely sensed data (aerial photographs 1967 and 1984 plus a TM satellite image of 1995) were analysed for the period 1967 to 1995 within two year sets as 1967/1984 and 1984/1995. The distribution of the swamp would be explained by the influence of its neighbour landcover. Risk potential zones represented in two model scenarios were established indicating relative influence of the landcover based on change rates and distance as criteria. The criteria evaluation was done in a Decision Support System and results combined spatially in a GIS. The papyrus area declined at a rate of 71 % between 1967 and 1995. The major influence and risk to the swamp area in order of magnitude were open water, shrubland, agricultural area, woodland, grassland and built up area. The integration of climatic regime, ground water level, soil drainage/depth, topography and anthropogenic factors as grazing and burning should be considered for improved explanations.

1 INTRODUCTION

1.1 Background

The distribution of the papyrus swamp at Lake Naivasha has generated interest due to the need for management intervention to the problem of the fluctuating swamp area. A decreasing trend spells danger to the surrounding communities that derive livelihoods from the swamp. Though there had been observed dynamics involving fluctuations and succession, (e.g. Gaudet 1977; Denny 1985; Herper et al 1995), the spatial context had not been evaluated, projected and explained for management priority implications.

The interest in landcover maps for analysis is the wide range of possibilities of their use. This is because of the range of surface features that the maps can depict for example water, different kinds of vegetation, rocks, sand and evident man made structures. From observed patterns, it is believed that some phenomenal interactions can be deduced (Leps, 1989). As such landcover maps have been convenient in ecological studies, for example the AFRICOVER project (FAO, 1997); identification of hot spots (Chandria and Surendra 1995); and wetlands monitoring (Yashioka et al 1993).

Effective management response can be supported by explaining the past and the present and using both for predicting the future. This is because within planning and decision making contexts, an explanation beyond the present is desirable especially by simplified representations through modelling. In situations where various factors and /or constraints interact, the development of criteria for identifying the extent of each one's role in the process can be put into evident scenarios to support prioritised management response. The manipulation of multiple criteria has evolved through manual mathematical calculations to sophisticated computerised models. These models can be built within Decision Support Systems. The 1990s indicated more of spatial analysis (in GISs) as independent components of the evaluation (e.g. Meijerink et al 1993; Patrono and Oriolo 1995, cited by Patrono 1995), or embedded within the same system as in a Spatial Decision Support System (Eastman et al 1995).

In this study, the objectives were as follows:

- 1- To establish the spatial and temporal distribution of the papyrus swamp
- 2- To model the potential risk of the landcover types to the swamp area
- 3- To assess other factors influencing the distribution of the papyrus swamp.

With reference to Grillas, (1996) two indicators, *surface area per habitat* and *trends* were selected, with the former translated into change rates of the surface of the swamp relative to other landcover types while the latter showed the rate of papyrus area loss or gain over the time of analysis (1967 -1995). The results were used as model inputs to produce risk potential zones of the papyrus area through criteria evaluation.

1.2 The study Area

The study was undertaken in the Lake Naivasha riparian area (also known as the "Lake Zone") covering an area of 30,000. It is located in the eastern rift valley of Kenya between 194000m E, ⁹⁹32000mN, 215000mE, ⁹⁹08000mN. The area is dominated by flat to gently sloping topography, except for the western offshore areas, which are moderately steep. Lake Naivasha is a fresh water crater lake, surprisingly in alkaline environs. This is believed to be a result of underground water inflows plus the inflow of Gilgil, and Malewa rivers. One spectacular characteristic of the lake is its oscillating nature over the past years, recorded between 1800s to 1990 (John Goldson Associates, 1993; Stuttard et al 1995).

The vegetation forms a zonation along a topographic gradient starting from the lake dominated by a papyrus fringe. There are other macrophytes to the immediate fringe of the lake. Other vegetation include shrublands, grasslands and woodlands.

