INTERNATIONAL HYDROLOGICAL PROGRAMME

Ecohydrology

Science and the sustainable management of tropical waters

A summary of the projects presented to the Conference
Naivasha, Kenya, 11-16 April 1999

Edited by
David Harper
Maciej Zalewski

Technical Editor
Malgorzata Lapinska

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CONTENT

PREFACE

The management of waters in the tropics is beset by difficulties more severe than those in the temperate zone. The moist tropics – wet rainforest and high altitude areas – experience a surplus of water which is distant from human settlement uses, and as a consequence water systems are relatively natural but their problems relate to reservoir and river regulation schemes. The arid tropics in contrast, are often those areas where human development is concentrated, increasing pressure upon limited natural water cycles and water stores through pollution and regulation as well as creating new ones.

In temperate zone countries, industrial and agricultural development over the past hundred years has created similar problems which resulted in inadequate water quantity or water quality, and the societies which recognised them have made some strides towards trying to solve them. In the past fifty years there has been an increasing awareness among human populations concentrated in town- and city- dominated states of the value of the natural world and the importance of understanding the processes which underlie its stability. In water management, the most recent way of thinking, offering the greatest prospect of long-term sustainable success, is Ecohydrology. Put simply, this paradigm regards a water catchment more like a Platonian 'superorganism', which has properties of resistance and resilience against stress that can be used as sustainable management tools in the future.

The range of papers presented here illustrate the problems inherent in the management of tropical waters but they also illustrate the additional work which is necessary to put Ecohydrological principles in place. It is for that reason that the UNESCO IHP 2.3/2.4 activities supported the conference, promoted the concept of its activities and its Advanced Study Courses (Europe 1999, Africa 2001) and increased its network of active scientists.

The publications in this Technical Document introduce the range of activities which are being developed in the tropics aimed at Sustainable Management of catchment systems. They illustrate the progress which is being made towards an holistic style of management of water systems and they demonstrate the extent to which Ecohydrology can help in long-term sustainable management solutions.

David Harper, Maciej Zalewski

D. Harper
University of Leicester
Leicester, LE 17RH
UK

M. Zalewski
International Centre for Ecology, Polish Academy of Sciences, Warsaw
Marii Konopnickiej 1, 05-092 Lomianki, Poland
Department of Applied Ecology, University of Lodz
Banacha 12/16, 90-237 Lodz, Poland

Science and the Sustainable Management of Tropical Waters

SECTION 1

LAKE NAIVASHA AND ITS BASIN, EASTERN RIFT VALLEY, KENYA

Preface

Environmental Controls on the Functioning of Shallow Tropical lakes

Shallowness and **tropicality** primarily relate to the physical aspects of environmental regulation. These concern water input and output, with correlates of water level and salinity; energy balance and heat distribution, with correlates of temperature and density; and largely wind-driven water movements, with consequences in chemical and biological distributions.
Shallowness in a water column affects the quantitative relationship between many stock quantities and flux-rates per unit surface area. Evaporative loss of water is one familiar example; sensitivity to surface energy exchanges provides others. Somewhat different are processes that depend on transmission with depth. Here light penetration, convective penetration and wind-generated turbulence/flow depth relations are illustrative.
Tropicality further influences through climatic factors, especially of rainfall and radiation. Energy balance tends to year-long elevated water temperatures at all depths, but at a level dependent upon altitude. The magnitude and seasonal periodicity of water input is dependent upon the intertropical convergence zone in atmospheric circulation. In the semi-arid and arid tropics the lakes may lie in closed drainage basins and be influenced by evaporative concentration with salinization.

Jack Talling, FRS
Freshwater Biological Association
Cumbria, UK

In many of these pages, shallow lakes of mainly tropical Africa illustrate these varied environmental constraints and some biological consequences. Many pages also show, in order to conserve this varied biology for future generations, the directions in which we must travel and the means that we must use, to achieve sustainable management – the integration of a resource's utilisation with its intact ecological functioning.

This is also the goal of the new paradigm of Ecohydrology – using the properties of an ecosystem to direct its sustainable management. This volume brings Ecohydrology to tropical ecosystems for the first time. We hope that the readers of its pages will find as much to benefit them as the participants in the conference did.

David Harper and Maciej Zalewski
The Editors

PREFACE

Science and Sustainable Management of Tropical Waters: The Conference at Naivasha, Kenya, April 11-16th 1999

The conference was originally conceived, in 1997, by Lord Enniskillen (Chairman of the Lake Naivasha Riparian Association) and by David Harper (Principal Investigator of the Earthwatch-Institute funded Naivasha Research Group) as a means of jointly bringing the scientific research results and the achievements of Naivasha's Ramsar Site Management Plan together to the scientific and political communities and the general public. One of the key pillars of the Plan is to ensure that it's principles are based on current scientific wisdom. It was an unexpected bonus when in 1998, just as conference plans had entered their final phase, it was announced that the LNRA would be awarded the 1999 Ramsar prize (jointly with the management organisation at Lake Prespa, Greece/Albania). This was subsequently presented at a ceremony in Costa Rica, in May 1999.

The conference was opened by Dr Richard Leakey, Head of Kenya Wildlife Services. He is a former palaeontologist who first had first been appointed to head KWS a decade ago when poaching threatened to drive elephant and rhino populations in east Africa to extinction and was then re-appointed in 1998. Several politicians including members of the National Assembly Committee on Agriculture and Water Resources attended the opening ceremony and heard, besides Dr Leakey, Professor Maciej Zalewski introduce the concept of ecohydrology and its importance to an understanding of the sustainable exploitation of water resources; and Dr Dirk Vershuren, from Belgium, deliver a timely reminder of the unpredictable climate of tropical regions through his paleo-ecological studies of the last few hundred years at Oloidien lake, Naivasha..

This conference was the first step in taking the Vth International Hydrological Programme "Ecohydrology" of UNESCO to tropical Africa - and 201 delegates from 26 countries participated in four days of scientific presentations and discussion which ranged from reservoirs of north-east Brazil through inland and coastal waters of Africa to shallow floodplain lakes of Indonesia. This diversity of geographical coverage of the conference theme was not the only strength of the meeting. Others were the diversity of approaches to the problems of shallow waters conservation and not least the presentation styles of the speakers. Few delegates would have imagined in advance that one presenter's representation of wetland conservation in the song of the community's youth group could have generated as much interest as the computer-driven presentation of the first successful modelling of Lake Naivasha's water level fluctuations.

The conference confirmed the international significance of Lake Naivasha and its catchment in the scientific context, as well as the conservation context recognised by the Ramsar award, with over 40 presentations of work carried out on the lake and its basin (40 of them reproduced here). The proceedings were formally closed by Dr Klaus Topfer, head of the United Nations Environment Programme, based in Nairobi, with Dr Leakey. Dr Topfer stressed the continued vital importance of water in development but the growing realisation that the world does not have enough available freshwater: the balance between human needs and nature's needs will be a crucial one in the next century. To meet these problems the concepts of ecohydrology have a central role to play.

Sponsors beside UNESCO IHP V were:
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Lake Naivasha Riparian Association
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Kenya Airways
Rockefeller Foundation
Earthwatch Institute
ITC, Netherlands
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Kijabe Ltd.
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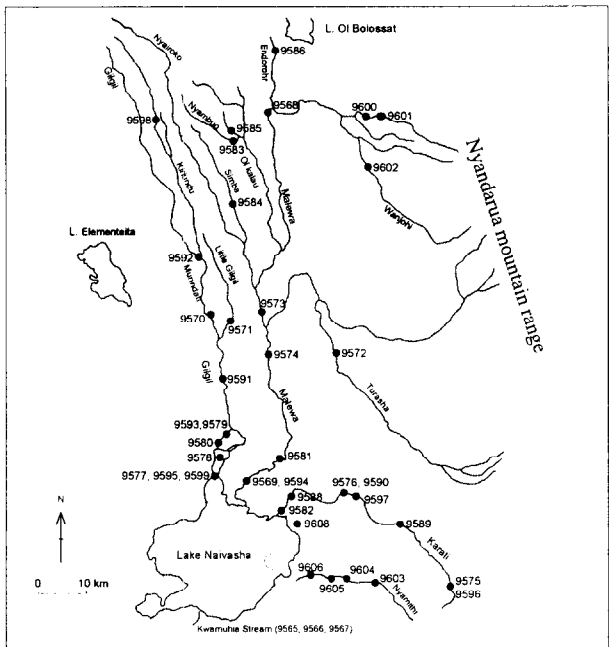
Zeneca (Kenya) Ltd.
Kenya Shell Ltd.
African Conservation Centre
NeDA (Netherlands Development Agency)
University of Leicester.

David Harper and Andrew Enniskillen

THE ECOHYDROLOGICAL APPROACH AT LAKE NAIVASHA, KENYA

Author
DAVID HARPER
Department of Biology,
University of Leicester, UK

Study Area
Lake Naivasha is the only freshwater lake in the chain of water bodies which run down the Eastern (Gregory) Rift valley through Kenya – the others are either moderately (Lake Turkana), or highly (Lake Nakuru), alkaline. With an area currently around 100 km^2, it is the largest body of freshwater (after the Kenyan share of Lake Victoria). Its freshness is maintained by high altitude rainfall upon the Nyandarua (Aberdare Mountains) rising in excess of 3500 m. on its north-western watershed.



LAKE NAIVASHA AND ITS CATCHMENT

Introduction

The lake was well explored by early scientific expeditions in the 1920s and 1930s, and studies of its limnology started from the University of Nairobi in the 1970s. The high biodiversity of wetland plants in its ecotone, aspects of its water balance and the primary productivity of its basins in relation to their alkalinity were published at that time.

This section of the Technical Document summarises the research that has been carried on since 1982 at Naivasha in co-operation with the University of Nairobi, National Museums of Kenya and the Lake Naivasha Riparian Association. Much of the research has been supported by the Earthwatch Institute, Boston and Oxford, and aided by Earthwatch volunteers, since 1987. We have been able to always collaborate with, and some times aid, the work of the numerous Kenyan organisations which is also described on the following pages, to build up one of the most comprehensive pictures of a lake basin in tropical Africa.

Working Hypotheses

1. Inflow to Lake Naivasha comes from two streams – the Malewa and the Gilgil both from the north. Their perennial flows, due to their high altitude sources, make the lake fresh but its level responsive to global climatic patterns. Human impact upon the unpredictable nature of this discharge has become more severe over the past fifteen years, so that the level fluctuations now put at risk the resistance and resilience of the lake ecosystem.
2. The introduction of alien species to the lake – the first came in 1926 and the most recent in 1988 – has further damaged the resistance and resilience of the aquatic system.
3. Receding water levels and the impact of alien species upon the food web have combined to make possible the ecological and anthropomorphic destruction of the land-water ecotone.
4. Ecohydrological approaches to understanding these problems provide a firm basis for recommendations to management agencies.

Results

The pages following in this section illustrate the approaches to the problems and their solutions over the past twenty years.

LONG-TERM SIMULATION OF THE WATER LEVELS IN LAKE NAIVASHA

Authors
ROBERT BECHT
ITC, PO Box 6, 7500AA Enschede, Netherlands
SAMUEL MMBUIE
Ministry of Water Resources, PO Box 30521, Nairobi, Kenya

Working Hypothesis

The simulation of the lake levels of Lake Naivasha is one component of the hydrological and environmental research carried out in the lake basin, under the working hypothesis 1. Expressed by Harper the main objectives are to:

1. Design a model, which allows the simulation of lake levels.
2. Establish a reliable water budget for the lake including the quantification of abstractions.
3. Investigate whether the lake level variations can be explained by purely meteorological/hydrological factors or by other (tectonic) factors.
4. Study the effect of the abstractions on the lake levels.

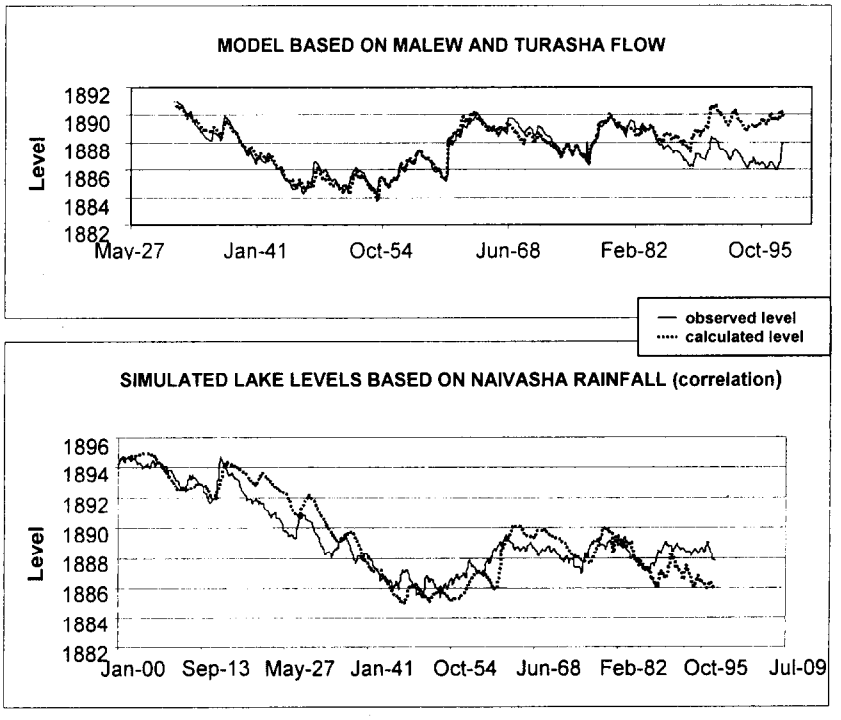
The Simulation Model

The lake receives water from rivers, direct rainfall, groundwater inflow and looses water by evapotranspiration and seepage. It is surrounded by highly permeable and porous aquifers, which dynamically interact with the lake. A constant outflow to a deep aquifer system exists, keeping the lake fresh. The model was programmed in a spreadsheet. For monthly intervals the lake levels are calculated based on the stage-area-volume relationships, inflow, direct precipitation, groundwater outflow and interaction with the surrounding aquifer. The main calibration parameter is a constant groundwater outflow followed by the parameters controlling the lake-aquifer interactions.

Preliminary Results

The first graph shows that the lake levels can be accurately simulated for the full record period (1931-present). It clearly shows the effect of the abstractions which started in the mid-80's and allows their quantification. The derived abstraction of 60 MCM tallies perfectly with abstraction estimates based on consumptive use and the area under irrigation.

The second graph shows the lake levels from 1900 to present, where the inflow series is generated from therainfall series. It clearly shows that the large variations of the lake levels before abstraction started can be explained by meteorological factors only.



Ecohydrological Implications of this Study

The off take of water can now be quantified. The users of the lake – at catchment and at riparian spatial scale now have to agree a plan which conserves the essential ecological processes in the lake to allow the use to achieve sustainability.

THE PHOSPHORUS SOURCES TO LAKE NAIVASHA, KENYA

Authors
NZULA KITAKA
Department of Zoology, Egerton University,
Box 536 Njoro, Kenya
DAVID HARPER
Department of Biology,
University of Leicester, UK
KEN MAVUTI
Department of Zoology,
University of Nairobi, Box 30197, Nairobi

Working Hypotheses

1. That the ecotones of the lake and its inflowing rivers are degraded so that their ecological processes are no longer able to metabolise the nutrients.
2. That the major inflows to Naivasha – the Malewa and Gilgil – are thus sources of phosphorus to the lake.
3. That lakeside riparian land uses – horticulture, sewage effluent, urban runoff are major point sources.
4. That Lake Riparian land users may construct artificial wetlands that successfully mitigate nutrient input.

Methods

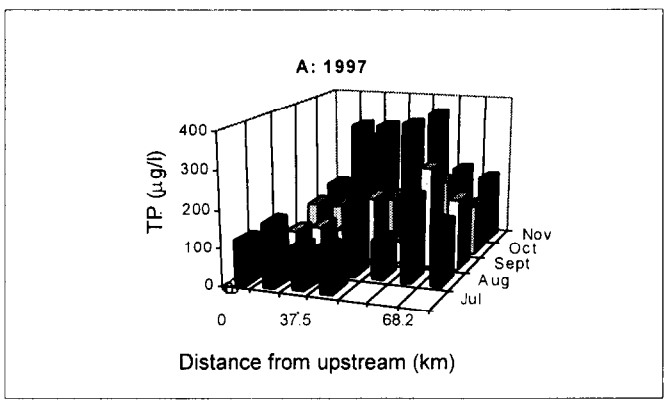
Analysis of inflow discharges and concentrations of phosphorus forms by standard chemical methods.

Results

During the start of heavy rains in November 1997 high total phosphorus quantities flowed into Lake Naivasha from its catchment rivers, originating in the middle reaches where human settlement is highest and agriculture is intense. During dry seasons the inflows are considerably reduced.

In the lake the impact of the inflowing swollen Malewa is apparent as a plume for up to one kilometre of higher P, suspended solids with lower conductivity. High concentrations are also found offshore of individual point sources.

The phosphorus concentrations passing through and leaving an artificially constructed riparian wetland taking runoff from one of the largest horticultural industries were reduced down to those of the lake water.

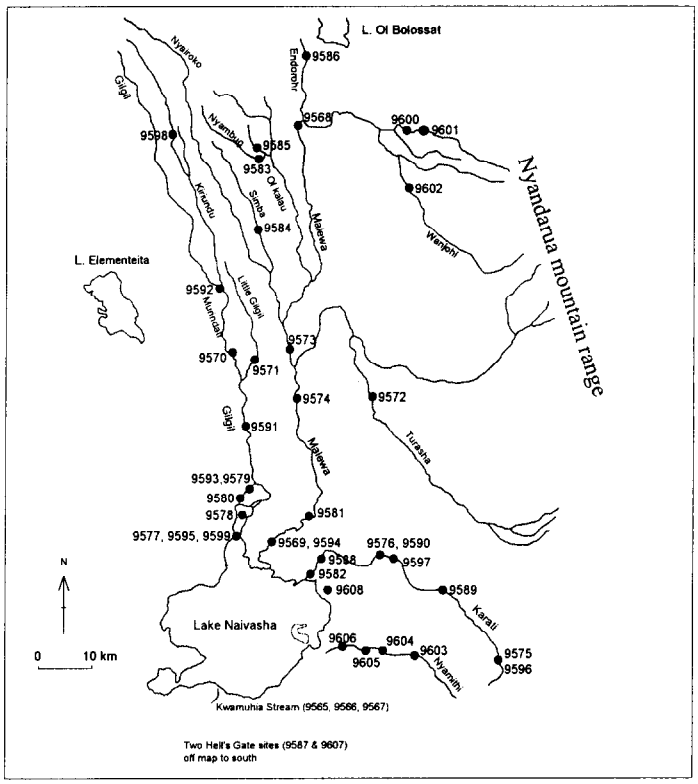


Ecohydrological Implications of this Study

The improvements available as a result of riparian ecotone construction need to be demonstrated on rivers and quantitatively estimated for catchment-scale effects. Additional riparian ecotones need to be constructed to receive the sewage effluent and urban runoff of the town of Naivasha, and other intensive horticultural enterprises.

THE INTEGRITY OF THE NAIVASHA CATCHMENT STREAMS AND WETLANDS

Authors
MARK EVERARD
Director of Science, The Natural Step UK,
9 Imperial Square,Cheltenham, UK
JACQUELINE VALE
Environment Agency, Bristol, UK
ANTHONY KURIA
East African Natural History Society,
Nairobi, Kenya
MICHAEL MAINA
Department of Ornithology,
National Museums of Kenya,
Nairobi, Kenya
DAVID HARPER
Department of Biology,
University of Leicester, UK



Working Hypothesis

1. The riparian corridors of the catchment rivers provide functioning ecotones, which can be utilised, for the nutrient and sediment trapping to protect Lake Naivasha and maintain the processes of the lake basin.
2. Existing wetlands within the lake basin are intact and provide a biodiversity and functioning.

Preliminary Results

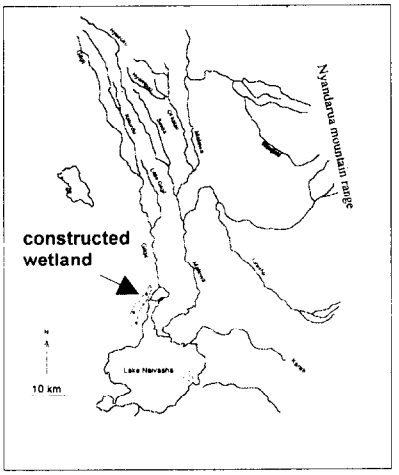
Semi-quantitative assessment using the River Habitat Survey technique demonstrates a diversity of habitats and erosion/sedimentation patterns. Flowering plant distribution along the river corridors appears most strongly correlated with altitude, whilst bird abundance and diversity correlate inversely with distance along river corridors away from the lake.

Wetland systems in the catchment have been defined and preliminary visits made, but several formerly significant headwater wetlands have been drained and converted to agriculture and the most significant change appears to be the almost total conversion of the Gilgil inflow wetlands since water levels declined in the early 1980s to irrigated agriculture swamp. The ecotone was formerly known as the 'North Swamp' and shown to be very extensive on 1950s maps (see location map on Harper's page).

Ecohydrological Implications of this Study

Sustainable management of the lake inevitably depends upon an understanding of the behaviour and pressures upon the catchment, since changes in land use patterns and intensity even remote from the lake itself can significantly influence hydrological, chemical, microbial and biotic inputs to the lake. They can also adversely affect habitat diversity and biological diversity, as well as the long-term economic viability of development in the catchment. A full inventory and quantification of the values of ecotones and wetlands in the system is urgently required and underway.

A "SEQUENTIAL WETLAND" AS A PRIMARY TOOL FOR THE RESTORATION OF NAIVASHA

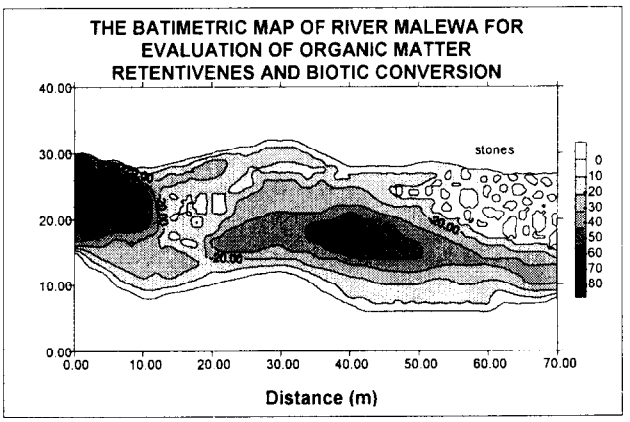


Authors
MACIEJ ZALEWSKI
International Centre for Ecology,
Polish Academy of Sciences, Warsaw
DAVID HARPER
Ecology Unit, Department of Biology,
University of Leicester, UK

Study Area
Lake Naivasha (Kenya), an important water source for domestic use for over 100 000 people and intensive horticulture (15 % of Kenya's horticultural export).

Working Hypothesis
The sharp increase in human population during last 20 years, from 20 000 to 200 000 people in the river basin, has resulted in degradation of the catchment cover. Thus to a great extent, increased erosion and nutrient transfer by the river system into the lake which has affected eutrophication, illustrated by the reduction of water transparency.
To reduce and reverse the eutrophication processes, a primary measure could be the reduction of nutrients, organic and mineral matter provided by the Malewa River. As the main part of the annual nutrient load is transported by fluxes during heavy rains, this fraction of the flood should be directed and retained in a constructed Treatment Wetland, where sedimentation processes and biogeochemical trapping should significantly reduce the load entering the lake. The evidence from the scientific literature indicate up to 80% reduction of suspended matter and over 50% of total phosphorus could occur during more than three days of residence time.

Methods
This constructed wetland should possess the sequential structure to reduce economic costs of eliminating land from agricultural use. A first wetland, which will have the most complex structure and highest efficiency of organic matter and nutrients trapping will be near to the river, and should have its capacity adjusted to be sufficient to cope with the volume of water from the frequent, short, intensive rains. The capacity of a second stage should be adjusted to cope with heavy rains during the annual rainy season.



The land, which is periodically flooded, should be used for less demanding agricultural production. The capacity of a third stage could be calculated to contain the amount of rain in the intensive rainy periods that occur every 3 years. The land at a third stage might be used for various types of agricultural activities but with some limitations. Regular vegetation cropping will be necessary to maintain the high trapping capacity of first stage. The second and third stage could be agriculturally productive without fertilisation, as the nutrient and organic load collected in the whole Malewa catchment should be sufficient to maintain high agricultural activities.
For elaboration of the quantitative model of constructed wetlands it is necessary to:

1. Evaluate hydrological variability of flow at the river.
2. Evaluate quantity of nutrients, organic matter and minerals at different flood intensities and at various stages of floods.

Ecohydrological Implications of this Study
Such a "sequential wetland" could be the first step in an integrated strategy of restoration of Lake Naivasha. The conversion of the Malewa delta in its riparian area into the sequential wetland would be the most feasible and cost efficient element of an integrated restoration program and could be the first stage.

METAL CONTAMINATION OF SEDIMENT IN LAKE NAIVASHA AND ITS CATCHMENT RIVERS

Authors
HÅKAN TARRAS-WAHLBERG
Swedish Geological AB, Stockholm,
Sweden
DAVID HARPER
Department of Biology,
University of Leicester, UK

Working Hypothesis

The Lake Naivasha area has experienced rapid development in latter decades, most importantly the rise of high intensity agriculture. The agricultural developments have, in turn, caused population increase as well as having spawned some auxiliary industrial activity.
The hypothesis was that these developments have not led to metal contamination of the sediment in the Lake itself or its catchment rivers. A programme of sediment sampling and geochemical analysis was performed to confirm this.

Methods

The investigations were performed in July and August 1997, and comprised two parts:

1. Sampling and analysis of catchment rivers' sediment:
   Ten samples of sediment were collected, sieved through a 2 mm sieve, air-dried, and analysed by X –Ray Fluorescence spectrometry (XRF).
2. Sampling and analysis of lake sediment:
   Two sediment cores were taken, one from the central lake and one from near a papyrus swamp in the northern part of the lake. Ten sub-samples were then collected from each of the identified stratigraphic units of the two cores. The geochemistry of the sub-samples was determined by Plasma emission spectroscopy (ICP-AES), following digestion in Aqua Regia.

Results

Generally, the metal contents of the sediment are low, and there is no indication of significant metal contamination. Only two samples of Lake sediment contained somewhat elevated metal contents, most importantly cadmium concentrations of 7 mg/kg and 6 mg/kg respectively. Further work is needed to determine whether the sources of cadmium are natural or anthropogenic.

AVERAGE CONCENTRATION OF SOME IMPORTANT METALS IN RIVER AND LAKE SEDIMENT IN THE LAKE NAIVASHA AREA

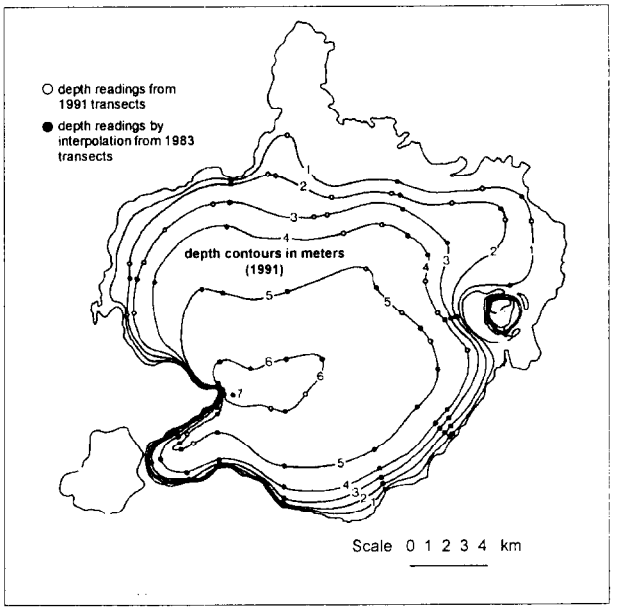
Concentration (mg/kg)	Cu	Cd	Ni	Pb	Zn
River sediment	10	-	11	14	153
Lake sediment	16	<3	27	<6	146

Ecohydrological Implications of this Study

The concentrations of metals in sediments in Lake Naivasha and its catchment rivers are low, and are probably representative of natural background conditions. However, some further work is motivated to elucidate the sources, pathways and bioavailabilty of somewhat elevated concentrations of cadmium in Lake sediment.

INVESTIGATIONS OF THE SEDIMENT STRATIGRAPHY OF LAKE NAIVASHA

Authors
HÅKAN-TARRAS-WAHLBERG
Swedish Geological AB, Stockholm, Sweden
DAVID HARPER
Department of Biology, University of Leicester, UK



Background

Lake Naivasha's waters are increasingly used for irrigation, and considerable areas of the Lake catchment have been converted for agricultural use. Additionally, lake levels fluctuate for natural reasons, and local tradition says that there was a time in the 19th century when the lake was completely dry.
These natural fluctuations, coupled with increasing human influence, have made the lake and the ecosystems that are dependent upon it, unstable and fragile. Investigations of lake sediment stratigraphy provide evidence of the effects of past water level and land use changes and, thus, may provide important insights needed for the present wise management of the lake.

Methods

Eighteen piston core, sediment sections were sampled at evenly spaced locations of the Lake. The sediment cores were extruded and each stratigraphic unit was described in detail with regards to its physical and biological characteristics.

Results

An idealised one-meter stratigraphic section of the central Lake Naivasha basin was established. The section is interpreted as stretching back in time to the 16th or 17th century AD, and contains layers laid down during high water levels, layers laid down when the lake was a shallow swamp as well as a distinct non-conformity caused by the lake drying out completely. Investigations of sediment characteristics at the sediment-water interface show that present-day sedimentation dynamics are governed by the presence of point sources of sediment, and the effects of wave-induced re-suspension of sediments. Sediments introduced by rivers in the north are transported in easterly and southerly directions, and are eventually deposited in the central and southern parts of the lake. The sedimentation rate in the central lake was found to be about 1 cm per year, whereas in the south, the rate may be as high as 3 cm per year. Some sedimentary deposition is also occurring in areas in the north which are protected by Papyrus vegetation. In the north-eastern part of the lake, historic low lake levels have led to the formation of a wide spread mineralised clay layer, present at or near the water-sediment interface.

Ecohydrological Implications of this Study

The stratigraphic evidence confirms that lake levels have fluctuated widely in the past, and thus, that the instability of the lake is in part natural. The changes in lake levels have been accompanied by distinct changes in the vegetation of the lake as reflected by varying amounts of swamp vegetation in different stratigraphic units. The lake's papyrus swamps are shown to be areas of sedimentation and, thus, their continued existence is vital in order to counteract tendencies for increased turbidity of the lake's water. The possible existence of a continuous clay layer in the north-eastern part of the lake may make impossible a previously postulated ground water recharge in this part of the lake, and therefore, other locations or other mechanisms for groundwater recharge may have to be sought.

THE ENVIRONMENTAL HISTORY OF LAKE OLOIDIEN, KENYA: IMPLICATIONS FOR THE MANAGEMENT OF RIFT VALLEY WATER RESOURCES

Authors
DIRK VERSCHUREN
CHRISTINE COCQUYT
University of Gent, B-9000 Gent, Belgium
JOHN TIBBY
Monash University, Clayton, Victoria 3168, Australia
PETER R. LEAVITT
University of Regina, Regina, SK S4S 0A2, Canada
C. NEIL ROBERTS
University of Plymouth, Devon PL4 8AA, UK

Study Area
Rift Valley lakes
Oloidien and Naivasha, Kenya.

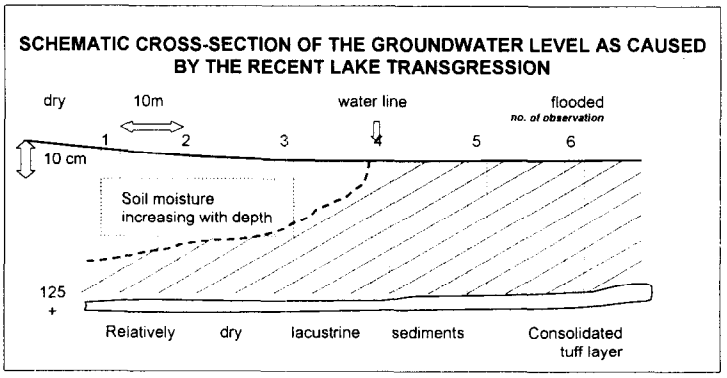
Working Hypothesis
The past history of the climate, through Rift Valley Lakes' sediment history, provides a guide to present-day management, through an explanation of the range of wetland environments which lake level change produced.

Results
Paleolimnological analysis of sediment cores from Lake Oloidien produced a detailed chronology of climate-driven environmental change since the early 1800s. During much of the 19th century and between about 1940 and today, Lake Oloidien was shallow, separated from Lake Naivasha, and inhabited by the productive algal and invertebrate communities typical of moderately saline lakes. Confluence with Lake Naivasha between 1890 and the late 1930s flushed dissolved salts out of Lake Oloidien and created a temporary freshwater phase during which the lake shore was fringed with papyrus swamp and extensive beds of submerged macrophytes, and the open water algal flora was dominated by diatoms and green algae. The timing and of these ecological changes in Lake Oloidien implies that agricultural development of the Rift Valley by British colonial settlers in the first two decades of the 20th century coincided with an unusual plentiness of water-resources, a remnant of high rainfall during the 1880s and early 1890s out of balance with the long-term average rainfall and evaporation. Episodes of drought during the 1920s, 1940s and 1950s may have been experienced as exceptionally severe only because the evaluation of land and water resources on which colonial agricultural development had been based was biased by the earlier imbalance between water-resource availability and climate. Lake-level decline and rising salinity of Lake Oloidien during the early 1990s, as well as the opposite trends that followed El Niño-related rainfall in 1997, are mostly a direct consequence of the lake's hydrological response to natural rainfall variability on interannual and longer timescales.

Ecohydrological Implications of this Study
Heavy anthropogenic water use around Lake Naivasha and the diversion of Malewa River water for cropland irrigation and industry in the Lake Nakuru area increasingly compromises the ability of high-rainfall years to compensate for water losses incurred during periods of relative drought. The ongoing transition of Lake Oloidien to a soda-lake environment is thus symptomatic for the threat that human activities may pose to the survival of Lake Naivasha and other shallow lakes and wetlands in the Kenya Rift Valley. An integrated strategy for long-term management of these aquatic ecosystems is needed to protect their diversity of natural and semi-natural habitat while maintaining their important economic functions. Sustainable development of dryland regions in tropical Africa requires general recognition that water is not a fixed resource but varies strongly at timescales from seasons to centuries.

WETLAND SOILS OF LAKE NAIVASHA

Authors
W. SIDERIUS
ITC Soil Division,
Enschede, The Netherlands
G. J. URASSA
National Soil Service,
Tanga, Tanzania

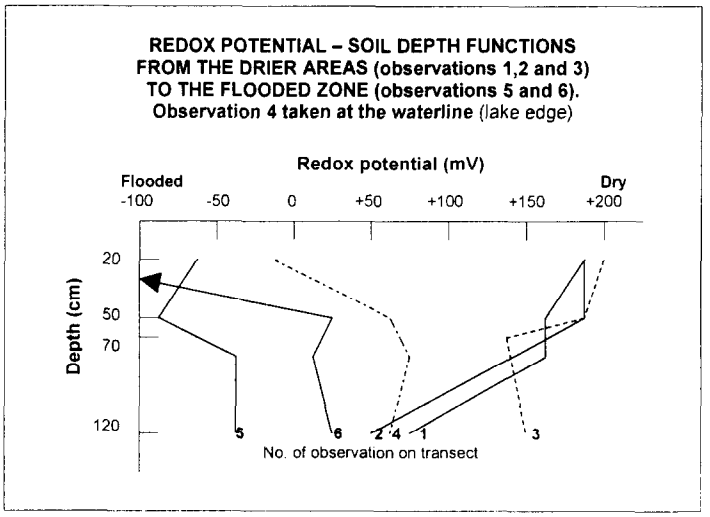


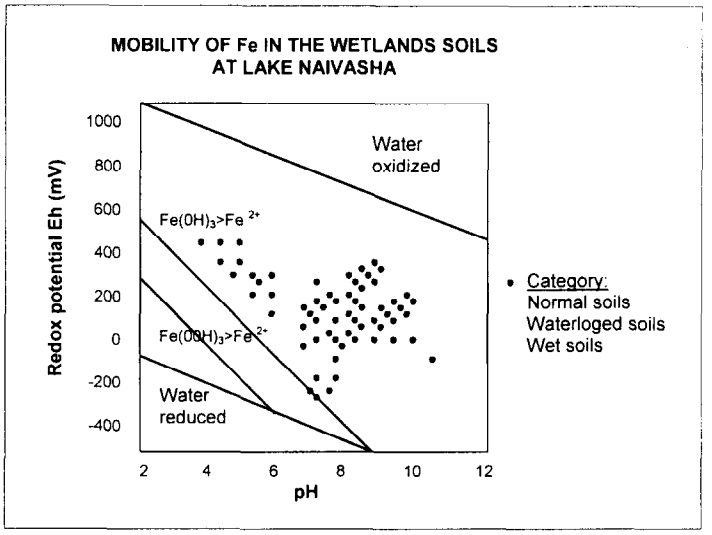
Methods

In 1998, just after the El Ñino-Southern Oscillation had caused a lake level rise, wetland soils which had been recently flooded were analysed for Eh, pH and Ece. 164 samples were taken from in 6 transects in the eastern and southern shores, where horticulture and urban development are greatest.

Results

Soils are deep and moderately well to poorly drained. Texture is sandy clay, giving way 20-50 cm to sandy clay loam. They are developed from lacustrine sediments formed from volcanic materials. Cation exchange capacity varies between 19-43 me/100 g soil; pH between 7.0-8.0. The soils are non-saline (Ece < 4.0 mS), with topsoils having the lowest salinity due to leaching. Redox potential decreases rapidly in flooded soils, marking anaerobic conditions, which indicates the process of reduction to become active in a short period. The cluster between pH and Redox potential is similar to mature soils, which may induce a greater mobility of cations such as iron as soil acidification develops.



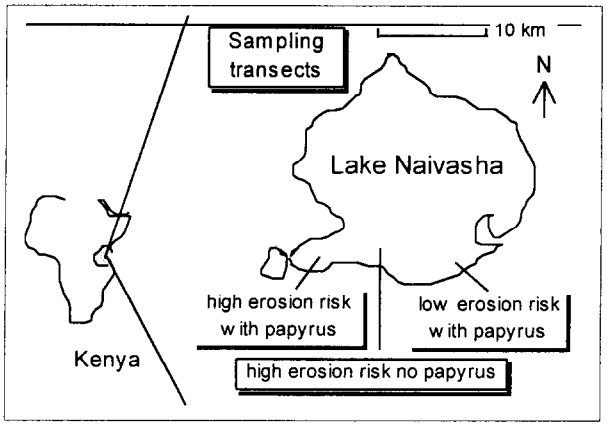


Ecohydrological Implications of this Study

Studies on the ecotones of this lake have largely focussed upon the biotic components, with little attention paid to wetland soils. Their position warrants further study however, as they act as the important buffer for surface water runoff because of the porous nature of the soil which means that little water reaches the lake by overland flow.

