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Ecohydrology of a seasonal wetland in the Rift Valley: ecological characterisation of Lake Solai

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Abstract -

The following research describes through an ecohydrological approach, the first assessment of the ecology of Lake Solai, with a particular emphasis on the vegetation. Lake Solai is located 50 km north of Nakuru in the Rift Valley in Kenya at E36°80’- 36°84’ – N00°05’- 00°08’. It is a shallow lake which follows a very peculiar seasonal water regime, and which faces conflicts between agriculture and conservation water users. In the upper catchment, an overview of the agricultural practices was implemented and river water uses were identified to assess river flows. Crops/grassland and woodland/shrubland were the major land uses, covering about 65% of the catchment. Closer to the lake, vegetation samples were collected around the lake together with samples of environmental factors such as soil and water quality. Thirteen vegetation communities were identified within four main zonations: forest, grassland, river inlet and rocky outcrop. These communities showed abundance, distribution and diversity determined mostly by the human pressures, the flooding periods and the salinity. *Cynodon, Cyperus,* and *Sporobolus* genera were the most abundant.

Introduction

Seasonal wetlands are important features in tropical areas. More particularly, from a phytosociological point of view, plant communities in East Africa's wetlands are poorly described (Gouder de Beauregard & Mahy, 2004; Denny, 1985). The ecohydrology at the catchment level needs to be researched and understood in order to preserve and manage such environments.

The Lake Solai catchment, host to a seasonal wetland reaching 9 km² in wet periods, is located in the Eastern Rift Valley, Kenya, at E36°80'-36°84' – N00°05'-00°08'. The basin is located in a transitional climatic zone, so that it is described as semi arid to semi humid (FAO, 1978). The rainfall is highly variable within the catchment but averages, according to sources, from 700 to 900 mm of annual rainfall (Chemilil in Mulama, 1999; Koskei & Mara, 2000; Koyo & Ndetei, 2003). The pattern is bimodal with long rains in April and May and short rains in October. The driest season extends from December to March, and the evaporation is estimated at 1800 mm per year (DailyET 2003 after FAO 2004).

The lake is of great ecological importance, as it offers large habitats for waterfowl and is located between Lake Nakuru and Lake Bogoria in a bird migration highway. It plays also a significant economical role for livestock grazing and watering, and for a small ecotourism industry.

The objectives of this paper are to present a first assessment of the ecology of the Lake Solai with particular emphasis on the vegetation, by favouring the ecohydrological approach as advocated by Zalewski (2000) and Gouder de Beauregard, Torres & Malaisse (2002), which integrates the ecological, hydrological and agronomical issues.

Material and Methods

The study was carried out after a wet period in August-September 2003 and after an unusually dry period in June 2004.

Land use characteristics of the catchment were assessed from digitised topographic maps (KSS, 1973 and 1974), land cover maps extracted from the AfriCover database (FAO, 2000) and a LANDSAT image (27/01/2000). Ground truthing, which identified the specific land use types, was achieved using a hand-held GPS set (Garmin 76) and ArcGIS software (ESRI) was used to process the information.

River discharges were measured using the velocity-area method or volume timing (Mwakalila, 2003). For each river two variables were estimated: the base flow and the abstraction during the dry season. Base flow was estimated gauging the rivers' flow during the dry season. Water abstractions represented local consumption either for irrigation purposes or household water supplies. These figures were derived from agricultural surveys carried out with local farmers and water users. Lake bathymetry and topography were estimated with a clinometer on land and a meter rule in water along 13 transects.

For plant work, seven transects (T1 to T7) were selected along clear zonations around the lake, starting from dry land to open water, with 4 to 5 sampling points per transect, varying in distance according to vegetation changes (A to E). The minimal area for vegetation sampling was defined at each sampling site via the species-area-curve technique (Kent & Coker, 1995) The species-area curve is normally plotted by using quadrats of successively larger size, until no significant number of new species is encountered, at which point the minimal area is reached, defining a relevé. Abundance at each relevé, or sampling area, was estimated according to the Braun-Blanquet abundance scale (Kent & Coker, 1995). The Braun-Blanquet coefficients were then rescaled in van der Maarel coefficients and recorded in a raw data matrix (Kent & Coker, 1995). Plant specimens were collected and identified at the National Botanic Garden of Belgium and the National Herbarium of Kenya.