Most of the human activities are supported by the wetland through water supply and the ecological functions of the swamp. The characteristic species, *C. Papyrus* plays a vital role in the hydrological regime, modification of the water quality, and is habitat to a number of wildlife resources. Activities like agriculture (intensive irrigated horticulture; dairy and cattle ranching), tourism/recreation (popular black bass sport fishing; and sanctuary for about 350 bird species plus hippos, buffalo, Thompsons, Grants gazelles and impala) , and urbanisation (Naivasha town) are supported (e.g. John Goldson Associates 1993; Gaudet 1997; and Gaudet 1980).

2 METHODOLOGY

2.1 Landcover Mapping

The indicator, *area per habitat* was derived through mapping of the landcover for the years of analysis, 1967, 1984, and 1995. Following ITC procedures (Groten 1995), the 1967 aerial photographs (panchromatic) of scale 1:50,000 were interpreted and both the tilt as well as flight error corrected using a pantograph. The corrected interpretation was digitised in a GIS (ILWIS 2.1). The 1984 aerial photographs (panchromatic) of scale 1: 12,000 were interpreted. In addition to the tilt /flight error correction, the scale was reduced to 1: 50,000 using the pantograph. The scale reduction was done to allow for the overlay with the map of 1967, which was at 1: 50,000. The corrected interpretation was digitised in a GIS (ILWIS 2.1). A satellite image TM of 1995 was interpreted and digitized on screen. This was verified with field data on vegetation structural classes. For each map, areas for landcover types were calculated using the HISTOGRAM function in ILWIS 2.1

2.2 Change Detection

A change analysis of the land cover types was undertaken to establish *trends* and this was done in a GIS (ILWIS 2.1, MAPCROSS function) for the years 1967 to 1984, and 1984 to 1995. In anticipation of obvious change between the year of study 1997 and the image date of 1995, the 1984/1995 change map results were evaluated using a *rule based* interpretation (Mariumni, 1997) . The process is able to check the mapping inconsistencies based on established rules that take the form: **'If condition then Inference'**

Two criteria were used to develop the rules:

- 1- A threshold area (a minimum of 0.01 ha) below which a change could be established was used with the assumption that an area that is realised as changed should be at least twice the pixel size (50 m)
- 2- The expected change direction using own knowledge, for example a reasoning that a built up area may not change into papyrus between 1984 and 1995.

A list of rules were identified and applied in assessing the change and scores of positive (+) and negative (-) assigned to each land cover type that changed to or from papyrus respectively.

2.3 Deriving model inputs

2.3.1 Criteria 1: Risk based on distances to papyrus areas (pixels): It was assumed that the nearer the papyrus to the landcover the higher the risk. Equal chance was assumed for all the land cover types assuming no constraint. From the land cover map of 1995, individual landcover type maps were extracted using a map calculation (MCALC) function in a GIS (ILWIS 2.1) resulting in the respective cover type maps. For each land cover type map a DISTANCE function was used to characterise each pixel in the study area with the distance from the cover type. To get the potential risk for papyrus, a map calculation was done for each distance land cover type map to get the area of papyrus within. The risk index was developed from the range of the values in all the land cover maps by a normalisation process (Eastman et al. 1995) using the following formula:

$$X_i = (R_i - X_{\min}) / (X_{\max} - X_{\min}) \quad (1)$$

Where:
 X= standardised pixel
 R= raw score (raw pixel value)
 Xmax is the maximum pixel value
 Xmin is the minimum pixel value

According to the criteria, the nearer the papyrus pixel to a land cover, the higher the potential risk, so, the *Xmin* was translated into the highest risk, while the *Xmax* was translated into the lowest risk. The index was used to slice (reclassify) the land cover type distance to papyrus maps into regular 10 classes showing respective risk levels from 1 (low level), to 10 (high level).

2.3.2 Criteria 2: Papyrus change in area (ha) by the other land cover types: A land cover that had higher area (ha) overtaken from papyrus was assumed to have a higher potential risk to the swamp. The land cover change maps 1967/1984, and 1984/1995, the areas calculated for each land cover type according to the change to papyrus (positive or gain for papyrus)or from papyrus (negative or loss to papyrus) were aggregated to get the total change to papyrus area between 1967 and 1995.