ENVIRONMENTAL MAGNETISM AS A TRACER FOR SOIL EROSION ALONG THE SOUTHERN SHORELINE OF LAKE NAIVASHA

Authors
ROS BOAR
School of Environmental Sciences,
University of East Anglia,
Norwich UK
DAVID HARPER
Ecology Unit, Department of Biology,
University of Leicester, UK



Working Hypothesis

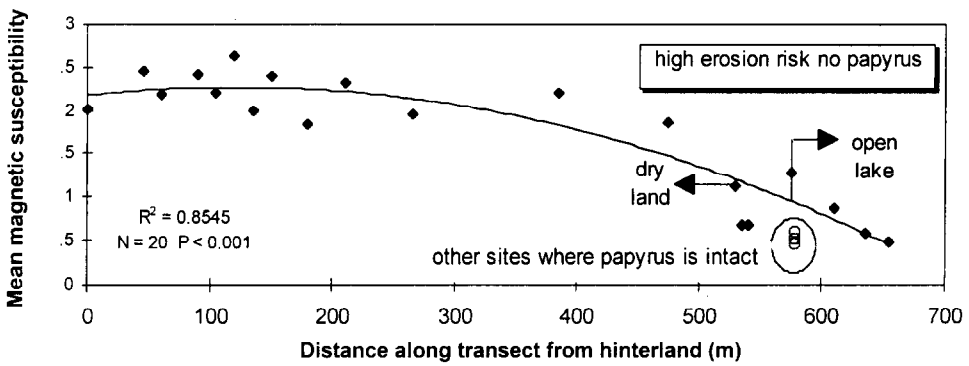
1. Intact ecotone papyrus swamps intercept soil particles that have eroded from riparian land.
2. Papyrus swamp is impermeable to large (>2000 μm), medium (2000-63 μm) and small (<63 μm) soil particles.
3. The magnetic properties of sediment particles in Lake Naivasha will reveal their source.

Methods

1. Wet sieving and dry weighing of size fractions of top soil and lake sediment sampled at intervals along three transects running from upland, through swamp and into open lake.
2. Mass specific magnetic susceptibility and magnetic resonance measurements of the < 63 μm size fraction of topsoil and lake.

Results

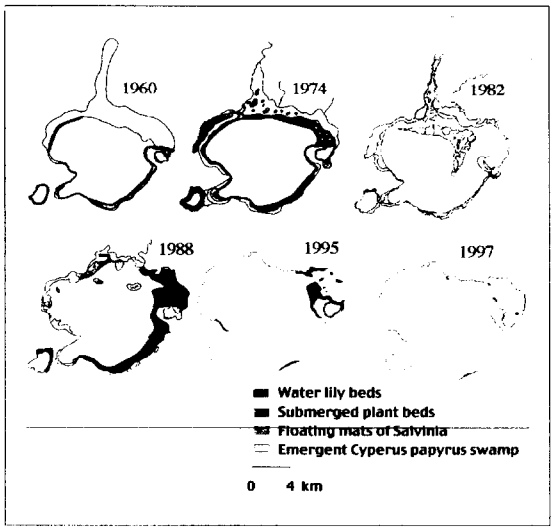
1. At high risk of erosion, large (>2000 μm) particles are retained by marginal papyrus swamp.
2. At high risk of erosion in the absence absence of marginal papyrus, large particles (>2000 μm), sands (2000 μm - 63 μm), silts and clays (<63 μm) enter the lake.
3. The magnetic susceptibility of the <63 μm fraction varies from upland to lake sediment.
4. Magnetic properties of sediment along the southern shore of the Lake where papyrus has been removed suggest that silts and clays in lake sediment have come from erosion of the hinterland.



Ecohydrological Implications of this Study

Conservation or the recreation of a continuous papyrus ecotone, to intercept fine particles, is of the highest priority. Otherwise surface runoff may carry into the lake ecosystem contaminants from horticultural land and human settlements, particularly along the southern shore of the Lake where such developments are greatest.

THE SEVERE LOSS OF THE AQUATIC PLANT COMPONENT OF THE LAND-WATER ECOTONE AT NAIVASHA; ITS CAUSES AND POSSIBLE RESTORATION



Authors
DAVID HARPER
Ecology Unit, Department of Biology,
University of Leicester, UK
ANNE-CHRISTINE GOUDER
Faculties Universitaires de Gembloux, Belgium
CHRIS ADAMS
Environment Agency, Ipswich, UK
PHIL HICKLEY
Environment Agency, Worcester Road,
Kidderminster, UK

Working Hypothesis

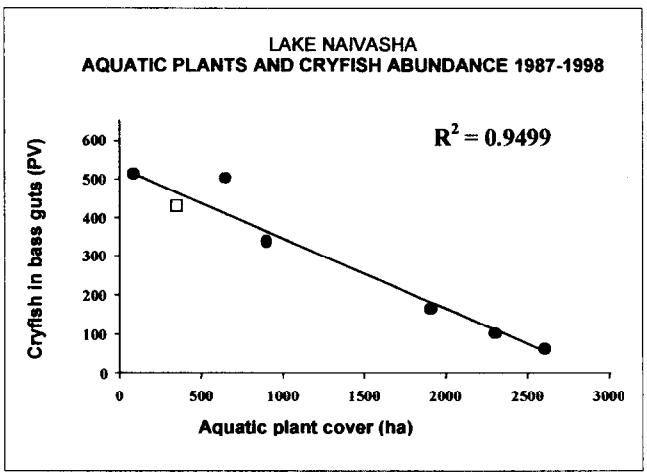
For the past twenty years there has been dramatic fluctuations in the submerged, floating-leaved and free-floating plants in the lake. Since 1987 we have worked on the hypothesis that these fluctuations are caused by the grazing impact of the alien Lousiana crayfish, *Procambarus clarkii*, introduced as a potential fisheries crop in the early 1970s.

Methods

Submerged plant abundance is recorded by spot sampling with a grapnel followed by identification and GPS location. Crayfish abundance is recorded in floating plant quadrates and also as prominence value in the gut contents of large-mouthed bass from experimental gill netting.

Results

Both the emergent component of the ecotone, dominated by *Cyperus papyrus*, and the submerged/floating component have been severely reduced. The emergent component has primarily been lost through agricultural destruction as a result of the legal permission to cultivated Riparian land (see Enniskillen) during low lake levels dating back to 1929. The floating-leaved and submerged component has been destroyed by grazing impacts of crayfish, whose abundance is best measured by their value as food to large-mouthed bass (see Figure).



Ecohydrological Implications of this Study

High water levels, such as those experienced between December 1997 and February 1998 as a consequence of the effect of heavy rains following the El Nino, mitigate the problem of emergent *C. papyrus* for as much as 10 years. The current ecotone structure of *C. papyrus* all germinated during May 1988 when there were heavy rains causing a 1 vertical m water level rise. However the submerged macrophyte destruction can only be mitigated by some kind of biological control over the crayfish. Such biomanipulation includes removal by a healthy bass population (see Hickley), a diverse piscivorous bird population (see Childress), a strong crayfish industry (see Smart) or by the periodic cycling which occurs with crayfish populations. If the latter, then the processes of the ecotone are unlikely to recover to provide effective protection from catchment sediments and nutrients.

ENVIRONMENTAL CONDITIONS IN THE LAGOONS AND SWAMPS OF THE NAIVASHA ECOTONE

Author
DAVID HARPER
Ecology Unit, Department of Biology,
University of Leicester, UK

Working Hypothesis

The combination of lake level changes of several metres over the past twenty years, with destruction of papyrus by humans, destruction of submerged plants by crayfish and the influx of floating alien plant species, have created rapid and unpredictable changes in the lake ecotone. Recognising the ecotone's development causes and understanding the physical conditions created is a pre-requisite to understanding how efficiently it may function in the lake ecosystem.

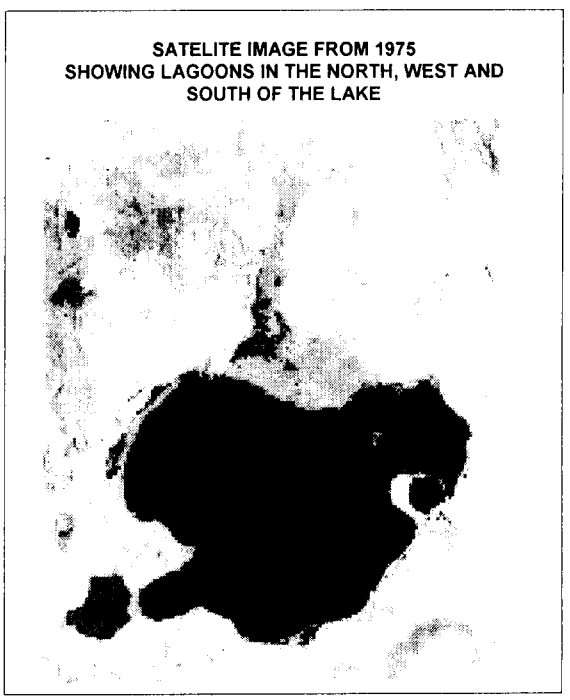
Methods

Physicals recording of size, depth, position of lagoons using a GPS were made, in relation to lake level. Transects of vegetation from land to water were measured. Temperature and oxygen were recorded in water of various depths throughout the day. Subsequently satellite images of key periods were obtained and studied using GPS.

Preliminary Results

Lagoons are created in a number of different ways during high or rising water levels: a) floating *C. papyrus* islands becoming stranded in shallow water (the dominant method up to the end of the 1970s), b) high water level flooding through rooted C. papyrus and open lagoons forming on the landward side of the *C. papyrus* stand (dominant in the early 1980s, the early 1990s and 1998), c) inside floating mats of *Eichhornia* or *Salvinia* where some obstruction retains them (the mid-1980s).

These lagoons are important parts of the changing ecotone. They provide spawning areas for fish, feeding areas for juveniles, germination areas for submerged and floating-leaved plants in newly flooded land (before they are reached by crayfish) as well as feeding foci for aquatic birds. Temperatures rise to 30°C in the early afternoon and de-oxygenation may occur.



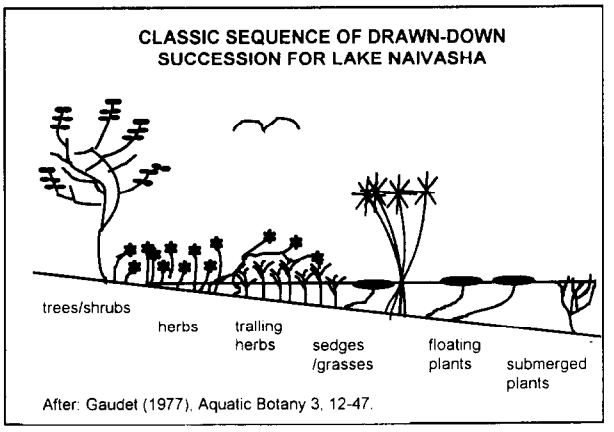
SATELITE IMAGE FROM 1975
SHOWING LAGOONS IN THE NORTH, WEST AND SOUTH OF THE LAKE

Ecohydrological Implications of this Study

The processes inherent in a natural ecotone is/will be severely disrupted by these changes in structure. Future measurement of processes, such as nutrient relationships, will be able to assess the ecosystem-scale importance once the spatial and temporal extent of these structures is fully quantified.

THE DYNAMICS OF FLOATING PLANT MATS IN LAKE NAIVASHA

Authors
CHRIS ADAMS
Environment Agency, Ipswich, UK
DAVID HARPER
Department of Biology,
University of Leicester, UK



Working Hypothesis

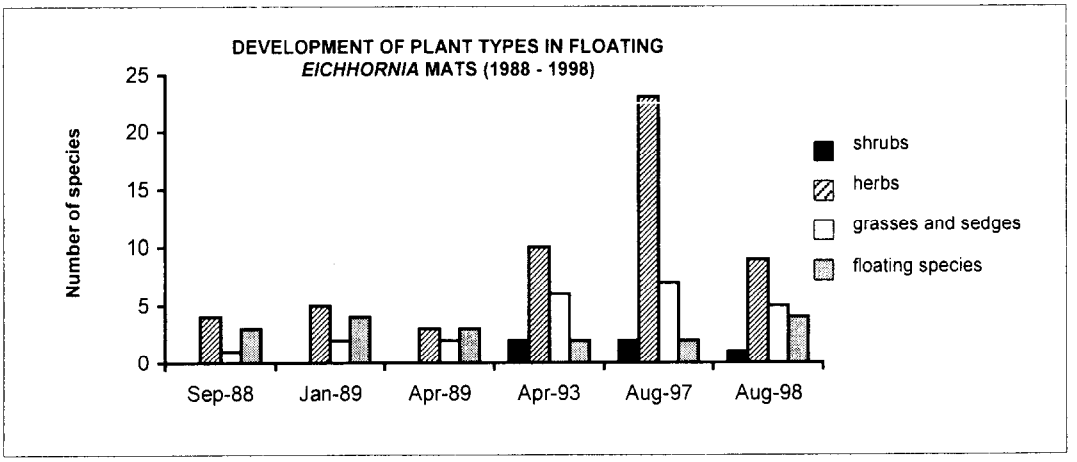
Hydroseral succession was well described by Gaudet in the 1970s when the ecotone of the Lake Naivasha riparian zone was almost natural. Since that time it has been invaded by alien floating species as well as undergoing degradation as a consequence of human activities as low discharges. Our hypothesis is that floating mats of *Salvinia* and *Eichhornia* have no effect on the dynamics of hydroseral succession in Lake Naivasha.

Methods

1. Percentage cover in 4 m x 2 m quadrates was recorded in up to 155 sites around the edge of the Lake at intervals over the period 1988 to 1998.
2. All plants were identified to species. Species have been grouped into: herbaceous plants, grasses and sedges, floating species and shrubs.

Results

Lake Naivasha currently supports four main species of submerged *macrophytes (Potomogeton pectinatus, P. schweinfurthii, P. octandrus* and *Naias horrida*), together with the floating water lily *Nymphaea caerulea* when its growth is possible (see previous project). Since the mid 1970s, there have additionally been floating mats of *Salvinia molesta* and, since 1998, of *Eichhornia crassipes* (water hyacinth).
Salvinia molesta dominated these mats until 1989 when 81% of 155 sites surveyed had a percentage cover of > 75% *Salvinia*. By 1993, when 132 sites were surveyed, only 5% of sites reached the same high density of floating *Salvinia*. However, *Eichhornia crassipes* had by then reached > 75% cover in 63% of the sites.
There has been a development of plant types between 1988 and 1998. Moreover, an increase in the species richness of herbaceous plants and of grasses and sedges is apparent.



Ecohydrological Implications of this Study

The classic, ordered sequence, of plant succession from open water to shoreline shrubs still occurs in paces with little change in species lists. However, the movement of floating mats re-distributes seral stages so that plant succession no longer follows a classic spatial sequence. Introduction of floating plants has not necessarily been undesirable, since there is no evidence of any decline in species richness of mid-successional plants, particularly of herbs, grasses and sedges. The starting hypothesis is thus supported in that temporal sequences appear unchanged although spatial patterns have become chaotic.

INVESTIGATIONS OF FLOATING VEGETATION, *EICHHORNIA CRASSIPES AND SALVINIA MOLESTA,* ON LAKE NAIVASHA

Authors
NILS TARRAS-WAHLBERG
HÅKAN TARRAS-WAHLBERG
Kyrkeryds Lillegård, 355 92 Växjö, Sweden
DAVID HARPER
Department of Biology,
University of Leicester, UK

Study Area

The floating water plants *Salvinia molesta* and *Eichhornia crassipes* were introduced to Lake Naivasha, *Salvinia* in the early 1960's and *Eichhornia* in the late 1980's. Both these alien plants have periodically thrived and, consequently, attempts have been made to eradicate them. Control of *Salvinia* was unsuccessful until the early 90s when, roughly after the introduction of the weevil *Cyrtobagus salviniae*, the plant almost totally disappeared. It is, however, unclear whether the disappearance of *Salvinia* was caused by the weevil or by other concomitant environmental changes. *Eichhornia* is now the Lake's most important floating plant, and it is feared that the propagation of *Eichhornia* may convert the lake into a marshland. Therefore, a weevil *(Neochetina)* has been introduced to the lake in an attempt to control *Eichhornia*, although whether this weevil has been successfully established is not known.

Working Hypotheses, Methods

A survey of the floating plant vegetation of Lake Naivasha was performed in September 1996. The aims of the survey was twofold:

1. To study the distribution of floating vegetation on the Lake and in so doing, suggest mechanisms that may explain identified changes in plant distribution.
2. To investigate the mesofauna associated with the *Salvinia* and the *Eichhornia* vegetation.

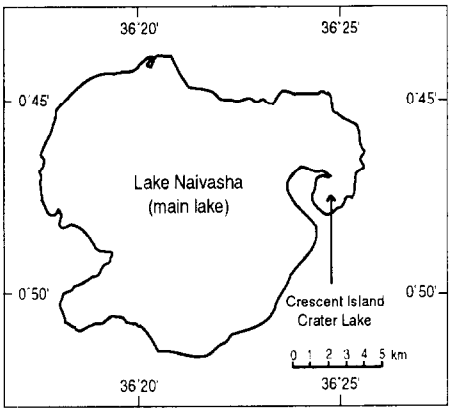
Results

Previous work has shown that *Salvinia* exposed to the windy and wavy conditions of an open lake quickly perishes. During this survey, *Salvinia* was only found in a sheltered area at the northern end of the lake. Furthermore, no individuals of the weevil *Cyrtobagus salviniae* were found in these *Salvinia* plants. These findings strongly imply that the weevil has not caused the disappearance of *Salvinia* from the lake, and that instead environmental change, in turn related to lake level change and human activity, have led to a loss of suitable *Salvinia* habitats in the main Lake. No individuals of the weevil *Neochetina* were found in *Eichhornia* plants, implying that the weevil's introduction has been unsuccessful. However, *Eichhornia* plants do support a rich mesofauna, concentrated in the layer in between the plants' leaves and aquatic roots. In this zone, dead plant material is continuously being broken and soil is formed. The most important organism in this process appears to be the earthworm *Almia emini.*

Ecohydrological Implications of this Study

The introduction of weevils seems to have had negligible effects on the Lake's floating vegetation. Instead, environmental changes (water level change and human activity) appear to have caused the disappearance of *Salvinia* from the lake. *Eichhornia* plants represent nuclei for soil-forming processes. Such processes may accelerate the loss of open water areas, and consequently represent a different threat to the lake. Therefore, further investigation of the Lake's *Eichhornia*-based ectonal ecosystem, aimed specifically at the rate, extent, stability and functioning of soil formation on floating mats, are needed.

THE SPATIAL AND TEMPORAL DISTRIBUTION OF LOUISIANA CRAYFISH



Authors
ANNE-CHRISTINE GOUDER DE BEAUREGARD
SOPHIE SCHMIDT
Faculties Universitaires de Gembloux, Belgium
ANDY SMART
STEPHANIE COLEY
Cornwall College, Cambourne, Cornwall, UK
DAVID HARPER
Department of Biology, University of Leicester, UK
KAMAU MBOGO
Kenya Marine and Fisheries Institute, Naivasha

Working Hypotheses

For 25 years, aquatic vegetation has been changing in time and in location on Lake Naivasha. The modifications observed on the plant communities appear at the same time the Louisiana crayfish population began to be important and widespread all over the lake. The hypotheses are as follows:

1. The crayfish population is responsible for the changes observed in the macrophytes.
2. Crayfish have a spatial and a temporal impact on the aquatic vegetation dynamics.
3. Crayfish eat and damage plant communities, more especially submerged macrophytes.

Methods

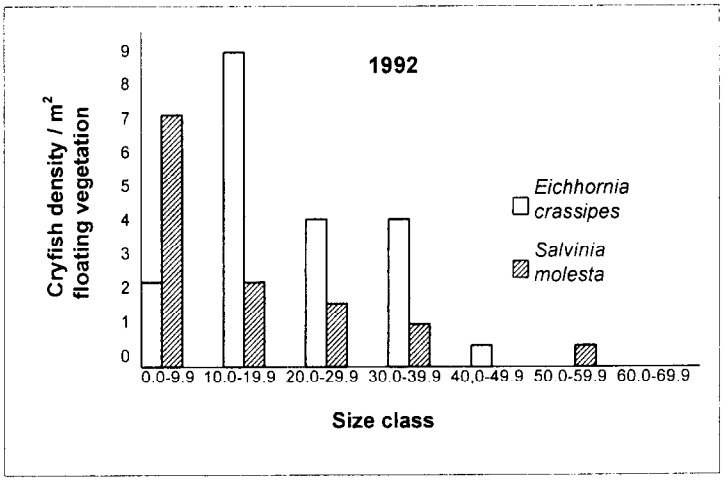
Long term monitoring :

1. Annual crayfish survey (hand-net, quadrat, trap) all over the lake shoreline.
2. Annual mapping of crayfish population (GPS).
3. Annual mapping of vegetation communities (GPS).

Experimental design, Preliminary Results

Crayfish are widespread on the lake. They are present on the shoreline particularly where macrophytes are established. A high crayfish density are found in floating/grounded plants of *Cyperaceae* or *Eichhornia crassipes*. Very few crayfish are found along a cleared shoreline or next to small clumps of vegetation.

Inside the vegetation, crayfish live in different habitats according to their size. Juveniles are found in *Salvinia molesta* Mitch. mainly, then in *Eichhornia crassipes* when they are bigger. Most of the adults are found in the papyrus fringe.

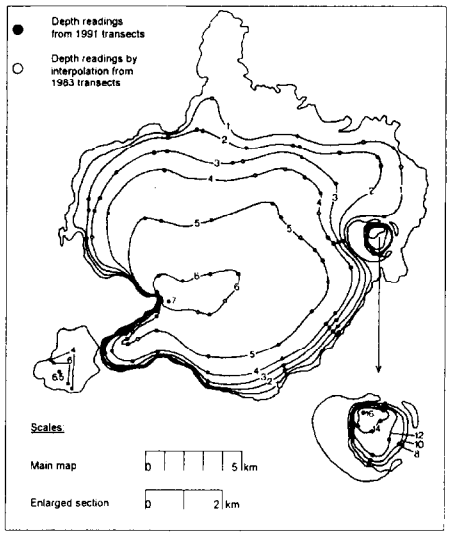


The relation between the papyrus fringe and the submerged plants was linked with crayfish density in 1998. Submerged macrophytes were absent when the shoreline was composed of *Papyrus spp.*, thus where the crayfish density is higher. And submerged macrophytes were present when there was no papyrus fringe, in other words where the crayfish density was low. The dynamics of *Papyrus spp.*, *Eichhornia crassipes* and *Salvinia molesta* seemed to be independent of the crayfish population. Laboratory experiments and ecological survey on the lake tend to show that there were little or no relations between them.

Ecohydrological Implications of this Study

In order to fully understand the crayfish dynamics in the aquatic ecosystem we need to understand more clearly its food base, its effect upon plant species and its predators. This gives us the best opportunities for restoration of the ecotone.

THE POPULATION STRUCTURE AND DISTRIBUTION OF LOUISIANA CRAYFISH (*PROCAMBARUS CLARKII*, GIRARD) AT LAKE NAIVASHA, KENYA



Authors
STEPHANIE COLEY
ANDY SMART
Cornwall College, Cambourne, Cornwall, UK
DAVID HARPER
KAMAU MBOGO
Department of Biology, University of Leicester, UK

Introduction

The changes in the ecology of Lake Naivasha have been monitored extensively over the last decade and changes in vegetation have been linked with changes in the population of introduced crayfish *Procambarus clarkii*. The distribution of the vegetation around the lake is possibly linked to the crayfish.

Working Hypothesis

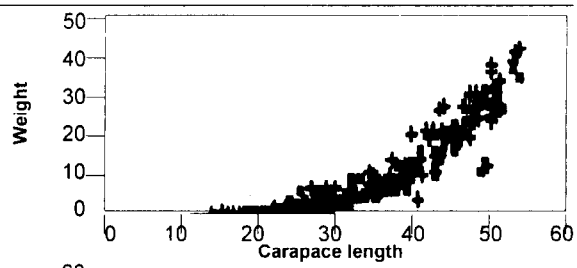
There are no differences between the temporal and spatial distribution of crayfish of different size and sex around Lake Naivasha. Measurement of carapace length is a valid measure of size and weight of crayfish at Naivasha.

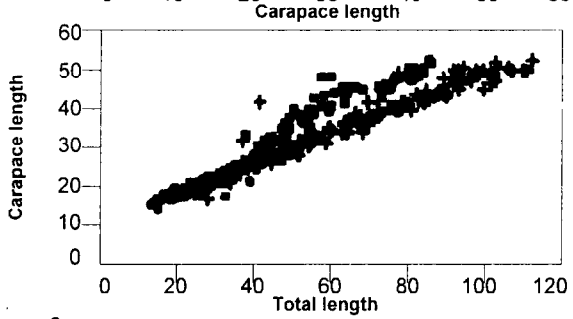
Methods

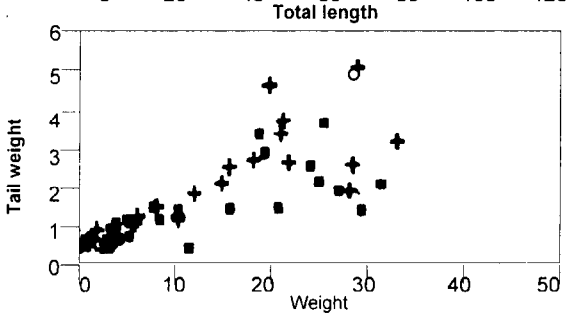
1. Animals were collected from around the lake, sexed, weighted and measured. Analysis of measurements showed relationships between field measurements and actual dimensions of animals.
2. Different locations around the lake were sampled and the sex ratios and size ratios examined.
3. Mark-recapture was attempted using fish traps set along the edge of the shore.

Preliminary Results

1. Male and female crayfish show a different relationship between carapace length and size and weight. A relationship between carapace length and tail weight was established.
2. The overall sex ratio was established as 1:1 and did not vary from year to year; berried females and small juveniles were not found throughout the year suggesting that breeding is no longer continuous as previously reported.
3. Mark-recapture of crayfish over two periods in 1992 and 1994 proved inconclusive, despite large numbers of animals marked few recaptures were recorded suggesting that animals may have no fixed areas in which they live.







Ecohydrological Implications of this Study

Variations in the temporal and spatial distribution will affect the bass fishery and may have implications for the aquatic macrophytes. An understanding of the crayfish ecology is central to the understanding of the lake's food web.

THE DISTRIBUTION OF LITTORAL ZONE MACROINVERTEBRATES AT LAKE NAIVASHA, KENYA, BETWEEN 1992 AND 1994

Authors
A.C. SMART
S.J. COLEY
D.M. HARPER
Department of Biology, University of Leicester,
Leicester LE1 7RH, UK

Introduction

The changes in the ecology of Lake Naivasha have been monitored over the last decade. Benthic and littoral macro-invertebrates were surveyed in detail during 1982-1984 and subsequent changes in vegetation and lake levels have been recorded in detail. A repeat survey of the lake using similar methods was undertaken during 1992-1994 to establish whether any changes had occurred during this period.

Working Hypothesis

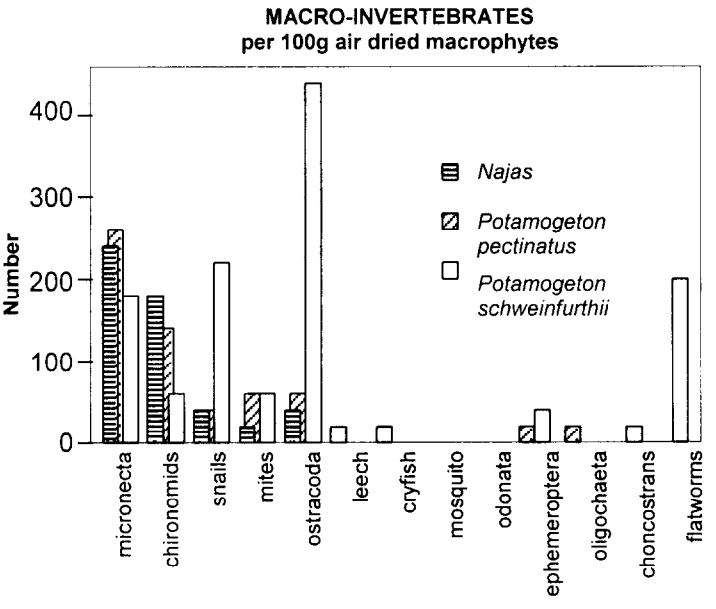
There is no difference in the spatial distribution of littoral macro-invertebrates around the lake shore and the density of macro-invertebrates on different macrophytes does not vary with species.

Methods

1. Semi-quantitative samples of macro-invertebrates were removed from a series of stations around the lake shoreline.
2. Semi-quantitative samples of macro-invertebrates were removed from the three main aquatic macrophytes and the two main species of floating vegetation.

Preliminary Results

1. Taxa varied around the lake with vegetation and substratum. Notable differences were the presence of a Chonchostracan in both 1992 and 1994 and the absence of the majority of the Hemipteran fauna and Anisoptera on the main lake.
2. The macro-invertebrate community varied considerably on different plants; *Najas* and *Potamogeton pectinatus* dominated by *Micronecta* and chironomid larvae; *Potamogeton schweinfurthei* dominated by Ostracoda, snails and flatworms.

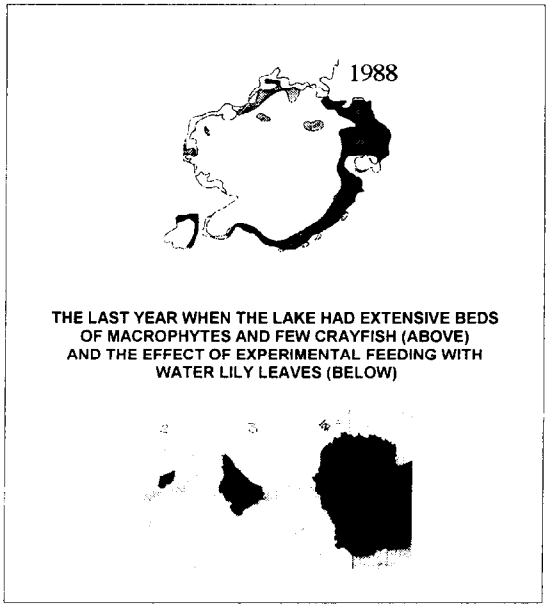


Ecohydrological Implications of this Study

The changes in macro-invertebrate fauna will have implications for the fish and fishery on the lake.

THE DIET OF LOUISIANA CRAYFISH (*PROCAMBARUS CLARKII*, GIRARD) AT LAKE NAIVASHA, KENYA

Authors
ANDY SMART
STEPHANIE COLEY
ANNE-CHRISTINE GOUDER DE BEAUREGARD
SOPHIE SCHMIDT
DAVID HARPER
Department of Biology
University of Leicester, UK



Introduction

The changes in the ecology of Lake Naivasha have been monitored extensively over the last decade. Changes in vegetation have been linked with changes in the population of introduced crayfish. The role of the crayfish in African ecosystems has significant implications for the structure of the food web and the control of parasitic vectors through the digestion of snails.

Working Hypothesis

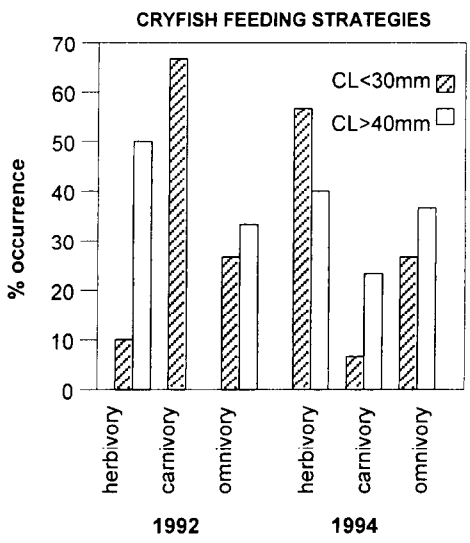
There are no differences between the diets of different stages of crayfish and all animals will eat food without showing any preference.

Methods

1. Live animals were subjected to food choice experiments with animal and plant material that could be weighted and measured as evidence of consumption.
2. Live animals were placed in cages in the lake with choices of plant material that could be weighted and measured as evidence of consumption.
3. Different sized animals were collected and stomach analysis undertaken to establish stomach contents at time of collection.

Preliminary Results

1. No obvious variation between crayfish predation on invertebrates; Oligochaeta; chironomid larvae; Micronecta, snails (both animal and shell) and *Alma* (swamp worms) are all eaten by crayfish juvenile and adult stages.
2. Adult crayfish and juveniles eat *Najas* in the greatest quantity but *Potamogeton pectinatus* is selected by adult crayfish when offered a choice. Water hyacinth is not eaten to any extent. For both adults and juvenile crayfish, the quantity of plant material eaten is reduced if animal material is present.
3. Adult and juvenile crayfish stomachs show different levels of predation and herbivory in 1992 and 1994. Overall 47% of stomachs contained plant material (*Najas* and unidentified detritus); 37% contained *Micronecta*; 14% chironomid larvae; and 11% others including; caddis fly larvae; Coleoptera; snails; mosquito larvae *Alma* and other crayfish.



Potential Implications of this Study

The link between cryfish, invertebrates and macrophytes is a pivotal position within the food web and greater understanding is required to model the system effectively.

BIODIVERSITY OF BIRD SPECIES IN THE LAND/WATER ECOTONE

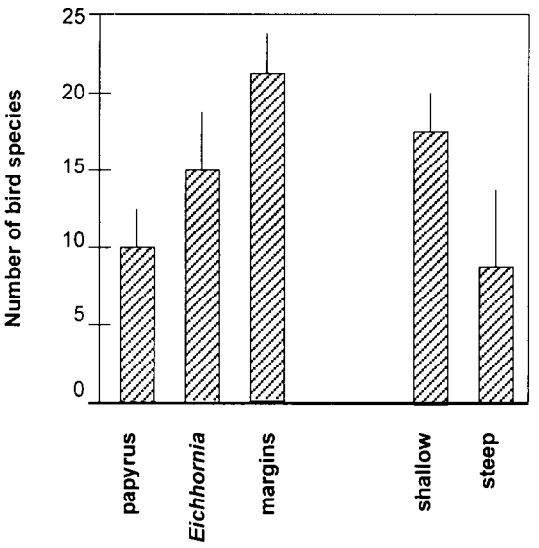
Authors
IAN HENDERSON
British Trust for Ornithology,
Thetford, UK
DAVID HARPER
Department of Biology,
University of Leicester, UK

Methods

Lake Naivasha supports a rich bird fauna of c. 350 bird species, including around 90 aquatics, utilising a range of habitats Boat transects were carried out on three major aquatic habitats: 1) Papyrus fringes, 2) the introduced floating water hyacinth *Eichhornia crassipes* (usually admixed with dispersed papyrus), 3) flooded margins or lagoons. Repeated 15-minute counts were made of 50m-wide sections of each habitat.

Results

General Linear Poisson models of the 1998 data in isolation, indicate interaction between a combination of a shallow shore and flooded marginal habitats (Likelihood ratio (LR): χ_1^2=4.1, P<0.05), the latter supporting the greatest number of bird species of the three habitats, with an abundance at least one order of magnitude greater than in the other two habitats (LR):χ_2^2=14.2, P<0.001). This degree of difference is unlikely to be explained by differences in bird detectability between habitats, and indicates the potential importance of newly created margins for foraging birds. Otherwise the species profile of papyrus is most notable for several specialists (e.g. greater, lesser and little rush warblers) restricted only to that habitat. Of specific interest, 400 red-knobbed coots were counted in an area of Crescent Island which supported the only significant growth of submerged macrophytes (e.g. *Potomogeton* spp.) currently found on the Lake.



This number of coots is an order of magnitude higher than counts in recent years, though still short of the 1000 birds recorded in 1987 (Henderson & Harper, 1991), and the tens of thousands of waterfowl recorded in the early 1980s (Van Someren pers. comm.). The significance of this is that coots indicate the presence of submerged plants, which are integral to the lake's ecology as fish nurseries and as support of important invertebrate populations. The submerged macrophytes, invertebrates and fish populations are all thought crucial to the lake's abundance and richness of bird species. On the small adjacent Oloidien Lake, coot (638) and grebes (2000+) were still abundant over the submerged macrophyte zone. These macrophytes persist probably in the absence of the introduced Louisiana crayfish (*Procambarus clarkii*) and its intolerance to the more saline conditions there.

Ecohydrological Implications of this Study

Birds are large and mobile members of the biota, potentially offering a rapid indication of the potential health of the food web of the ecotone at different stages of degradation/development and through their feeding guild structure, some insight into functioning. Further studies are necessary to clarify such issues.

CHANGES IN THE FEEDING ECOLOGY OF THE AFRICAN LILY TROTTER *ACTOPHILORNIS AFRICANUS* (GMELIN) AT LAKE NAIVASHA, KENYA

Authors
RACHEL ADATIA
STEPHANIE COLEY
ANDY SMART
DAVID HARPER
Department of Biology,
University of Leicester, UK
PAUL OBADE
KMFRI, Naivasha, Kenya

Submerged and floating plants in 1998 – Lily trotter habitats

Introduction

The changes in the ecology of Lake Naivasha have been monitored extensively over the last decade. During 1992 and 1994, measurements of the feeding ecology of the lily trotter were made comparing small and large beds of the floating fern *Salvinia molesta*. Subsequent changes in vegetation and lake levels have led to the decline of Salvinia and an increase in mats of water hyacinth (*Eichhornia crassipes*). The lily trotter now fequent the fringe of the lake since no large mats of *Salvinia* exist and are present in lower number.

Working Hypothesis

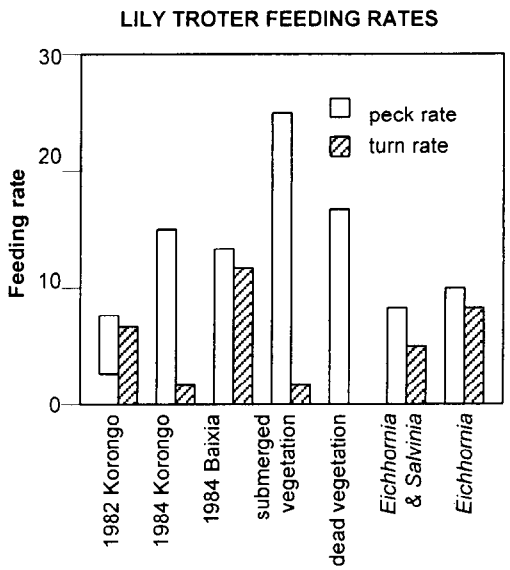
There are no differences in the feeding rates of lily trotters on invertebrates under and on different macrophytes.

Methods

1. Semi-quantitative samples of macro-invertebrates were removed from *Salvinia* and *Eichhornia*.
2. Measurements of feeding rates of lily trotters were made on floating vegetation on the lake and a lily pond adjacent to the lake.
3. Numbers of lily trotter on the lake were recorded during bird surveys.

Preliminar Results

1. *Salvinia* did not support the same levels of macro-invertebrate in 1992 as in 1982 and in 1984. *Eichhornia* supported a different community, particularly small crayfish (1984).
2. Peck rates and turn rate varied with vegetation and were particularly higher in submerged macrophytes. Additional information relating to 'probe rate' was collected along with records of number of times birds ate in each habitat.
3. Lily trotters were found to be present in greater density on the submerged macrophyte beds.



Ecohydrological Implications of this Study

The changes in lily trotter feeding rates on vegetation may be an indicator of how the macro-invertebrate fauna is changing on the lake with subsequent implications for other birds and the fishery.

POPULATION SHIFTS BETWEEN SYMPATRIC GREAT AND LONG-TAILED CORMORANTS (*PHALACROCORAX CARBO* AND *P. AFRICANUS*): THE EFFECTS OF NICHE OVERLAP OR ENVIRONMENTAL CHANGE?