Environmental parameters of water and soil were determined for each vegetation sampling site, in 2003 and 2004. At each dry sampling point on each transect, the top soil was analysed. pH was determined with a pH kit, soil texture was given a scale between sand and clay and soil colour was described using a Munsel chart. For flooded sampling areas, a multimeter (Consort C532T) was used to record pH, electrical conductivity and temperature with a Secchi disk for water transparency. Samples for BOD, total nitrates and phosphorus, total dissolved and suspended solids were collected once for analysis at the KWS Nakuru laboratory. The methods used are listed in the Table 3.

Results

Upper catchment

The Lake Solai catchment covers an area of 175 km^2 and is orientated NE-SW, with escarpments clearly delimitating the eastern and western boundaries (Figure 1). Four permanent rivers flow from the eastern escarpment: Maji Tamu and Kasururei originate on the plateau and Kamolo and Chemuka discharge as springs from the hillside (Table 2). There is no surface outflow.

Catchment land use classes (five) are shown in Table 1 and the distribution of the dominant classes are visible in Figure 1. Land use is driven by soil, topographic, hydrologic and anthropogenic variables. Large agricultural fields (>0.25 ha) are located on deep brown and red soils with woodland and shrubland on shallow soils and slopes or following rivers. Land close to the lake is grazed and areas more distant are cropped. Hence, the spatial distribution of land uses follows a centripetal trend where grazing areas favour proximity to the lake’s edges and where cropped areas are located in further positions from the centre of the catchment. Woodland and shrubland are either located on remote positions or on prominent landscape features which cannot be exploited for agrarian purposes.

Lower catchment

Lake Solai lies in a shallow basin (Figure 2) with soils around the lake ranging from silty loam to heavy clay. Brown silty loam soils (FAO cambisols) are in both transitional and deposit-receiving areas. Heavy dark clay soils are distributed around the lakeshores. These are often waterlogged with high salt concentration and can be related to the FAO vertisoils and Solonchaks (Driessen *et al*., 2001). Inflowing river water is near neutral (pH 7.3) with low conductivity (135 μS/cm) but rises to pH 9.0 and conductivity of 2398 μS/cm in open water. Secchi transparency is around 12 cm with highest suspended and dissolved solids concentrations during the dry season (Table 3). Water temperature varies between 20°C in the morning to 35°C at midday. The various environmental factors determined with their sampling numbers (n) are compiled in Table 3 according to vegetation zones.

Phytosociology

Fifty-eight plant species in the wet and 36 species in the dry season were recorded. Their abundance-dominance coefficients are presented in Table 4 for the years 2003/2004. Thirteen vegetation communities (C1 to C13) were identified (Figure 2) and eleven of these (excluding rocky areas and a seepage zone) are illustrated in Figure 3. Communities fell into four main zones: dry land, swamp, open water and river inlet.

At the head of the dry land zone, the *Acacia xanthophloea* Benth. sets the landscape, while the dominant species are at grass level, with the *Cynodon dactylon* (L.) Pers., *Sphaeranthus suaveolens* (Forsk.) DC., *Cycnium tubulosum* (L.F.) Engl. and even the *Commelina diffusus* Burn. in the wet season only. Within the zone described as swamp, the abundant and wide spread species were *Cynodon dactylon*, *Cyperus laevigatus* L., *Cyperus dives* Del. and the *Acacia xanthophloea*, the *Panicum repens* L. and the *Sporobolus robustus* Kunth. The open water zone contained in dry periods mostly *Cyperus dives*, *Panicum repens*, *Pistia stratiotes* L., *Typha domingensis* (Pers.) Steud., *Sporobolus robustus* and in wet periods, significant concentrations of *Lemna* sp., *Ludwigia stolonifera* (Guill. & Perr.) Raven and *Utricularia* spp. Finally, the river inlet was dominated by *Cyperus dives*, *Pistia stratiotes*, *Ludwigia* sp., *Polygonum* spp.,*Commelina* sp. and *Leersia* spp.

Discussion

Upper and lower catchment

The Lake Solai ecosystem relies on (bio)communities which adapt to changing environmental conditions, resulting from the combination of the land and water uses in the catchment, the lack of lake outlet, the precipitation pattern and the high evaporation.