2.3.3 Criteria 3: Change rate in area(ha) per year of the individual land cover types: It was assumed that if a landcover type was increasing at a faster rate, it had a higher threat tp papyrus area. Area(ha) for each land cover type was calculated for 1967, 1984, and 1995 from the respective land cover maps in ILWIS using the HISTOGRAM function . The histogram table was imported into excel for calculating the change rate using the following formula:

$$(y_2 - y_1) / t \quad (2)$$

Where:
 y1 the initial year,
 y2 the final year
 t is the difference between y2 and y1

2.4 Multicriteria Evaluation and Modelling

To distinguish between human impacts and more natural influences, two scenarios were developed:

- ⇒ Scenario 1: impact of land cover types, including open water as most influential factor
- ⇒ Scenario 2: impact of land cover types, excluding open water

2.4.1 Weights of land cover types by the criteria and their ranking : For the criteria 2 and 3, to be used in Scenario 1 and 2, a set of weights were derived using the Regime multiple criteria evaluation module of DEFINITE, a Decision Support System (Janssen and Herwijnen, 1994). A decision or effect table was created. For criteria comparison purposes a normalisation (standardisation of the scores) is required, and this was done by quantitative ratio scale (Eastman et al 1995) before the evaluation process as:

$$\text{standard score (i)} = \text{raw score(i)} / \text{row maximum} \quad (3)$$

The standard score is the new criterion score standardised,
 The raw score is the criterion score before standardisation
 The row maximum is the maximum criterion score by the same row.

Weight assignment to each criterion and finally ranking of the land cover types from lowest to highest risk was done using the Regime method, which is based on the following formula:

$$\text{if } C_{ij} - C_{ji} > 0 \quad (4)$$

then alternative i is better than j.

where : **C**- is the criteria, **i** and **j** are the alternatives

In the evaluation, the relative importance of criterion 1 (papyrus change) was assigned to be higher than that of criterion 2 (land cover change rate), using the option rank order. The corresponding appraisal scores were inverted to express the influence (in terms of risk) of the land cover types to Papyrus thus the lower the coefficient the better. The resulting appraisal scores were used as the weights in the final risk modelling involving the two scenarios but after a sensitivity analysis.

2.4.2 Sensitivity analysis: Sensitivity analysis is the process of ascertaining the consistency of the results of the evaluation model. The analysis was carried for effects and weights uncertainty given 20% probability. If found consistent, then the results would be suitable for input to the model.

2.5 Risk potential to papyrus swamp (maps) combining the criteria

Multi -criteria spatial models mostly aim at deriving the suitability of the choice options (e.g. Eastman et al. 1995). The model expression would take the form:

$$S = \sum w_i x_i \quad (5)$$

Where

- s** = Suitability to the objective being considered
- w_i** = Weight of factor i
- x_i** = Criterion score of factor

However, the application of the above expression implied suitability than the intended risk. Therefore the derived coefficients were inverted by dividing the highest coefficient (score) by each resultant coefficient.

The final risk potential map for papyrus area was spatially derived by a linear additive function for the weighted landcover types in a GIS (ILWIS 2.1). The final expression took the form:

$$\text{Risk map} = \text{Factor1} * P1 + \text{Factor2} * P2 + \text{Factor3} * P3 \dots \quad (6)$$

Where: **factor** are the modifying factor as distance risk index maps (for the land cover types)

P is the weighted position (coefficient) suggested by DSS from the rate of change of land cover types and the change in area of papyrus by the land cover type (from temporal analysis).

Thus the expression for Scenario 1 based on equation 6 was as follows:

$$\text{Fin1} = (\text{shrmca} * 1 + \text{watmca} * 0.85 + \text{Agmca} * 0.74 + \text{Wdmca} * 0.28 + \text{Gramca} * 0.21 + \text{bumca} * 0.17) \quad (7)$$

Where: **Fin1** = Potential risk combining all land cover types, and the three criteria.