Authors
R. BROOKS CHILDRESS
LEON A. BENNUN
Ornithology Department,
National Museums of Kenya, Nairobi, Kenya
DAVID M. HARPER
Department of Biology,
University of Leicester, UK

Working Hypothesis

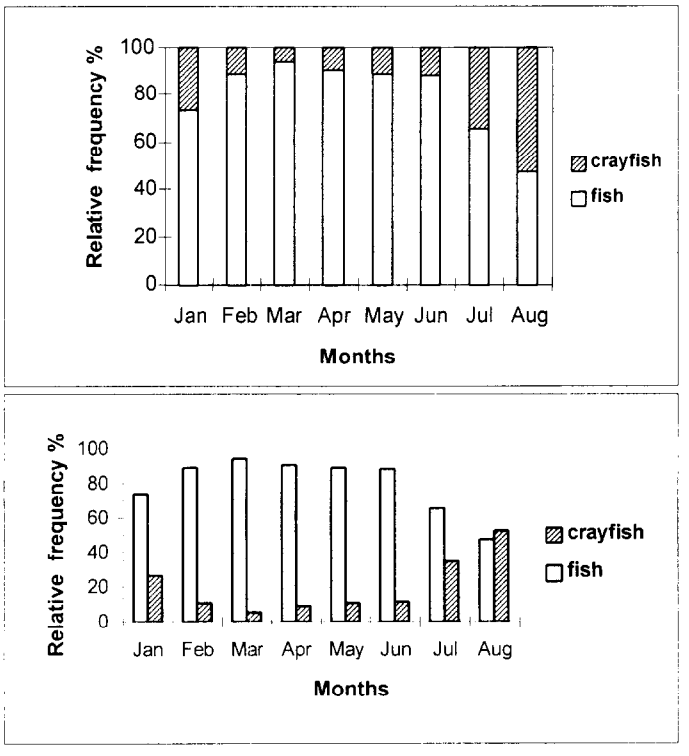
Numbers of the great cormorant, *Phalacrocorax carbo*, at Naivasha, have gone up since the mid-1990s whilst those of the sympatric *P. africanus* have declined. The hypothesis was that this occurred through unconnected environmental changes rather than as a result of direct competition.

Methods

Censuses have been carried out on a monthly basis by boat and on foot at the *P. carbo* breeding colony. Remains of prey dropped from nests were regularly examined.

Results

Between January 1993 and January 1995, the number of Great Cormorants (*Phalacrocorax carbo*) using Lake Naivasha for foraging and resting increased 56%, while the number of sympatric Long-tailed Cormorants (*Phalacrocorax africanus*) decreased 64%. The increase in Great Cormorants was probably the result of immigration from Lake Nakuru due to extreme water level reductions there. Lake Naivasha also experienced falling water levels and transparency during this period, but these changes were not as severe and are not considered likely reasons for the decline in Long-tailed Cormorant numbers. Despite some probable dietary overlap, the two species were well separated in terms of foraging locations, foraging methods, resting habitats and breeding timing. The decline in Long-tailed Cormorant numbers may be connected with increased disturbance by fishermen along the lake littoral ecotone, this species' primary feeding location.



Ecohydrological Implications of this Study

Cormorants are the most abundant piscivorous bird on the lake and their abundance relates to the availability of fish and crayfish food as well as habitat suitability: *P. carbo* is a more open-water species roosting in trees, whilst *P. africanus* is a littoral ecotone species, feeding inshore and roosting in reeds. *P. carbo* plays a small role in predation upon crayfish. A third cormorant species, the African darter, was formerly recorded from the lake but has not been seen for many years, perhaps due to a similar decline in ecotone structure as is affecting *P. africanus*.

THE AFRICAN FISH EAGLE *(HALIAEETUS VOCIFER)* POPULATION AT LAKE NAIVASHA: NUMBERS, DISTRIBUTION AND CONSERVATION

Authors
MAUREEN HARPER
DAVID HARPER
MUNIR VIRANI
ANDREW SMART
RACHEL ADATIA
IAN HENDERSON
Department of Biology, University of Leicester, UK

Working Hypothesis

The African fish eagle reaches its greatest density in Lake Naivasha and the site is famous as a major location for the studies of Leslie Brown, who wrote a book about the bird, in the late 1960s. Concern about the status of the bird rose from the late 1980s when it was realised that the proportion of juvenile birds was declining. Hypothesised causes were decline in food, loss of ecotonal breeding habitats, pesticide poisoning. The null hypothesis was that the birds are experiencing no decline in their feeding or breeding environment.

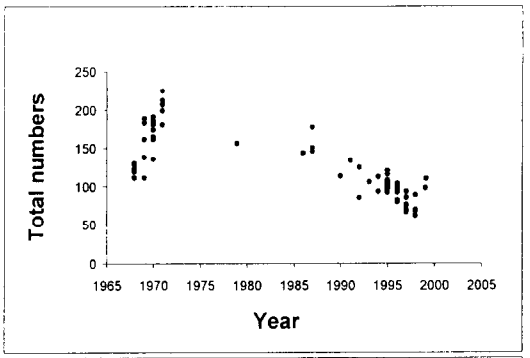
Methods

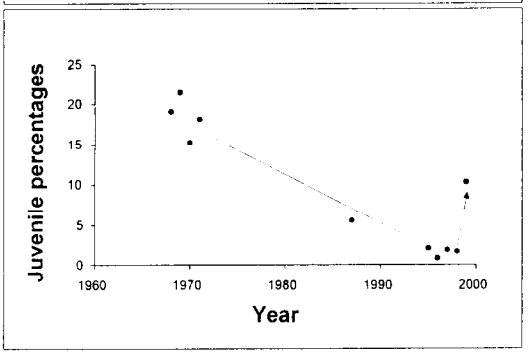
Censuses have been carried out by boat several times each year between 1987 and 1999. Paired individuals, breeding sites, juvenile numbers, territory habitat, shoreline length and shoreline tree cover, were recorded.

Results

Both the total number of birds and the proportion of juveniles have fallen steadily since the early 1990s. The numbers follow the reduction in shoreline length due to water level decline, the reduction in *Acacia*-fringed shoreline the decline in fish and the declines in coot (*Fulica cristata*), an alternative avian food which is itself herbivorous, dependent upon the submerged plant beds which themselves have declined as a result of crayfish consumption (see Gouder *et al.*).

The heavy rains in late 1997, which were related to the ENSO effect, resulted in a rapid rise in lake water level. This caused an increase in the area of shallow lagoons, which was followed by an upsurge in fish, submerged plants and *F. cristata*. A rapid increase in breeding of the birds followed very soon after. The rise in numbers and juveniles suggests that prior to 1998 the population had been primarily food limited because the rapid change in fortunes could not have caused by any ecotone structural changes or decrease in pesticides that rapidly.



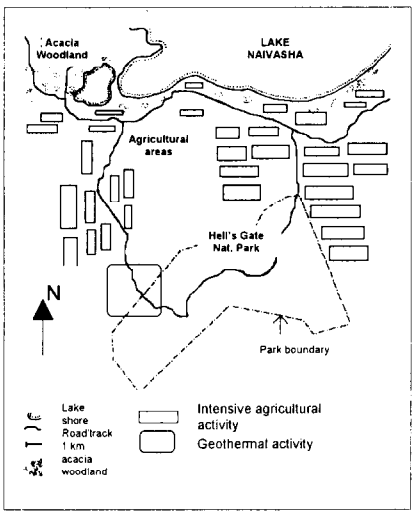


Ecohydrological Implications of this Study

The causes of the fluctuation in numbers indicate the importance of the interaction between ecotone structure, alien species disruption of the ecosystem and water level fluctuations. Future monitoring of the population changes at the same time as careful measurement of important parameters in their breeding and feeding biology should enable the species to be used as a rapid indicator of system environmental health.

THE AUGUR BUZZARD *(BUTEO AUGUR)* POPULATION IN CONTRASTING LAND USE TYPES AT THE EDGE OF LAKE NAIVASHA

Authors
MUNIR VIRANI
DAVID HARPER
Department of Biology,
University of Leicester, UK



Working Hypothesis

The augur buzzard is a common raptor found in Kenya's central highlands and Rift Valley. Although common, very little was known about the species' basic biology. In many parts of Kenya, numbers have declined due to habitat changes as a result of increased human population pressure. Concern about the decline led to an investigation on impacts of changing land-uses in the littoral region of Lake Naivasha, with the null hypothesis that different land uses did not impact upon the species.

Methods

Populations of Augur Buzzards were intensively studied over a period of three years (1995-98) in three different habitats (see map). These were:

1. Hell's Gate National Park.
2. *Acacia* woodland/pasture running down to the lake edge.
3. Intensive agricultural areas bordering on the lake.

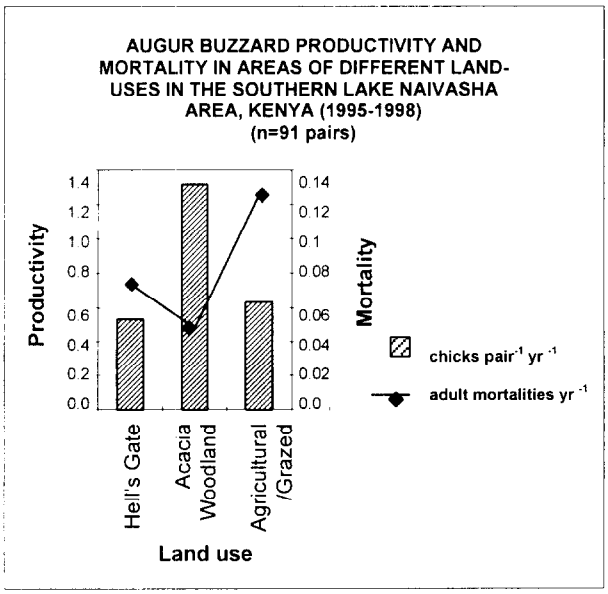
Ecological aspects studied were: distribution, breeding behaviour, feeding and foraging patterns, home range size, prey availability and breeding success.

Results

Clear ecological differences were found between augur buzzards in Hell's Gate National Park & the two areas of the lake environs. Prey availability, and augur buzzard productivity and mortality rates, were all lower in the Park than in the lake environs.

Augur buzzard diet comprised mainly rodents (74.4%), while birds (6.4%), reptiles (3.9%), dassies (3.8%) and insects (1.3%) formed the rest. Prey delivery rates to the nest differed at different stages of the nesting period as well as when there was more than one chick in the nest.

Augur Buzzard productivity was highest in undisturbed *Acacia* woodland (1.32 chicks pair^{-1} yr. $^{-1}$) and lowest in agricultural areas and Hell's Gate National Park (0.64 and 0.53 chicks pair $^{-1}$ yr $^{-1}$ respectively). Mortality rates were lowest in undisturbed *Acacia* woodland and highest in agricultural areas. Forty percent of the mortalities were as a result of human persecution and poisoning.



Ecohydrological Implications of this Study

On the terrestrial side of the land-water ecotone, this raptor is a good indicator of the health of the human-modified ecosystems, to the extent that it is most successful in semi-natural pasture woodland. The importance of this lies in the species' value as an indicator of ecosystem health and the development of sustainable agricultural systems.

THE NUMBERS AND DISTRIBUTION OF HIPPOPOTAMUS IN LAKE NAVASHA BETWEEN 1987 AND 1999

Authors
ANDY SMART
STEPHANIE COLEY
DAVID HARPER
Department of Biology,
University of Leicester, UK
ERIC NDONGA
KWS Wildlife Training Institute,
PO box 842 Naivasha, Kenya

Introduction

Accurate survey of hippopotamus in a lacustrine ecosystem is a difficult task, depending on surveys of animals during the day when they are in the water, using counts from land, boats and aerial surveys. Aerial surveys using photography as been suggested as the most reliable method, but this is costly relative to boat surveys.
Lake Naivasha contains a relatively isolated population of hippopotamus spread throughout the lake, papyrus swamp and Malewa River areas. Lake levels are variable and the pressure on hippopotamus around the lake is increasing with developing agriculture and increasing population.

Working Hypothesis

1. There are no differences between results provided by counts from boat and from the air.
2. There is no relationship between hippopotamus incidents (with the population around the lake) and the number of hippopotamus in the lake.
3. There is no change in the daytime distribution of hippopotamus around the lake at different lake levels.

Methods

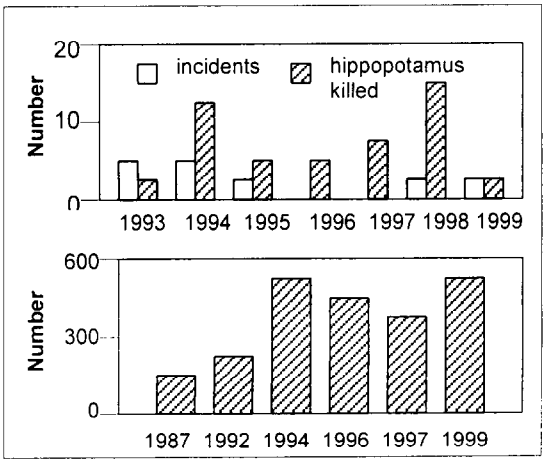
1. Repeated surveys were undertaken between 1987 and 1999 estimating numbers of hippopotamus using boat and aerial surveys.
2. The location of hippopotamus groups around the lake were recorded and marked on maps.
3. Data for the number of hippopotamus incidents and lake levels were collected.

Preliminary Results

1. Hippopotamus population counts vary from 218 (1987) to 532 (1999). There is no obvious pattern between lake levels and population counts.

2. Incident records do not follow particular patterns with the greatest number of incidents recorded in 1994 and 1988.

3. The location of groups around the lake appears to be stable throughout the survey period, with little variation, only 2 groups changing location over a ten-year period.



Ecohydrological Implications of this Study

The changes to numbers of hippopotamus are a reflection on survey techniques and a shift in the location of hippopotamus around the lake.

COLONISATION OF THE FLOATING ISLANDS OF LAKE NAIVASHA

Authors
DAVID HUBBLE
DAVID HARPER
Department of Biology,
University of Leicester, UK

Working Hypothesis

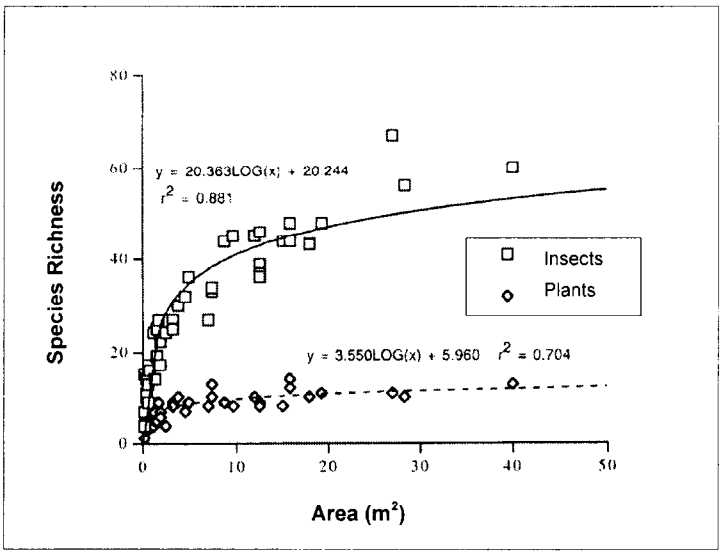
There have always been floating islands on Naivasha. For most of this century there have been large islands of papyrus *(Cyperus papyrus)* but in the past decade they have been primarily made up of the exotic alien species *Salvinia molesta* (early 1990s) and *Eichhornia crassipes* (late 1990s). These are colonised by many other semi-aquatic native species of sedges, rushes and grasses. The working hypothesis was that there was a relationship between island size and biodiversity, and that the islands made a contribution to the overall biodivesity of the lake.

Methods

Plant and invertebrate species were removed from the islands and identified, and islands measured across two axes together with shape estimation so that their total area was computed.

Results

Species richness increased with island size, but plant species richness reached a plateau (there were 22 contributing species), regardless of increasing size. Insect density was maximal on small islands and there was a clear relationship between insect species richness and plant species richness (r^2=0.64).

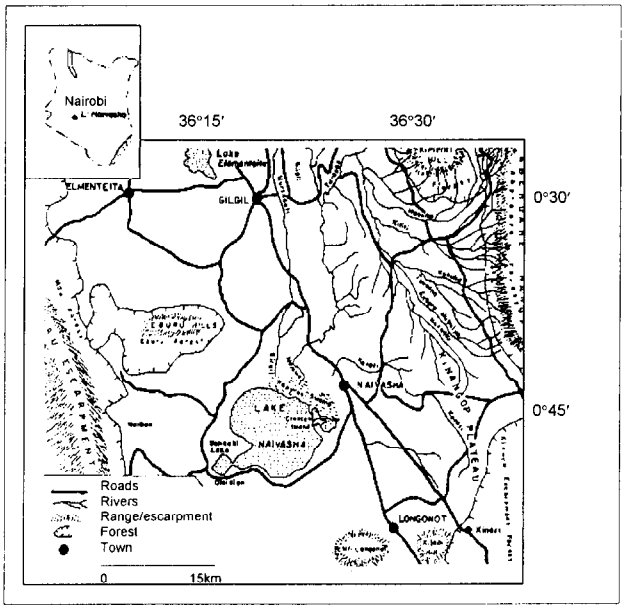


Ecohydrological Implications of this Study

Islands break off from larger, more immobile mats of vegetation which form the water-edge of the 'new' ecotone of Lake Naivasha when there are no submerged macrophytes due to crayfish grazing effects (see paper by Gouder). As such they add biodiversity to the open water of the lake which is utilised by wading birds and insectivorous water birds. The future of the alien plants, which make up the support-base of the islands is uncertain as biological control is applied (see paper by Gitonga), but in the absence of floating papyrus islands with the natural ecotone destroyed and the lake subject to increasing hydrological control (see paper by Becht), these island have an ecological benefit.

SUSTAINABLE HARVESTING OF *CYPERUS PAPYRUS* L. IN LAKE NAIVASHA, KENYA.

Authors
F. W. KARIUKI
F. M. MUTHURI
Botany Department,
Kenyatta University,
P.O. Box 43844, Nairobi, Kenya
M. B. JONES
Trinity College, Dublin ,Eire



Working Hypothesis

The major plant species of the ecotone, *Cyperus papyrus*, could be conserved as well as utilised on a sustainable basis if a harvesting strategy was established. This study assessed the optimum-harvesting interval for papyrus and its potential for a sustainable yield.

Methods

Sustainable harvesting was assessed in terms of above ground biomass and culm density using five harvesting intervals; control, harvesting at intervals of 6, 12, 24 and 36 months each replicated five times in a Latin Square Design.

Above ground biomass was assessed indirectly from regression of culm-girth and culm dry weight using equation: Log_{10} W=2.94Log_{10}G-0.85 (W=culm dry weight (g) and G= culm girth at the top of the outermost scale leaf).

Culm density (culms/m^{-2}) was assessed in terms of age class structure.

Results

Harvesting at 6 months interval reduced the above ground biomass by 40, 65, 32 and 68% of the original biomass on successful harvesting while that of 12 months intervals decreased it by 60 and 46% on the 2nd and 3rd harvests respectively.

The above ground biomass for the 24 and 36 months intervals were approximately equal to those of the unharvested crop (control).

Repeated harvesting at 6 and 12 months intervals increased the densities of juveniles and senescent culms while reducing that of mature culms.

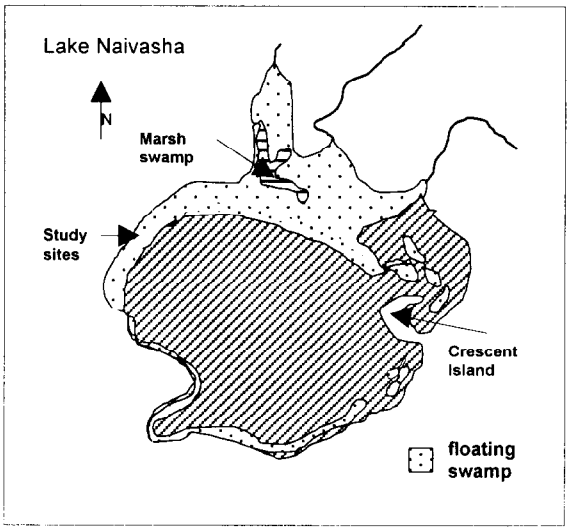
In the 24 and 36 harvesting intervals, the rate of recruitment was higher than that of mortality, an indication of a stable community.

Ecohydrological Implications of this Study

The minimum-harvesting interval for papyrus should be 24 months. The age class structure could be used to monitor the regeneration and conservation status of papyrus after harvesting. It is thus feasible for a management plan to include sustainable use the main plant species in the Naivasha ecotone rather than allow it to be destroyed piecemeal.

THE IMPACT OF PAPYRUS ON ECOSYSTEM FUNCTIONING

Authors
MICHAEL JONES
Botany Department,
Trinity College,
Dublin, Eire
STEPHEN HUMPHRIES
Department of Applied Science,
Brookhaven National Laboratory,
New York, USA



Working Hypothesis

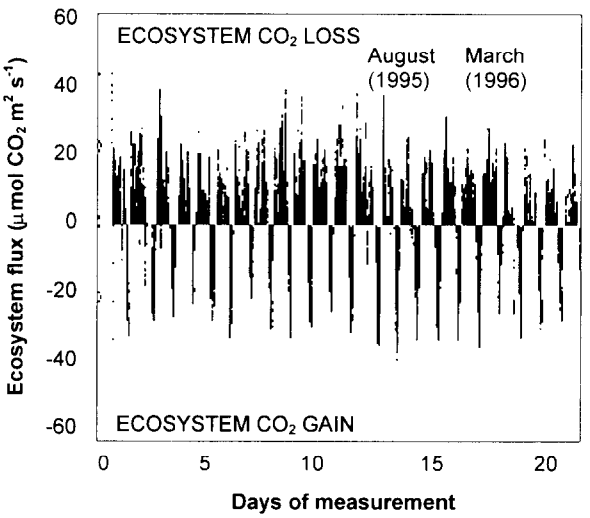
The fluxes of carbon and water between vegetation and the atmosphere are strongly influenced by the functional characteristics of the vegetation. Many wetlands in Africa are dominated by *Cyperus papyrus* L., (papyrus), large herbaceous sedge with C^4 photosynthesis. This functional attribute confers advantages in terms of light and water use efficiency. High efficiency of light energy conversion into dry matter suggests that papyrus swamps have the potential to sequester large amounts of carbon when detritus accumulates under anaerobic conditions. The high water use efficiency of C^4 papyrus can also explain why evaporation from papyrus is less than from the open lake.

Methods

Papyrus wetland ecosystem fluxes of CO_2 and water vapour were measured using the eddy covariance technique. A total of four weeks of continuous records were obtained over two periods of the year when weather conditions were different. The data were used to test a 'bottom-up' model of ecosystem gas exchange, which can be used to predict annual cycles of carbon and water vapour exchange.

Results

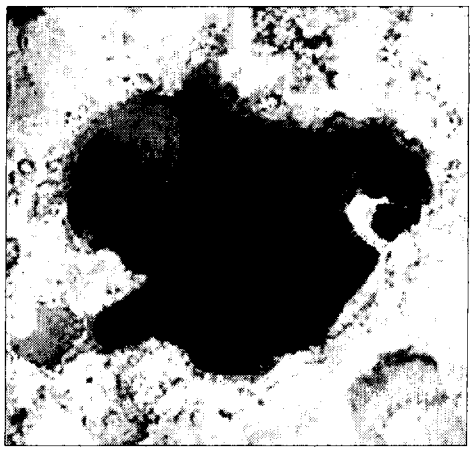
The papyrus community has the potential to fix some of the largest-ever-measured amounts of carbon on a ground area basis. The papyrus wetland ecosystem has the potential to be a strong net source or sink for atmospheric CO_2 depending on the hydrological status of the wetland. Measurements of evapotranspiration from the papyrus wetland show that swamp vegetation, on a diurnal cycle, is less than open water evaporation.



Ecohydrological Implications of this Study

The work shows that the conservation of papyrus wetlands is beneficial for the carbon and water status of wetland regions. Papyrus is extremely productive and the carbon accumulated is potentially a major sink for atmospheric CO_2. Papyrus vegetation is also beneficial in terms of water conservation in wetlands as less water evaporates than from open water. Naivasha was once extremely well served with papyrus swamp (map) but now has lost all its swamp, with the plant reduced to fringing strips only. Restoration of the inflow papyrus swamps should be of prime management importance. This would also replace the role of the swamps as buffers of inflowing river water.

MANAGEMENT OF WATER *EICHHORNIA CRASSIPES*, *SALVINIA MOLESTA* AND *PISTIA* IN LAKE NAIVASHA



Authors
W. GITONGA
A.M. MAILU
S.N. NJIHIA
National Agricultural Research Centre,
Nairobi, Kenya

Working Hypothesis

Lake Naivasha and its environs are important for biological diversity and freshwater resources. Three species of exotic free-floating plants – water fern, water hyacinth and water lettuce, have infested the lakes in recent decades, suppressing and occupying ecological niches previously inhabited by native flora. They have also interfered with irrigation, domestic and industrial water supply, fisheries and tourism activities.

Methods

Cyrtobagous salviniae was used in the early 1990s to control water fern. Subsequently *Neochetina bruchi, Neochetina eichhorniae, Sameodes albiguttalis* and *Orthogulmna terebrantis* are being used for control of water hyacinth. *Neohydronomus affinis* is intended for water lettuce control. Release levels were 2970 adults and 12565 eggs of *N. bruchi*, 100 adults of *N. eichhorniae*, 150 larvae of *S. albigutialis* and 1000 adults of *O. terebrantis*, between 1995 and 1997.

Results

Establishment of the weevils *N. bruchi*, and *N. eichhorniae* occurred at all release sites. However, *S. albigutialis and O. terebranti* failed to establish. Drought conditions in late 1996 and early 1997, followed by the heavy rains associated with the effects of ENSO (El Nino Southern Oscillation) both interfered with water hyacinth growth and appear to have affected the biological control agents. Preliminary results indicate the mean number of *N. bruchi*, to have increased from 0.3/plant in late 1997 to 3/plant in early 1999. During the same period the number of feeding scars increased from 5.5/leaf to 74.9/leaf.

Ecohydrological Implications of this Study

The floating exotic plants in Naivasha exacerbate the effects of the unpredictable inflow regime and the impact on the lake of the abstractions (see Becht paper). Consequently their control has ecohydrological benefits and biological control agents offer a viable option. Water fern has been reduced in Naivasha, and water hyacinth has been reduced in Lake Victoria. The involvement of stakeholders in the monitoring of such experiments should be encouraged.

PESTICIDE CONTAMINATION IN WATER, SEDIMENT, AND SELECTED ORGANISMS IN LAKE NAIVASHA (KENYA)

Authors
SAMUEL GITAHI
School of Environmental Studies, Moi University,
P.O. Box 3900, Eldoret, Kenya
ROSEMARY NG'ANG'A
Pesticide Chemistry Laboratories,
Kenya Plant Health Inspectorate Service (KEPHIS),
KARI-NARL, Nairobi, Kenya

Working Hypothesis

There is a significant level of organochlorine and organophosphate insecticide contamination in the Lake Naivasha ecosystem arising from the adjacent intensive floriculture/horticulture. Upland catchment areas are also significant sources of organochlorine and organophosphate insecticides entering the lake system.

Methods

Pesticide residue analysis from the lake food chain and a survey of commonly used insecticides in the riparian lands and in the wider catchment. Collections were made of lake and river Malewa water, bottom sediment, the Louisiana (redswamp) crayfish *(Procambarus clarkii),* and the largemouth bass *(Micropterus salmoides).* Pesticide extraction and Florisil column chromatography cleanup was followed by identification and quantification by GLC (Varian 3400 series, equipped with ECD and NPD of Organochlorines lindane, aldrin, dieldrin, ß-endosulfan, o,p'- and p,p'-DDT, and p,p'-DDE and organophosphates: malathion, parathion, diazinon.

Results

Organophosphates, carbamates and pyrethroids are the insecticides most commonly used within the lake's catchment, including in the riparian floriculture. Organophosphates are not detected in the environmental samples although they are known to have acute ecological impacts Organochlorines are found in tissue extracts at fairly low levels (mean concentrations in *M. Salmoides* from 16.1 ppb to 100.5 ppb, for p,p'-DDE and lindane, respectively), but which indicate fairly recent usage.

MEAN, RANGE AND % FREQUENCY OF OCCURRENCE OF ORGANOCHLORINE PESTICIDE RESIDUE LEVELS (μGKG^{-1}) IN BLACKBASS FROM LAKE NAIVASHA[A]

	o,p'-DDT	p,p'-DDT	p,p'-DDE	lindane	ß-endosulfan	dieldrin	aldrin
Mean[b] (± SD)	34.2 (54.0)	28.3 (30.0)	16.1 (16.1)	100.5 (266.0)	21.6 (30.5)	34.6 (56.0)	16.7 (18.8)
Minimum	1.5	2.6	0.5	3.7	1.2	1.8	0.8
Maximum	186.6	100.7	58.2	1595.9	161.8	265.8	70.7
Positive[c] (% frequency)	20 (57.1%)	27 (77.1%)	23 (65.7%)	35 (100%)	31 (88.6%)	25 (71.4%)	28 (80.0%)

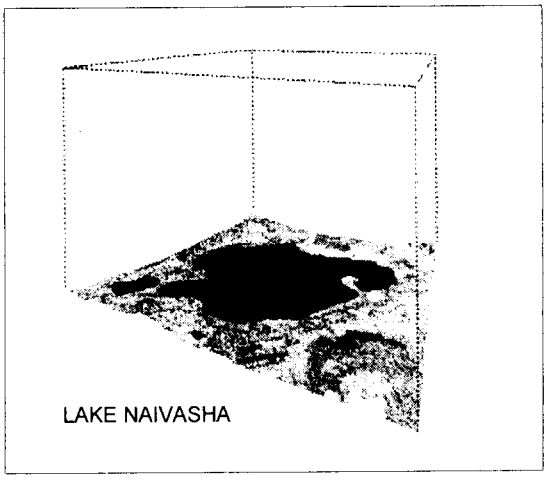
[a] 0.2 μgkg^{-1} = lowest working concentration (below which residues could not be quantified)
[b] Residue levels given on wet weight basis. Mean was calculated for positive samples
[c] Total samples = 35

Ecohydrological Implications of this Study

The study shows that the pesticide contamination of lake Naivasha is limited by discernable. Prudent management would address ecohydrological means of minimising lake contamination, through ecotone structural improvements and artifical wetlands, before contamination becomes serious.

ENVIRONMENTAL FATE AND RISK ANALYSIS OF AGRICULTURAL USE AROUND LAKE NAIVASHA

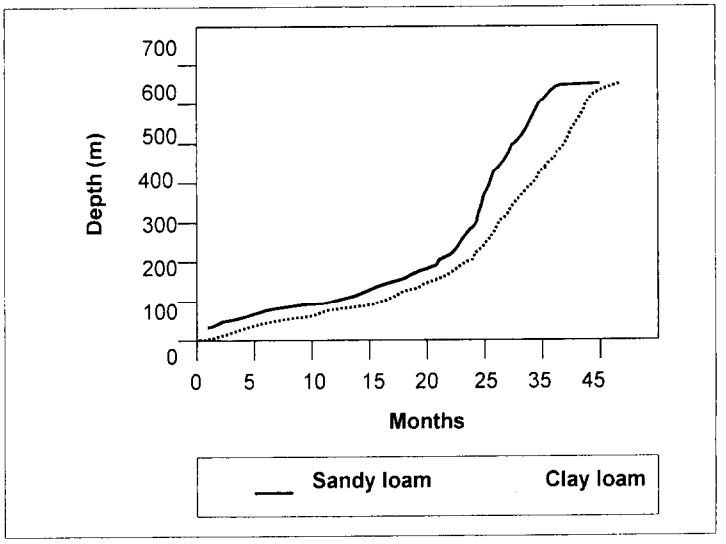
Authors
C. MANNAERTS
TANG ZHEN XU
Water Resources and Environmental Studies
W. SIDERIUS
Soil Sciences Division,
International Institute of Aerospace Surveys
and Earth Sciences (ITC), Enschede, Netherlands



Working Hypothesis
The increase in agricultural and horticultural activity around the shores of Naivasha brings with it a high risk of contamination of groundwater and surface water from agricultural use chemicals. The objective is to determine the fate of agrochemicals and hence their risk.

Methods
Ecosystem partitioning analysis has been carried out using a simplified ecosystem concept representing a 20x20km^2 area (see map). Mapping of fertiliser and pesticide use, hydro-geochemical characterisation, micropollutant residue analysis and water quality analyses are all carried out in the field. Models are then compared for the major fate and transport processes, such as soil accumulation, leaching, volatisation and bioaccumulation.

Results
The majority of chemical uses in conjunction with climate and the hydrological soil environment pose a minimal risk to hydrologic environment and human health. Certain scenarios, such as combinations of chemical type, crop type, irrigation practice, soil type and vadose zone conditions, do represent potential risk to the ecosystem. Spatial and temporal aspects represent important factors in risk assessment.



Ecohydrological Implications of this Study
The land use pattern around Lake Naivasha has severely disrupted the hydrological cycle of the lake and its ecotone. The management of the horticultural industry requires that its risks be identified and quantified as well as its ultimate movement towards a sustainable 'footprint' on the lake. These techniques have potential implementation in that environmental management.

MICROBIAL MONITORING OF LAKE NAIVASHA

Authors
E.C. MWACHIRO
C.C. KAMAU
A. GACHANJA
K.S. MAKHANU
Jomo Kenyatta University of Agriculture and Technology,
Nairobi, Kenya

Working Hypothesis

Lake Naivasha is surrounded by a population of approximately 200,000 people. Most of them live without sanitation, or utilising pit latrines. Consequently there is a risk of contamination of the lake. The null hypothesis is that Lake Naivasha pathogenic bacteria population levels are below WHO (1985) the recommended levels.

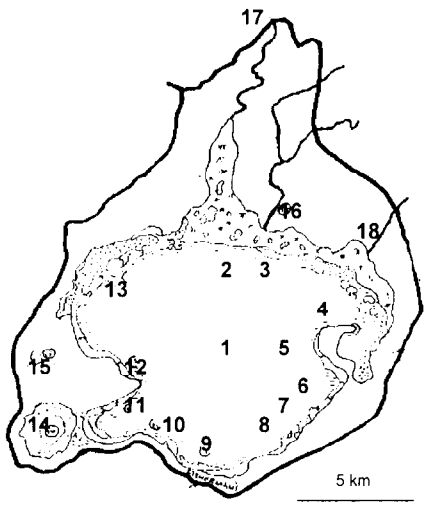
Methods

Multiple tube fermentation techniques were used to determine the fecal and total coliform counts. Samples were collected under sterile conditions. The '5 test tubes technique' was adopted using McConkey's broth media, in single and double strength in series. One Durham's vial was put inverted in each test tube. All positive test tubes were subjected to confirmatory complete tests. The final coliform counts were obtained from the standard tables of Trivedy and Coel (1984) and APHA, AWWA and WPCF (1989).

Results

The results showed that the highest faecal and total coliform bacterial count was obtained in site 8 (Kwa Muya) of between 11.2/100ml-14.0/100ml. The lowest count was in site 10 (Elsamere) with 0/100ml-1.6/100ml.

Sampling sites	Coliform count faecal	total
1. Lake Centre	1.5	2.7
2. Gilgil In	2.5	2.7
3. Malewa In	2.0	9.0
4. Crescent In	5.2	11.7
5. Crescent Out	1.0	2.7
6. Safari Land	0	3.5
7. Sher Agencies	3.5	7.0
8. Kwa Muya	11.2	14.0
9. Fisherman Camp	2.6	5.0
10. Elsamere	0	1.6
11. Burton	1.0	4.3
12. Hippo Point	2.3	7.0
13. Korongo	2.0	2.6
14. Oloiden Lake	1.5	5.0
15. Crater Lake	0	2.0
16. River Malewa	4.5	10.5
17. River Gilgil	4.3	10.0
18. River Karati	2.0	9.0



Map of Lake Naivasha sampling sites

Ecohydrological Implications of this Study

The levels of faecal and total coliform bacterial in Lake Naivasha are below the WHO (1985) recommended levels and so the water may be used for domestic, animal and irrigation purposes. However there is a need to closely monitor those sites with high faecal bacterial count so as to avoid outbreaks of Cholera and Salmonella, which have been reported in the past. The pattern of coliforms indicates that levels are highest where the population density and ecotone destruction are greatest. Management policy in the long term needs to address these links.

ORGANIC POLLUTANTS MONITORING OF LAKE NAIVASHA, KENYA

Authors
A.GACHANJA
E.C. MWACHIRO
C.C. KAMAU
K.S. MAKHANU
Jomo Kenyatta University of Agriculture and Technology,
Nairobi, Kenya

Working Hypothesis

Lake Naivasha is susceptible to contamination by organic pollutants, arising from the range of agro-industries on the lake shore reliant upon lake water for irrigation and passing their waste water back in the lake either directly or after groundwater seepage. The null hypothesis was that organic pollutants were not detectable in the lake water.

Methods

Eighteen sites were used for sample analysis, substantially the same sites as shown by Mwachiro. Water samples were collected in glass containers, and then stored for 24 hours at 4°C. EPA method 525 for sample analysis was used. Organic compounds were extracted from the water samples using dichloromethane (DCM) and dried with anhydrous sodium sulphate. The volume of DCM extract was then reduced to about 5 ml. The solvent was then removed using a stream of air and residue re-dissolved hexane. An aliquot of 1 µl was injected into a GC-MS and compounds identified by retention time and mass spectrometric data through on-line Library search. Separation was achieved using a DB 5 coated, 30 M x 0.25 mm capillary column under temperature programmed conditions.

Results

The study was conducted over a six-month period between June -November 1998. Sampling was done every two weeks and covered the whole lake Naivasha the adjacent Lakes - Sonachi (Crater) and Oloiden and the rivers entering into the Lake - Malewa, Gilgil and Karati. The results show the identifications of major organic compounds, above 50 ppb in the lake waters. Though the major activity within the lake is horticulture and floriculture farming, no pesticides were identified at these detection levels

Retention time (min)	Organic compounds
7.807	Tinox (somer-1/benezene) 1,3-d initro
11.98	Octadecane/naphthalene 12,3 trimethyl-4-propene
11.98	Myristic acid
12.7	Phenyltoloxamine M-$(CH_3)_2$ NoH
13.5	Deipramine-M (RINQ)
15.49	Linoleic acid
15.8	Oxyphenbutazone artifact
17.01	Diphenhydramine Isomer
24.68	Stearic acid
28.00	Propofol me/phenol 2, 2 - methylenebis 6-(1,1 dimethyl)
30.13	Disooctylphthalate
37	Cholestrol H_2O
3.6	Pirprofen artifact
20.9	Palmitic acid
40.3	Stigmastan-3-ol, 5 chloro-acetate

Ecohydrological Implications of this Study

It is interesting to note that the compounds identified are pharmaceutical and veterinary drugs, a plasticiser, organic acids from detergents and soaps, all most probably originating from domestic and municipal waste disposal. Naivaisha municipal waste is disposed of into the lake. The results provide support for the proposal to protect the lake from the point source discharges of the town (sewage treatment works and surface runoff) by the construction of an artificial wetland (see paper by Raymer).

CHANGES IN THE WATER CHEMISTRY OF NAIVASHA 1982-1999

Authors
NZULA KITAKA
Department of Zoology, Egerton University, Njoro, Kenya
DAVID HARPER
Department of Biology, University of Leicester, UK

Working Hypothesis

The water chemistry in the lake changes as a consequence of changes in the hydrology of the system – made up of fluctuating inflow volumes and increasing offtake volumes by industrial activities (see Becht). The null hypothesis is that chemistry changes occur with water volume change but that nutrient changes do not.

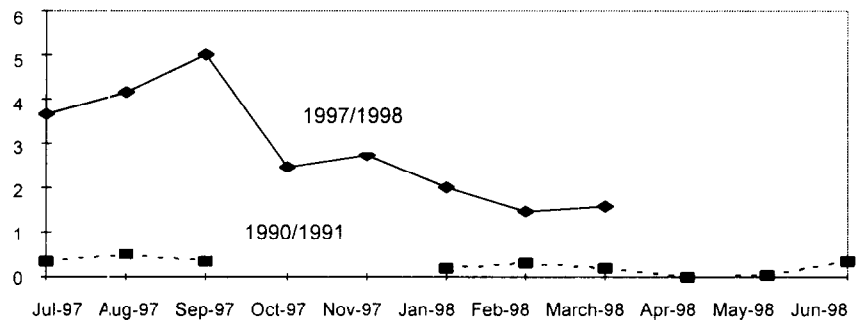
Methods

Water samples have been taken at irregular intervals since 1982 and measured for major ions and nutrients using standard methods.