It was shown that up to 50% of the upper catchment is cultivated; rivers have no buffer zones and water is abstracted, most intensely during dry seasons. The latter reduces and sequences the surface recharge to the lake and leads to flashier responses to rainfall events.

As locals confirm (Von Kaufman, pers. com.) the catchment used to be widely forested before 1975, and the lake was smaller. Kervyn de Meerendré (2004) observed through modelling the catchment's hydrology that the impact of woodland and shrubland on the water balance results in the increase of evapo-transpiration, reduced runoff and deep percolation. The root systems of such covered land are generally deeper than those of short vegetation or agricultural crops. In dry climates woodland can maintain transpiration at high rates for longer, depleting the soil moisture to a greater depth (Mwaura & Moore, 1991). Hence, the impact of human land use in the catchment through deforestation and intensive farming has changed the hydrology drastically allowing more water to reach the rivers and the lake through runoff.

Closer to the lake, there was obvious pressure from cattle grazing on the vegetation and soil. The chemical water study, on its side, indicated that inflowing river water was dilute with relatively low concentrations of suspended material. Concentrations were much higher in lake water where changes in pH and alkalinity suggest high productivity. Total phosphorus concentrations were exceptionally high, perhaps revealing a geochemical origin. The lack of phosphorus accumulation in the lake compared to the river could indicate that phosphorus is removed in the river inlet by the dense vegetation (Carter, 1955; Viner, 1975). Furthermore, it was observed that the shallow depth of the lake, continuously favouring a mixing of the layers, lead to the light being available for photosynthesis only within the upper surface, making it a potential controlling factor for pelagic primary production.

Finally, in comparison to the 630 – 1510 mg/l of Lake Solai, Tarras-Wahlberg, Harper & Tarras-Wahlberg (2003) record suspended solids values of 760 mg/l for lake Baringo and 52 mg/l for what they called a reference undisturbed freshwater lake (Lake Kichiritith) south of Baringo. They highlight how the high values of pH (8.9), conductivity (1760µS/cm), alkalinity (670mg/l $CaCO_3$), and suspended solids of the Lake Baringo, which relate closely to the Lake Solai, reflect on a high environmental stress originating in irrigation agriculture and excessive grazing in the catchment.

The vegetation communities described around the lake are thus results of seasonality and of drivers originating in the catchment. As the Figure 3 illustrates, three main environmental factors affect the vegetation communities of Lake Solai: flooding regime, salinity and human impacts. The hydrology through its seasonality drives the two first factors but is itself influenced by human practices. The determining factor for those plant communities relates to the flooding regime. Water depths have indeed been reported to be one of the most important factors that influence vegetation distribution and species assemblages (Lind & Visser, 1962) in wetlands. The flooding regime furthermore drives the salinity which appears high as testified by the EC and the salt flowers. Denny (1985) and Howard-Williams (1975) who studied inland wetlands in Africa do also confirm the significant role of flooding and salinity in the abundance, composition and distribution of vegetation.

Phytosociology

The Lake Solai vegetation shows three main zonations around the lake: the forest, grassland and river inlet. A rocky outcrop on a steep slope in the North West presents a fourth zonation.

The grassland extends along the widest zone. The slope is very small and large monospecific communities can be found. As the slope is little, large salt patches are created through evaporation increasing the soil salinity. It is also a place where cattle are regularly brought in large numbers. This heavy grazing, high salinity and flooding regime leave therefore place only to highly resistant species. *Cynodon* and *Sporobolus* genera can grow. In the wet periods, the composition and abundance of the communities booms.

Much of the grassland was originally forest and turned over through human interventions. *Acacia* sp. used to stand in numbers but faced cutting down for charcoal and field clearance. To the west of the lake where the slope is steeper, some of such forest communities remain. They create a very special habitat for birds and host the

Aeschynome pfundii, which in the East African herbarium (Agnew & Agnew, 1994) was only recorded in Lake Solai.

The vegetation communities identified for these two zonations show similarities to the description Howard-Williams (1975) made after a drought period on the Lake Chilwa in Malawi. It highlights how the change in water level creates an environment suitable for few species, such as *Aeschynomene* spp. and *Sporobolus* spp., where salinity is prominent.

Besides this, Lake Solai presents a zonation which is by far the most abundant and diverse. The fresh input from rivers flooding the delta and then encountering the brackish water from the lake are host to a dense vegetation of emergents and euhydrophytes.