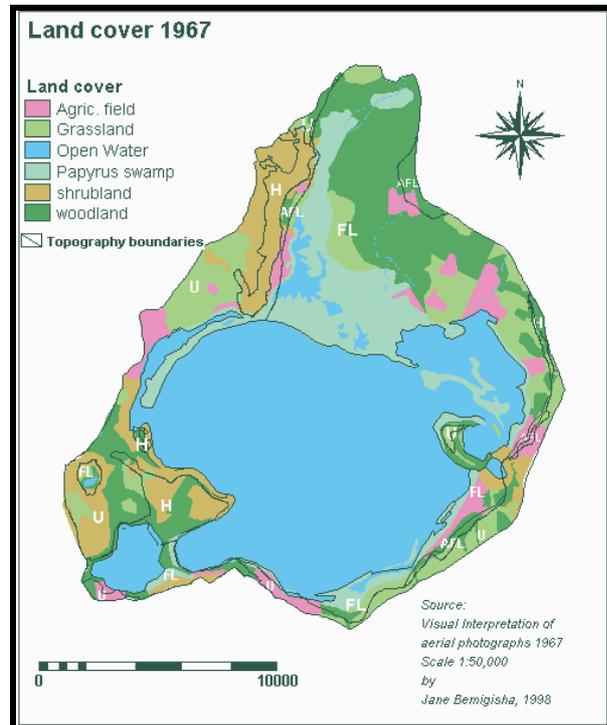
shrma= shrubland, **watmca**= open water, **Agma**= Agricultural fields, **Wdmca**= woodland, **Gramca**= Grassland, **Bumca**=built up area. (see also appendix 13)

A similar expression (but excluding open water) was applied for scenario 2

3 RESULTS

3.1 The distribution of Papyrus swamp and other land cover types in 1967, 1984, and 1995

In 1967, the papyrus swamp was mainly concentrated in the northern shore of the main Lake Naivasha, as part of the flat lacustrine plain (Figure 1). There were fragmented clumps on the lake especially in the eastern part. The swamp covered about 12% of the total land cover area. Other land cover types included open water covering the highest area, grassland, agricultural fields, shrubland (mostly *Senna didymobotry*, *Polygonum spp*, *conyza spp*, and *sphaeranthus spp*) and woodland (mainly *acacia spp*) which dominated the natural vegetation. The 1984 papyrus swamp was still mainly concentrated in the north east flat lacustrine plain, but reduced to the river mouths of the Malewa and Gilgil. Fragmented clumps were found on the western side of the lake. The swamp area comprised only 5% of the total land cover area. In addition to the cover types observed in 1967, built up area was identified, covering an area of 158.6 ha. In 1984 the lake level was higher than in 1967. Of the natural vegetation cover, woodland still took the highest area, but was 1000 ha less than in 1967. Agricultural fields increased in area about 2.5 times as large as in 1967. In 1995 the papyrus swamp was further reduced to an almost uniform fringe along the main Lake Naivasha, covering about 3% of the total land area (see also figure 2). Open water covered 13276.7 ha. Of the other natural vegetation, shrubland had the highest cover, followed by woodland and grassland. Agricultural fields increased by about 1500 ha, compared with 1984, while built up area increased by about 80 ha.



Topography classes
 FL- Flat Lacustrine plain
 AFL- Almost Flat Lacustrine Plain
 U- Undulating (plain to upper elevation)
 H- Hily