Results

There are four lake basins at Naivasha; three of them more or less continuous and one is an isolated small saline crater lake, Sonachi, close to the western edge of the main Lake Naivasha. The three main basins are shallow and usually fresh (see figure). At periods of high water level the main, a large shallow depression, is connected with Crescent Island Crater and with Lake Oloidien. At moderate lake levels, Oloidien loses its surface water connection but is still connected by groundwater as its fluctuations mirror those of the main lake. Crescent Island lagoon becomes a distinct basin only at very low water levels, this century they only occurred in the 1940s. The chemistry of the water bodies reflects these spatial relationships, since only the main basin receives any surface inflows. In 1982 compared with 1996, specific conductivities ($\mu S\ cm^{-1}$) of the basins were:

Main lake	Crescent Island	Oloidien	Sonachi
260	265	375	30,000
330	400	2900	-



Throughout the 1980s the level of Naivasha declined such that its conductivity rose to 550 and in periods of fluctuating levels ranged between 200-500. Oloidien levels, although fluctuating, have continued to increase in concentration over the past decade, a consequence of its isolation since the last high water of 1980. In the past decade, the nutrient content of the water in the main lake has risen. Part of the reasons for this may be the increase in settlement and agriculture in the upper catchment and part by overgrazing in the more arid lower catchment. Lakeside horticulture, which uses large quantities of lakewater for irrigation, has also been blamed, although responsible operations ensure the lake is protected by buffer zones.

Ecohydrological Implications of this Study

Increases in phosphorus levels greater than the changes in water level would imply that the lake is becoming eutrophic. Means for counteracting this depend upon the cause, and the most likely is a damaged riparian ecotone and consequent input of all the catchment's nutrient and sediment runoff. The restoration of the ecotone up to now has depended upon the lake level – low lake level resulted in its damage/destruction by human activities as occurred in the mid-1980s, but a high lake level then restored it by flooding and germination of aquatic plants. A greater intervention may now be necessary.

PHYTOPLANKTON OF LAKE NAIVASHA – WHAT DOES IT INDICATE?

Authors
DAVID HUBBLE
DAVID HARPER
Department of Biology, University of Leicester, UK

Working Hypothesis

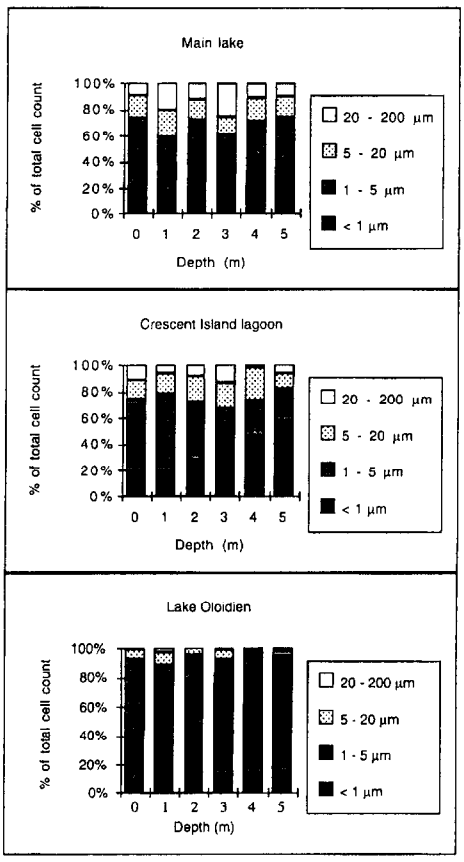
Over the past few decades, Lake Naivasha has lost its transparency at the same time that it has lost the structure of its littoral ecotone. Only a small part of the increased turbidity is due to suspended sediment, most is due to phytoplankton. The working hypothesis is that this has increased as a result of nutrient input and that the phytoplankton of the lake now indicate the trophic state that the lake is now in.

Methods

Samples collected over a year from the three main basin types using a 1.25 litre limnological sample bottle, and identification using sedimentation and an inverted microscope. Primary production was measured by the oxygen difference in light-dark bottles.

Results

The phytoplankton was dominated by *Aulacoseira*, which formed on average 50% of the population and 70% at 7 m in Crescent Island basin. Both productivity and *Aulacoseira* numbers increased with the rainy season. Size fractions in the phytoplankton community were very different, with over 80% by number below 5µ in Crescent Island basin (conductivity circa 2000 µS/cm) compared with 60% in Crescent Island basin and the Main lake Primary productivity was much higher than recorded in earlier studies, at over 400 mgC m^{-2} day^{-1}.



Ecohydrological Implications of this Study

The nutrient concentrations of lake water are often low, implying a mesotrophic state. However, this belies the tropical nature of the lake and the high daytime water temperature, which ensure a rapid cycling of nutrients into algal cells. The change in magnitude of primary productivity occurred after the early 1980s, coincident with the first complete loss of submerged macrophytes from the ecotone, although it is impossible to attribute a precise cause and effect now. In a search for indicators of the state of the lake, phytoplankton species and productivity give important information.

ZOOPLANKTON COMMUNITY STRUCTURE IN THE OPEN WATER OF NAIVASHA

Authors
KAMAU MBOGO
Kenya Marine and Fisheries Research Organisation, Naivasha, Kenya
DAVID HARPER
Department of Biology, University of Leicester, UK
KENNETH MAVUTI
Department of Zoology, University of Nairobi, Kenya

Working Hypothesis

In Lake Naivasha, characterised by poor fish stocks and diversity, no true adult zooplanktivorous fish occurs. Only three species of fish, *Oreochromis leucostictus, Tilapia zilli,* and *Micropterus salmoides*, are exploited commercially in this lake. The only predation realised on the zooplankton is by the fish juveniles of the species above where the zooplankton contribute between 60 - 65 % of their food (see Uku) with their importance as food item reducing with age of the fish. The predation pressure by the juvenile is more significant in the littoral zone and during the high lake water levels where the emergent Papyrus and floating *Eichhornia* vegetation fringing the shoreline provide breeding and nursery grounds for the fish. The working hypotheses during this study were:

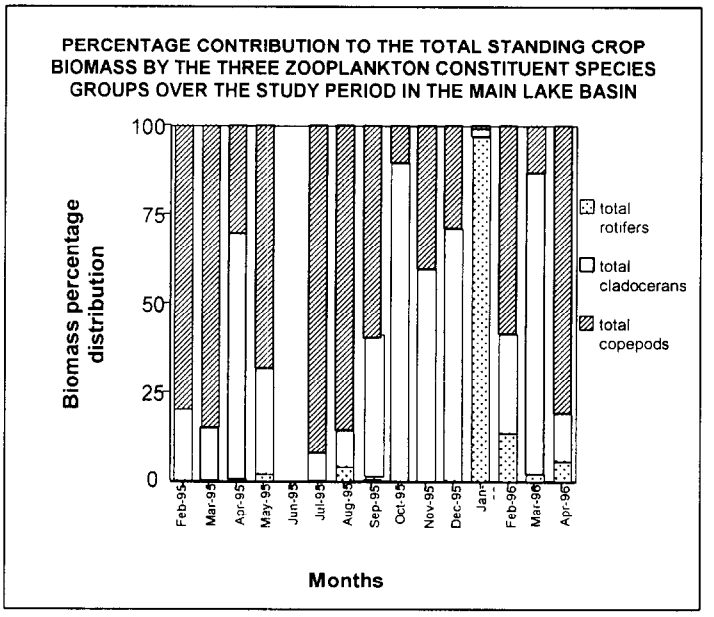
1. No predation by fish on the zooplankton occurred in Lake Naivasha.
2. In the absence of fish predation, the zooplankton community of the lake will be dominated by large body sized individuals of mainly cladoceran crustaceans.
3. Due to the high density of large sized cladoceran individuals, low phytoplankton biomass will be experienced.
4. The zooplankton community size structure of the lake will be determined by other factors and not fish predation at all.

Methods

Samples were collected over one year in the three basins of the lake using a 10 litre Patalas sampler. Replicate samples were taken at one site in the centre of each basin.

Results

In both Crecent Island Lagoon and the Main Lake basin, 30 species of zooplankton (19 species of rotifers, 3 species of copepods and 8 species of cladocerans) were recorded. Oloidien basin had lower species diversity with only 22 species (14 species of rotifer, 1 species of copepod and 7 species of cladocerans). The zooplankton biomass was greatest in Oloidien Bay, followed by the Main Lake and Crescent Island Lagoon, – 473 279 and 204 mg.dry wt m^3 respectively. Neither size structural measurements nor phytoplankton biomass gave support to the hypotheses, although the predominance of cladocerans in the main lake did.



Ecohydrological Implications of this Study

In order to maximise the sustainable uses of the lake it has been proposed that additional fish species be introduced. However, the fishery is in a poor state at present due to heavy exploitation and the near-absence of a lake edge ecotone, consequent on low water levels and human damage. The biomass and taxonomic composition of zooplankton suggest that zooplanktivorous species could be sustained, even though the evidence suggests some open water planktivory.

SPECIES COMPOSITION AND PATTERNS OF ABUNDANCE OF MACROBENTHOS IN THE PROFUNDAL ZONE OF LAKE NAIVASHA

Authors
PHILLIP RABURU, Department of Fisheries, Moi University, Eldoret, Kenya
DAVID HARPER, Department of Biology, University of Leicester, UK
KENNETH MAVUTI, Zoology Department, University of Nairobi, Nairobi, Kenya

Working Hypothesis

Studies carried out on the fisheries and fish biology within Lake Naivasha have revealed that the profudal zone of the lake was a zone not fully utilised by the existing fish species. Against this background, the fishery of the lake was declining. The study set to investigate the types and abundance of macrobenthos available within the profundal zone, which could be, exploited as source of food for benthic feeding fish species. This was done with a view to consider the possibilities of introducing a suitable fish species to exploit the resources available in this zone.

Methods

Macroinvertebrates were sampled by a 15 x 15 cm Eckman gab on four transects each with five sampling stations 500 meters apart. They were sieved through a 0.3 mm mesh size, sorted, identified, grouped into different taxa and counted. Variation in abundance among stations, transects and months was established using analysis of variance and Student Newman Keuls Multiple range test. Organic carbon content and bacterial biomass of the sediment was determined by Walkley-Black and Plate Count methods respectively. Multiple regression analysis was used to determine the relationship between macroinvertebrates and physico-chemical characteristics while biological association among species was tested using Kendall's Tau test.

Results

The profundal benthos is very poor in species diversity and is dominated by the tubificid oligochaetes *Limnodrilus hoffmeisteri Claparede, Branchiura sowerbyi Beddard, Potamothrix heuscheri Bretscher* and a naid, *Dero sp.* Others included a microtubellarian worm and chironomid larvae dominated *by Chironomus formosipennis* Kieffer. *L. hoffmeisteri* is the most numerically abundant species followed by *B. sowerbyi* with a mean annual density of 1097 individuals m-2, and 373 individuals m-2 respectively. A shift in species composition has occurred, from a naid-oligochaete domination in 1933 to a tubificid domination in 1989-1990. The common macroinvertebrates are widespread but patchily distributed throughout the lake, distribution controlled by depth-related changes in substrate type, food supply and interspecific association. Seasonality in abundance was found to be directly associated with rainfall patterns in Lake Naivasha basin.

MEAN MONTHLY DENSITIES OF MACROINVERTEBRATES

Months	L. hoffmeisteri	B.sowerbyi	Other oligochaetes	Chironomid larvae	Microtubellaria
Sep-89	1001	317	44	20	
Oct-89	1520	363	207	46	
Nov-89	876	348	746	99	
Dec-89	1146	163	803	165	
Jan-90	975	216	864	202	
Feb-90	1022	270	1710	260	
Mar-90	637	332	700	155	
Apr-90	1427	411	709	309	60
May-90	1015	493	692	387	256
Jun-90	766	443	804	289	219
Jul-90	1175	471	582	407	302
Aug-90	1601	646	939	361	463

Ecohydrological Implications of this Study

At present none of the fish species found in Lake Naivasha inhabits the profundal zone, but the area has high densities of macroinvertebrates which goes directly to the decomposer food chain. There exists a possibility of introducing a benthic feeding fish to exploit these resources, to broaden the utilisation of the lake and make the fishery more sustainable.

RECENT CHANGES IN THE MACROBENTHOS OF LAKE NAIVASHA

Authors
JO DARLINGTON
Department of Zoology, Cambridge University,
Cambridge, UK
LAURA HENDERSON
DAVID HARPER
Department of Biology, University of Leicester, UK

Working Hypothesis

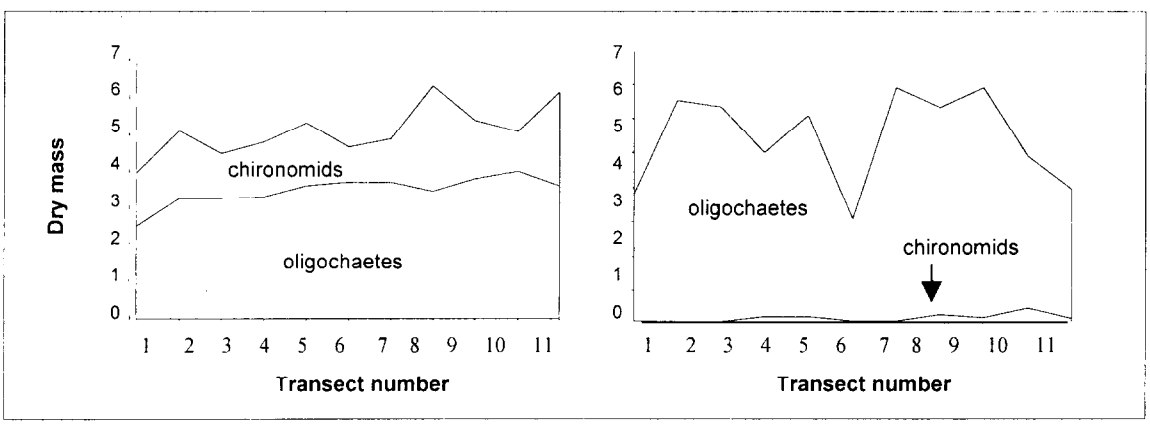
Following the recommendation that a benthic-feeding species of fish should be considered for introduction into the lake, the characteristics of the benthic invertebrates were examined with the hypothesis that the community is stable enough to support a new addition to the food web.

Methods

The bottom mud was sampled using an Ekman Grab and sieved in situ through fine (250μm) mesh cloth. Animals were counted and weighed in the laboratory. Eleven sites were sampled along a transect at the western end of the lake. At each site five grab samples were taken, spaced two m apart. The results were combined to give an estimate of the number and biomass per square metre of mud.

Results

The transect was first sampled in 1996, at a time when the lake level was low. At that time chironomid larvae dominated benthic biomass. In 1998 the samples were repeated at the same time of year, although the water was twice as deep. This time there were few chironomid larvae, but the tubificid worms had doubled in biomass . The most obvious difference between 1996 and 1998 was the increase in water depth from about three to about six metres. This is still very shallow in relation to the size of the lake, and there was no evidence of stagnation in the bottom water. So it is unlikely that depth alone would cause such a difference. A more probable explanation is that winds from the south had driven emerging adult chironomids away before they could mate and lay their eggs. If this is the true explanation, then it is very interesting that tubificid worms should have increased. It suggests that there is some antagonistic relationship between the worms and the chironomid larvae. Perhaps they compete for bacterial food, or perhaps the carnivorous larvae feed directly on the worms, as well as on their fellow larvae. An alternative possibility under investigation is predation upon the larvae by the crayfish *Procambarus clarkii*, a species already under suspicion of causing the earlier faunal changes in the lake.



Ecohydrological Implications of this Study

The sustainable management of this lake, which has an abbreviated food web as a result of its unstable Holocene hydrological regime, sets out to increase the number of exploitable species. The benthic community is clearly not stable, for reasons that are at present unclear. Further studies are necessary to find the cause of the changes in the composition of the community, and the significance of them to proposed management aims.

THE FEEDING DIFFERENCES BETWEEN LARVAL *OREOCHROMIS LEUCOSTICTUS* IN OLOIDIEN LAGOON COMPARED WITH THE MAIN LAKE NAIVASHA, AND BETWEEN LARVAE OF *O. LEUCOSTICTUS* AND *MICROPTERUS SALMOIDES*

Authors
JACKIE UKU
KENNETH MAVUTI
Zoology Department, University of Nairobi, Nairobi, Kenya

Working Hypothesis

The feeding of the larval fish species in Naivasha is barely known, and the destruction of the ecotone by the combination of crayfish grazing upon submerged plants and human damage to the fringing emergent vegetation, means that the prime larval habitat has been impaired. The null hypotheses investigated is that there was no difference between the larvae in Oloidien and the main lake, and that there are no differneces between spoecies.

Methods

The larval fish was obtained from the shallows of the lakes using a seine net. From each station a total of 35 fish were dissected and the gut contents were analysed using a compound microscope. The date based on food items in the fish gut was analysed using the numerical method, availability factor and selectivity index. The selectivity index (E) of Ivlev (1961) was used to indicate the food selectivity of the fish based on the food content in the water and the food items found in the fish guts .

Results

The fish gut contents of *Oreochromis leucosticta* and *Micropterus salmoides* confirmed that larval fish do feed on zooplankton even if the adult is herbivorous as is *Oreochromis*. The latter larvae from main Lake, which had a high animal food content in their guts (32 out of the 35 fish dissected) contrasted with those in Oloidien Bay which showed a low animal content in their guts with only (16 fish out of the 35 fish dissected. M.salmoides showed a high animals content (all but one of 35). Differences in the selectivity index are shown.

FOOD SELECTIVITY BY ORECHROMIS LEUCOSTICTUS IN OLOIDIEN; IN NAIVASHA; AND BY MICROPTERUS SALMOIDES

Orechromis leucostictus Oloidien				
Food organism	**% Fish gut**	**% in water**	**AF**	**E**
Copepoda	5.63	2.45	2.29	0.39 *
Cladocera	94.06	41.44	2.27	0.39 *
Rotifera	0.03	56.11	0.005	-0.99 #
Orechromis leucostictus Naivasha				
Food organism	**% Fish gut**	**% in water**	**AF**	**E**
Copepoda	19.72	37.78	0.52	-0.31 @
Cladocera	77.93	27.00	2.89	0.49 *
Rotifera	2.11	35.22	0.059	0.89 #
Micropterus salmoides.				
Food organism	**% Fish gut**	**% in water**	**AF**	**E**
Copepoda	88.68	37.78	2.35	0.40 *
Cladocera	11.32	27.00	0.42	-0.41 @
Rotifera	0.00	35.22	0.00	-1.00 #

AF = Availability factor
E = Electricity (selectivity) index.
@ = Moderate rejection
* = Moderately selected for
# = High rejection

Ecohydrological Implications of this Study

Studies have shown in Naivasha that the submerged macrophyte beds have a substantially higher density of Cladoceran zooplankton that open water, and this suggests the link which makes an intact ecotone such an important nursery ground for fish larvae of all species. Oloidien lacks an ecotone more because of its salinity than its human impact. The consequences for *O. leucostictus* are apparent in a population that has been observe to be highly stunted.

THE STATUS AND FUTURE OF THE LAKE NAIVASHA FISHERY, KENYA

Authors
PHIL HICKLEY
ROLAND BAILEY
DAVID HARPER
RODRICK KUNDU
MUCAI MUCHIRI
RICK NORTH
ANDY TAYLOR
University of Leicester, UK.

Working Hypotheses

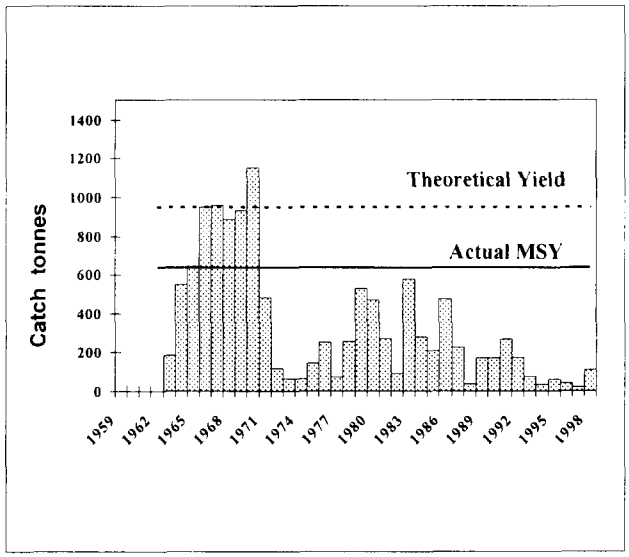
Lake Naivasha has only five fish species, all of which have been introduced. Actual fish yield does not match the theoretical yield that would be expected from a shallow tropical lake. Also, several feeding guilds of fishes are absent. It is proposed that further species introductions could enhance the species balance and productivity of the fishery.

Methods

Commercial fishing using gill nets began in 1959 and fish landings have been recorded since 1963. These catch statistics were analysed to provide information on actual yield. Various formulae incorporating either morpho-edaphic index or primary productivity data were used to calculate theoretical yields. Fine mesh survey nets were set annually to provide specimens for food web determination.

Results

Evidence suggests that the Lake Naivasha fishery is under-performing. The maximum sustainable yield (MSY) was estimated at 641 t y^{-1}. During the early years of the fishery very large catches were taken but since the peak of 1970 (1150 t y^{-1}) catches have been mostly below the MSY. The results of theoretical yield calculations suggest that 950 t y^{-1} is a possible target MSY. In comparison with other tropical lakes the fish fauna of Lake Naivasha is impoverished. Of the dominant three species *Micropterus salmoides* (largemouth bass) is a carnivore (invertebrates and crayfish), Oreochromis leucostictus is a microherbivore and Tilapia zillii is omnivorous (detritus, macrophytes and insects). Potential vacant niches thus exist of which the most convincing is that for a benthic feeding species.



Ecohydrological Implications of this Study

The principle of introducing new types of fish into Lake Naivasha should be accepted, taking into account the isolation of the basin couple with the instability of the lake hydrology, which are the reasons why there was only one native species in the lake, extinct since 1964. Full feasibility analyses should now be carried out on suitable candidate species. Any introductions that are made should be part of an overall management programme that should include fish conservation measures, improved enforcement of legislation and a raising of awareness within user groups.

SUSTAINABLE HORTICULTURE WITHIN A RAMSAR SITE?

Author
C. DONAGHUE
Lake Naivasha Growers Group,
Naivasha, Kenya

Working Hypothesis

Horticultural management issues involving shallow lake wetlands are largely centred on utilisation and protection of the water resource and the adjoining land. These issues have become even more real in Naivasha as the industry and the population have grown. To address these issues a group of farmers in the area have created a Code of Conduct. Our working hypothesis is that this Conduct will result in the implementation of responsible environmental practices and minimise impacts.

Socio-Economic Implications:

1. Generation of employment and income.
2. Increase in population.
3. Growth of satellite industry.
4. Strains on infrastructure.
5. Best management Practices.

Potential Environmental Impacts:

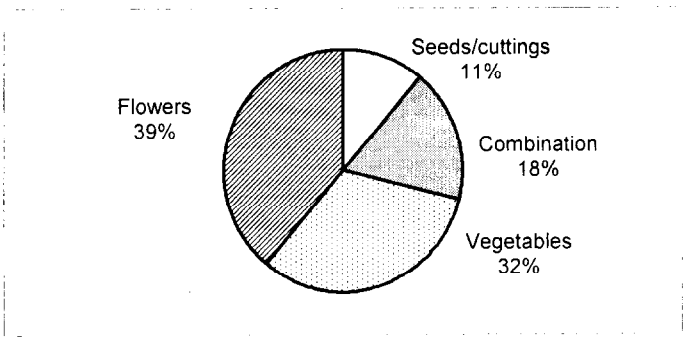
1. Excessive water use.
2. Encroachment on habitat and vegetation.
3. Threat of pollution.

Primary areas within the Code of Conduct are:

1. Maintaining appropriate documentation.
2. Integrated crop management.
3. Minimising water use.
4. Fertiliser and chemical storage, handling and use.
5. Disposal practices.
6. Workers' safety and welfare.
7. Care for riparian land.

Site visits are made to assess the level of implementation and more outreach efforts have been initiated. Developing a series of key action points to reduce potential environmental impacts are being established for each LNGG member.

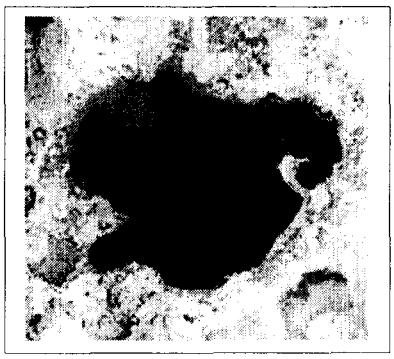
GENERAL CLASSIFICATION FOR MEMBERS OF LNGG



Ecohydrological implications of this Study

The sustainable management of the lake is a pre-requisite for a successful horticultural industry. A drying lake will have water quality which is no longer acceptable for irrigation. Consequently the overall health of the ecosystem has importance to horticultural growers and ecohydrological measures to maintain and restore that health are vitally important.

ORGANIC PEST CONTROL AND MONITORING ON HORTICULTURAL PREMISES



Authors
LILIAN W. GATUBU
Department of Horticulture
ROY MUGIRA
Department of Botany,
Egerton University,
Njoro, Kenya

Working Hypothesis

Organic methods can be used to control insect pests in horticultural crops more easily and with greater environmental sensitivity that conventional means. This has a consequential benefit for the lake system. The effectiveness of neem *(Azadiracta indica)*, hot pepper *(Capsicum annum)* and Mexican marigold *(Tagetes minuta)* in control of roses was tested.

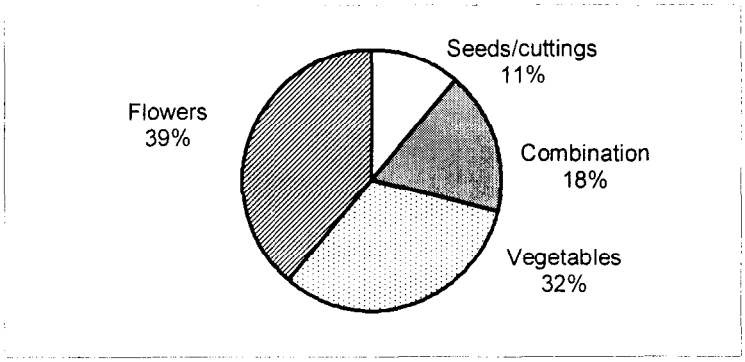
Methods

Plant extracts of *A. indica, C. annum and T. minuta* were separately prepared and a fourth extract prepared from a mixture of all three. Extracts were diluted, mixed with 10% detergent and then sprayed for eight weeks at fortnightly intervals.

Results

The percentage control of roses was 94 and 95% respectively with *C. annum* and *T. minuta* and 92% with the mixture, but only 55% with *A. indica*. The technique has the possibility of reducing environmental impact to both land and water ecosystems.

GENERAL CLASSIFICATION FOR MEMBERS OF LNGG

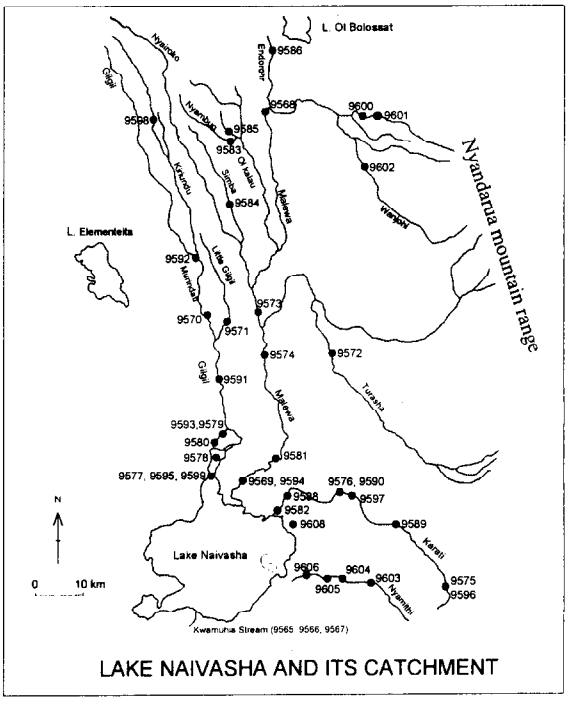


Ecohydrological Implications of this Study

Horticulure has been a major growth industry at Lake Naivasha for about 15 years. The environmental impact of chemical pest control methods requires a clearer estimation that it has had at present (see Gitahi paper). One option, on farms which are devoid of most natural features, would be to utilise the monitoring power of plant-microbial interactions. Lichens, Micorrhizae, Phylloplane epiphytic bacteria and Rhizobia have previously been used to gauge pollution. A regularly utilised method would help to protect the lake and encourage the development of ecohydrological methods for waste water treatment.

THE CONSERVATION VALUE OF LOW INTENSITY CATCHMENT LAND USE TO MAINTAIN BIODIVERSITY

Author
MUCHAI MUCHANE
Percy Fitzpatric Institute of African Ornithology,
University of Capetown,
South Africa



LAKE NAIVASHA AND ITS CATCHMENT

Working Hypothesis

The catchment of lake Naivasha to the east of the lake is the Kinangop plateau, an area high enough in altitude to support intensive subsistence, mainly rain-fed agriculture. Areas like this, once montane grasslands, originally supported the rare bird Sharpe's Longclaw, now confined to the Kinangop. Understanding the causes for the decline, and promoting the conservation of this species through habitat conservation, would have beneficial effects upon the lake through reducing erosion.

Methods

Territories were mapped and extensive censuses, using 'flush-and-count' techniques were made. Individual birds were followed to estimate home-range size and habitat preferences. Vegetation measures were made and land uses recorded in each territory.

Results

The preferred habitat for the bird is short grassland interspersed with tussocks. There is a mean density of four birds per 10 ha, and the individuals are sedentary and territorial. Land use data showed an alarming decline in preferred habitat, due to conversion of grassland to cultivation or woodlots. In addition the mean size of agricultural unit is decreasing, causing an additional increase in pressure upon land.

Ecohydrological Implications of this Study

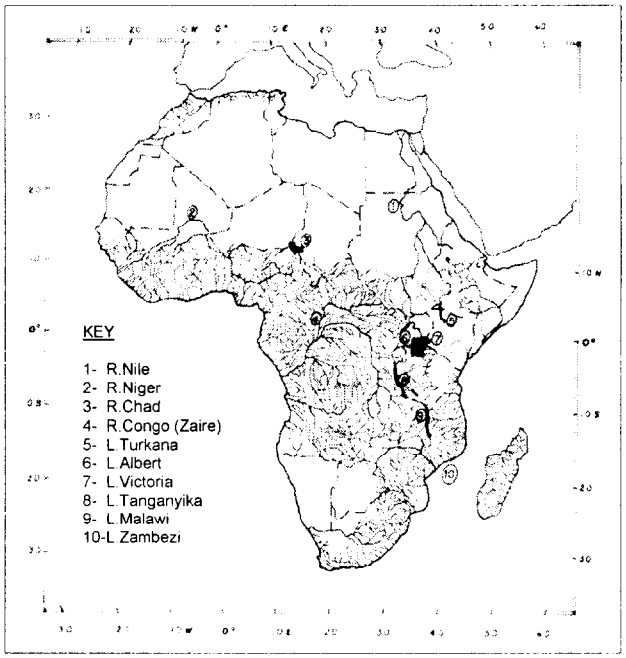
The land use changes, which are occurring in an area which consists exclusively of small private farmers, demonstrate that financial incentives are necessary to prevent conversion of grassland into arable and persuade farmers to adopt conservation-friendly approaches. Such approaches would benefit water quality because they would help protect land against erosion. The work shows there are benefits from adapting the findings of terrestrial research to guide holistic approaches to catchment management.

SECTION 2

ECOHYDROLOGY IN AFRICA

ENVIRONMENTAL CONTROLS ON THE FUNCTIONING OF SHALLOW TROPICAL LAKES

Author
JACK TALLING
Freshwater Biological Association,
Ambleside, Cumbria



Working Hypothesis

Shallowness and tropicality primarily related to physical aspects of environmental regulation. These concern water input and output, with correlates of water level and salinity; energy balance and heat distribution, with correlates of temperature and density stratification; and largely wind-driven water movements, with consequences in chemical and biological distributions.

1. Shallowness:

Shallowness in a water column affects the quantitative relationship between many stock quantities and flux-rates per unit surface area. Evaporative loss of water is one familiar example; sensitivity to surface energy exchanges provides others. Somewhat different are processes that depend upon transmission with depth. Here, light penetration, convective penetration and wind-generated turbulence/flow-depth relations are illustrative.

2. Tropicality:

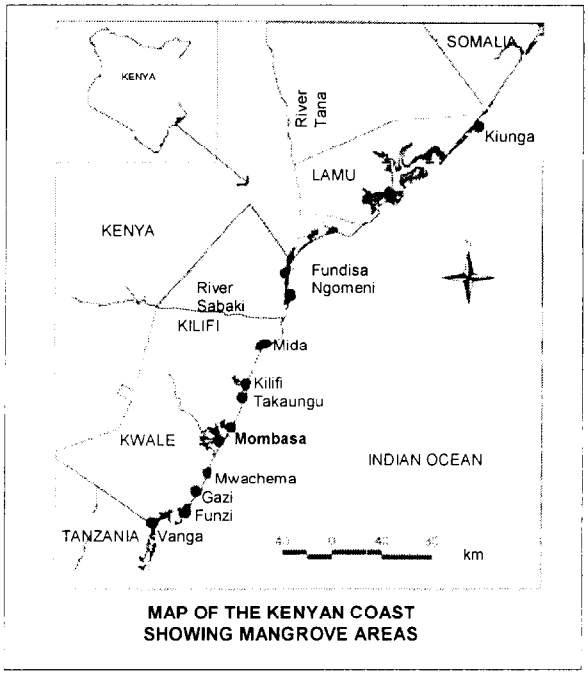
Tropicality further influences by climatic factors, especially of rainfall and radiation. Energy balance tends to yearlong elevated water temperature at all depths, but at a level dependent upon altitude. The magnitude and seasonal periodicity of water input is dependent upon the Intertropical Convergence Zone in atmospheric circulation. In the semi-arid and arid tropics the lakes may lie in closed basins and be influenced by evaporative concentration with salinization.

Ecohydrological Implications of this Study

Shallow lakes of mainly tropical Africa are used to illustrate these varied environmental constraints and some biological consequences.

MANGROVE SWAMPS IN KENYA'S DELTA'S: HUMAN PRESSURES

Author
PAMELA ABUODHA
Kenya Marine and Fisheries Research Institute,
Mombasa, Kenya



MAP OF THE KENYAN COAST SHOWING MANGROVE AREAS

Study Area

The Kenya coastline extends from 1° 40' S to 4° 41'S approximately 574 km long from Kiunga in the north to Vanga in the south. There are about 52,980 ha representing about 0.1 % of the total area of the state or 3.8 % of the total forest cover in Kenya.

Working Hypothesis

Ecologically, mangroves are producers of detritus that contribute to offshore fertility, they are nurseries to numerous fish and shellfish and a home for wildlife and birds. They control the water quality by acting as a sink trap for pollutants through filtering land run-offs and removing organic matter. Mangroves also prevent siltation of coral reefs and offer protection against coastal erosion. Economic importance of mangroves is that they provide timber for boat building and housing, firewood, charcoal and poles for fish traps. Most importantly, they provide fishing areas for local fishermen.

Methods

The state of mangrove swamps has been recorded at all locations. The causes of decline have been identified, and where possible the consequences of this decline also identified.

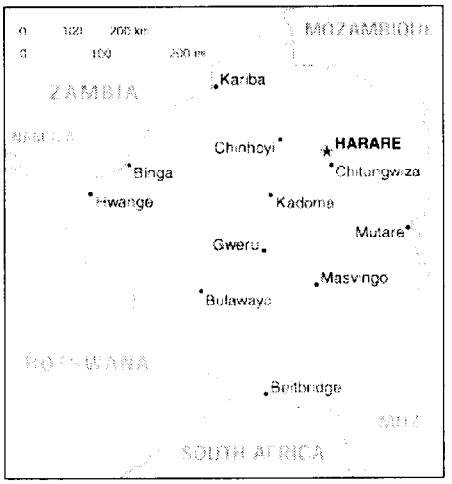
Results

Over cutting of mangroves at the south coast for poles and charcoal causes hydrodynamic changes in inshore circulation that tends to increase shoreline erosion. Continued loss of mangroves is associated with decline in fisheries. Between 1983-1993 five tanker accidents occurred in Mombasa and its surrounding waters spilling a total of 384,000 tons of oil. The oil clogged the mangrove roots leading to suffocation and thus death of mangroves and associated organisms. Mangroves take 20 years or longer to recover from oil spills. Conversion of forests to other uses such as mariculture ponds and salt production at Ngomeni, housing and a dumping site at Tudor mangrove creek has drastically reduced the mangrove areas.

Ecohydrological Implications of this Study

There should be formulation of mangrove management plan as part of integrated coastal zone management. Single use management of the mangrove system should be avoided and instead a multiple use approach encouraged. Restoration of clear felled areas should be carried out and there should be formation of a national body which will advice the forest department and other stakeholders on roles and values of mangroves.

TOXIC ALGAL OUTBREAKS IN ZIMBABWE: SYMPTOMS AND CAUSES



Authors
ANNADOTTER H.
CRONBERG G.
Institute of Ecology,
Lund University, Sweden

Study Area

Lake Chivero (17° 54´S, 30° 48' E, area 26 km2, mean depth 9m, max. depth 27 m) is a man-made lake situated 35 km south-west of Harare. Lake Chivero is the drinking water reservoir of Harare. The lake is highly eutrophic since its three feeder streams, Manyami, Mukuvisi and Marimba Rivers, are polluted by sewage from the cities of Harare and Chitungwiza.

Working Hypothesis

A malaria/influenzalike syndrome with fever, malaise, muscle pains, chest tightness and respiratory-tract symptoms was observed in Harare 1994-1998. The illness started 1.5-5 h after hot showers and bath tub baths, lasted for 24 h and was repeated after a new shower or bath. Infection was ruled out as a cause of the syndrome since the attacks were very short and could be recurrently triggered after another hot bath. The clinical picture was similar to symptoms triggered by inhalation of endotoxins from organic dusts like airborne particles of vegetable, animal or microbial origin. Endotoxin is a part of the cell wall of gram-negative bacteria and cyanobacteria. It was hypothesized that the observed syndrome in Harare was caused by inhalation of endotoxins in aerosols from hot tap water.

Methods

In October 1998, water quality studies of Lake Chivero and Harare tap water was carried out. Water for analysis of endotoxins was collected in pyrogen-free tubes and immediately frozen. Endotoxin was analysed quantitatively by the chromogenic Limulus amoebocyte lysate assay (CLAL, Chromogenix, Mölndal, Sweden). The endotoxin was analysed as European Units, eu, but the values were converted to µg by using an conversion factor of 0.1 (10 eu =1 µg). As a comparison, tap water was collected from hotel La Rochelle in the mountains outside Mutare, in Masvingo and in Bulawayo, from the Kenyan towns Naivasha and Nairobi, the city of Zanzibar, Tanzania and from the Swedish villages Staffanstorp and Vittsjö. Water for quantitative phytoplankton analysis was collected in 100 ml glass bottles and preserved with 1 ml Lugol's solution.