It appears finally that the changes undergone with the seasons by the vegetation communities are mostly in abundance and composition, such as shown around the river inlet and the lake edges. It is however interesting to notice that the free floating macrophytes *Lemna* sp. and *Utricularia* sp. were not to find in the drier period although they were very abundant when the lake was more extended. While BOD and alkalinity undergo the strongest seasonal changes, it can be thought that oxygen demands reaching 600 mg/l, high alkalinity and high EC will not favour growth. There was only one floating plant which seemed to thrive, the *Pistia stratiotes*. In the literature, *P. stratiotes* were reported to have a toxic level mostly determined by an EC around 2680 μS/cm (Sooknah & Wilkie, 2004). Further species which seemed absent or in low abundance in the drier period were the *Commelina diffusus*, a euhydrophyte and *Cycnium tubulosum*, a grassland emergent.

Conclusion

The study of a type of wetland rarely researched in Eastern Africa necessitates a catchment wide approach, which is well integrated within the ecohydrology concept.

This paper has presented upper catchment data where land use and rivers were analysed, so that the dynamics of the plant community in the lower catchment could be approached holistically.

The significant human impacts and hydrological changes on the Lake Solai offer a rough environment to survive in, where plants such as *Cynodon, Aeschynomene* and *Sporobolus* find their niche and where as much as 13 plant communities co-exist.

The protection of some of these plant communities could benefit the particularly rich birdlife around Lake Solai, this as consequence enabling ecotourism activities based on bird watching to develop. The knowledge and understanding of such environment through the ecohydrological assessment receives thus all its relevance and appears as an appropriate step towards sustainable development.

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Tables

Table 1- Land use proportions through the Lake Solai catchment

Land Use	Proportions (%)
Grassland	8
Woody grassland	11
Rainfed crops	14
Woodland and Shrubland	33
Crops and Grassland	34

Table 2- Rivers' flows, abstractions and lengths in the Lake Solai catchment

River	Discharges in m^3/s Base flow	Abstractions	River Length (km)
Maji Tamu	0.094	0.107	10.7
Chemuka	0.019	0.016	7.0
Kasururei	0.017	0.015	7.4
Kamolo	0.004	0.002	5.8

Table 3. Water and soil quality assessment of Lake Solai (mean ±SD). If different, the number of samples is in brackets. Nutrients (N-NO3, TP), suspended solids, BOD, alkalinity were sampled once on the vegetation transects T5, T2, T2, T4.

	Dry land	Swamp	Open water	Open water	River inlet	Method
	2003	2003	2003	2004	2003	
No of samples	11	9	13	5	7	
Soil						
pH top soil	6.7 ± 0.9	8.0 ± 1.0 (6)	-	-	-	pH kit
Munsel colour soil	10YR 3/3	10YR 3/1	-	-	-	Munsel chart
Texture	SL-LC	L-HC	-	-	-	Texture scale
Water						
Water temperature (°C)		25.5 ± 2.7	28.1 ± 4.0	29.5 ± 3.3	21.4 ± 1.3	Multimeter (Consort)
Secchi transparency (cm)		11.8 ± 12.2 (6)	2.4 ± 0.5 (8)	2 ± 0.0	10.5 ± 2.2 (4)	Secchi disk
Maximal water depth (cm)		60	100	100	60	Meter
pH water		7.9 ± 0.3	8.1 ± 0.3	9.0 ± 0.1	7.3 ± 0.1	Multimeter (Consort)
Conductivity ($\mu S\ cm^{-1}$)		1541 ± 723	776 ± 111	2398 ± 166	135 ± 13	Multimeter (Consort)
T. Nitrates (mgN-NO3 l^{-1})		<0.01	0.15	-	0.03	Cadmium reduction
T. Phosphorus (mgP l^{-1})		18.70	12.20	30.70	10.40	Stannous chloride
T. Suspended solids (mg l^{-1})		17	630	1510	47	Photometric
BOD (mg l^{-1})		84	101	603	<5	5 days
Alkalinity (mgCaCO3 l^{-1})		1050	300	1460	60	Titrimetry

Table 4. Phytosociological table with van der Maarel coefficients, for 2003 and 2004 if applicable (x/x). T represents the transects, and the letter (A to E) gives the relevé site.