Figure 1. Land cover maps for 1967

3.2 Changes in the papyrus swamp cover from 1967-1984 and from 1984-1995:

The papyrus swamp that remained without change for the period 1967-1984, comprised 851.25 ha, mainly concentrated along the North and North-west shore of the main lake. In 1984, 1959 ha of papyrus was lost to water area especially in the flat to almost flat areas. Of the natural vegetation, the largest part of the papyrus (304 ha) was converted into shrubland, followed by grassland (254.8 ha), and woodland (182.3 ha), while 100.8 ha of papyrus was converted into agricultural fields. Some areas formally fringing the swamp were changed to papyrus especially the agricultural fields (104 ha), grasslands (94 ha), and woodland (109 ha) on the north eastern shore. A small papyrus fringe of 156 ha remained unchanged between 1984 and 1995. This was mainly located on the northern shore of the lake. Most of the fringe that was lost to open water in the period 1967-84 was regained (823 ha), while the floating clumps in the Western part of the lake changed again into water (164 ha). Most of the papyrus was converted into shrubland (555.25 ha), followed by agricultural fields (387.5 ha), woodland (195.3 ha) and only a minor area (8.8 ha) was converted into grassland.

3.3 Potential risk to papyrus swamp area by other land cover types

In this section, the three criteria and their quantification are presented, followed by the risk model results based on the two scenarios. The model inputs were derived from the status of the swamp between 1967 and 1995 (the results of the temporal analysis described in the previous sections).

Criterion (1) : the distance of land cover types to the present papyrus: Papyrus risk index for each land cover type was shown by a value in the papyrus area representing the actual distance to the land cover type. The results are shown in table 1. The potential risk for papyrus swamp to be taken over by agricultural fields was found to be mainly in the northeast and southern areas with ranges of medium to high for the whole area. Built up area risk was found on the eastern papyrus swamp area with 23% of papyrus area at low to medium risk, while 77% was between medium and high risk. The open

water potential risk was manifested all around the shore with medium to high-risk level. The southwest papyrus area was at high risk by woodland and tended towards medium in the northern area. 1% of the total papyrus area was found within low to medium risk potential, while 99% was within medium to high risk by woodland. Most of the north swamp was at high risk being taken over by shrubland and tended towards a medium to high risk on the southwestern area.

	Risk level			
	Low - Medium		Medium -High	
Land cover type	Area(ha)	%ge	Area(ha)	%ge
Agricultural fields	0	0	1044.9	100
Built up area	244.1	23	800.8	77
Open water	0	0	1044.9	100
Woodland	11.3	1	1033.6	99
Shrubland	0	0	1044.9	100
Grassland	0	0	1044.9	100

Table 1. Risk of land cover types based on distance to papyrus swamp

Criterion (2) : Change in area(ha) of papyrus by each land cover type:For each land cover type, the total area changed from or to papyrus, from 1967 to 1995 was calculated. Open water had the highest risk (with a loss of 1023.25 ha of papyrus), followed by shrubland (814 ha), agricultural fields (372.25 ha), woodland (256.25 ha), grassland (153 ha), and built up showed no effect (see table 2) . The negative scores indicate the loss of papyrus area, and positive scores a gain.

	67/84	84/95	Total change
Papyrus to agricultural fields	3.5	-375.75	-372.25
Papyrus to open water	-1682.25	659	-1023.25
Papyrus to woodland	-73	-183.25	-256.25
Papyrus to shrubland	-273	-541	-814
Papyrus to grassland	-160.5	6.75	-153.75
Papyrus to Built up area	0	0	0

Table 2 Change in area (ha) of papyrus by other landcover types

Criterion (3): Rate of change of landcover types: It was assumed that the higher the rate of change of a particular land cover type, the higher the risk in terms of impact on the present and future papyrus area. In table 2 the rate of change (ha/year) was calculated for each of the seven land cover types over the period 1967-1995. Agricultural fields had the highest rate (129.2 ha/yr) , followed by shrubland (58.3 ha /yr), built up area (8.5 ha/yr), open water (-18.8 ha/yr), Woodland (-41.7), and Grassland (-42.9 ha/yr).