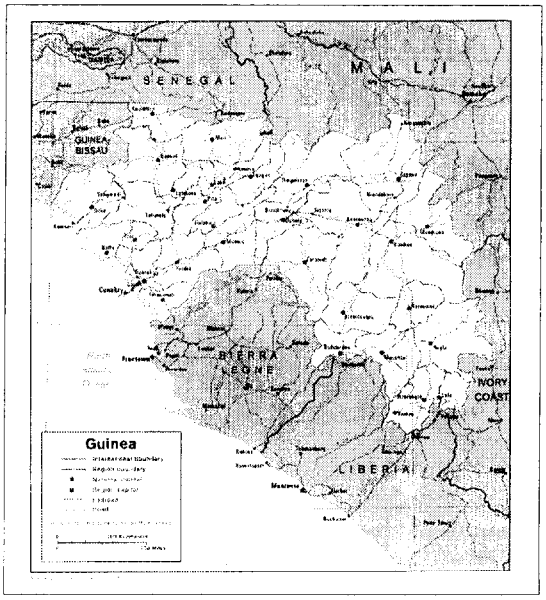
Results

The endotoxin concentrations in Lake Chivero varied between 100 and 775 µg/ml. In Harare tap water, they were between 6 and 25 µg/ml, but lower at other places in Zimbabwe - 1.3 µg/ml in both Bulawayo and Masvingo and 1.9 µg/ml at La Rochelle outside Mutare. In tap water from the Kenyan towns Naivasha and Nairobi, the concentrations were 0.024 and 0.066 µg/ml, in Zanzibar town 0.053 µg/ml. whilst the Swedish villages Staffanstorp and Vittsjö yielded 0.10 and 0.16 µg/ml respectively. The phytoplankton community of Lake Chivero was dominated by the cyanobacteria *Anabaena sp.* and *Microcystis aeruginosa*. The total biomass was 1 mg/l. In the Harare tap water, 2 millions phytoplankton cells/l constituting 0.89 mg/l, was found. The sample was dominated by isolated cyanobacterial cells (1 980 000 cells/l; 0.16 mg/l), the diatoms *Fragilaria sp.* (82 000 cells/l; 0.72 mg/l) and *Aulacoseira sp.* (2900 filaments/l; 0.016 mg/l). The Lake Chivero raw water is treated with coagulation and flocculation, sedimentation (clarification, floatation) filtration, stabilisation with 15 mg lime/l and disinfection with chlorine. This conventional treatment is evidently not efficient enough to reduce unhealthy biological toxins from the raw water.

Ecohydrological Implications of this Study

The nature of toxic algae in tropical situations is poorly known, although the causes are similar to temperate outbreaks. Future work is necessary to understand the occurrence of endotoxins and identify the optimal methods for ecohydrological control of the reservoirs.

QUANTITATIVE ECOLOGICAL ASSESSMENT OF LARVICIDES TREATMENTS IN GUINEAN RIVERS



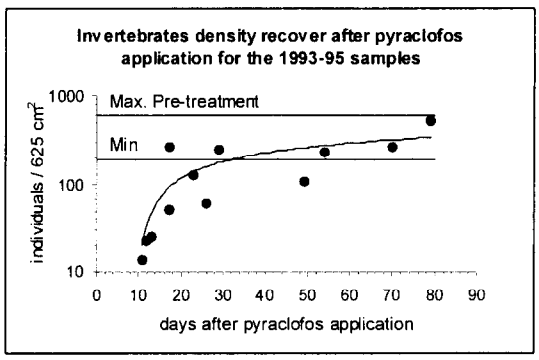
Authors
G. CROSA
Dipartimento di Scienze dell'Ambiente e del Territorio, Università degli Studi di Milano, Milano, Italy
L. YAMÉOGO+
Onchocerciasis Control Programme in West Africa, Ouagadougou, Burkina Faso
D. CALAMARI
Department of Structural and Functional Biology, University of Insubria, Varese, Italy
D. K. NABÉ
F. KONDÉ
Equipe Nationale ONCHO, B.P. 237 Kankan, Guineé

Study Area
Niandan, Milo and Dion rivers, Guinea - West Africa.

Working Hypotheses
The regular long-term application of larvicides in rivers for the control of the blackfly *Simulium damnosum*, vector of the human parasitic worm *Onchocerca volvulus*, could cause side effects on the non target aquatic organisms.
Although short term side effects on the non target fauna can be accepted as an unavoidable consequence of the adopted parasite control strategy, long term or permanent effects on the aquatic communities are not ecologically acceptable and have to be experimentally evaluated.

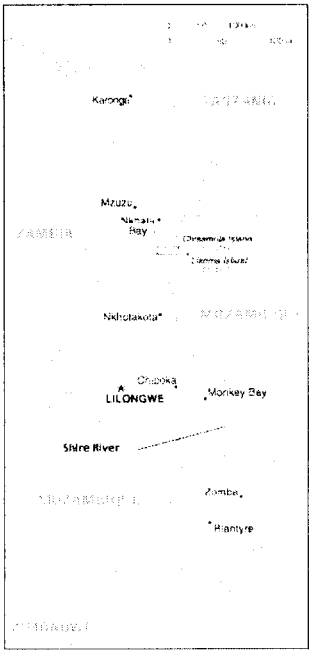
Methods
Invertebrates collected from 1984 to 1998 and classified according their taxonomic and trophic levels, are analysed. Discharge data are used to explain the seasonal and flow related biological variation. For the measure of the biological variation, Principal Component Analysis was applied to the log-transformed abundance of the invertebrates.

Results
Most of the invertebrates variations results were flow-related.
In the long term the rarefaction of some invertebrate systematic units (i.e *Tricorythidae*) did not cause a significant reduction of the total invertebrate densities because of the corresponding increase of other taxa (i.e. *Hydropsychidae*).
After one month of each larvicide application, the invertebrates showed densities close to those measured before the beginning of the treatments.
Considering that in the natural situation the studied aquatic communities would rarely be in equilibrium because of the drought and spate events, the biological variations measured are to be considered ecologically acceptable.



Ecohydrological Implications of this Study
The study emphasised the capability of the biological communities to contrast stress factors by switching their taxonomic composition in such a way that their thermodynamic dissipative function was not modified. This approach has other applications in explaining the importance of change in ecosystems as a consequence of human management actions.

BIOLOGICAL CONTROL OF WATER HYACINTH (*EICHHORNIA CRASSIPES*) IN MALAWI



Authors
R. DAY
G. HILL
G. PHIRI
CAB International Africa Regional Centre, Nairobi, Kenya
F. NJAYA
S. CHIMATIRO
P.PHIRI
Fisheries Department, Lilongwe, Malawi
M. HILL
Plant Protection Research Institue, Pretoria, South Africa

Study Area
Lower Shire River, Malawi, including Lake Malombe.

Working Hypotheses
1. Biological control can significantly reduce adverse impacts of water hyacinth in Malawi.
2. Increased community awareness and participation will assist control efforts.
3. Water hyacinth has a negative impact on biodiversity.
4. Water hyacinth has a negative impact on riparian communities.

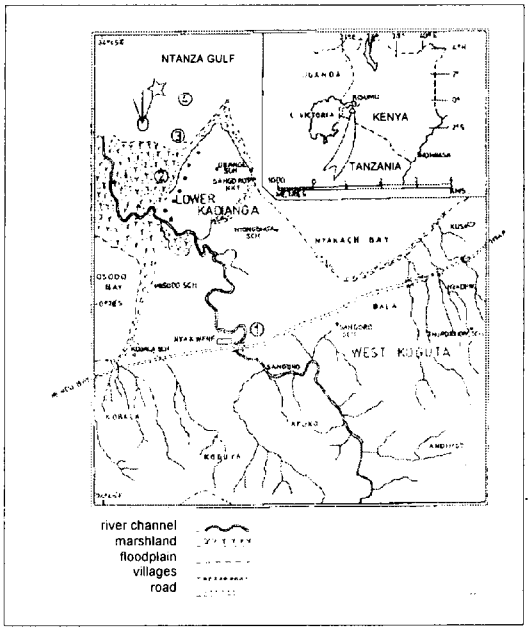
Methods
1. Four species of biocontrol agent (*Neochetina bruchi, N. eichhorniae, Eccritotarsus catarinensis, Niphograpta albiguttalis*, all insects originating in South America and previously released in one or more countries in Africa, have been imported to Malawi. There they are being reared and released in the Shire River. Post release monitoring at 10 sites in the Upper and Lower Shire assesses population density of the insects (plus naturally occurring pathogens and a mite), level of damage caused to the weed, and health of the weed.
2. A public awareness campaign (posters, press, radio jingles, open days) has been mounted; riparian communities have been exposed to the aims and methods of biological control, and are taking part in releases of biological control agents.
3. Permanent sample sites have been established to monitor biodiversity and water quality in relation to water hyacinth infestations.
4. A participatory rural appraisal was conducted in 6 villages in the Lower Shire. Tools used included resource maps, transect walk/canoe, historical and seasonal trends, problem listing and ranking, institutional analysis.

Preliminary Results, Experimental Design
Over 100,000 *Neochetina* beetles have been reared and released. They are established in all parts of the river, but populations are building up faster in the Lower Shire. Mites and indigenous pathogens are also causing significant damage to the weed.
Public awareness has been heightened, and riparian communities are expressing demand for biocontrol agents.
Oxygen levels are reduced below weed mats which will affect invertebrate and fish abundance and diversity.
Water hyacinth is precipitating a vegetation succession, facilitating colonisation by *Pycreus, Ludwigia, Vossia.*
Water hyacinth was a priority problem in all villages, exacerbating low water levels, harbouring crocodiles (so preventing women washing and collecting water), and interfering with fishing.

Ecohydrological Implications of this Study
Further releases of *Niphograpta* and *Eccritotarsus* will be conducted until establishment is confirmed; extension of biological control is planned to other parts of Malawi. Continued monitoring of the effects of biocontrol and the impact of the weed on riparian communities and indigenous biodiversity is planned. The weed usually has a negative impact upon native systems, and biological control represents the least intrusive method for its control in aquatic systems. As such it offers a more sustainable management future than chemical or physical means of control where this is desired.

THE USE OF STABLE CARBON ISOTOPES AS TRACERS OF ECOSYSTEM FUNCTIONING IN CONTRASTING WETLAND ECOSYSTEMS OF L. VICTORIA (KENYA)

Authors
J. GICHUKI
Kenya Marine and Fisheries Research Institute, Kisumu, Kenya
L. TRIEST
F. DEHAIRS
Vrije Universiteit Brussel, Brussels, Belgium

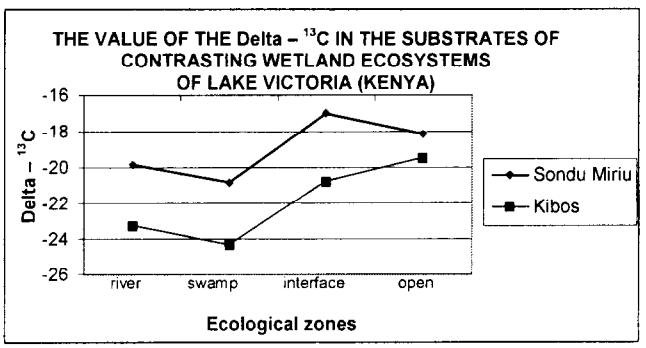


Study Area
Sondu Miriu wetland (00°18'49''S, 034°46'44''E is a large pristine wetland covering an area of 5.5 km^2. Kibos wetland (00°14'27''S, 034°46'00''E) is a small wetland influenced by discharges of municipal origin from Kisumu town.

Working Hypothesis
Marshland detritus is important in the carbon export to the nearshore ecosystems. We determined the stable isotope ratio of macrophytes, detritus and sediments in contrasting wetland ecosystems. We investigated the contribution of macrophyte detritus to the carbon export to the nearshore to the nearshore ecosystems.

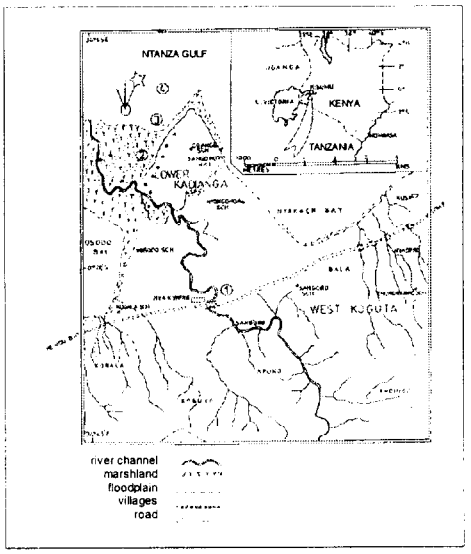
Methods
Biological material analysed consisted of leaves, stems, roots and sediments.
Finely ground samples were weighed in tin cups and combusted in Erlenmeyer (Carlo Alba NA 1500) elemental analyser. The resulting CO_2 was cryogenically trapped and analysed with a Delta E. Finnigan mat isotope mass spectrometer.

Results
Of the dominant macrophytes, *Cyperus papyrus* was more enriched and *Eichhornia crassipes* depleted. These distinct signals allow in this ecosystem the use of stable carbon isotopes in tracking carbon flow from the macrophytes to nearshore ecosystems.
In the sediments, there was a higher depletion in Kibos compared to Sondu Miriu inferring the influence of terrestrial derived carbon.



Ecohydrological Implications of this Study
The technique applies a new method for identifying carbon flow in aquatic ecosystems in the tropics, which will assist with their understanding and sustainable management. An important component of an ecohydrological understanding of systems is the role of decomposition and the source and fate of detritus carbon.

UTILISATION AND MANAGEMENT OF MACROPHYTES OF THE LOWER SONDU MIRIU (L. VICTORIA) KENYA



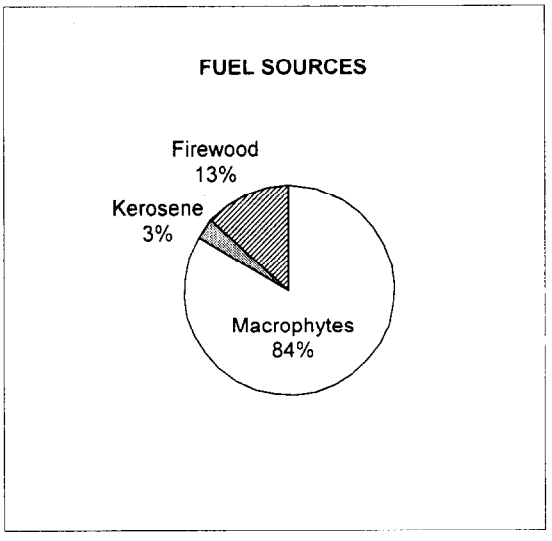
Authors
J. GICHUKI
J. MUGO
C.O RABUOR
Kenya Marine and Fisheries Research Institute,
Kisumu, Kenya
F. DAHDOUH GUEBAS
L. TRIEST
F. DEHAIRS
Vrije Universiteit Brussel, Brussels,
Belgium

Study Area
Sondu Miriu wetland (00°18'49S034°46'44''E is a large pristine wetland covering an area of 5.5 km^2.

Working Hypothesis
We made an inventory of the keystone macrophyte species and evaluated the socio-economic benefits of the wetland to the adjacent rural poor where poverty is endemic.

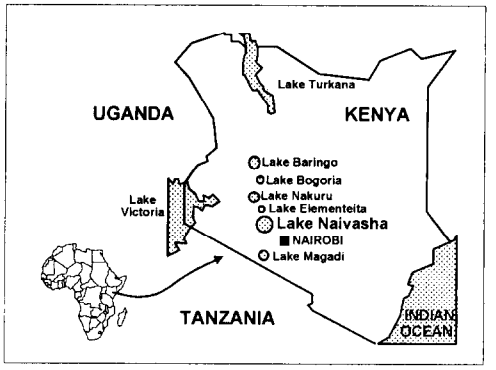
Methods
Distribution of macrophyte taxa was examined by making careful collections of plant parts with diagnostic features such as fruits, flowers and rhizomes. Identification was by the use of standard keys. A questionnaire based on a key-informant system was developed to evaluate the socio-economic benefits of the wetland to the adjacent rural poor where poverty is endemic.

Results
35 species of aquatic macrophytes were identified. The dominant macrophytes were *Cyperus papyrus*, *Eichhornia crassipes, Vossia cuspidata* and *Phragmites australis* in a descending order of dominance.
We observed dependence on macrophytes for supply of food, medicinal plants, building material and cooking fuel. Other uses consisted of provision of green pasture for domestic and wild animals during the dry season. The bulk of the fish caught consisted of indigenous fish species of Lake Victoria.
Thus the lower Sondu Miriu forms an integral and essential life-support system both economically and ecologically.
We recommend traditional utilization compared to commercial level and industry based on macrophytes since subsistence utilization is compatible with sustainable utilization



Ecohydrological Implications of this Study
It is clear that in future, ecohydrology will be integrated with the socio-economic implications of water management. Fundamental to ecohydrology is the concept of low-cost, high-technology applications, and it this study shows that the use of aquatic plants for subsistence farming represents that.

LESSER FLAMINGOES AND THEIR CONSERVATION IN THE ALKALINE LAKES OF KENYA



Authors
J.M. GITHAIGA
K.M. MAVUTI
University of Nairobi, Department of Zoology,
P.O. Box 30197, Nairobi, Kenya

Study Area
Kenya, Lake Nakuru, alkaline 43 km^2, Elmenteita, alkaline, 22 km^2, Bogoria, alkaline, 33 km^2, all shallow.

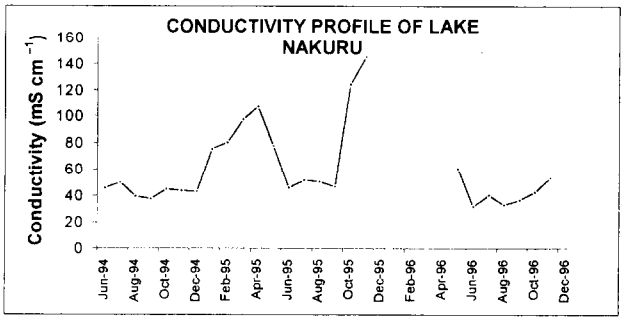
Working Hypotheses
The ecology of lesser flamingos in the alkaline lakes is a function of seasonal and spatial salinity environmental gradients in the alkaline lakes that determine the structure and species composition of their phytoplankton communities. Climatic variables and geological features determine the hydrology and limnology of these lakes, and through their effects on phytoplankton species composition and water chemistry precipitate the spontaneous nomadic movements that a characteristic feature flamingo ecology in these lakes.

Methods
Lesser flamingo numbers were determined in the study lakes from April 1994 to November 1998. Variables such as rainfall, lake levels and river flow regimes were recorded during the same period. Conductivity, pH, temperatures, dissolved Oxygen were measured in situ and nutrient concentrations determined from water samples. Samples were collected for phytoplankton densities and species composition.

Results
Hydrology plays a crucial role in water chemistry governing phytoplankton species assemblages and succession patterns. These subsequently influence flamingo utilization patterns of the alkaline lakes. Periods of low lake levels and high temperatures are characterized by the disappearance of *Spirulina platensis* in the shallower lakes of Nakuru and Elmenteita and its replacement by *Microcystis* and *Anabaena* spp. When lake levels are below 1 meter. In Bogoria, a relatively deeper lake, the ascendancy of *Microcystis* into co-dominance with *S. platensis* occurs during periods of high water temperatures and evaporative concentration. In these periods, there is shift to diatom feeding by flamingos in the shallower lakes and avoidance of areas where *Microcystis* and *Anabaena* spp. predominate in all the lakes.

Fresh water inflows into the lakes from rivers and springs were found affect flamingo residence in the lakes and their distribution within the lakes. In the shallower lakes of Nakuru and Elmenteita, mass desertions were associated with dry-out periods and concentration around springs as desiccation proceeded. In Lake Bogoria, heavy concentrations were observed around the perennial hot springs and a major shift in the population to river mouths when flow resumed.

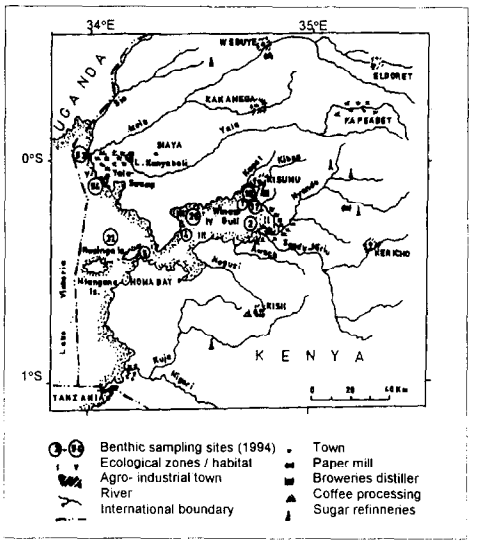
Flamingo populations in Lake Nakuru and Elmenteita have a strong positive correlation (R^2 = 0.716, $p<0.05$, n = 27) implying that the two lakes are essentially part of a single ecosystem. A negative correlation was found between flamingo populations in Lake Nakuru and Bogoria. Periods of low numbers in Lake Nakuru coincide with high numbers in Lake Bogoria, indicating the latter's importance as a refuge and feeding ground.



Ecohydrological Implications of this Study
The alkaline lakes are simple and easily impacted ecosystems that are of great economic importance through tourism and scientific value.. The result demonstrates a case for conservation of the two lakes of Nakuru and Elmenteita as a single habitat, and emphasizes the need for more conservation inputs into Lake Bogoria. The simple food web system of these lakes is dependent on catchment integrity and malfunctioning can serve as important indicators of ecological disruptions in their catchment areas and climate change affecting hydrological processes.

MACROINVERTEBRATES ASSOCIATED WITH WATER HYACINTH *EICHHORNIA CRASSIPES* IN LAKE VICTORIA, KENYAN WATERS.

Authors
J. MULI
Kenya Marine & Fisheries Research Institute, Kisumu. Kenya
K. M. MAVUTI
Department of Zoology, University of Nairobi, Nairobi. Kenya.
M. NTIBA.
Lake Victoria Fisheries Organization, Jinja, Uganda.

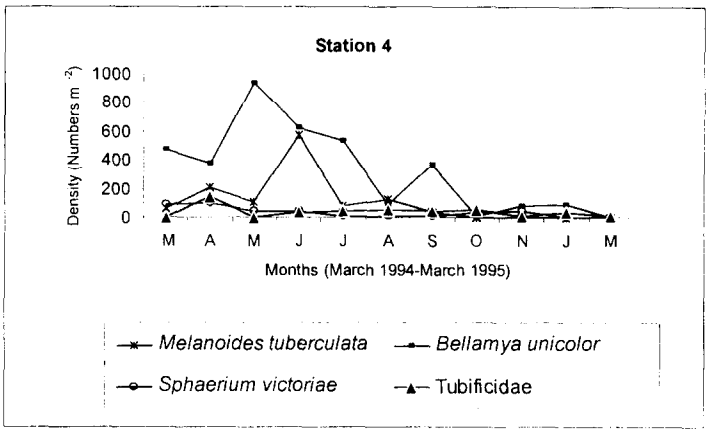


Study Area
Kenyan waters of Lake Victoria.

Working Hypothesis
Water hyacinth is now a widespread nuisance in Lake Victoria. This study started with the hypothesis that it fulfilled an ecological role. The hypothesis was that macroinvertebrate species and species diversity associated with water hyacinth was high, and that it provided a habitat for vectors of human and /or livestock.

Methods
Macroinvertebrates were sampled using a handnet of mesh size 300μm from five ecological habitat/zones in Kenyan waters of Lake Victoria. The survey was carried out from January to December 1998.
Water parameters O_2, temperature, pH, Conductivity, turbidity and transparency were measured in situ using appropriate meters and Secchi disk respectively.

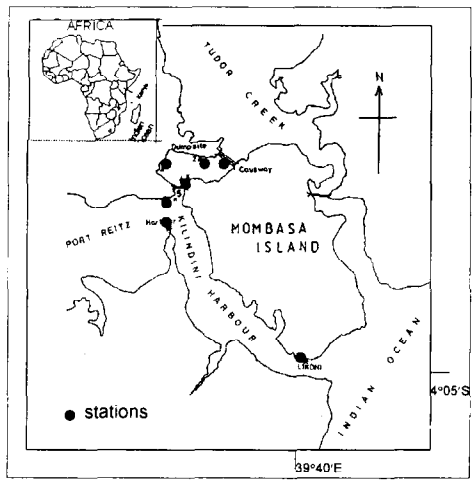
Results
Overall 96 taxa were collected during the sampling. Insecta was the most abundant group composing 83% of the mean total abundance. Most macroinvertebrates on water hyacinth form food items of most fish species in the lake. Thus hyacinth contributes indirectly to fish production.
Six molluscs that are vectors of vectors of various flukes causing Schistosomiasis (bilharzia) and related diseases in man and his domestic stock were collected. These are *Lentorbis junodi, Bulinus forskalii, Bulinus truncatus, Biomphalaria sudanica , Lymnaea collumella* and *L. trunculata.* Other vectors of human diseases which were found on water hyacinth were larvae of mosquitoes of the genera *Anopheles spp, Aedes spp* and *Culex spp.*
Abundance of this vectors was very low suggesting that infestation of hyacinth in the lake may have not substantially increased the occurrence of water-borne diseases in the lake basin.
There was significant difference in all the water parameters measured between various habitats ($P<0.05$). The effect of large and dense hyacinth mat on water quality is deoxygenation to almost zero and increase in ionic content twofold.



Ecohydrological Implications of this Study
Many tropical lakes are seriously degraded by the ecological effects of alien, exotic species. Lake Victoria is no exception. The size of the lake means that control is very expensive or impossible and so a realistic approach should ascertain the uses of the plan – both ecological and social – before any action is taken.

HEAVY METAL DISTRIBUTION IN AN INDUSTRIAL ESTUARY

Author
JOSEPH N. KAMAU
Kenya Marine and Fisheries Research Institute,
Mombasa, Kenya



Study Area

Makupa Creek (39^0 38'E, 4^0 02' S) is located in Mombasa District, Kenya. The total creek area is about 1.1 Km ^{2}. Most parts of the creek are shallow with depths often less than 3.0m. The deepest zone is the frontwater section where depths on the spring tide reach 13m.

The country's main harbour is located at the Killindini creek, which borders the Makupa creek connecting it to the ocean. In this study, seven stations were identified.

Working Hypothesis

Heavy metals distribution along Makupa and Killindini Creek sediments will reflect the industrial activity at the port, and be higher than a natural estuarine situation.

Methods

Sediments were collected using a gravity corer with P.V.C core-liner, 4 cm of the surficial sediment was extracted from the P.V.C core-liner. Instrumental analysis was by atomic absorption spectrometry (varian spectra AA10)

Results

The ratios of trace metal levels at the inner sections relative to the outer were Cd 7:1, Cu 13:1, Fe 5: 1, and Zn 21:1. Iron behaved differently from the others, significantly higher at the Killindini Habour ($P<0,05$) There was a decline in concentrations of, copper and zinc from the inner stations to the frontwater zone at Makupa creek. Spatial variations of cadmium were not significant $P>0,05$ (95%), between inner and frontwater zones of the Makupa creek, and also between Makupa and the Harbour. There was however a significant difference $P<0,05$ (at 95% confidence level) between Likoni and Makupa.

CD, CU, FE AND ZN DISTRIBUTION IN SEDIMENTS AT MAKUPA AND KILINDINI CREEKS

	Cd	Cu	Fe	Zn
Makupa. 1	11.8	114	22680	1429
Makupa. 2	13	68.5	26577	353
Makupa. 3	11.7	55.7	25342	223
Makupa. 4	10.4	70.5	27719	329
Makupa. 5	10.4	57.3	25205	166
Harbour	3,5	20,5	28657	69,25
Likoni	1,75	5,5	5484	23,3

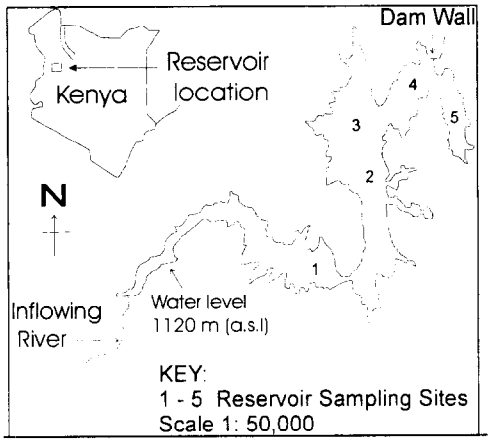
Ecohydrological Implications of this Study

Lack of proper flushing and high energy events have caused Makupa Creek to act as a sink. There is better flushing at the front waters as opposed to the backwaters. Kibarani dumpsite is the main trace metal source at Makupa Creek. Chipping on the ships while docking is significant as indicated by the high Iron levels at the Kilindini harbour. The results indicate that, in estuarine creeks, the hydrological flushing is an important contribution to local pollution. However, this moves the problem into the marine environment, and the only sustainable solution is

EFFECTS OF INFLOW VARIATION ON PHYTOPLANKTON OF TURKWEL GORGE RESERVOIR, KENYA

Author

KIPLAGAT KOTUT
Botany Department, Kenyatta University,
Box 43844 Nairobi Kenya



TURKWEL GORGE RESERVOIR

Study Area

Turkwel Gorge Reservoir and its principal tributary (River Suam), NW Kenya.

Working Hypothesis

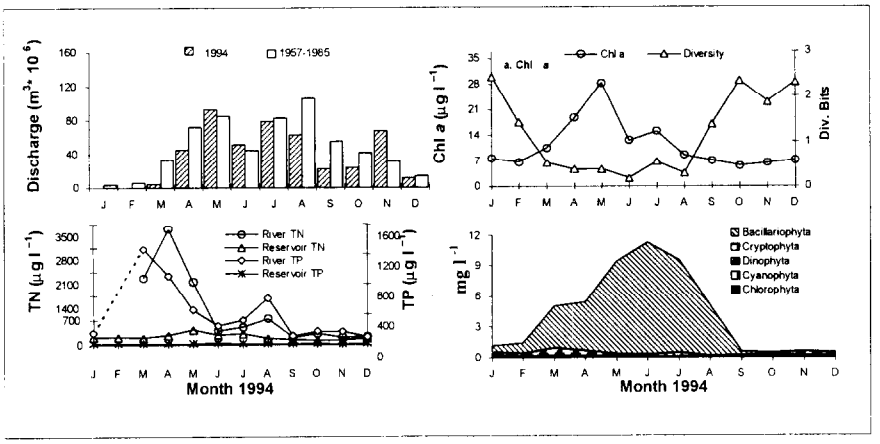
To assess the influence of discharge variation on the physicochemical conditions of inflows into the reservoir.
To establish the extent to which variation in inflow volume and quality influences the phytoplankton and physicochemical structure of the reservoir.

Methods

Monthly sampling at 5 reservoir and 1 inflowing river stations for selected hydrological and physicochemical conditions. Monthly sampling at the reservoir for phytoplankton properties, viz.; composition, diversity, biomass (as chlorophyll a and as fresh weight) and primary production.

Results

Two seasons were recognized at the reservoir, low inflow (dry) season and high inflow (wet) season. During the low inflow season, high levels of electrical conductivity (EC), total alkalinity (TA) and low levels of dissolved oxygen (DO), pH, total phosphorus (TP), total nitrogen (TN) were noted at the inflowing river and the reservoir. The converse was the case during the high inflow season with the highest nutrient levels and loads in the inflowing river being measured at the resumption of river flow.
Phytoplankton biomass and primary production showed a wet season increase. In the case of biomass, the increase was mostly due to biomass increase of Achnanthes catenata, the dominant diatom during the wet season. Phytoplankton diversity declined during the wet season.



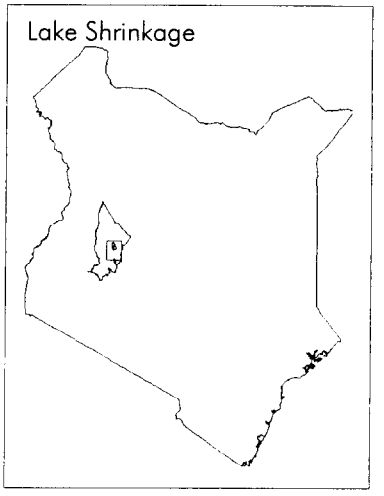
Inflow volume (total monthly for 1994 and mean monthly for 1957-1985) and seasonal changes in TN and TP of river inflow and the reservoir.
The doted line represents the period with no inflow.

Seasonal changes in selected phytoplankton properties at the reservoir

Ecohydrological Implications of this Study

Inflow hydrological pattern exerts a dominant control on reservoir physicochemical and phytoplankton structure.

STRUCTURAL AND FUNCTIONAL LANDSCAPE CHANGES OF LAKE BARINGO



Author
BENJAMIN NJORE MWASI
School of Environmental Studies,
Moi University,
Nakuru, Kenya

Study Area
Lake Baringo, Rift Valley, Kenya.

Working Hypotheses

The observed shrinkage of Lake Baringo is related to structural landscape changes in the area surrounding it and these structural landscape changes are directly related to socio-economic trends of the area. These changes have affected the landscape's ability to perform its ecological and socio-economic function.

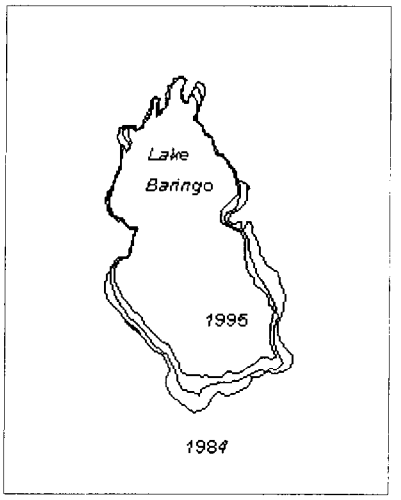
Material and Methods

Three Landsat-TM images acquired in August 1984, March 1989 and January 1995 were processed and classified using IDRISI™ image processing software to determine the lake shrinkage patterns and structural landscape changes. The processed images were compared to population trends, agricultural statistics, road infrastructure development and human settlement patterns using ARC/INFO™ GIS software to determine relationship between the lake shrinkage patterns, structural landscape changes and the distribution of these changes in relation to the selected socio-economic trends.

Results

Results from the satellite imagery show that the Lake size has decreased in area from approximately 145.68 km^2 in 1984 to 119.45 km^2 in 1995. The shrinkage is greatest in the southern half of the Lake and minimal from the northern half.

A structural landscape analysis of the area surrounding the Lake reveals that changes in vegetation conditions and spectral texture are greater towards the southern and the south-eastern shores of the Lake than in the northern side, an indication of more human presence. Analysis of population data confirms that changes in human settlement patterns have been faster and more intensive in the southern than in the northern shores of lake. This is further confirmed by a comparison of sediment levels from different points within the lake from the three imaging times. It was found that sediment content decrease as you move northwards. Settlement centres within 5 km from paved roads exhibit more signs of change than those that are further.

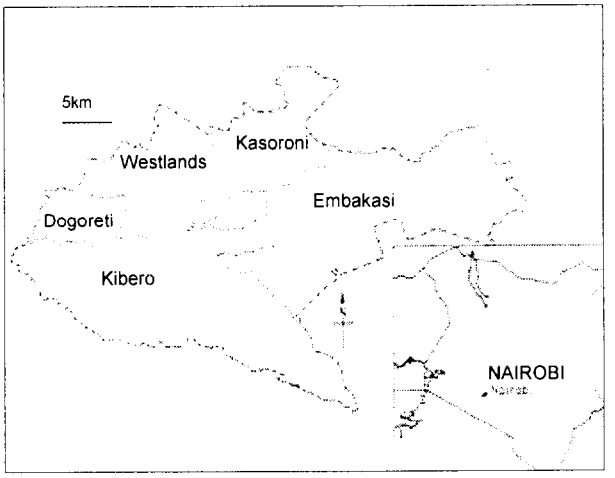


Ecohydrological Implications of this Study

In order to protect the lake in the long term and makeits utilisation sustainable, local action needs to be successfully imploemented. The pace of land registration should be increased and all land on steep slopes gazetted. Soil erosion should be reduced by creating biological barriers through fencing out plots for vegetation to regenerate on the steep slopes, the Baringo Fuel and Fodder Project (BFFP) regeneration plots have proved effective. More efficient irrigation systems are needed to reduce water losses through evaporation, this will allow more water to get to the Lake.

A CONSTRUCTED WETLAND TREATING WASTE WATER IN THE TROPICS

Authors
DEE RAYMER
Machakos, Kenya
KHISA KELVIN
School of Environmental Studies,
Moi University, Eldoret, Kenya
JANE NYAKANGÍO
IHE, Delft, The Netherlands
WILLIAM WOOD
Kingston University,
Kingston, Surrey, UK



Study Area

A constructed wetland of 4500 m^2, on the outskirts of Nairobi, Kenya, altitude 1785m, with temperature range 15.5-26.5 °C and mean annual rainfall 1080 mm.

Working Hypothesis

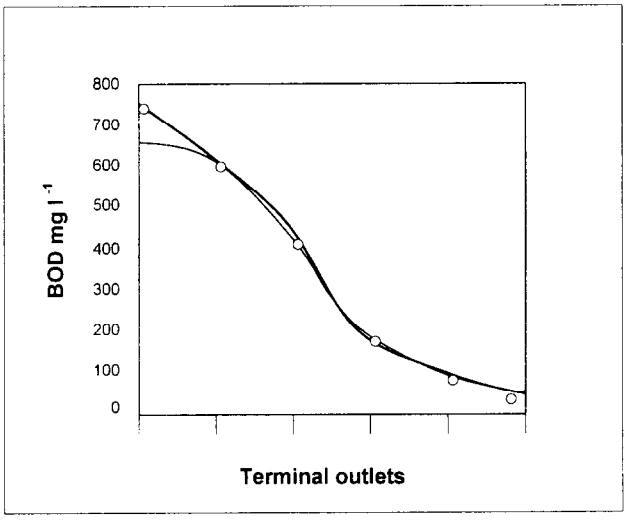
In the developing world many areas have no mains sewage connections. Effluent disposal is often haphazard, leading to pollution and an increase in faecal diseases. Freshwater supplies are oftern oversubscribed. It is hypothesised that constructed wetlands may provide an answer to inadequate waste treatment, breaking the cycle of contamination of drinking water supplies in addition to increasing biodiversity.

Methods

A constructed wetland was designed in 1994 at a major restaurant on the outskirts of Nairobi to handle 80 m^3 day^{-1}.

Results

Three years results show significant purification. Initial dry season reductions achieved were TSS 84%, TDS 11%, BOD 45%, COD 21%, orthophosphate 41% and *E. coli* 99.9%. Third year studies showed treatment efficiencies of BOD 98%, SS 85%, COD 96%, Faecal coliforms 99%, Total N 90%, Ammonia N 92% and phosphate 88%. The aesthetics and the biodiversity of the systems showed positive results (130 bird species). Problems caused by clogging of substrate within the initial gravel bed treatment by non-biodegradables occurred and have been rectified.

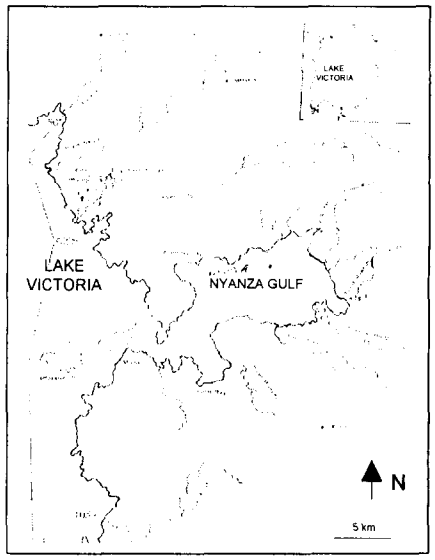


Ecohydrological Implications of this Study

There are now 5 constructed wetlands in Kenya, and they play an important role in environmental education of schools and colleges, as well as in cost-effective wastewater treatment. They have enormous potential in promoting the low-cost, efficient technology of waste water treatment in tropical environments.