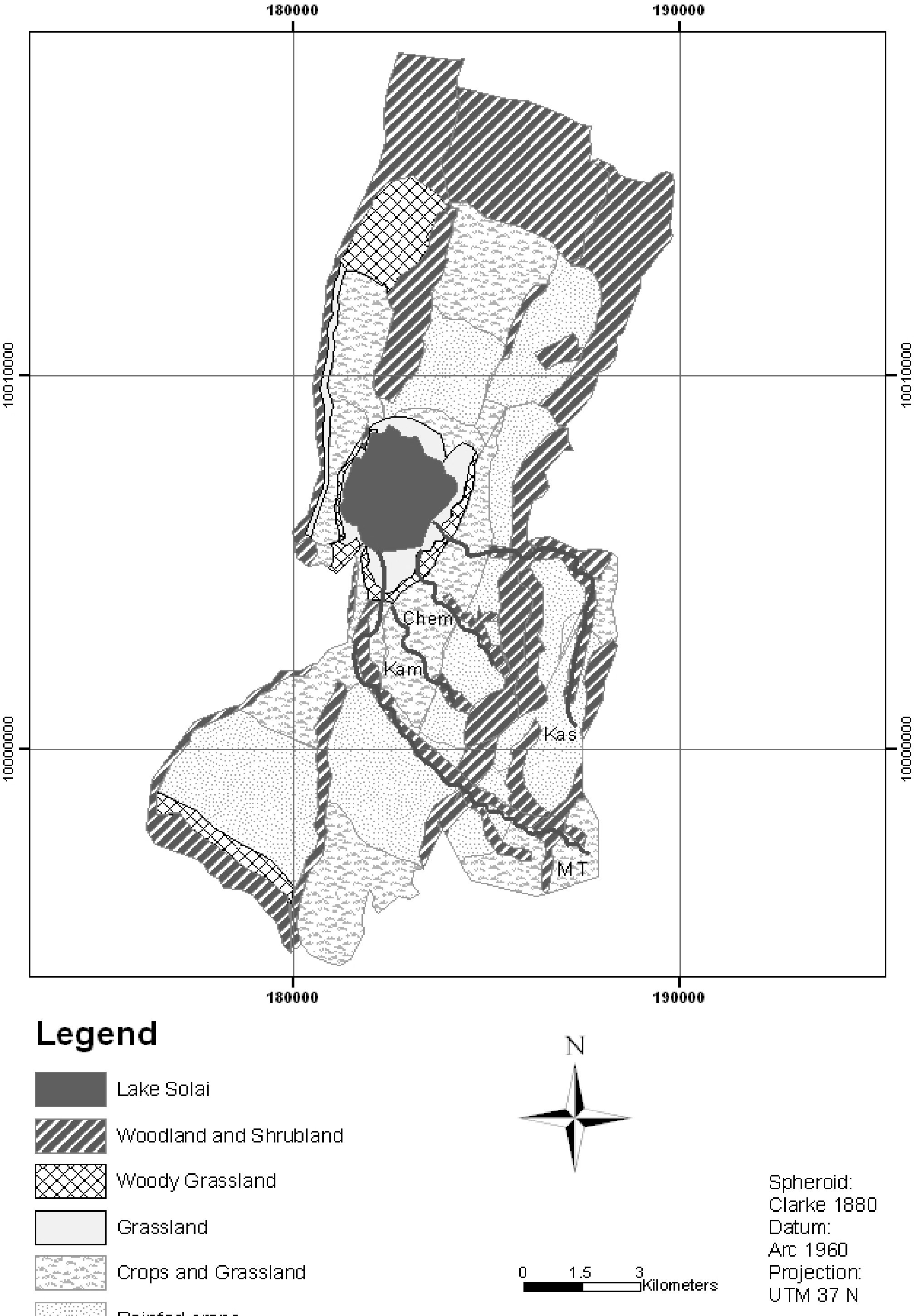
	Land													Swamp										Open water					
Species/Station 2003/2004	**T1A**	**T2A**	**T3A**	**T4A**	**T5A**	**T6A**	**T7A**	**T1B**	**T2B**	**T3B**	**T5B**	**T6B**	**T7B**	**T1C**	**T2C**	**T3C**	**T5C**	**T7C**	**T1D**	**T2D**	**T3D**	**T7D**	**T5D**	**T1E**	**T2E**	**T4E**	**T3E**	**T5E**	**T7E**
Acacia xanthophlea Kruger	5/5	3/	/2												/1			7/7				5/7							
Achyranthes aspera L.													3/																
Aeschynomene elaphroxylon (Guill.&Perr.) Taub.																				/1			1/						
Aeschynomene pfundii Taub.																						7/5							/7
Asystasia mysorensis (Roth) T. Anders.																		5/											
Bolboschoenus maritimus (L.) Palla											2/																		
Ceratotheca sp.						1/3						1/																	
Chloris gayana Kunth.	3/																												
Chloris pycnothrix Trin.		2/										2/																	
Cissus cactiformis Gilg.						5/5																							
Commelina diffusus Burn.	3/				5/		3/1			5/						5/		2/											
Contoisina assimilis ?		1/																											
Crassula rhodesica (Merxm.) Wickens & Bywater						3/						3/																	
Croton dicogamus Pax.						5/5						2/																	
Cyanotis foecunda Hassk.						3/						3/																	
Cycnium tubulosum (L.F) Engl.	/3	3/3	/3					3/		5/																			
Cynodon dactylon (L.) Pers.	7/7	7/8	9/8	9/9				9/5	2/5	7/2		5/2	7/7		3/7	5/3	5/5	/5		5/5	5/				5/3				
Cyperus articulatus L.																						3/							/7
Cyperus difformis L.									2																				
Cyperus dives Delile															5/5					8/7		5/5		/3	7/7	2/2	5/		/5
Cyperus laevigatus L.												/2		5/3	5/		7/3		9/8				5/5	5/5					
Cyperus rotundus L.										5/	5/3	/2			/3	5/3				/5	2/								
Dactyloctenium aegypticum (L.) Beauv.												5/																	
Eriochloa fatmensis (Hoschst. & Stend) W.D. Clayton		5/										5/	3/																
Euphorbia hirta L.												5/																	
Galinsoga parviflora Cav.						1/						1/																	