3.3.1 Weights for Scenario 1 and 2 : Table 3 shows shrubland with the highest potential risk to the swamp (1), followed by open water (0.85), agricultural fields (0.74), woodland (0.28), grassland (0.21), and built up (0.17). The results were consistent with the following order: Bu > Gra > Wdl > Ag > Ow > Shr

Priority assignment to the criteria (by rank order)					
Papyrus change(ha)		1			
Increase rate (ha/yr)		2			
Ranking of land cover types					
Land cover	Rank	coefficient (the higher, the lower the risk)		inverted coefficient (the lower the lower the risk)	
		Senario 1	Senario 2	Senario 1	Senario 2
bu	1	1	1	0.17	0.11
gra	2	0.8	0.75	0.21	0.15
wdl	3	0.60	0.5	0.28	0.22
Ag	4	0.23	0.14	0.74	0.8
Ow	5	0.20	-	0.85	-
Shr	6	0.17	0.11	1	1

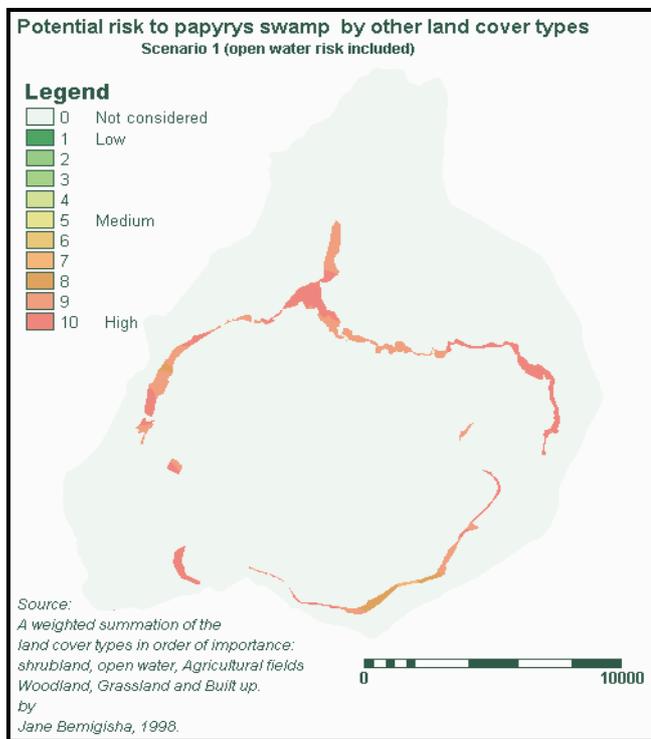
Codes: Ag -agricultural field, Ow- open water, Wdl- woodland, Shr- shrubland, Gra- Grassland, Bu -Built up

Table 3. Weights in terms of risk for land cover types: Scenario 1 and 2

For scenario2, (table 3) where open water was excluded, shrubland was found with the highest risk to papyrus (coefficient 1), followed by agricultural fields (0.8), woodland (0.22), grassland (0.15) and built up area (0.11). The sensitivity analysis showed consistency as: Bu>Gra>wdl>Ag>Shr

3.3.3 Risk potential to papyrus swamp combining the criteria in a GIS:

Scenario 1 (Including open water) showed all the papyrus areas with potential risk levels ranging from medium to high. Most of the high risk areas were found to be in the north (see figure 2).



In scenario 2 , where open water was excluded, more papyrus area was found to be with low to medium classes of potential risk than in scenario 1. About 543 ha of papyrus was found at low to medium risk, which was 52 % of the total papyrus area, while the medium to high risk area covered 502 ha, 48% of the papyrus area (table 4).

Figure 2. Risk potential to Papyrus area by other landcover

	Low - Medium		Medium - High	
	Area (ha)	%ge	Area (ha)	%ge
Scenario 1	0	0	1044.9	100
Scenario 2	542.9	52	502	48

Table 4. Risk levels to Papyrus: Scenario 1 and 2

4. DISCUSSION

The results demonstrate a clear vegetation zonation from the lake shore to the adjoining higher elevation especially the one of 1967 that was similar to the one identified by Gaudet (1977). Interference from human activity was continuously increasing evidenced by agricultural fields and built up area by 1995. The zonation commonly started with the lake water, then papyrus swamp, but the subsequent classes were not in consistent order. In the different years, the order was exchanged amongst the different landcover types. Shrubland had the fastest change rate between 1984 to 1995, had the highest natural vegetation area, and followed papyrus in the zonation by the 1995. It also exhibited the highest total area change from Papyrus to natural vegetation, by the same year (table 2).