THE EFFECTS OF ENVIRONMENTAL PERTURBATIONS ON THE COMPOSITION, ABUNDANCE, DISTRIBUTION AND SPECIES DIVERSITY OF PHYTOPLANKTON IN LAKE VICTORIA BASIN

Author
LEWIS SITOKI
Kenya Marine and Fisheries Research Institute,
Kisumu, Kenya



Study Area
Satellite lakes and dams in the Lake Victoria basin, Western Kenya.

Working Hypotheses

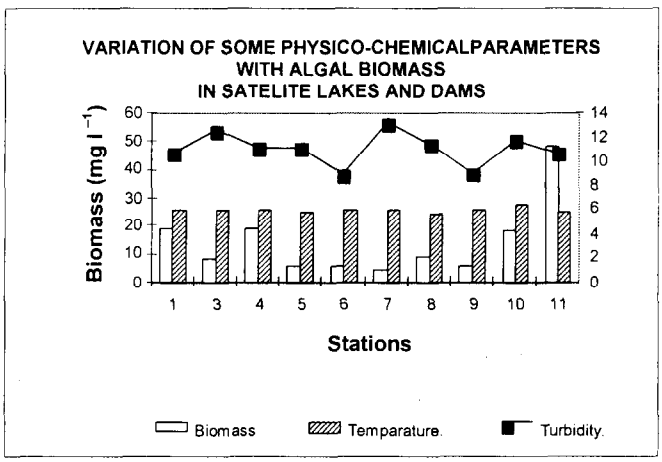
1. Phytoplankton composition abundance, distribution and species diversity are affected by pollution, hydrological patterns, anthropogenic activities and geomorphology of the area.
2. Phytoplankton species or species groups can be used to characterize ecological zones as pointers to the status of the water quality and the process of self-purification in the water bodies.

Methods

Long term monitoring of the satellite lakes and dams in the basin to provide data on the status of aquatic systems on a regular basis to be used in improving our predictive potential. Standard sampling methods for phytoplankton analysis, physico parameters (oxygen concentration, secchi depth, turbidity, conductivity, pH and temperature. Hydrochemical parameters ($P\text{-}PO_4$, SiO_2,NO_2 / NO_3) data collected alongside the biological samples.

Results

1. Phytoplankton species diversity is significantly higher during the dry season than in the wet season.
2. Particular algal species dominate stations with high concentrations of nutrients.and turbidity.
3. There is no significant difference in the vertical distribution of algal species.
4. Algal biomass increases with intensification of agricultural activities within the catchment and effluents from the surrounding areas.

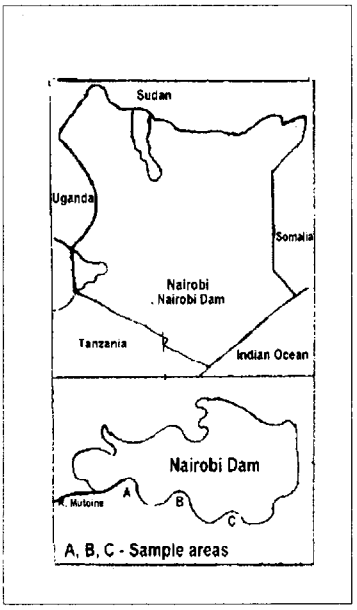


Ecohydrological Implications of this Study

Management of satellite lakes and dams requires a multidisciplinary approach in order to achieve sustainable resource utilization. A fast and efficient way of assessing and understanding of our environment is necessary. Studies on water quality and its biological characteristics is vital in enhancing quality water availability besides developing foresight as a useful management tool.

HUMAN IMPACT ON A TROPICAL MAN-MADE WETLAND: NAIROBI DAM

Author
ALICE MACHARIA
Department of Geography,
University of Nairobi, Nairobi, Kenya



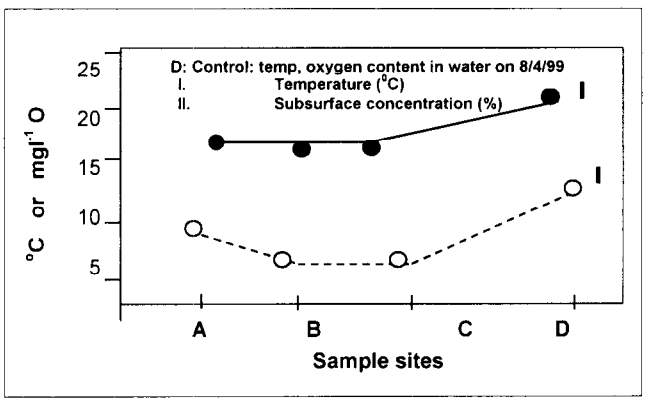
Study Area
Nairobi Dam, southern edge of Nairobi: $1^0$19' South and $36^0$48'E, average altitude 1,500m average annual rainfall 900mm. It is about 1.3km long and has an area of 26ha. Mean temperature is about 20^0C.

Working Hypotheses
The dam is highly polluted and infested with *Eichhornia crassipes* which blocks 100% of the surface. The study was to assess the origin and effects of organic pollutants in the Nairobi dam, and establish the main human activity on and around the dam.

Methods
Field visits to the adjacent human settlement and exploring the methods in which they dispose their waste. Field observations and literature survey to compare the status of Nairobi dam with that 3 years ago. Measurement of physical factors (temp, pH, conductivity, dissolved oxygen TDS).

Results
The main human activity in the area is settlement of the Nairobi people down to the edge of the dam. Waste disposal in the overpopulated Kibera slums (northern side) and Nyayo Highrise estate (south east) occurs as:

1. Overflowing pit latrines – connect the Mutoine river which is an in let to the dam.
2. Random dumping into the inflowing river.
3. Dumping by Nyayo Highrise residents directly into the Nairobi dam.



The water surface area had diminished due to siltation and human settlement from 28ha to 26ha. The invasion by the water hyacinth *Eichhornia crasipes* had covered the dam since 1997. Fishing has been hampered greatly by water hyacinth. Recreational facilities such as the sailing club were no longer in operation.

Ecohydrological Implications of this Study
The major human activity around the Nairobi dam is human settlement. Kibera, an unofficial slum, covers an area of 110ha and has 15,000 structures with a population of greater than 700,000 people. Its increase is estimated to be 7% p.a. Dumping takes place into the dam due to lack of adequate facilities in the area.. The management should have three strands:

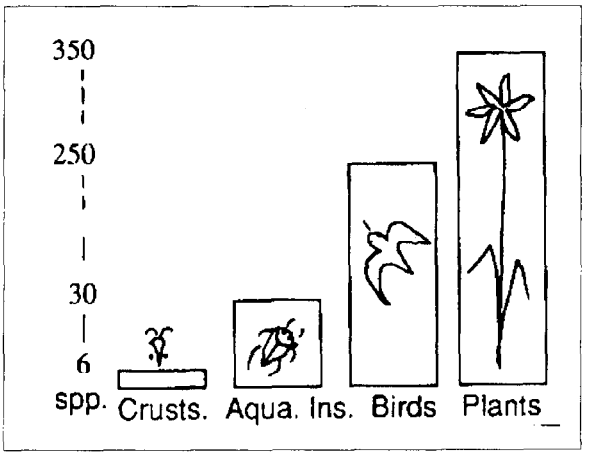
1. Urgent ways to eradicate water hyacinth in the Nairobi dam - surface water harvesting is feasible.
2. Treatment of pollution - the inflow is an ideal site for an artificial wetland waste treatment construction. The shoreline is ideal for the re-creation of an ecotone.
3. Creation of awareness of the potential of the Nairobi dam and the consequences arising from sewage.

The most urgent is the supply of drinking water to prevent the use of the reservoir as an unofficial collection area. The location of the dam close to the city centre makes it possible to use the location as a demonstration area for the low-cost, high-technology benefits of ecohydrology.

SEASONAL WETLANDS: BIODIVERSITY-RICH, BUT INVISIBLE TO MOST PEOPLE

Author
FLEUR NG'WENO
Nature Kenya,
Nairobi, Kenya

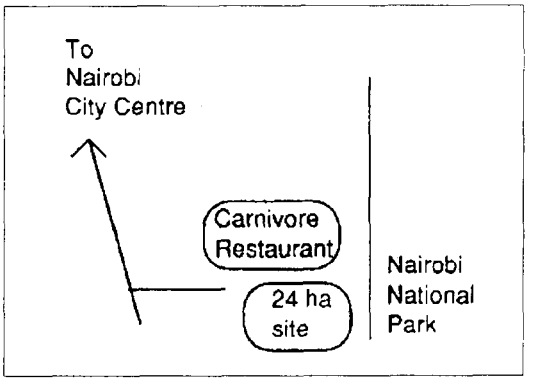
Study Area
Nairobi, Kenya.



Working Hypothesis
A flooded rock slab is an ephemeral wetland; but to a surveyor, a road engineer or a contractor, it is a rocky hillside. It will appear as a rocky hillside in aerial photos, which are usually taken in the dry season. It is rain that turns a rock outcrop into a flower-filled wetland, sheltering plants found in no other habitat, including *Drimia calcarata*, *Euphorbia brevitorta* and *Murdannia clarkeanna*. The project set out to quantify this value.

Methods
Seasonal wetlands, including rock slabs, riverine marsh, flooded grasslands and seasonal pools, springs, streams and seeps were surveyed on 24 ha south of Nairobi. Plants, birds and invertebrates were identified and changes recorded over a 10-year period.

Results
In total 350 species of plants, 250 species of birds, 30 genera of aquatic insects and 6 orders of crustacea were identified. Eight reptiles and 5 amphibians were noted. One Anostracan was new to Nairobi region and 4 plants were rare/local.

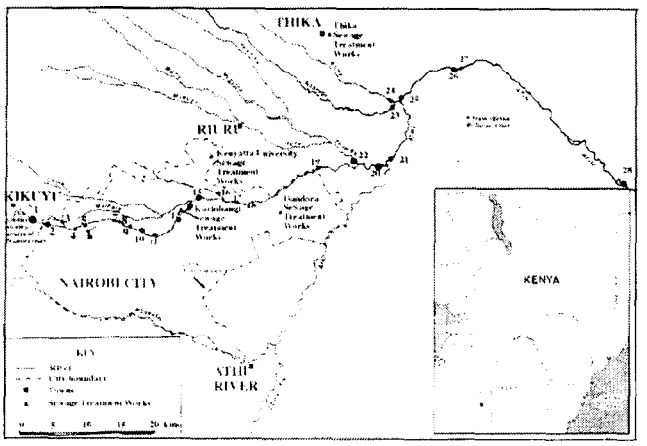


Ecohydrological Implications of this Study
This diversity is unseen in the dry season. Plants survive by being therophtes or cryptophytes and hemicryptophytes. Insects survive as dispersed adults, crustaceans as resting eggs and amphibians burrowed. The land is dry rocky and apparently suitable for development. During the 'El Niño' rains in Kenya in 1997-8 structures built on seasonal wetlands suffered extensive damage.
In Africa, seasonal wetlands cover a greater area than permanent wetlands. They are creations of drought and flood, some appearing after as long as 30 years. Scientists and decision makers need to take note of seasonal wetlands, that they may continue to serve their functions, among them, regulating the flow of water, harbouring unique biodiversity, and giving us joy.
In the tropics, seasonal wetlands represent an extension of the 'floodplain' that ecohydrologists are familiar with, and their ephemeral nature needs to be included in the concepts that they are working with.

THE MACROINVERTEBRATE BENTHOS OF AN URBAN TROPICAL RIVER (NAIROBI, KENYA)

Authors
NICOLA PACINI
DAVID HARPER
Department of Biology,
University of Leicester , UK

Study Area
The Nairobi river, Kenya.



Working Hypothesis

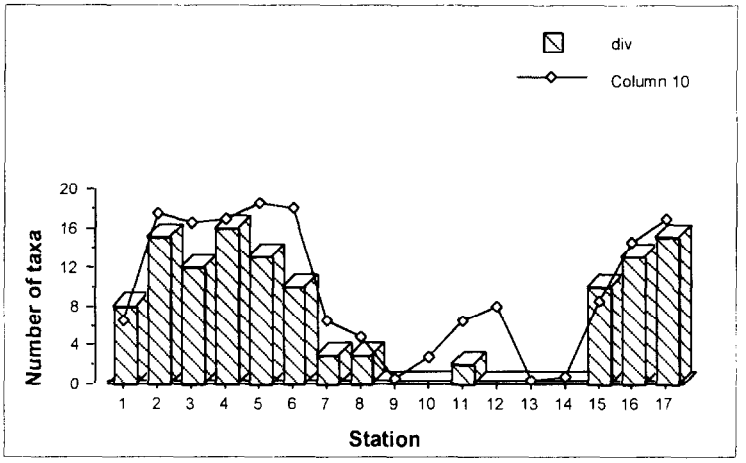
To record the distribution of macroinvertebrates as a baseline for the assessment of future changes in the ecology of the basin. To establish links between environmental variables and the distribution of the benthic invertebrate fauna.

Methods

Oxygen, conductivity, pH and current speed were recorded by instrumentation. Invertebrates were collected by Surber sampler from the substrate and by hand-netting amognst the trailing vegetation. Aquatic plants from cahnnel and riparian zone were collected and identified.

Results

The aquatic plants showed a progressive zonation as the river widened with downstream passage, without any clear relationship with human impact discernable. Physico-chemical and invertertebrate data however, showed a distinct divison into four zones. The first one, upstream of the city, was characterised by turbulent, clear water rich in diversity. The second stage, passing through the city limits, was characterised by anaerobic, sluggish conditions and few pollution-tolerant or even no taxa. The third stage may be described as the recovery stage, 18-20 km east of the city, where turbulent conditions and a range of taxa returned to the river. The fourth stage is characterised by the increase in size of the river and in-stream habitat features such as pools, islands and waterfalls, which return a high taxonomy diversity.

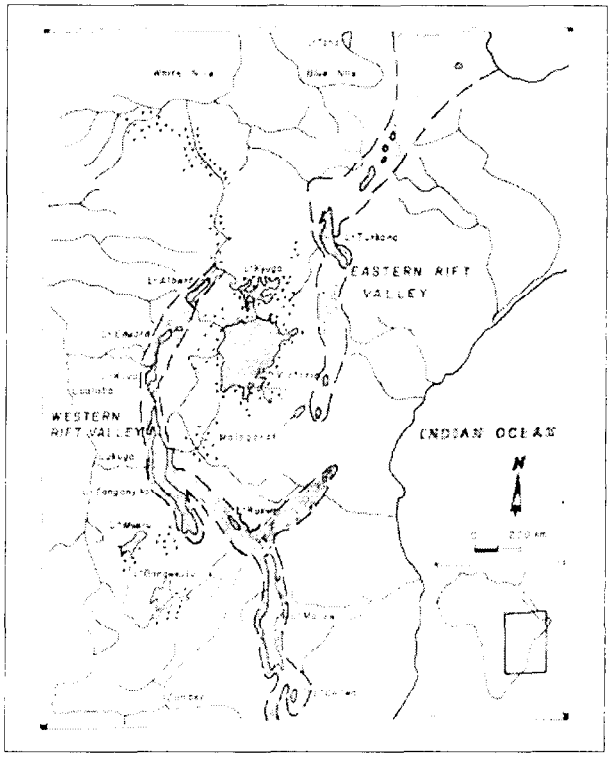


Ecohydrological Implications of this Study

The river at present forms a drinking water supply in its upper reaches but is almost totally unmanaged thereafter, with informal use both as a source of water and a depository for human and industrial wastes widespread in the city. Such a river provides the ultimate challenge for the application of ecohydrological theories, although they cannot be successfully applied at present in the absence of official policy and public acceptance.

EXTERNAL AND INTERNAL PROCESSES INFLUENCING ORIGIN AND MAINTENANCE /CONTROL OF TROPICAL INLAND WETLAND ECOTONES

Author
FREDERICK WILLIAM BUGENYI
Fisheries Research Institute,
Jinja, Uganda



Working Hypothesis

Tropical water-terrestrial ecotones are zones interacting actively between two adjacent ecosystems. These ecotones play major roles in – capture-release regulatory function, filtering activities, protection zones and habitats for the fauna, as well as socio-economic benefits.

Water and other aquatic resources problems are increasing in the tropics because of poverty, from African structures and international economic structures, population increase, urbanisation and environmental degradation - deforestation, soil erosion, over-exploitation of aquatic resources.

Methods

There is need to formulate conservation and management strategies for African tropical aquatic resources through a full understanding of the processes which influence wetland ecotone formation(and destruction), functioning and maintenance.

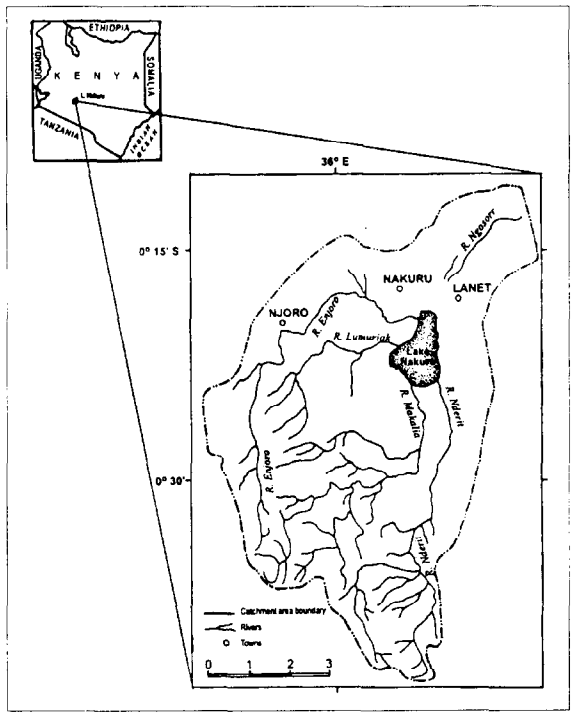
Ecohydrological Implications of this Study

The ecotone concept is strongly related to geomorphic processes creating border zones between freshwater bodies and dry land. Factors responsible for creation/destruction of wetland ecotones are human-induced as opposed to naturally induced factors/perturbations: Through mis-managed exploitation (by encouraging development at the expence of conservation) of the resources, catchment activities-biomass harvests, burning, devegetation, deforestation, agricultural practices, industrial and domestic wastes passed through the wetland ecotone zones, introduction of foreign species into system.

Tropical Africa should build capacity adequate enough to address the above problems. A clear understanding of the scientific basis on which wetland-ecotones are formed and destroyed is necessary. Fluvial geomorphic processes and their function should be held uppermost when collective management and conservation measurers are envisaged.

A SYNOPTIC ECOPATH MODEL OF BIOMASS FLOWS IN LAKE NAKURU

Authors
JACQUES MOREAU
TANGUY DAUFRESNE
Inland Fisheries Department INP/ENSAT,
Auzeville Tolosane, France
KENNETH MAVUTI
Department of Zoology,
University of Nairobi,
Nairobi, Kenya



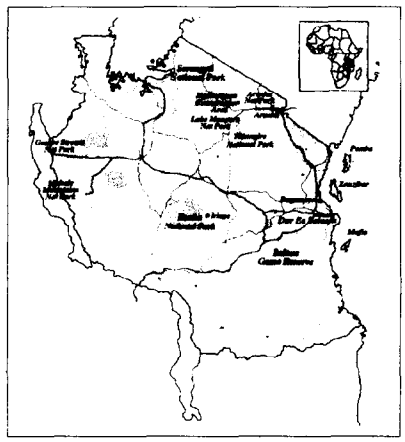
Study Area
Lake Nakuru, Kenya.

Working Hypothesis
Trophic relationships inside Lake Nakuru ecosystem during two different phases are described by using the ECOPATH model. The hypothesis is to provide representations of production and biomass relationships and the trophic functioning of the lake corresponding to examples of two critical periods, i.e. 1972 (high primary productivity) and 1974 (low primary productivity).

Results
The present ECOPATH model quantitatively expresses and explains some of the trends observed during the two phases. Most often, the ecotrophic efficiencies for all groups are lower in the 1972 than in the 1974 phase. This means that the less abundant resources in 1974 led to a more efficient utilization of the available biomass and higher competition by the consumers resulting in decreased flows to the detritus. This situation is further evidenced by the general decrease of trophic level of several consumers leading to an increase of the second level and also by the changes in the feeding habits of most consumers.
In 1972, *Spirulina platensis* biomass was in excess of the consumers requirements. This situation, however, changed in 1974 with the massive decline in biomass of *S. platensis* subsequently becoming a limiting factor for most primary consumers, particularly lesser flamingos. Whereas the fish could switch their feeding habits to new food items within the lake, the lesser flamingos could not and were, therefore, forced to migrate to other lakes in search of food, thus making a major reduction in flamingos biomass on Lake Nakuru. Simultaneous to the decline of *S. platensis* was similar crash in Copepods and Heteroptera, and a subsequent increase in Rotifers biomass. Consequently, although the combined predation of Rotifers by fish, flamingos and heteroptera was substantial in 1974 their production exceeded their mortality through predation and subsequently more biomass was retained in the system as can be discerned from the ecotrophic efficiencies over the two periods.

Ecohydrological Implications of this Study
The present contribution shows that the use of ECOPATH has made it possible to balance the biomass and annual production of the key interacting groups in two successive phases of the life of Lake Nakuru. This was achieved by using the data from the literature on the lake and through the personal knowledge of the lake by resident scientists. The ecological instability from one phase to the other and the trends for the further recovery of the lake ecosystem could be explained partly by the model. The full explanation of the interactions of the lake, which has remained very unstable through the thirty years since it was studied in detail to the present day, requires a knowledge of the hydrological and hydrochemical changes in the lake's inflows, which have changed dramatically as a result of agricultural settlement in the south and industrialisation of the town of Nakuru in the north.

WATER AS THE FORCE DRIVING THE SERENGETI ECOSYSTEM, TANZANIA



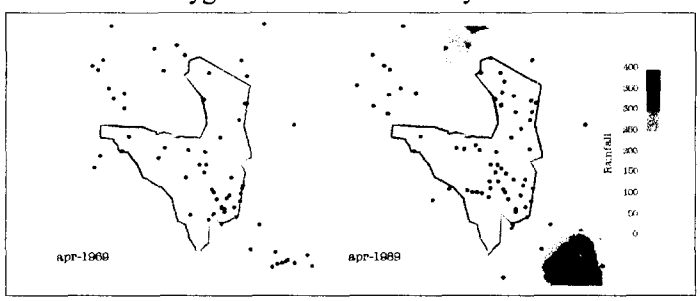
Authors
ERIC WOLANSKI
AIMS, Townsville, Queensland, Australia
EMMANUEL GERETA
TANAPA, Arusha, Tanzania

Study Area
Serengeti National Park, Tanzania.

Working Hypothesis
38 years of rainfall data from 232 sites, 5 years of river discharge data from 3 rivers, 3 years of animal migration data and 3 years of water quality data at 60 sites were explored to quantify the driving role of water in the Serengeti ecosystem.

Methods
pH, salinity, dissolved oxygen concentration and temperature near the surface of most waters rivers and water bodies in the park were measured for 3 years at 49 stations at about three monthly intervals.

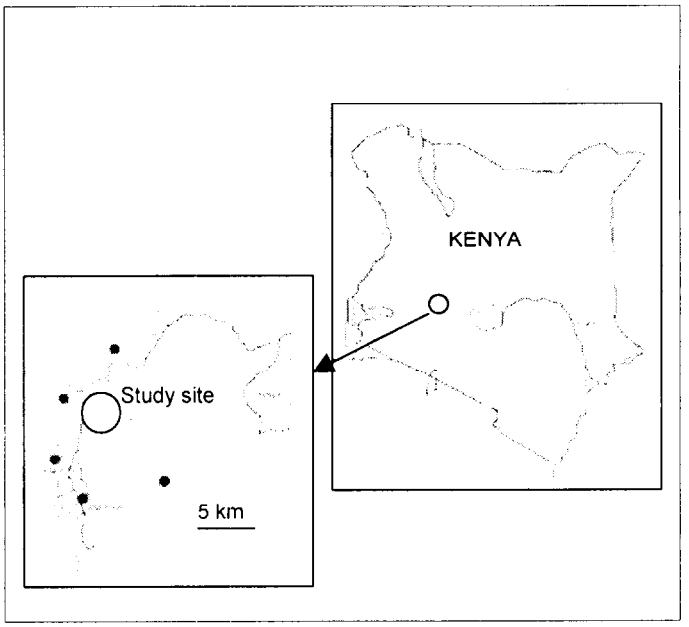
Results
Seasonal variations in rainfall are largely predictable; inter-annual fluctuations are huge and not predictable solely from the Southern Oscillation Index. Except for the Mara River, all other rivers are commonly ponded, with ponds having a flushing rate of 1 month in the wet season and zero flushing in the dry season. These ponds form the only source of water for wildlife for several months a year. In the southern plains the wildebeest and zebras start their annual migration well before surface water runs out and when the salinity of surface waters becomes excessive. The timing of the migration appears predictable from a salinity model. Salinity is also important for the vegetation because high salinity of surface waters coincide with the transition between wooded savanna and grassland. This transition has moved markedly southward in the last 30 years, this change coincides with increases in annual rainfall over 25 years. The water quality varies spatially and temporally. pH values vary between 10 in the southern plains to 5.9 in the north and are highly correlated with salinity. Surface waters are heavily eutrophicated from animal dung. As a result, the dissolved oxygen concentration near the surface fluctuates widely between 1 and 200% of saturation. The oxygen stress is measurably lessened in wetland-fringed water bodies as a result of filtering. The water in the river ponds are very turbid, therefore direct solar heating is restricted to the top few cm. Anoxic conditions are common in bottom waters; overturning due to bottom heating from decaying organic matter occasionally ventilates these waters. It is suggested that poor water quality may affect wildlife health and production.



Ecohydrological Implications of this Study
Water is driving the Serengeti ecosystem. Firstly rainfall determines the salinity of the Mbalageti and Seronera Rivers, the two rivers that drain the grasslands, this in turns controls the discontinuity between open grassland and wooden savanna. Secondly rainfall variations at decadal time scales are large (50% of the mean); they may shift southward or northward (i.e. upstream or downstream) the location of the salinity threshold determining this discontinuity. In turn this introduces changes at decadal time scales in vegetation. Thirdly excessive salinity, and not available forage and water may be the trigger starting the annual migration of wildebeest and zebras at the end of the wet season. We suggest that the rainfall-runoff model of the Mbalageti River could thus be used to hindsight salinity, hence migrations, over the past 38 years. This could be related to historical data from aerial observations of the migration routes. This information, together with data on changes of vegetation, could thus be used to construct a deterministic model of the Serengeti ecosystem. Such a model would be useful for the management of the Serengeti National Park. Indeed it would enable one to separate the effects on both migrating and resident wildlife of rainfall-driven variability, over which management has no control, to that due to other processes (e.g. bush fires, storing surface waters) over which management has control.

QUANTIFICATION OF SMALL -SCALE HUMAN ACTIVITY IN A RIFT VALLEY STREAM

Author
JUDE MATHOOKO
Department of Zoology,
Egerton University,
Njoro, Kenya

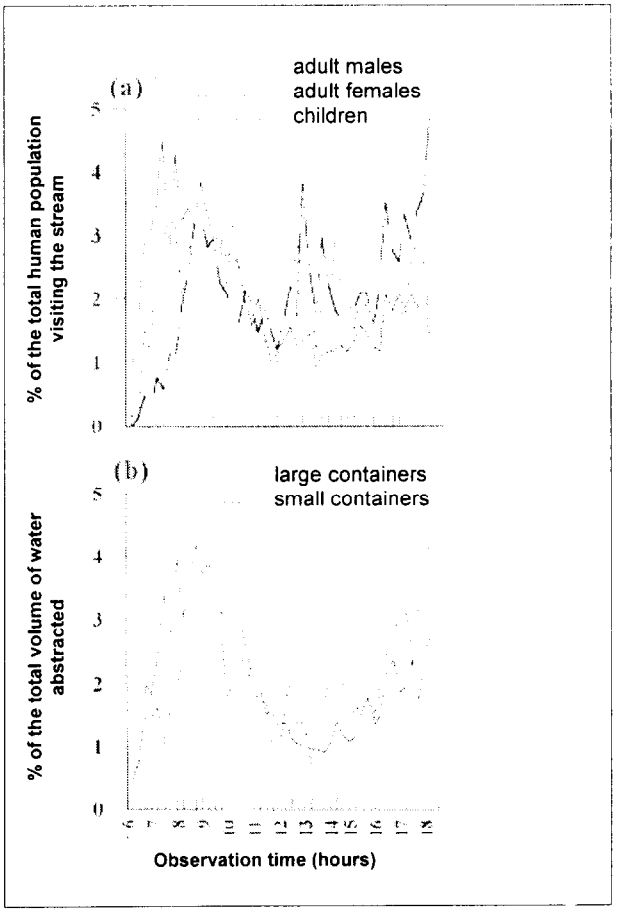


Study Area
River Njoro, Nakuru, Rift Valley, Kenya.

Working Hypothesis
Daily small-scale water abstractions and other activities influence the river hydrology and biology. These daily visits are controlled by seasons.

Methods
Measuring of human visitation and activities by direct observations and counts. Recording the number of containers (10 l and 20 l) filled. Sample collection of benthic macroinvertebrates from impacted and control sites, identification and estimated of distribution.

Results
The diurnal visitation by humans for domestic water collection and animal watering was bimodal, peaks between 0600-1100 and 1600-1800. Adult women formed the first visiting group at dawn followed by adult men and children in the afternoon. Trampling of the riverbed by humans and cattle alters the invertebrate community by redistribution and reduction of faunal crowding and patchiness.



Ecohydrological Implications of this Study
For the first time a measure of the informal abstraction of water has been made this influences hydrological management decisions. Water quality effects by informal visits – essentially diffuse source pollution in a river basin - are also quantified. River management in the tropics needs to consider such effects but has rarely done so.

LITTER INPUTS FROM RIPARIAN VEGETATION TO A SMALL STREAM - RIVER NJORO, KENYA

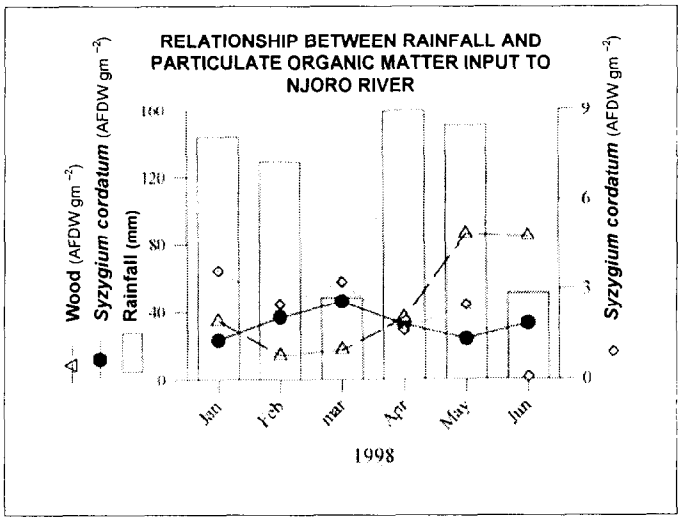
Author
ADIEL MAGANA
Department of Zoology,
Egerton University,
Njoro, Kenya

Study Area
River Njoro, Nakuru, Kenya.

Working Hypothesis
Litter inputs vary in quantity and quality spatially and temporally in a tropical river. These are determined by rainfall and by density and composition of the riparian vegetation.

Methods
Climatic parameters – rainfall, humidity and wind speed were measured. Litter inputs were collected at closed and open canopy sites using aerial (collecting leaf-fall) and bank (collecting overground movement) runoff traps.

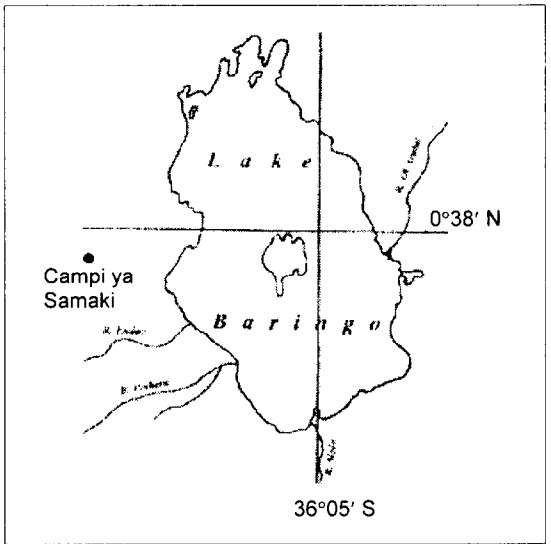
Results
Riparian species – e.g. *Syzgium cordatum* – had continuous leaf litter input with a slight increase associated with rainfall. Terrestrial species growing in the riparian zone – e.g. *Rhus natalensis* – had intermittent litter input triggered by a shortage of rainfall. Wood litter input generally increased with rainfall. Wind was not an important factor in transporting litter over long distances to the stream.



Ecohydrological Implications of this Study
In order to estimate the need for the conservation and restoration of the riparian ecotone in tropical streams, its is first necessary to understand their role in providing streams with organic matter, secondly to quantify the extent to which they have been degraded. This study for the first time in Kenya provides information about the first of these issues.

LIMNOLOGICAL EFFECTS OF DAM CONSTRUCTION AND CATCHMENT DEGRADATION – LAKE BARINGO, KENYA

Authors
NICHOLAS GICHURU
KMFRI, Campi ya Samaki,
Baringo, Kenya
PENINA ALOO
Aquatic Research Centre,
Nairobi, Kenya

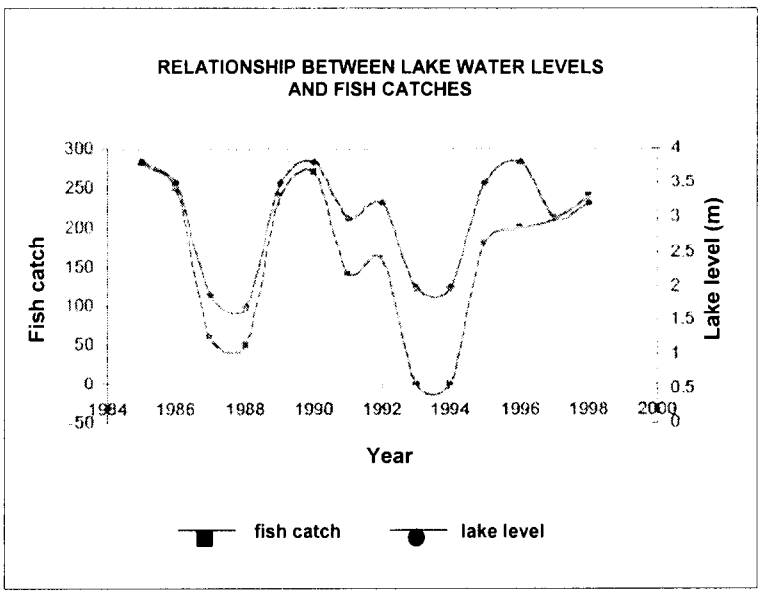


Study Area
Lake Baringo and its catchment, northern Kenya.

Working Hypothesis
The decline in water level and fishery of Lake Baringo has been due to human impacts in the catchment. The construction of catchment reservoirs has been counter-productive.

Methods
Standard sampling methods for water chemistry, transparency, and phytoplankton. Long-term monitoring of the effects of lake level and transparency on commercial fisheries catches, the recorded using monitoring of fishermen landings.

Results
The lake has been very turbid for several decades, attributed to severe erosion in the semi-arid catchment area where the main activity is pastoralism. The lake's fisheries are directly proportional to the lake transparency and this to lake level. Below a mean depth of 3m, transparency of below 3.5cm and the fishery becomes uneconomical. The inflowing rivers are all dammed to construct small reservoirs upstream. Although this has reduced the silt load entering the lake it has also affected the breeding pattern, ecology and behaviour of the anadromous fishes. It has also reduced the water volume available to the lake.
The fishery of the lake is presently dependent upon one cichlid, *Oreochromis niloticus baringoensis*. The growth of this is stunted.



Ecohydrological Implications of this Study
The quantitative impact of catchment stream damming needs to be understood in terms of the hydrology and the sediment yields. Catchment erosion needs to be addressed. The lake ecotone might have been able to lower silt input to the lake but its degradation is widespread. Soil conservation methods adopted by local farmers should be encouraged and implemented.

ECOLOGICAL CHANGES TO TWO ETHIOPIAN LAKES CAUSED BY CONTRASTING HUMAN ACTIVITIES

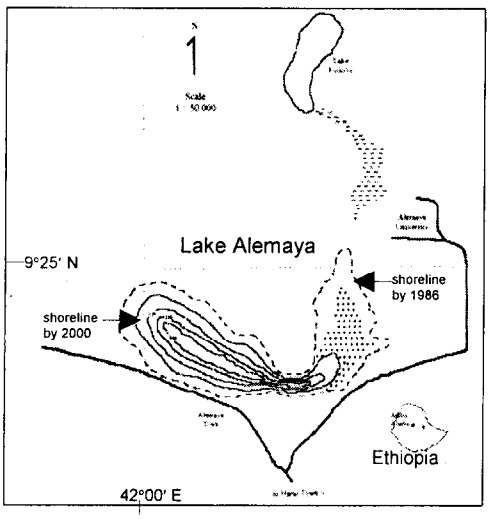
Author
BROOK LEMMA
Alemaya University,
Dire-Dawa,
Ethiopia

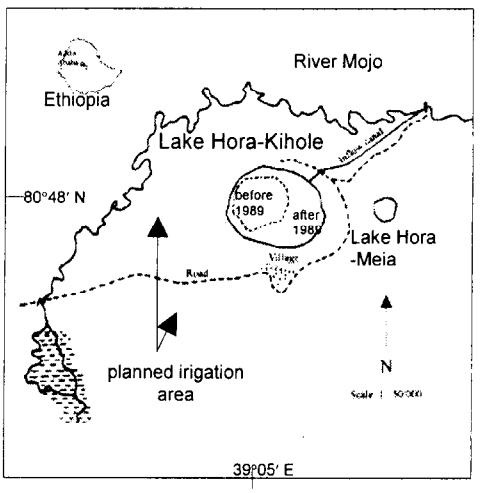
Study Area
Ethiopia, central plateau south of Addis (Lake Kihole) and the south-eastern plateau margin bordering the southern Afar (Lake Alemaya).

Working hypothesis
Contrasting human activities causes opposite effects on the two lakes – one increased in volume due to diversion of a river, the other decreased due to exploitation. The effects of these practices are not beneficial.

Methods
Basic limnological analyses to compare morphometry, physico-chemical features, phytoplankton, zooplankton types and biomass.

Results
Lake Alemaya is continuously shrinking by water removal and by siltation as a result of deforestation and irrigation. Lake Kilole, once known to be grouped among the unique saline sales of Ethiopia important for its *Spirulina* and lesser flamingos (lakes: Arenguade, Chitu, Abijata, Shala) has now drastically increased in volume as a result of inflow from the river Mojo. This has reduced the salinity of the water, altered the plankton component and introduced riverine fish species.

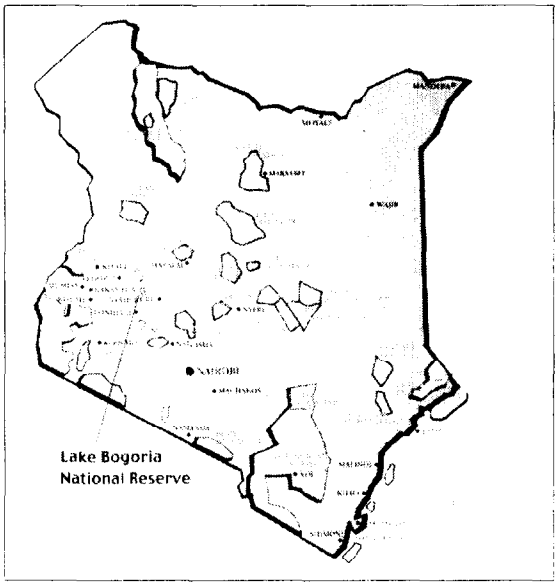




Ecohydrological Implications of this Study
The ecological implications of these limnological transformations contribute a baseline understanding for resource manipulation in the tropics. Both involve severe changes to the hydrological regimes of the lakes leading to biological changes. At least one of them is non-sustainable, while the other produces a permanent change of limnological state.