Gomphrena celosioides Mart.						1/1																							
Hydrophila auriculata (Schumach) Heine						3/					2/3																		
Justicia exigua S. Moore	3/																												
Leersia hexandra Sw.					8/7						7/7																		
Lemna gibba L.																					2/			5/	5/	3/			
Ludwigia stolonifera (Guill. & Perr.) Raven																								3/		5/5			
Melanthera scandens (Shum. & Tornn) Roberty					2/																								
n° 100 - sticky grass													/3					2/2											
n° 27 - Grelotte			/2	/2						5/					8/	5/													
n° 4 - Lamiaceae	7/						3/						5/					3/											
n° 49 - Polygonum sp.																													
n° 76 - white rock						5/						2/																	
n° 82 - Cyperus sp.						3/2						5/2																	
n° 87 Cyperus sp.												2/																	
Ocimum suave Willde													/5					5/2											
Panicum repens L.											5/3				/3	5/	8/5			5/7	5/7	/3	2/2		5/5		/5	7/7	
Pistia stratiotes L.												5/3								/3		5/		5/5	5/5	5/7	5/5	7/3	/7
Polygonum pulchrum Blume																													
Polygonum setosulum A. Rich.																													
Pycreus sanguinolentus (Vahl.) Nees											/2					5/													
Rhus natalensis Bernh.																		2/											
Sacciolepis africana C. E. Hubb & Snowden																													
Sesbania sesban (L.) Merr.					5/7						7/7											5/3				7/			
Solanum incanum L.			/2										/3					5/5											
Sphaeranthus suaveolens (Forsk.) DC.	2/2	2/2	1/2	3/				2/2	1/1	1/		5/3	/1																
Sporobolus helvolus (Trin.) Dur. and Sch.		/2							9/5	/5				5/3															
Sporobolus robustus Kunth.																5/5					8/7		9/8	5/3			8/7	8/8	
Sporobolus spicatus (Vahl) Kunth			5/					5/5		/5				8/8					5/3										
Typha domingensis Pers.					3/												2/3					/5				2/3	/3	/3	/5
Utricularia inflexa Forsk.												3/			3/							3/		3/		3/	2/		
Vernonia richardiana (Kuntze) P. Sermolli													/1									3/3							
Zea mays L.							8/8																						