The tendency for shrubland to dominate the process of overtaking papyrus, could be due to the indirect effect of climate and lake level or /and induced by human interference. Changes during climatic cycles have been found not to be accompanied by return to original state as a result of complete or almost complete dying off of species dominating at the beginning of the cycle or as a consequence of invasion of new more competitive species therefore leading to succession (Van de valk, and Welling, 1988). This fluctuation can be elaborated with the situation of flooding /inundation and drawdown which corresponded to the 1967/84 situation and 1984/1995 respectively.

Inundation/flooding:. Between 1967 and 1984 the Lake Naivasha water increased in extent, and most of the Northern papyrus swamp was flooded, as well as part of the natural vegetation and agricultural fields in the lower areas. Most of the north papyrus swamp changed to water, leaving a little concentration to the northeast. The rest of the natural vegetation types decreased in extent as well. On a study about papyrus response to flooding, Gaudet (1977) found that the survival got minimal especially the young papyrus plants, which could tolerate flooding only after reaching a certain stage of development. On the other hand, some herb species could succumb to the flood like *Sphaeranthus* which has shown a high percentage of survival due to its cell structure that is adaptable to both flood and dry conditions (Gaudet, 1977).

Drawdown:. Between 1984 and 1995 the lake water levels dropped even below the 1967 level. According to Gaudet (1977), the drawdown succession should eventually succeed to a papyrus swamp. Indeed papyrus overtook the water ward immediate shore but it continued to decrease in the extent (table 3). By 1995, the strikingly evident north swamp decreased further still below the 1984 area (1). The zonation changed with woodland which had followed papyrus by the 1967 status, having its position taken over by shrubland after the flood in 1984.

There was an extensive interference of agricultural fields on all sides which could be that farmland expansion took advantage of the receding water because of improved drainage condition for cultivation. Between 1967 and 1984 100.8 ha of papyrus was converted into agricultural fields; between 1984 and 1995 this was 387.5 ha. It was found that dykes and channels were made to limit flooding on the farmlands. This process could be practically irreversible. Once a field is established, it will be hardly abandoned, and even if so, the conditions might be no longer suitable for papyrus. Shrub species like *conyza floribunda* which seem to have high reproductive rates and wider tolerances (Gaudet , 1977) stand a higher chance to out-compete papyrus on abandoned fields.

Other forms of human interference, though not included in the model were grazing and burning observed during fieldwork for the same study. In addition, Gaudet (1977) indicate that cattle graze the papyrus especially the young ones on the study area. The after-effects of grazing on vegetation have been studied by Verweij (1995) who found that short herb species benefited from increased light moisture and nutrients after the higher structural vegetation are grazed especially by cattle. On the other hand, burning has been found to encourage bush encroachment (Luttge, 1997) so that shrub species could have an advantage of flourishing against papyrus after the burn. Build-up area so far had no direct effect on the distribution of papyrus cover.

5. CONCLUSION

Lake water levels (open water) have a high impact on the distribution of the papyrus swamp with shrubland taking the most advantage of both drawdown and flooding conditions to overtake the swamp. If the water level is high, papyrus is flooded and dies , particularly the juvenaile stands. If the lake water level goes down again, papyrus recovers and new plants can be established from seeds stored in the muddy soils. However, during flooding, shrub species like *conyza floribunda* get higher chances to survive due to their high tolerance to flooding. In the case of drawdown, human activities exert further influence for example the reclamation of riparian land by agricultural fields or grassland for grazing, or burning. Once more, shrub species take advantage due to their high reproductive rates.

Considering the highest influence of the water levels, the integration of related factors like climatic regime, ground water level, soil drainage/depth, and topography would improve on the explanations. Anthropogenic factors as grazing and burning should also be considered for the model improvement. Appropriate temporal and spatial scale remote sensed data should be given particular attention.

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