THE CONSERVATION OF LAKE BOGORIA NATIONAL RESERVE THROUGH COMMUNITY PARTICIPATION

Authors
WILLIAM KIMASOP
MUSA CHERUIYOT
Lake Bogoria National Reserve,
Marigat, Kenya



Study Area
Lake Bogoria, Northern Kenya,
300km north of Nairobi, 12km north of the equator.

Working Hypothesis
The effective protection of an internationally important reserve can only be effective if it involves the local community.

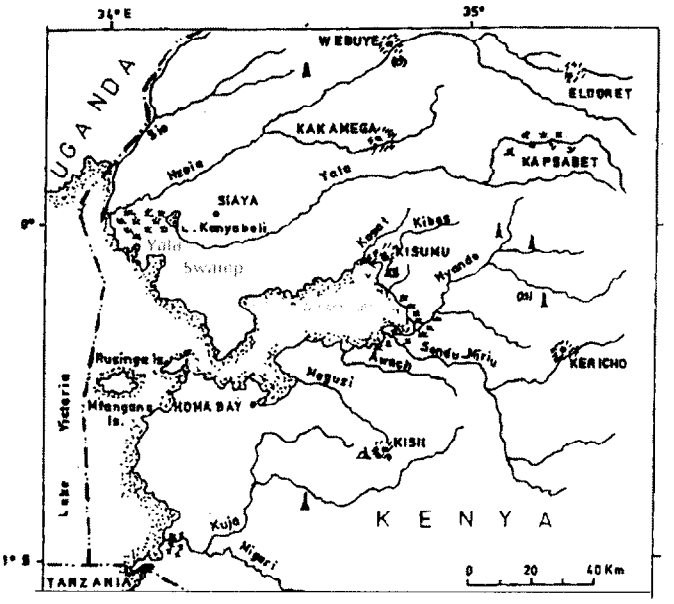
Methods
The lake was gazetted as a reserve in 1972. The lake is a critical habitat for the lesser flamingo and its land boundaries for greater kudu and mountain reedbuck. The adjacent communities are about 8000 people of the Tugen sub-tribe of the Kalenjin, practising agro-pastoralism with some irrigation and beekeeping. WWF-Kenya established a Community Based Wetlands project in 1996 in order to secure the sustainable future of the reserve. It has three components – awareness creation, resource inventory and small-scale income-generating projects. A Participatory Rural Appraisal exercise was conducted in 1997.

Results
The PRA revealed that land tenure and reserve status were important issues. The concept of a gazetted reserve excluding people was anathema. Sustainable utilisation of some resources has been successful – papyrus for example – whereas others, such as settlement near fresh water springs or corridor areas, or fuel exploitation, are more problematical. Community participation is decision-making on management issues is now accepted by all parties.

Ecohydrological Implications of this Study
The major driving force for the establishment of the reserve in 1973 was the revenue generation for the famous hot springs and geysers. Little or no consideration was taken for the functioning of the ecosystem. The need to understand the system is urgent, but it cannot be understood (nor managed) by an exclusion of the region's inhabitants. An understanding of the inter-relationships of region's ecohydrology – springs, surfaces streams, hot springs and the alkaline lake – is an essential contributor to the management progress.

COMMUNITY AWARENESS AND CONSERVATION NEEDS AT LAKE KANYABOLI YALA SWAMP WETLAND, KENYA

Author
ROMULUS ABILA
Department of Zoology,
Maseno University,
Maseno, Kenya



Study Area
Yala Swamp, Western Kenya,
17,500 ha and three satellite lakes.

Working Hypothesis
The local community plays an important role in the development planning, management and conservation of the system.

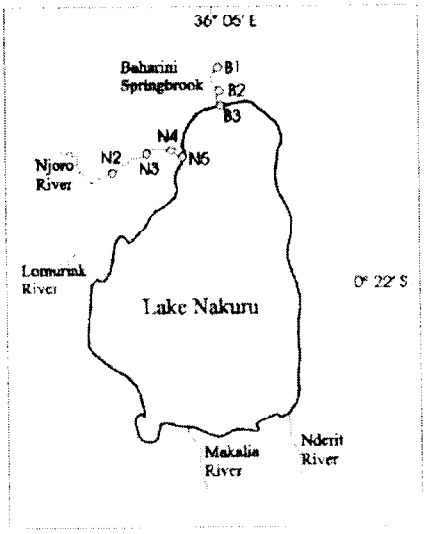
Methods
We collected data on the social, cultural and economic values of the wetland and peoples' perception of the wetland.

Results
The wetland is important ecologically as a biodiversity conservation site, economically as a source of food and other resources. The main economic activities are fishing, agriculture, papyrus harvesting, hunting, fuelwood gathering, grazing, brick making and pottery. Socio-cultural values include provision of medicinal plants and sacred sites. The conservation needs of the wetland include control of papyrus exploitation, controlling overfishing, hunting and restoration of degraded land. The majority of respondents did not support creation of a protected area but did support community-based conservation.

Ecohydrological Implications of the Study
A wetland system such as this one, heavily utilised, can only remain intact if it is sustainable managed. To do this an understanding of the ecohydrology of the system is needed, including the extent to which exploitation is disrupting the natural processes. Ultimately however, ecohydrology has to be incorporated in with socio-economics, as at other locations where the lives of the people are intimately woven with the wetland values (see Kimasop & Cheruiyot).

HYDROLOGICAL STRUCTURING OF INVERTEBRATE COMMUNITIES IN TWO STREAMS FLOWING INTO LAKE NAKURU, KENYA

Author
WILLIAM SHIVOGA
Department of Environmental Science,
Egerton University, Njoro, Kenya

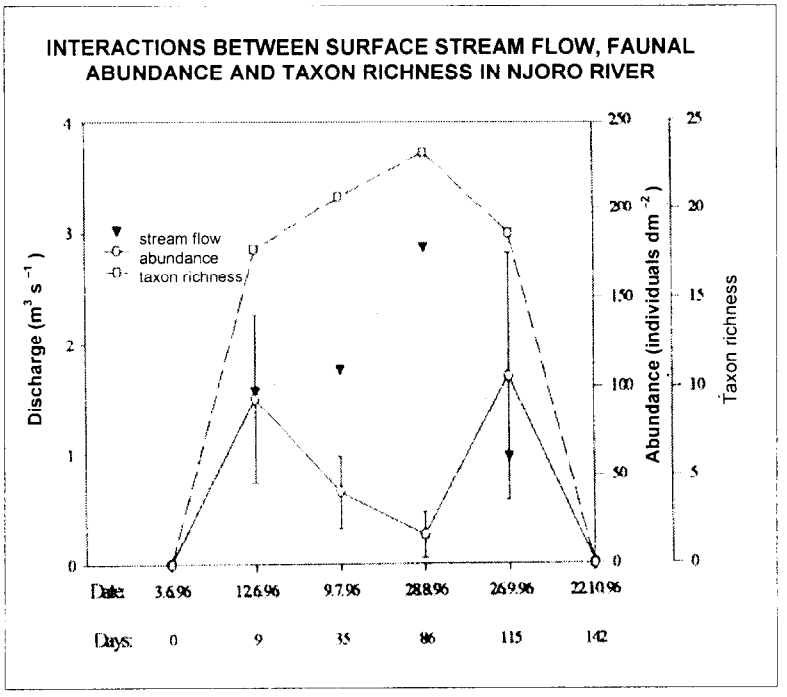


Study Area
Lake Nakuru catchment – the Baharini Springbrook and the Njoro River, Kenya.

Working Hypothesis
Hydrological variability determines the stability and complexity of stream habitats and consequently structures the lotic invertebrate communities. Null hypotheses are that faunal species composition of intermittent and permanent streams is the same; that lotic species have no specialised adaptation for surviving drought, and that spates caused by heavy rainfall do not affect faun al abundance.

Methods
Invertebrate sampling by Hess sampler and physical parameters – conductivity, dissolved oxygen, temperature and water velocity – by instrumentation.

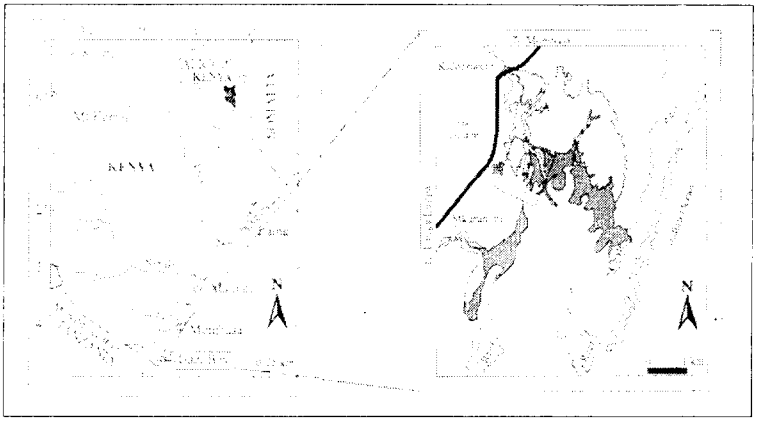
Results
Baharini springbrook has a low and steady perennial discharge, 0.05-0,4-m3 sec^{-1}, cv 50-57%. The Njoro river is highly variable, 0,07 – 2.9 m^3 sec^{-1}, cv 95-108%. Mean faunal abundance of Njoro is consistently lower than Baharini. 64 taxa were identified, 50 common to each stream. No specialised adaptations were found. Small spates do not affect fauna in Njoro but large spates after the rainy season reduce abundance, which takes on average 29 days to recover.



Ecohydrological Implications of this Study
An understanding of the pattern of discharge is essential to interpret the faunal community and through that, make a recommendation for the management of the streams in the Lake Nakuru catchment.

MANGROVE DISTRIBUTION AND DYNAMICS AT THE ESTUARINE CREEK AT GAZI, KENYA

Authors
FARID DAHDOUH-GUEBAS
ILSE VAN POTTLEBERGH
JAMES KAIRO
NICO KOEDAM
Laboratory of Botany and Nature, Management Vrije Universiteit Brussel, Pleinlaan, Belgium

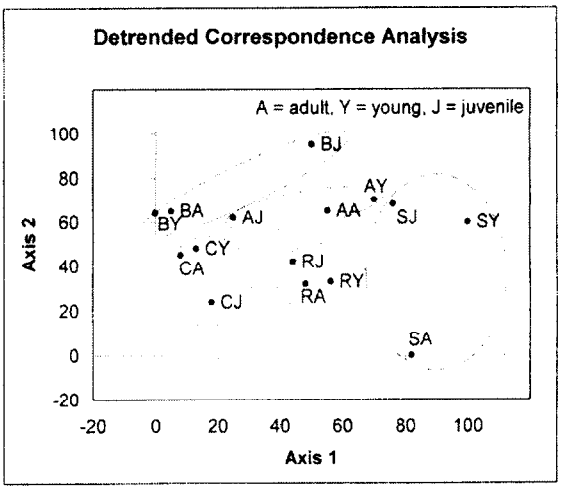


Study Area
Gazi Bay, Kenya.

Working Hypothesis
Human degradation of the estuarine mangroves is extensive. Evaluation of the extent and the causes will enable sustainable management to be promoted.

Methods
Analysis and mapping of airborne and remotely sensed data 1972-1992. Collection of adult, young and juveniles along six ground-truth transects with environmental variables. Species ordination by DCA to explore the link between distribution and environmental factors.

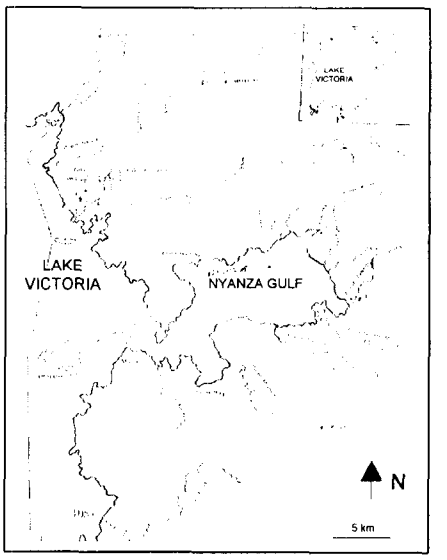
Results
Over-harvesting is the main cause of decline. Density has obviously decreased, but not species composition. There is land-water zonation: *Avicennia marina* zone, mixed zone, *Rhizopora mucronata* zone and then *Sonneratia alba* zone. *R. mucronata* is omnipresent in all classes. The distribution of young individuals is more related to adults. Juveniles are spread over a wide area but their survival is greater closer to the adult trees. The distribution of young, juvenile and adults of different species suggest that there are no future dynamic shifts in species distribution, despite the exploitation problem.



Ecohydrological Implications of this Study
It is necessary to understand the past as well as the present (and future) dynamics of estuarine mangrove distribution in order to contemplate successful management and restoration projects. Mangroves represent a land-water ecotone in tropical estuarine and creek systems essential for sustainable management (see Liyanage, this volume). Hence their maintenance is an essential component of the ecohydrological approach to the lower end of river catchments.

THE CURRENT PROBLEMS IN CONSERVATION OF THE LAKE VICTORIA ECOSYSTEM

Author
HENRY LUNG'AYAI
LEWIS SITOKI
Kenya Marine and Fisheries Research Institute,
Kisumu, Kenya



Study Area
Kenyan waters of Lake Victoria.

Working Hypothesis

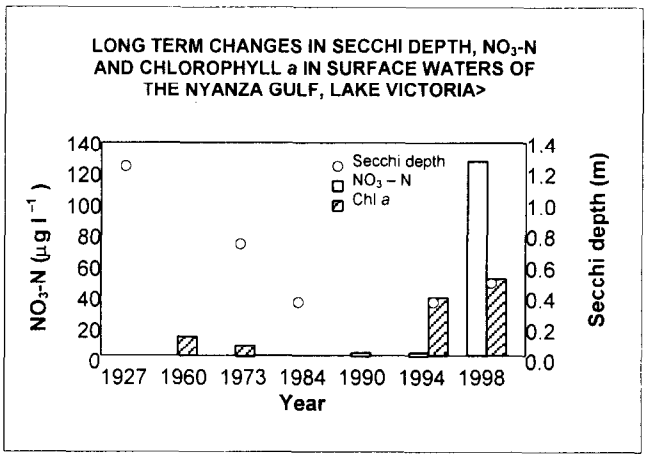
The changes in the environment of Lake Victoria are identifiable by following previous and recent records of physical, chemical and biological parameters.

Methods

1. Analysis of physical and chemical parameters:
   PO4-P, NO3-N, SiO2, NH4-N, alkalinity, chlorophyll 'a', conductivity, dissolved oxygen, pH, turbidity, temperature, Secchi disc.
2. Comparison of the recent data with previous records of physical, chemical and biological parameters.

Results

1. Levels of NO3-N are higher than expected.
2. Secchi disc transparency has reduced, indicating increase in turbidity.
3. Chlorophyll 'a' has increased.
4. Our observations confirm the general decline in the quality of the environment of Lake Victoria in the last few decades. Other notable ecological changes include increase in anoxia and loss of biodiversity of the phytoplankton, zooplankton, benthos and fish. Influencing factors include human population density, deforestation, land use changes, urban and industrial waste contamination, introduced species and general mismanagement of the resources.



Ecohydrological Implications of this Study

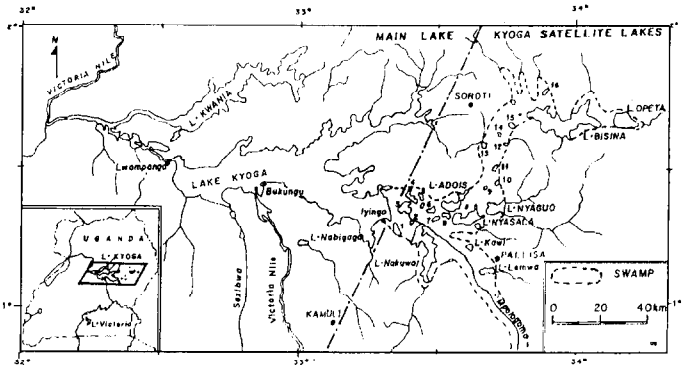
Lake Victoria is one of the largest freshwater resources in Africa, shared by three countries directly and several more as a drinking water supply and source of the Nile. Its management this century has been uncoordinated and addressing single issues. It is now in a debilitated state and its successful management can only come from a holistic approach to its problems - considering the lake ecosystem, the workings of the whole catchment and all its uses - ecohydrology.

ECOLOGICAL AND EVOLUTIONARY STATUS OF FISH FAUNA IN THE LAKE VICTORIA REGION AND LAKE ALBERT-VICTORIA NILE SYSTEM: THE ROLE OF MINOR SATELLITE WATER BODIES

Authors
W.W. MWANJA
A.S. ARMOUDLIAN
B.S. B. WANDERA
C.L. KAUFMAN
P.A. FUERST
Department of Evolution,
The Ohio State University, USA

Study Area
Lake Victoria region.

The Kyoga system as an example of Satellite lakes formed by swamps – encroachment and regular flooding and receding of a relatively low land basin. The identified lakes in the system are:
1. Nawampasa; 2. Muwulu; 3. Namasajeri; 4. Kiondo, 5. Naragaga; 6. Pachoto; 7. Kadiko; 8. Meito; 9. Kodiki; 10. Gawe; 11. Kochobo; 12. Kasago; 13. Opare; 14. Ajama; 15. Semere; 16. Owapet.



Working Hypotheses

Satellite lakes of Lake Victoria Region have acted as 'life boats' to the cichlid fish fauna during the dry spells and drastic limnological changes that characterize the history of the region's large water bodies, generating new 'protypes' that act as progenitors of new species in the large lakes following the recovery from such drastic changes. Understanding the modes of formation will enable us to establish the connection both in hydrological and biological diversity between the minor satellite lakes and the bigger lakes. Our postulation is that there are three main modes of formation: via fragmentation of larger lakes through drop in lake level and swamp encroachment, via desiccation where one large lake turns into one or more tiny lakes and via volcanism.

Methods

Paleolimnological and hydrological characterisation. Fish faunal survey and limnological analysis.
Isotopic analysis of trophic system. Genetic characterisation and phylogenetics estimations.

Results

So far we have found significant portions of the cichlid fauna in several of the satellite lakes, most of species we found were previously thought to be extinct from the LVR. Some of the satellite lakes such as the Nabugabo lakes have only a small number of species while others such as the Kyoga lakes have a wide variety which includes both known species and several undescribed species that are equivalent to species of the big lakes. Although previous studies revealed no marked genetic differences for various Lake Victoria haplochromine species, new sets of molecular markers (microsatellite DNA markers) developed in our laboratory can differentiate populations and species even at a very fine scale and are currently being used to analyse the haplochromine species for phylogenetic and macroevolutionary questions. Whether the contents of these small water bodies are of recent origin or reflect historical changes in LVR , is of great importance in elucidating evolutionary and hydrological processes that have shaped the LVR system.
Significant populations the two native forms of the tilapiines, that have been displaced completely from the main lakes, occur in several of the satellite lakes. Molecular analysis has revealed strong population structuring and differentiation among the remnant populations, and evidence of genetic interaction among the native and introduced species. Tilapiine swamp forms such as *Oreochromis leucostictus* have been found to be less differentiated than strict lacustrine species like *O. esculentus*. It is possible that limnological changes from diatom-dominated lakes to cyanobacterial-dominated big lakes, accompanied by persistence of diatoms in satellite lakes, may account for the displacement of the most important commercial species of LVR, *O. esculentus*, from the big lakes and its relegation to the minor ones.

MINOR SATELLITE WATER BODIES OF LAKE VICTORIA REGION, THEIR POSSIBLE MODES OF FORMATION, APPROXIMATE SIZES AND LAKE BASIN OR REGION IN WHICH THEY ARE FOUND

System	Satellite lakes	Mode of formation	Approximate size Km^2	Basin
Nabugabo Basin	Nabugabo, Manywa, Kayanja, Kayugi, Nabugabo lagoons	Tectonic, receding waters and swamp encroachment	2 to 150	Lake Victoria
Kioki Basin	Mburo, Kijanebalola, Kachera, Nakivali	Tectonic and swamp encroachment	10 to 50	Lake Victoria

Kyoga	Nawampasa, Kasudho, Muwuru Gigate, Bisina, Nyaguo	Swamp encrochment, flooding and dessication	0.5 to 100	Lake Kyoga Basin
Edward/George	Bunyoni, Kabaleka, Saka	Dyking by volcanic activity and swamp encroachment	0.5 to 100	Lake Edward Basin
Western Uganda Valley	Multitude of crater lakes	Volcanic activity	0.5 to 20	Western Rift
Yala Victoria Basin	Kanyaboli	Receding waters an swamp encroachment	>100	Lake Victoria
Eastern Rift valley lakes	Eyasi, Nakulu, Naivasha, Elementeita and others	Tectonic, dyking by volcanic activity	0.5 to 150	Eastern Rift

Ecohydrological Implications of this Study

In some of the minor lakes, such as Lake Bisina in Lake Kyoga Basin, the Nile perch flourished early in its establishment, but since been knocked down by selective fishing mortality. Here we have began to see an upsurge in the original native cichlid species. Such situations provide us with a natural experiment on the effect of the Nile perch and/or other factors that have been thought to have led to the decimation of fish species in LVR as a whole. Such studies are necessary for establishing the status of the species and drawing management options. Understanding of the biological history of the African Great Lakes would be incomplete if the theories put forward do not unite the history of the satellites in the various lake basins.

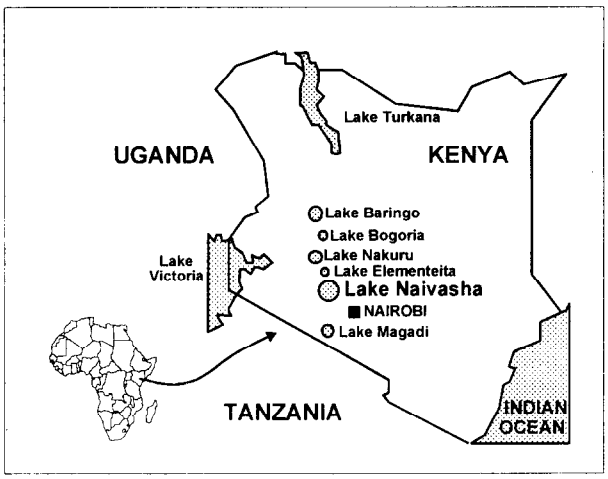
SECTION 3

ECOHYDROLOGY – RELATED PROJECTS

PATTERNS OF VARIATION IN WATERBIRD NUMBERS ON FOUR RIFT VALLEY LAKES IN KENYA 1991–1999

Authors
ALFRED OWINO
JOSEPH OYUGI
OLIVER NASIRWA
LEON BENNUN
Department of Ornithology,
National Museums of Kenya, Nairobi, Kenya

Study Area
Southern Rift Valley, Kenya.



Working Hypothesis
The annual waterfowl counts of the Rift Valley lakes over the past eight years provide date which can be interrogated to answer the following questions:- How does variability differ across waterbird groups? Do particular groups show correlated patterns at specific sites, and can these be related to ecological characteristics? Do particular groups show correlated patterns across sites? Different patterns of correlation can be related to different scenarios of waterbird populations and movements.

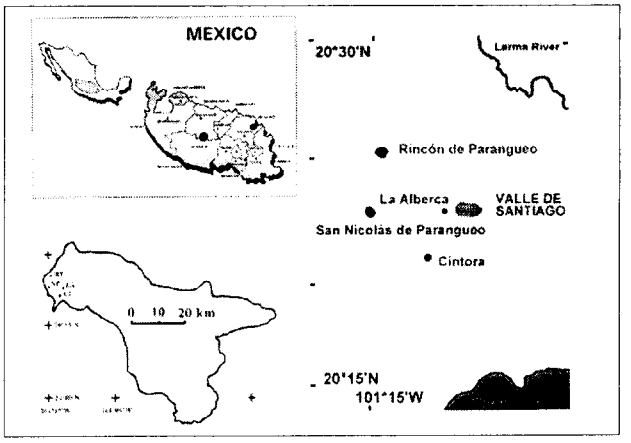
Methods
Waterbird populations are censused each January from 1991–1999 at Lakes Naivasha, Elmenteita and Nakuru and from 1992 at Lake Bogoria. Birds are grouped by family and where appropriate by migratory status (Afrotropical or Palaearctic) and feeding guild (i.e. large piscivores). The variation for different groups was analyzed for Lakes Naivasha, Elmenteita and Nakuru both combined and separately, and Lake Bogoria. Logarithmic indices of relative abundance were computed for each group: Index=log((observed abundance/mean abundance)*100)/2. Sample variances of these indices were used as a measure of relative variation.

Results
1. Lakes generally showed idiosyncratic patterns of variation across the different groups.
2. No group showed consistently high variance across all four lakes, but variance for birds of prey and kingfishers were consistently low (max. 0.036 and 0.042 respectively).
3. The variance for all birds (other than flamingos) combined was low (0.018 to 0.085) and similar across all lakes and for combined lakes (0.018).
4. For the combined lakes, the variance for flamingos was five times higher than for all other birds (F test, $p<0.05$), though the two variances were almost equal for Bogoria. Flamingos were the most variable at Naivasha (variance 0.281) followed by Elmenteita (0.177), Nakuru (0.101) and Bogoria (0.024, and significantly lower than all the rest; F test, $p<0.05$). This was opposite in order to the mean numbers of flamingos recorded at each site.
5. Patterns of variation within lakes were correlated for some groups, such as waders at Naivasha and large piscivores at Nakuru. These correlations could be related to local ecological conditions.
6. There were few large correlations across sites, and there were mainly positive.There were rather few substantial correlations in indices for particular groups across sites with no evidence of a fixed population of waterbirds distributing itself across sites according to conditions.

Ecohydrological Implications of this Study
Each lake seems to represent and independent entity, while the waterbirds they host evidently move much more widely afield than this portion of the Rift Valley. Changes can thus be considered without reference to conditions at other sites. There was no evidence that a fixed population of waterbirds was distributing itself across sites according to conditions. It is possible to find groups of waterbirds with reasonably stable populations at particular sites, where large changes in numbers should indicate real changes in ecological character. Changes in numbers are often similar across ecological guilds. Waterbird numbers combined across guilds may thus be useful for monitoring ecological character.

THE URGENCY OF IMPLEMENTING SUSTAINABLE WATER MANAGEMENT PLANS IN MEXICO

Authors
JAVIER ALCOCER
ELVA ESCOBAR
ALFONSO LUGO
Environmental Conservation
& Improvement Project,
UNAM Tlalneantia, Mexico



Study Area
The Valle de Santiago crater-lakes located in the southern portion of the Guanajuato state, central Mexico (20°25'N, 101°15'W, 1700 masl). The Valle de Santiago basin, belongs to the hydrologic region Lerma-Santiago (RH12), Río Lerma-Salamanca basin (B), and Presa de Solís-Salamanca sub-basin (a).

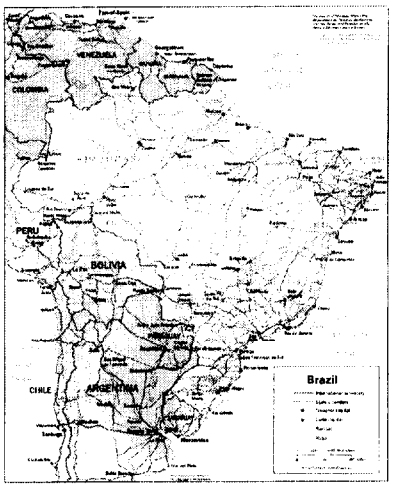
Working Hypotheses
There is a clear need to develop sustainable water use programs to be implemented at a catchment scale in Mexico. Just two projects have been initiated but far from implemented: Patzcuaro 2000 and Project Lago de Texcoco. Unfortunately, there is an evident lack of information to accurately evaluate the rate of ecosystem alteration. It seems that the accelerated desiccation rate of the Mexican lakes means that there will be no time to perform whole basin evaluations to establish sustainable water use programs before the lakes become dried.

Methods
The present project aims to draw attention to the need to understand the nature of Mexican limnological resources more accurately in order to be able to design sustainable water management plans. It uses the example of the crater-lakes of Valle de Santiago to highlight the drastic situation Mexican limnological resources are experiencing, especially those located in the arid and semiarid regions that represent two thirds of the Mexican territory.

Results
Vegetation clearance, overgrazing, abatement of phreatic waters, and salinisation have induced severe erosion and overall desertification (land degradation) in the basin for what it seems a long time (i.e., prehispanic times). In this way, human activities could be provoking at least the following negative consequences: a hotter and drier local climate, water scarcity, dust storms and soil salinisation. The aquatic (surface and groundwater) resources of the Valle de Santiago basin have been seriously threatened. Two out of the four crater-lakes are already dried, phreatic mantle abatement reaches up to 2.5 m per year.

Ecohydrological Implications of this Study
No sustainable water-use program has been established yet although the government declares long time ago this area, Valle de Santiago, restricted for groundwater extraction. Recently (11-21-97), the Guanajuato State government declared this zone "Natural Monument". In spite of this fact, the future scenery of this Mexican basin looks alarming like many other basins in the central and northern Mexican territories. Detrimental catchment/drainage basin activities, diversion of inflows, water pollution, physical impacts on lake basins and direct impacts on the biota must be strictly regulated in order to prevent further land desertification, salinization and shortage (quantity and quality) of surface and underground water resources availability. It is urgent to devote considerable scientific research and conservation efforts to Mexican lakes, many of which are of importance for wildlife, biodiversity and eco-tourism. Yet they are also essential for human activities including agriculture, industrial and urban development, as well as to local economy.

NORTHEASTERN BRAZILIAN RESERVOIRS: MULTI-PURPOSE USE AND ENVIRONMENTAL IMPACT.



Author
OLGA ODINETZ-COLLART
Fisheries Department,
Rural Federal University of Pernambuco,
Recife, Brazil

Study Area
Semi-arid Northeast Brazil

Working Hypotheses
About 70,000 public and private reservoirs have been built in the semi-arid Northeast Brazil since the beginning of the century.
Their multi-purpose use has been promoted through irrigation projects and stocking programmes, in order to sedentarize local populations and develop economically the semi-arid, with the guarantee of a permanent water supply for livestock and human consumption.

Methods
Long-term monitoring of reservoirs:
1. Standard sampling methods.
2. Hydrochemical and physical parameters.

Analysis of the multi-purpose use of reservoir waters:
1. Humans and livestock consumption.
2. Water fisheries survey.
3. Agro-pastoril activities.

Results
Reservoirs are the only permanent water resources in the semi-arid Northeast, used for human consumption, agriculture, cattle farming, fisheries and energy. Human adaptation to environmental constraints and economical context of the semi-arid is expressed by permanent switch in water dependent activities, as follows:
1. from subsistence agriculture to commercial irrigation, or
2. from agriculture during the wet season to fisheries during the droughts,
3. switch in fisheries techniques or strategy, seasonal migration to other reservoirs, to the São Francisco river or to urban centres.

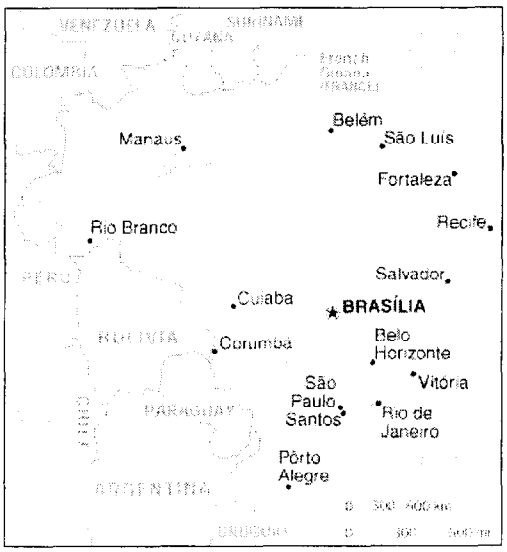
In water scarcity situations, the multi-purpose use of reservoir waters may generate a series of conflicts between antagonist water demands for agriculture, fisheries, pond-nets aquaculture, cattle farming and public water supply.
The States of Ceará, Rio Grande do Norte and Pernambuco already have their State Water Resources Programme supporting reservoir water conservation and management.

Ecohydrological Implications of this Study
This study will lead towards a risk analysis of multi-purpose use of reservoir waters. This will progress towards sustainable reservoir management.

WATER RESOURCES MANAGEMENT IN PERNAMBUCO STATE: POLITICAL OR CONSERVATION STRATEGY ?

Authors
OLGA ODINETZ-COLLART
MARIA AUXILIADORA GONÇALVES DA SILVA
Fisheries & Social Sciences Departments,
IRD/UFRPE-CNPq Research Convention,
Rural Federal University of Pernambuco,
Dois Irmãos, 52175-030, Recife, Brazil

Study Area
Semi-arid Northeast Brazil.



Working Hypotheses

1. The Federal Law dated January 1997 considers that water is a public good and a limited natural resource with an economical value. It gives priority for human consumption in scarcity situations, and recommends that water resources management should assure a multiple use of water. It also determines the river basin as the territorial unit for management and policy implementation and establishes a decentralised management based on the participation of federal and state authorities, as well as local consumers.
2. The Water Laws in Brazil were, mostly based on the social and hydrological conditions of the temperate and developed South of the country.
3. The semi-arid Northeast Brazil presents strong climatic and social particularities with permanent water scarcity, low technology, archaic social and political structures.

Methods

1. Monitoring Programme integrating ecological, social and economic analysis of the reservoir waters' multiple use.
2. Environmental education and awareness of conservation needs and water management methods.

Results

1. Water resources management, control and conservation are supported by the State Programme of Water Resources.
2. Development of long-term water resources monitoring programmes is hampered by technological deficiency and short-term political vision.
3. Implementation of participatory management of water resources is difficult due to low educational level, persistence of feudal customs based on dependence/domination and lack of citizenship awareness.
4. Sustainable water resources management requires a round table negotiation process with social, economical, political and technological integration.

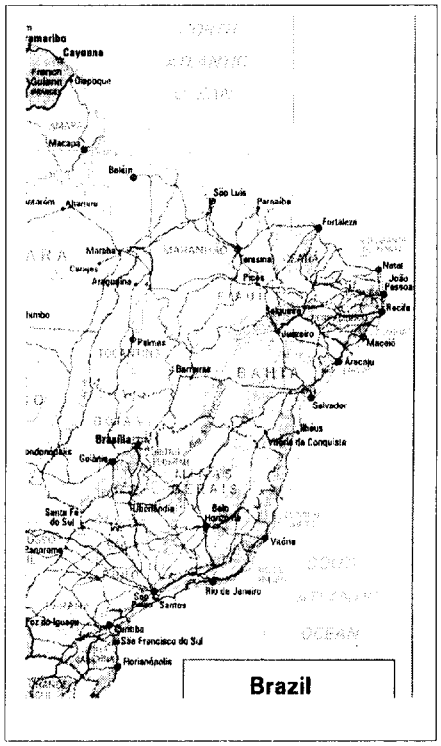
Ecohydrological Implications of this Study

The study will move the reservoirs towards integrated and sustainable water resources management. Part of this will be a long term water resources monitoring programme. This will involve participatory and democratic management of water resources, and environmental education and conservation awareness.

RESERVOIR FISHERY EXPLOITATION STRATEGIES IN PERNAMBUCO – NORTHEASTERN BRAZIL

Authors
OLGA ODINETZ-COLLART
Fisheries & Social Sciences Department,
IRD/UFRPE-CNPq Research Convention,
Rural Federal University of Pernambuco,
Dois Irmãos, 52175-030, Recife, Brazil

Study Area
Pernambuco state, Northeast Brazil.



Working Hypotheses
Since 1932, more than one million fingerlings, including 42 fish and prawn species, have been introduced by the National Department of Works against Drought (DNOCS) in public and private reservoirs of Northeast Brazil.
Tilapias stocking was the most sucessfull in all water bodies. In Pernambuco state, about 3 million fingerlings are introduced every year, but life quality of fishing communities is very low and most of reservoir fisheries development projects failed.

Methods
1. Reservoir fisheries assessment.
2. Analysis of fish market infrastructure.
3. Socio-economical study of fishing communities.

Results
1. Inland fisheries are low technological activities, based on the use of gillnets and castnets.
2. Fisheries structures vary from small-scale subsistence exploitations, with fish yields not exceeding 20 kg/person/day, to large-scale commercial systems with one or two hundred emigrant fishers and fish yields reaching 50 kg/person/day.
3. Simplified approaches of numerous and non-coordinated actions of development institutions and agencies, lack of financial support and professional training, as well as inadequate market infrastructure are the main limiting factors for inland fisheries development in Pernambuco.

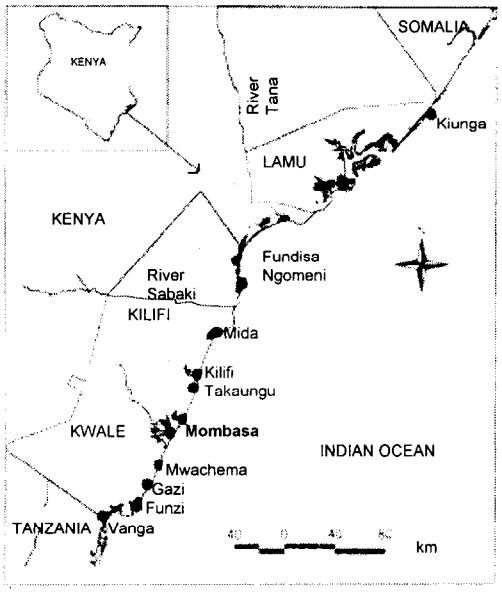
FISHERIES ASSESMENT IN PERNAMBUCO RESERVOIRS (1998)

Reservoir	Reservoir total capacity (million m^3)	Permanent fishers (1998)	Fish yield (1998) kg/day/person	Monthly fish catch (tons)
Pão de Açucar	55	<10 (outsiders)	50 kg	1 – 1.5 t
Ingazeira	4,6	20	6 kg	2 – 2.4 t
Arcoverde	14,4	25-35	5 kg	2.5 – 3.5 t
Ipanema	5	30-40	6 kg	3.6 – 4.8 t
Poço da Cruz	504	150	8 kg	16 – 24 t
Algodoes	54,5	<10	17 kg	2.7 – 3.4 t
Lagoa do Barro		10-20	20 kg	6 – 8 t
Chapéu	188	60	40 kg	40 – 45 t
Brotas	19,6	70-80	15 kg	21 – 24 t
Cachoeira II	21	20-30	9 kg	4 – 5 t

Ecohydrological Implications of this Study
This study will enhance reservoir fisheries and move the reservoir management towards sustainability but highlighting the obstructions to development.

SOCIO-ECONOMIC ASPECTS OF WATER MANAGEMENT IN ESTUARIES AND CREEKS OF KENYA

Author
JACOB OCHIEWO
Kenya Marine and Fisheries Research Institute,
Mombasa, Kenya



MAP OF THE KENYAN COAST SHOWING MANGROVE AREAS

Working Hypothesis

The Kenyan Coast is characterised by a narrow coastal plain (5-10 Km wide) stretching from Tanzania in the south to Somalia in the north. Many important rivers drain through this coastal plain into the Indian Ocean. The available livelihood opportunities and natural resources here have attracted high human population especially to the more developed urban centres. Population distribution along this coastal zone is quite uneven since it developed in clusters linked to artisan fishing, trade and port activities. The area's northern districts of Lamu and Tana River are sparsely populated due to harsh climatic conditions and lack of fresh drinking water. The majority of the region's population is concentrated in Malindi, Kilifi, Mombasa, Kwale and Taita-Taveta districts that receive fairly more rainfall per annum and are fairly better endowed with fresh drinking water.