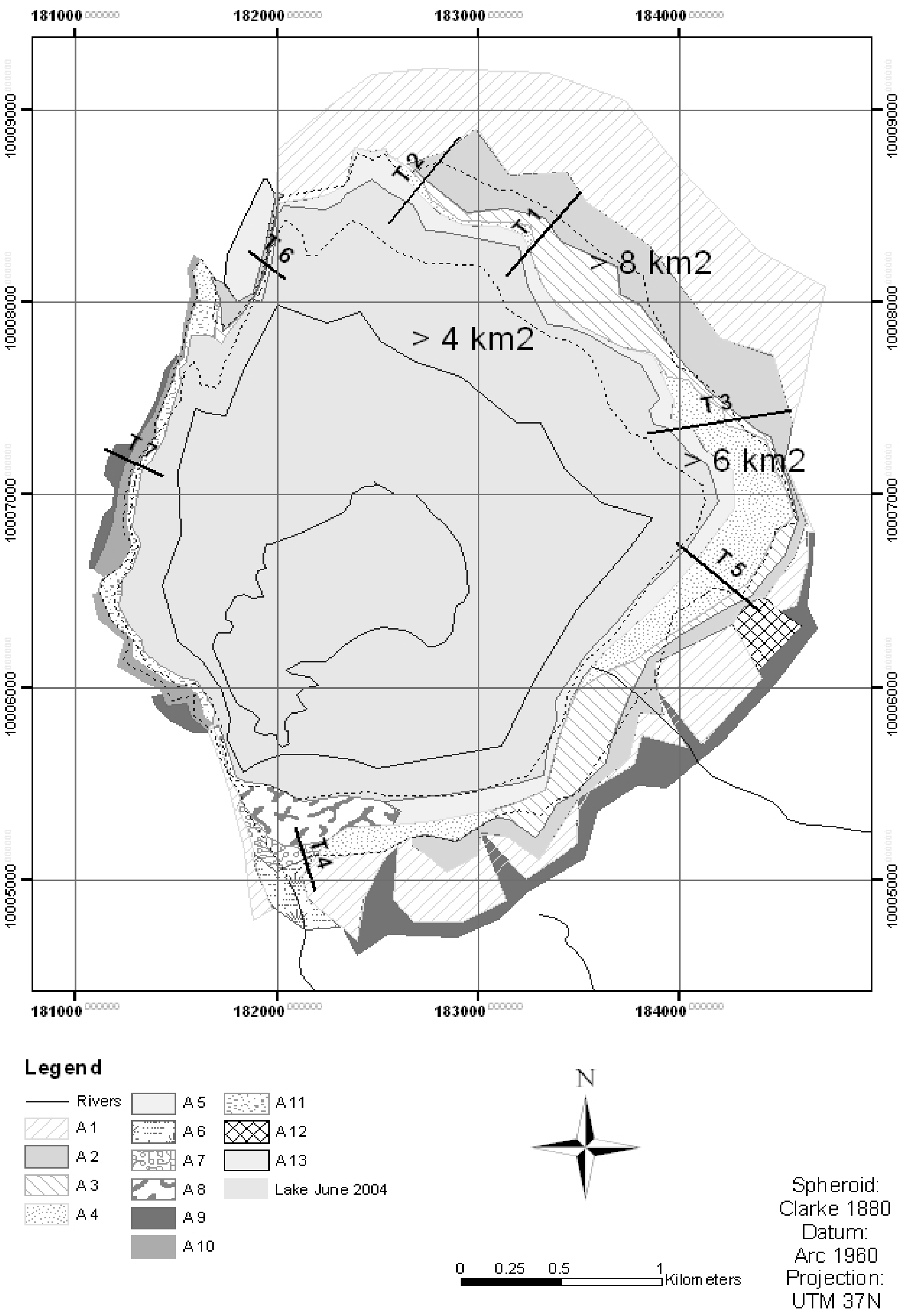
Figure Legends

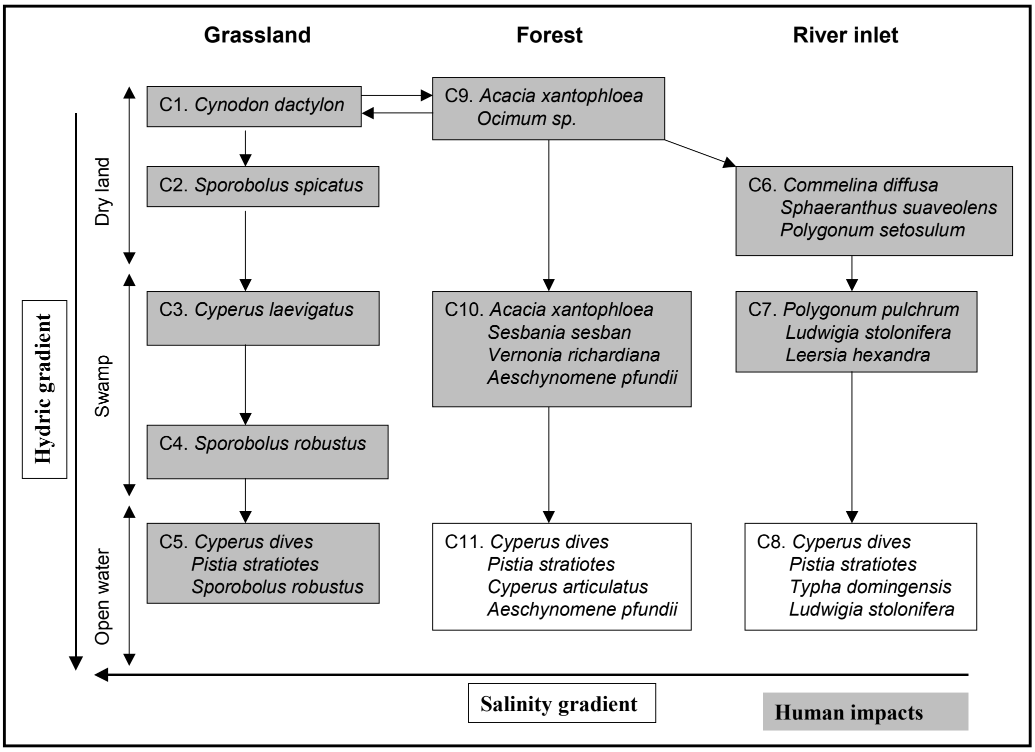
Figure 1: Map of a simplified land use of the Lake Solai catchment. The four main rivers are shown: Chem=Chemuka, Kam=Kamolo, Kas=Kasururei, MT=Maji Tamu.

Figure 2: Map of the vegetation communities (A1 to A13) and bathymetry of the Lake Solai (2004). T stands for transect.

Figure 3: Diagram of plant communities (C1 to C11) and determining environmental factors.


180000
190000
10010000
10000000
Chem
Kam
Kas
MT
Legend
Lake Solai
Woodland and Shrubland
Woody Grassland
Grassland
Crops and Grassland
Rainfed crops
N
0 1.5 3 Kilometers
Spheroid:
Clarke 1880
Datum:
Arc 1960
Projection:
UTM 37 N


181000
182000
183000
184000
10009000
10008000
10007000
10006000
10005000
T 1
T 2
T 3
T 4
T 5
T 6
T 7
> 8 km2
> 4 km2
> 6 km2
Legend
Rivers
A 1
A 2
A 3
A 4
A 5
A 6
A 7
A 8
A 9
A 10
A 11
A 12
A 13
Lake June 2004
N
0 0.25 0.5 1 Kilometers
Spheroid:
Clarke 1880
Datum:
Arc 1960
Projection:
UTM 37N


Grassland
Forest
River inlet
Hydric gradient
Dry land
Swamp
Open water
C1. Cynodon dactylon
C2. Sporobolus spicatus
C3. Cyperus laevigatus
C4. Sporobolus robustus
C5. Cyperus dives Pistia stratiotes Sporobolus robustus
C9. Acacia xantophloea Ocimum sp.
C10. Acacia xantophloea Sesbania sesban Vernonia richardiana Aeschynomene pfundii
C11. Cyperus dives Pistia stratiotes Cyperus articulatus Aeschynomene pfundii
C6. Commelina diffusa Sphaeranthus suaveolens Polygonum setosulum
C7. Polygonum pulchrum Ludwigia stolonifera Leersia hexandra
C8. Cyperus dives Pistia stratiotes Typha domingensis Ludwigia stolonifera
Salinity gradient
Human impacts