Watershed Management and Challenges Arising from Freshwater Shortage

The Kenyan Coast receives fresh water from rivers Tana, Sabaki, Ramisi and Umba. Other important sources of fresh water are Marere Springs, Mzima Springs, Tiwi boreholes and the lower slopes of Mt. Kilimanjaro. Traditionally, the coastal communities lived in harmony with their forest and water resources, however, human activities have changed thereby threatening future prospects. There is the greatest problem of rapid population growth which is leading to land use changes resulting from increased demand for settlement land, agricultural land, forest products and ground water. Urbanization, tourism and industrial development are also rising.

Since fresh water is scarce, people are forced to use poor quality water in some locations leading to rampant cases of water-borne diseases such as cholera, typhoid, scabby, etc. Scarcity has also led to freshwater becoming a marketed good with high demand in the market. People are therefore forced at times to consume less fresh water than they actually need during periods of great scarcity.

Management Needed

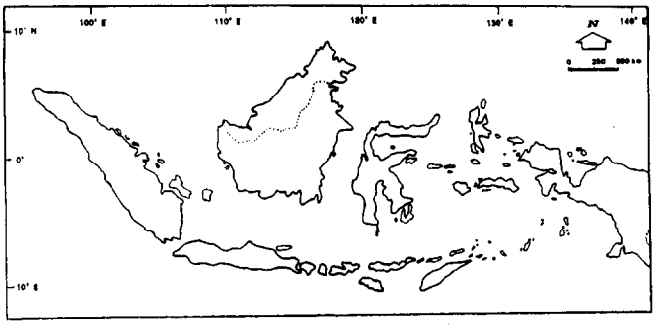
1. There is need to maximize rain water harvesting for use during dry seasons.
2. There is need to enforce the polluter pays principle to curb irresponsible raw sewage damping.
3. The local communities should be involved in the management of water catchments and wetlands.
4. Water catchments need maximum protection.
5. Collective digging and ownership of boreholes need to be encouraged with Government and NGO support.
6. Industrialists and hoteliers should be encouraged to recycle used water where possible.

Ecohydrological Implications of this Study

Freshwater supplies for human consumption are often shortest where available water is salty. In the coastal creeks of Kenya and elsewhere in the tropics, strategies have to be developed for the sustainable use of freshwater supplies and the re-use of waste water.

FRESHWATERS IN INDONESIA

Authors
PASI LEHMUSLUOTO
UNDP, Jl. M.H.Thamrin 14, Jakarta, Indonesia
BAMBANG PRIADIE
Research Institute for Water Resources Development, Jl. Ir. H.Juanda 193, Bandung, Indonesia



Study Area
Major freshwaters in Indonesia situated in Sumatra, Kalimantan, Java, Bali, Lombok, Sulawesi and Irian Jaya. They are important as water sources for humans and nature (some 400 km^3 with regional importance), for ecological diversity, conservation, irrigation, fisheries, hydropower development, transport, recreation, tourism and religious ceremonies.

Working Hypothesis
Reliable long-term freshwater data are very limited. Uncoordinated short-term studies have caused uncalibrated situations in results comparison and evaluation.
Many freshwaters may be preserved with good governance and planning but their properties (water quantity, water quality and habitats) and behaviors (ecological processes and biological production) need to be adequately known. They shall also be accounted for as national assets for their sustainable utilization and protection, and for preservation of natural freshwater heritage sites.

Methods
1. Long-term well coordinated monitoring of development in watershed areas and freshwaters with carefully chosen and indicative geographical, geological, volcanological, meteorological, hydrological, physical, chemical and biological variables.
2. Transformation of findings into development and policies, rules and regulations followed by their proper enforcement, in which monitoring and research are important tools.

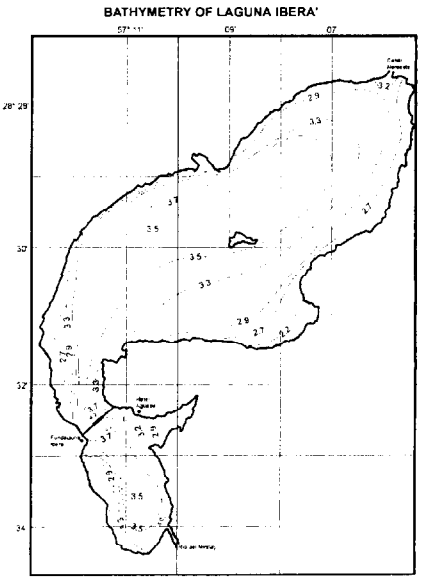
Results
1. Ecological health of freshwaters is still good with a few exceptions of rivers and shallow waters which are heavily silted, polluted, eutrophied or contaminated.
2. Freshwaters are still reliable sources of water and protein-rich food. Sustainable freshwater habitat and ecosystem management can be integrated in economic development.
3. Freshwaters are not bottomless sinks into which all manners of waste materials can be dumped, but ecological entities and they shall be treated as such. Data on their riparian systems, ecotones and watersheds, are urgently needed.
4. Major threats to freshwaters are uncontrolled land-use, forest clearing, uncontrolled agricultural practices, use of agro-chemicals, industrial wastes and effluents, domestic wastes and sewage, water flow and level regulation, and scenarios for future sea-level rise.
5. Inadequate information has previously lead to misunderstandings in decision making. Clear and credible research and monitoring concepts may presently be developed.

Ecohydrological Implications of this Study
Freshwater management has been based on economic objectives but now it can be through the ecohydrological approach together with multiple-objective and integrated planning giving more weight on non-economic objectives.
Goals for reduction of point and non-point loading can be set, together with better understanding of land-use and water interrelationship, and assimilative capacity and sensitivity of the receiving waters, including the surrounding sea areas.
Identification and prioritization of information, monitoring and research needs including requirements of decision makers and other users of data can be defined, and ways to asses quality of freshwaters can be established to provide timely information to outline environmental management strategies.
Monitoring and research can be directed towards issues of national importance with state and problem analysis, problem identification, goal definition and response and trend evaluation rather than of academic interest.

INSTRUMENTS FOR THE MANAGEMENT OF RESOURCE USE IN SHALLOW LAKE WETLANDS

Authors
STEVEN LOISELLE
SIMONE BASTIANONI
CLAUDIO ROSSI
Department of Chemical and Biosystems Sciences,
University of Siena, Pian dei Mantellini 44, 53100 Siena

Study Area
Laguna Ibera and Laguna Galarza, Esteros del Ibera, Corrientes, Argentina.

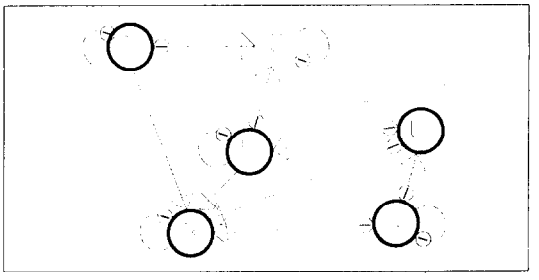


Working Hypothesis
Hydrological and ecological models can be used as the basis for the management of equitable wetland resource utilisation when combined in ecological-economic models.
Trophic web based goal functions, qualititative models and energy flow analysis can be used in predicting impacts of resource extraction to ecosystem integrity.

Methods
Long term continuous monitoring of hydrological parameters (water temperature, conductivity, pH, dissolved oxygen (and saturation), and turbidity, water height) and meteorological parameters (air temperature, ground temperature, humidity, wind direction, wind speed, atmospheric pressure, rain, global radiation, PAR, UV A, UV B, leaf wetness) is combined with monthly biological and ecological sampling.
Scenario analysis of potential future development in a series of public meetings with key provincial and local actors (teachers, university professors, clergymen, local business persons and politicians) to address both the small scale modifications of wetland use (water extraction for agriculture, tourism, controlled hunting ...) as well as regional projects related to the creation of large scale economic development (forestation, modification of nearby waterways for hydroelectric production and increased river transportation).
The development of ecological and hydrological models of the two lagoons to be used as analysis instruments in scenario analysis
The development of an ecological-economics model based on hydrological and ecological models
The development of evaluation instruments to examine effects of economic development on ecosystem integrity, these include; qualitative models using loop analysis, goal functions based on the aquatic trophic web and the overall energy flux in the lagoon, and a geographical information system utilising satellite images.

Results
1. During and after significant rains, significant variations in the Laguna Ibera's pH have temporal and spatial variations with variations up to 3 pH units (8.8 to 5.8) due probably to humic acids entering from large areas of floating vegetation (embalsados).
2. Qualitative models of top predators demonstrate that the prohibition on caiman harvesting could have a negative effect on large piscivorous bird populations that are important for tourism development.

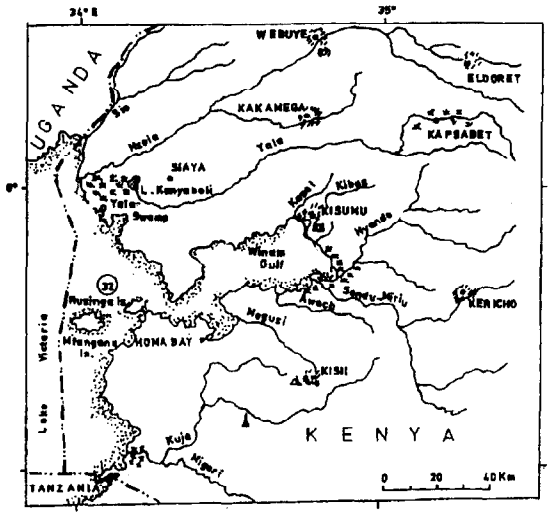
LOOP MODEL INCLUDING
CAIMAN **(C)**,
LARGE AND MEDIUM-SIZED AQUATIC INVERTEBRATES (DRAGONFLIES, WATER BEETLES, WATER BUGS, CRABS, MUSSELS AND WATER SNAILS) **(I)**, AMPHIBIANS AND REPTILES (FROGS, TOADS AND WATER SNAKES) **(AR)**, LARGE PISCIVOROUS BIRDS **(B)**, LARGE OMNIVOROUS FISH (ERYTHRINIDAE, RHAMPHICHTYIDAE, PIMELODIDAE) **(LF)**, PIRANHAS **(P)**, SMALL PLANKTIVOROUS FISH **(SF)**.



Ecohydrological Implications of this Study
Sustainable water management requires the integration of ecohydrological thinking with social and economic opinions to produce long-term policies. This method is advancing the process.

BENTHIC MACROINVERTEBRATES INDICATORS OF WATER QUALITY IN RIVERS ENTERING LAKE VICTORIA, KENYA

Author
JONES MULI
KMFRI, Kisumu Research Centre,
Kisumu. Kenya



Study Area
Rivers Kasat, Nyando, Nzoia, Sondu/Miru and Yala of Lake Victoria, Kenya

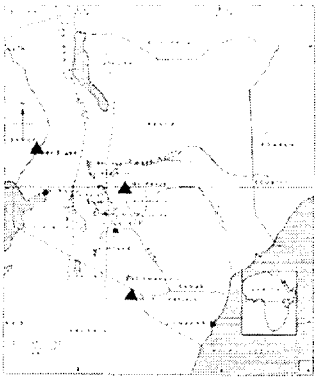
Working Hypothesis
As water quality decreases, species richness and diversity decreases. Few taxa with very high abundance of one or two taxa then indicates high environmental stress.

Methods
Monthly sampling from March 1994 to March 1995. A handnet (mesh size 300 µm) was used to sample for benthos from rivers In parallel physical and chemical water parameters O_2, pH, temp., conductivity, turbidity, water current, PO_4, NH_4 were measured using appropriate meters. Hardness and alkalinity was determined by titration in situ.

Results
The rivers Sondu and Awach harbours rich species composition with species which are indicators of clean water condition. These are *Heptagenia sp, Epeorus sp* (Ephemeroptera) and *Neoperla sp* (Plecoptera). On the other extreme, is river Kasat, which has few species among them Eristalis sp and Chironomidae of *the C. thummi plumosus* groups, all indicators of pollution. Presence of pollution was further indicated by absence of species, which indicate cleaner water condition. The other rivers, namely Nyando, Nzoia Yala in order of decreasing water quality, lay between these two extremes.Of special interest in the species composition is the presence of *Bulinus sp* at River Kasat which is vector of the *Bilharzia* causing *organism Schistosoma haematobium.*
Generally the number of taxa and their abundance didn't increase with increasing oxygen level. However sampling points upstream of effluent discharges compared to those after the discharge had generally higher oxygen level and higher taxa/abundance. This is distinct in the rivers Kasat, Nyando and Nzoia.
Values of hardness (CaCo3 mg/l) do not explain the distribution of Mollusca.

Ecohydrological Implications of this Study
Benthic macroinvertebrates can be used to assess water quality and it is possible to construct a biotic index for the rivers in Lake Victoria catchment area. However, more samples are still needed and more diverse sites should be sampled. Belgian Biotic index if modified, based on East African fauna, can be used in water quality assessment. in East African rivers. If developed, this biotic index can be used for routine monitoring of water quality in the East and central African region.

THE HISTORY OF LARGEMOUTH BASS *MICROPTERUS SALMOIDES* INTRODUCTION AND TRANSFERS IN EAST AFRICA



Authors
D.N. OENGA, S.M. MUCHIRI, B.C.C. WANGILA
Department of Fisheries, Moi University, Eldoret Kenya
KAREN L.VEVERICA
Sagana Fish Culture Farm, Sagana, Kenya

Working Hypothesis

Introductions of alien fish to new areas has resulted in increased fish production in some cases, decreased fish diversity in other cases or in some situations no notable effect.. Largemouth bass *Micropterus salmoides* a fresh water fish native to North America has been introduced to many parts of the world. In East Africa, it was introduced in 1928 in Lake Naivasha and dams in Central Province, Kenya.

Methods

Primarily this study involed a search of literature, archives and interviews with Government officers.

Results

In 1928 Lake Naivasha was stocked with six two year old *M. salmoides* and 98 fingerlings obtained from Surrey Trout Farm, which in turn had obtained their stock from the Netherlands.

By the 1960s, *M. salmoides* had practically exterminated the indigenous fish (*Haplochilichthys antinorii*) and established a predator/prey ecological equilibrium with *Tilapia spp.*

M. salmoides was introduced in the upper reaches of Sondu-Miriu River in 1943. By the late 1960's it had been transferred to, and established in several dams and reservoirs in Kericho, Bomet, Nandi, Kisumu, Uasin Gishu, and Transnzioa Districts all within the Lake Victoria basin.

Blue gill (*Lepomis macrochirus*) fish were imported and introduced to several water bodies in East Africa to serve as a forage fish to *M. salmoides*. The red swamp crayfish were introduced in the 1970's also to provide forage and as alternative fishery species.

EAST AFRICA WATER BODIES STOCKED WITH LARGEMOUTH BASS *Micropterus salmoides* L.

Date	water body	No. of fish	Source	Water- shed	District	Authority	Remarks
1928	L. Naivasha	104	Holland	R. Valley	Nakuru	GoK. Archives	died in 1940's
27/11/58	Lake Naivasha	220	Ruthagat iKenya	"	"	"	re-established.
19/11/68	Lessos Dam	60	Sagana Kenya	Lake Victoria	Nandi	"	Owned Eld. Mun.
12/1/68	Koisagat Dam	117	"	"	"	"	Tea Estate
4/62	Kipkaren		Kitale Kenya	"	T/Nzioa	"	no record of No.
9/6/64	Chemoni Estate		Sagana Kenya	"	Nandi	"	fish sent by rail
9/1/64	Kapchorwa Estate	100	"	"	"	"	"
1964	Two River Dam		"	"	Uasin Gishu	"	no record
2/61	Koibos Dam	43	"	"	T/Nzioa	"	supplied other dams too
19/9/62	Prisons Dam	5	"	"	"	"	sent by rail
1/73	Sotik Tea CO .Dam	50	"	"	Bomet	"	sent by air
1968	Mweiga Dam			Tana River	Nyeri	"	was being fished
about '52	Ruthagati			"	"	"	plenty of fish in 50's&60's
1/5/69	Solio Ranch Dam		Mweiga Kenya	"	Nyeri	"	had est. fish.
1952	Sagana F.C.Farm		Ruthagati Kenya	"	Kirinyaga	Former F.O's	bred & supplied
3/59	Runyenjes		Sagana Kenya	"	Embu	GoK archives	
9/1960	Kathekai	30	"	Arthi River	Machakos	"	sent by rail
14/1/70	Kapkiri Dam	60	"	Lake Victoria	Kisumu	"	with tilapia
18/3/65	Narosura Dam		"	"	Vihiga	"	sent by rail
4/49	Makindu		"			"	early batch doing well
8/69	Wesu Dam	30	"		Wundanyi	"	sent by rail
8/69	Kiu	25	"	Tana River	Kiambu	"	1st Stocking
6/62	Serengeti N. Park	14	"		Arusha TZ	"	doing well year later
6/10/64	Momella Dam	30	"		U.S River	"	doing welll
4/60	Twane Farm	50	Sagana Kenya		Iringa TZ	GoK archives	thro' Agr. Ministry of TZ
4/59	Lake Bunyonyi	60	Sagana Kenya		Entebe UG	"	gravid fish reported
4/60	Lake Mutanda	20	Kyamira F Centre		near Entebe	"	no catch reported
2/56	Lake Nkugute	16	9 Sagana Kenya & 7 from S/Africa			"	no record of establing
4/59	"	60	Sagana Kenya			"	"
5/59	Lake Saka				Ft.Portal UG	"	being caught by 1960's
3/59	Kigezi	35	Sagana Kenya		Uganda	"	CFO ordered fish

Ecohydrological Implications of this Study

There is limited information about alien species inhtroduced because they often do not have goo records kept of such transfers. Fish are often exceptions because of the records of angling and fishermen's catch. However, in Kenya there are few records collected and published. This adds an important dimension to aid our handling of exotic species in the future.

DISTRIBUTION OF *LABEO CYLINDRICUS* WITHIN THE MAJOR DRAINAGE SYSTEMS IN KENYA

Authors
OKEYO BENARDS
LUC DE VOS
Ichthyology Department,
National Museums of Kenya,
Nairobi

Study Area
Major drainage systems in Kenya.

Working Hypotheses
1. How does variability differ across the drainage systems in Kenya?
2. Are these subject to ecological characteristics, landuse patterns, varying water regimes especially in seasonal rivers and lakes. conservation and use?
3. Can the distribution show correlation between use and conservation?
4. What scientific cum sociological recommendations be enhanced to ensure the survival of the species and enhancement of the ecological functions of these fresh water ecosystems?

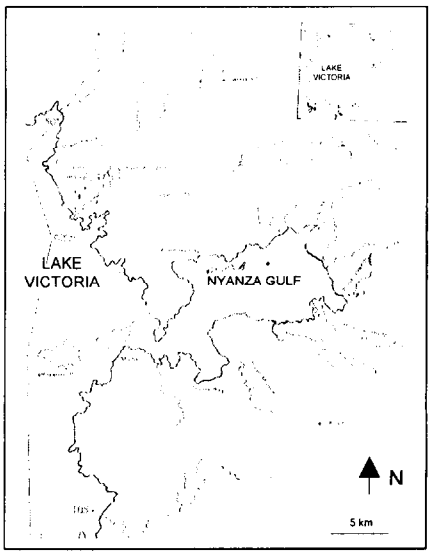
Methods
Fish collections with emphasis on *Labeo cylindricus* were made from all fresh water drainage systems within Kenya. Sociological and scientific data were collected about aspects of species ,water and its varying regimes, landuse patterns, deforestation. Logarithmic indices of relative abundance computed about each drainage system. Index=log (observed abundance /mean abundance)*100)/2 and sample variances of these indices used as a measure of relative variation.

Results
Labeo cylindricus seemed to be a common species in all drainage systems in Kenya. Use of species a source of food, had the least impact in species population. Greatest decline in *Labeo cylindricus* was more enormous in the Athi and Tana rivers drainage systems (this was attributed to high release of chemical toxins into the rivers). Smaller lakes like Kamnarok had low survival rates for the species due to high difference in water regimes, and extensive irrigational use.

Ecohydrological Implications of this Study
There should be controlled harvesting of fish species (especially *Labeo cylindricus*) this can be done through regulation of net sizes. Release of chemical toxins into fresh ecosystems should be regulated and all effluents subjected to thorough treatment first. Some kind of levy , should be imposed on chemical effluents , to spur research in chemical waste treatment. Management of fresh water ecosystems should involve local communities and should incorporate local concepts and traditions.

ZOOPLANKTON IN RELATION TO ENVIRONMENTAL FACTORS IN LAKE VICTORIA (KENYA)

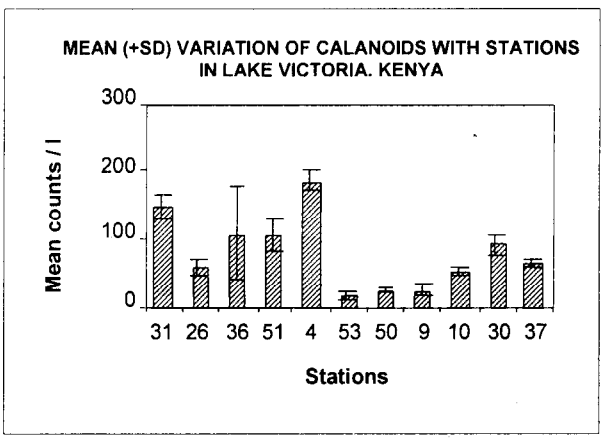
Authors
M.D MASAI
R.OMONDI
Kenya Marine and Fisheries Research Institute,
PO BOX, 1881, Kisumu



Study Area
Lake Victoria (Kenya portion) mainly stations influenced by river discharges.

Working Hypotheses
Hydrology of major affluent rivers influence the zooplankton community structure in Lake Victoria (Kenya). Other environmental parameters determine the distribution, occurrence and abundance of zooplankton.

Methods
Vertical hauls will be taken with a Nansen type net 50 μm. Identification will be carried using appropriate keys. Counting was done under a dissecting microscope (x40 magnification). Physical parameters (Temperature, pH, Conductivity, Dissolved Oxygen) were taken with a multi-parameter monitoring system (Hydrolab surveyor (II) unit). Hydrochemical parameters (PO_4-P, NO_2-N / NO_3-N, NH_4-N, SiO_2 were analysed.

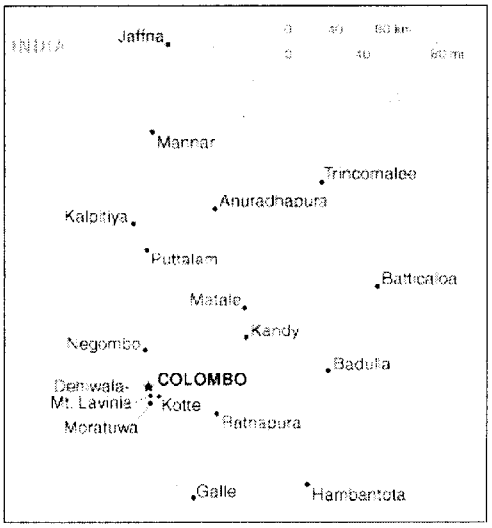


Results
High abundance of calanoid copepods in the inshore stations (31,36 and 4). But low abundance of calanoid copepods in the river-influenced stations (53, 50) where turbidity is very high.

Ecohydrological Implications of this Study
Information obtained is important in the management and utilisation of fisheries resources of L. Victoria. The inshore area is where there is greatest human influence and so an understanding of the precise effects of the inflowing rivers on the lake resources is needed in order to move towards sustainable management.

TRADITIONAL USE OF *RHIZOPHORA SPP.* IN THE BRUSH PILE FISHERY IN COASTAL ESTUARIES OF SRI LANKA: A SUSTAINABLE UTILIZATION SYSTEM FOR MANGROVES

Author
S. LIYANAGE



Working Hypotheses

Traditional fisherfolk of Sri Lanka are mostly concentrated along the large lagoons and estuaries, where fishing provides a basic employment for more than 100,000 families. The invention of multiple-day fishing craft has reduced the pressure for shallow sea fishing and people are moving to deeper areas for fishing. However, significant number of fishing families in Negambo and Chillaw lagoons of northwestern coast of Sri Lanka, still practice traditional fishing system called " brush-pile fishery".

Methods

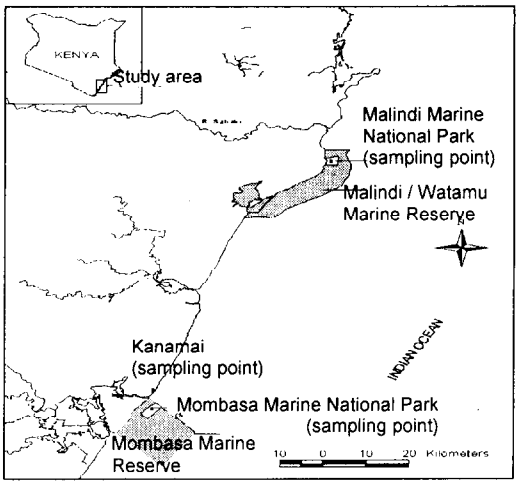
This is very skilled, traditional system, with separate and specific locations of the lagoon. Families who practice this fishing system demarcate these areas. with very close dependency on mangroves. Piling branches of mangroves in shallow lagoon bed creates a temporary habitat for fish as well as prawn. Most brush-piles are about 1-1.5 m in height and cover an area about 6-9 m^2. These stacked branches keep in the lagoon for nearly 4-6 weeks without any disturbances. In this period, fish become familiar with the place and seek the protection in side the pile. After 4-6 weeks the brush-pile is covered by with a small net fixed to the muddy lagoon base. Mangrove branches, are gradually removed, fish trapped in side are caught using a hand. Juvenile or smaller fish are released back to the lagoon immediately without any damages. Fishing is repeated every 4-6 weeks and a brush-pile used for 6-8 months until branches become decayed. After 6-8 months a new brush-pile is constructed.

Ecohydrological Implications of this Study

The brush-pile fishery is a sustainable, eco-friendly system, which has direct dependency on mangroves, and fishermen have protected mangroves from illicit felling and clearing. However, with the development of commercial shrimp farming, large areas of mangroves have been cleared and lagoon water polluted. This has created negative impacts on lagoon fish population reducing the breeding and feeding grounds, sedimentation and pollution of water from effluent discharge from shrimp farms. Recent studies show fish catch from brush-pile reduced by about 40% and shrimp catch by 60%. This situation is further aggravated due to sedimentation and flash floods due to other development and clearing of mangroves in the lagoon. Today, the brush-pile fishery does not provide adequate income for the fishermen who seek secondary employment. In view of this, Lanka Small Fisherfolk Federation (LSFF) has stepped into this issue and started lagoon resources conservation programme with local fishermen to enhance mangrove resources while supporting traditional brush-pile fishery. LSFF is working with these fishermen to conserve mangroves by replanting, rehabilitation and protection. The extractions of mangrove live branches for brush-pile also limited to actual requirement and cutting of mangrove trees is done in a less-harmful manner. Awareness campaigns have been carried out against opening of new shrimp farms and other development, which produced good results. Fishermen have got together to oppose new non eco-friendly development by pressuring local politicians and administration. Today, there is a hope that the traditional brush-pile fishery will survive for many generations in future.

CORAL STRESS AT THE SABAKI ESTUARY: TEMPERATURE OR SEDIMENT DISCHARGE?

Authors
RENNATUS MDODO
DAVID OBURA
KMFFRI, Mombasa, Kenya

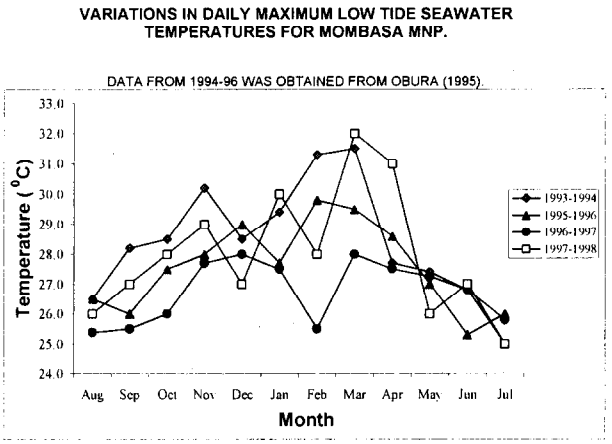


Study Area
Malindi Marine National Park.

Working Hypothesis
Temperature vs sediment cause different stresses on coral species. This will affect zooxanthellae/chlorophyll-a dynamics under different environmental conditions. Mitotic indices of zooxanthellae in different species may provide new techniques for assessing reef health that will enhance local and regional conservation of coral reef biodiversity and management of reef resources.

Methods
Zooxanthellae were extracted from coral tissue. Chlorophyll-a was extracted and determined using spectrophotometric methods. Mitotic Indices and percentage of zooxanthellae exhibiting a clear division furrow were calculated from replicate counts of zooxanthellae Healthy corals were obtained from the study site and transplanted into aquaria in the lab. Corals were then subjected to different level of both temperature and sediment stress and levels of tolerance measured.

Results
Higher temperatures 32°C and above causes stress to corals which respond by bleaching and death if the stress persists. Normal corals have significantly higher densities of zooxanthellae and chlorophyll-a concentrations compared to bleached coral. Sediments from the Sabaki river do not have serious effects on the corals in Malindi Marine Park by comparison with this temperature effect. Field measurements indicate a sharp rise in temperature in the study area in March and April 1998 rising from 28°C in February to 32°C in April). Percent live coral cover was 46.5 before the bleaching event. Mass bleaching occurred in April and between 50-90% mortality was recorded.



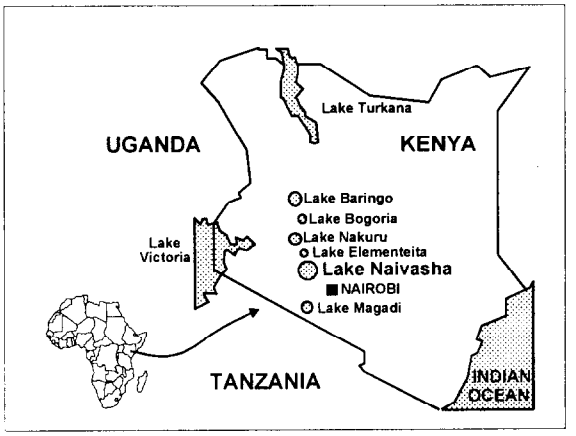
Chlorophyll-a concentration ranged between 0.002 mg/cm^2 and 0.284 mg/cm^2 for bleached corals and 0.176 mg/cm^2 and 0.795 mg/cm^2 for normal corals. Measurements from different species indicated significant differences between bleached and normal colonies ($p<0.002$) and between species ($p<<0.001$). Zooxanthellae density ranged between 0.7×10^6 and 4.5×10^6 per cm^2 for normal corals and 0.02×10^6 and 0.2×10^6 per cm^2 for bleached corals (total loss of zooxanthellae and pigment was recorded in a few coral fragments). Zooxanthellae densities showed significant differences between the different species and between normal and bleached fragments ($p<0.005$).

Ecohydrological Implications of this Study
Chlorophyll and zooxanthellae measurements can be used as an index for early warning of coral bleaching onset. This will enhance local and regional conservation of coral reef biodiversity and management of reef resources.

MICROBIAL DIVERSITY IN THE SODA LAKES OF KENYA

Author
W. E. MWATHA
Department of Botany,
Kenyatta University,
Nairobi, Kenya

Study Area
Lakes Elementaita, Nakuru, Bogoria, Magadi, Sonachi and Oloidien.



Working Hypothesis
We have extensively studied the microbial diversity in the alkaline-saline lakes of Kenya.
Several hundred strains of aerobic, non-photosynthetic organotrophs have been isolated from water and sediments of the lakes. The hypothesis is that the microbial diversity belies the low diversity of other taxa in these lakes.

Methods
Collection of water samples and standard microbial methods for isolation of strains and identification.

Results
1. The photosynthetic primary productivity of these lakes is supported by dense cyanobacterial blooms especially *Spirulina platensis* and *Cyanospira.* There is also a substantial contribution of primary productivity by anoxygenic phototrophic bacteria of the genus *Ecthiorhodospira.*
2. The lakes contain dense populations (10^7-10^8 bacteria/ml) of aerobic organotrophic bacteria supported by the high primary productivity. This dense population of organotrophic bacteria is fairly constant despite marked seasonal changes in salinity due to periods of heavy rain.
3. The lakes harbour novel organisms including *Igatibacter hanningtonni, Sodabacter nakuruai, Magatibacter afermentans, Dietzia natronolimnaios, Bogoriella caseilytica, Thermopallium natronophilum, Halorubrum vacuolatum, Natroalba magadii, Spirachaeta alkalica* and *Natrononiella acetigena* among others. Some of the novel microbes from these soda lakes may have biotechnological potentials and this currently under investigation.

Ecohydrological Implications of this Study
Soda lakes have either been exploited as a chemical source of soda (Magadi) or conserved as important feeding (Bogoria, Nakuru) or nesting grounds (Natron in Tanzania) of the lesser flamingo. Their value for microbial diversity is poorly known and the results of the present study both have value in their own right as well as having a possible applied use. The extent to which biodiversity is susceptible to changes in hydrological patterns is important knowledge for management of these lakes in an unpredictable climate.

EFFECTS OF HUMAN ACTIVITIES ON THE BIORESOURCES OF THE GANGA RIVER, INDIA

Author
R.J. RAO
School of Studies in Zoology,
Jiwaji University, Gwalior,
M.P. India 474 011

Study Area
Ganga River between Rishikesh and Kanpur in Uttar Pradesh, North India.

Working Hypothesis

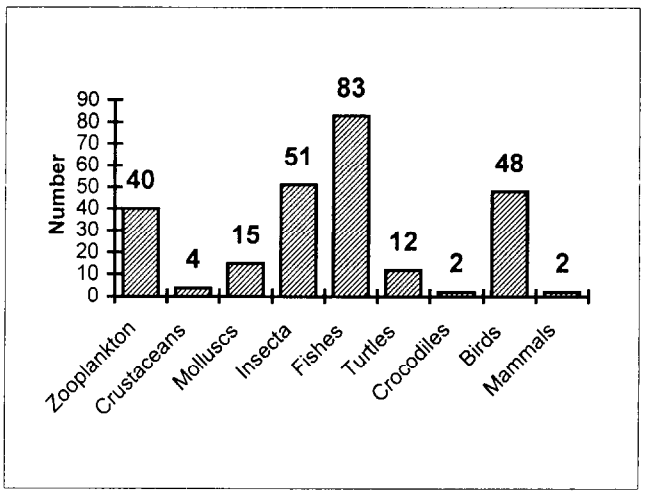
The Ganga River is a major Indian river and it is a good habitat for large number of aquatic animals. Due to human activities the river is polluted and needs restoration. The hypothesis is that programmes of Government, NGOs and riverside people have helped to achieve habitat restoration for the wetland animals.

Methods

No systematic survey has been conducted on the Ganga River in general and upper Ganga River, starting from Rishikesh downstream in particular. Faunal resources in the study stretch of the Ganga River have been surveyed by appropriate capture methods. Information on the human activities and their effects have been collected while conducting regular surveys along the study stretch.

Results

1. The do, bod, cod and tds (mg/l) values varied annually between 3.00-10.32, 0.32 - 18.5, 4.- 61.8 and 46.3 -357.6 respectively. Domestic sewage is reaching the river from all cities and towns including rishikesh, haridwar, anupsahar, narora, farrukhabad and kanpur. Industrial effluents were released at rishikesh from idpl, kachla ghat from sugar factories and chemical industries through the mohawa river, and tanneries at kanpur.
2. Despite this, in the ganga river there is still a rich biodiversity. Two mammals, 48 wetland birds, 2 crocodiles, 12 freshwater turtles, 83 fishes, 4 crustaceans, 51 insects, 15 molluscs and 40 additional zooplnkton species were identified. It was thought before starting the present study, that crocodiles and gangetic dolphins were extinct from the study area.
3. Identification of 12 species of freshwater turtles from this stretch of the ganga river is a major breakthrough in biodiversity studies. Populations of higher vertebrates are under constant threat due to heavy human activities, and immediate action is necessary to protect them.

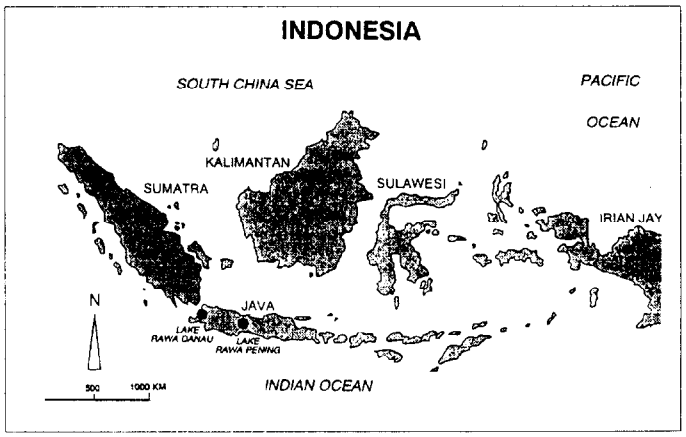


Ecohydrological Implications of this Study

The Government of India has declared an Action Plan for the biological restoration in the Ganga River There has been an establishment of a protected area on the Ganga River, from Bijnor to Narora, and this holds hope for aquatic fauna in Ganga River. However, it is essential for local people also to develop interest in conservation of the species for sustained protection of the animals and their habitats. The biodiversity of this river, compared to other tropical or temperate rivers, cannot be naintained without this social imperative.

MANAGEMENT OF LAKE RAWA DANAU JAVA; INDONESIA

Authors
VICENTE SANTIAGO
UNEP-IETC, Japan
JOHN WEIR
University of New England, Australia
SUTRISNO SUKIMIN
Sameo-Biotrop, Bogor, Indonesia



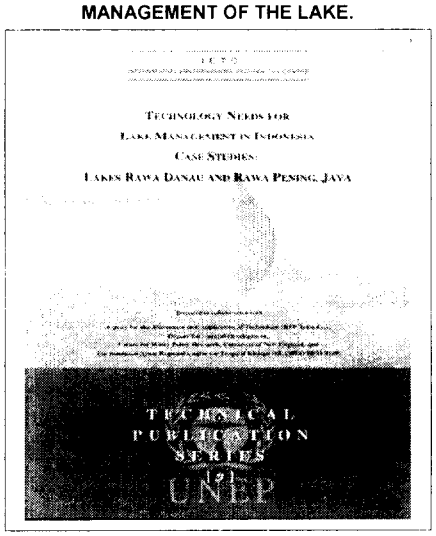
Study Area
What is left of the lake lies in an ancient caldera in the province of West Java, about 100 km west of Jakarta. Geographically it is located at 6 11' South and 105 59' East. The area of the lake is 11ha based on 1981 photographic data and the catchment area is 22,620 ha.

Working Hypotheses
Lake Rawa Danau is in the process of losing the last Swamp Forest growing in the Island of Java within the boundaries of the protected area or Cagar Alam. Increased demand of water by the industrial complex in Cilegon City will further endanger the survival of the lake unless sound management options and technological approaches are not put into practice.

Methods
The strategy to avoid the further degradation of the Swamp Forest will be the restoration of the water level of the lake to something approaching the level of the water prior to its partial drainage by the Dutch in 1825. At the same time the reproductive success of the endemic species of plants and trees in the lake must be assessed to ensure that conditions for successful, re-generation of these species can be determined.

Ecohydrological Implications of this Study
Flooding would actually destroy the swamp forest if it were to be to a depth of several metres and left permanently under water all year. In fact it is likely that the swamp forest might be helped to regenerate if subjected to a limited amount of flooding in the wet season and if the water does not freely drain from the sediment of the caldera into the rivers during the dry season. For the purpose there is a need to rise the water level in the caldera by means of a construction of a dam at its exit. It should be fitted with sluice gates to ensure that water can be released as necessary. Since this will involve storing a considerable volume of water for some months into the dry season and then releasing the water gradually is likely to meet some of the needs of the community in general. Still, the exact water regime, which should eventually be used, will have to be worked out over a period of years in relation to the biology and regeneration of the swamp forest trees.

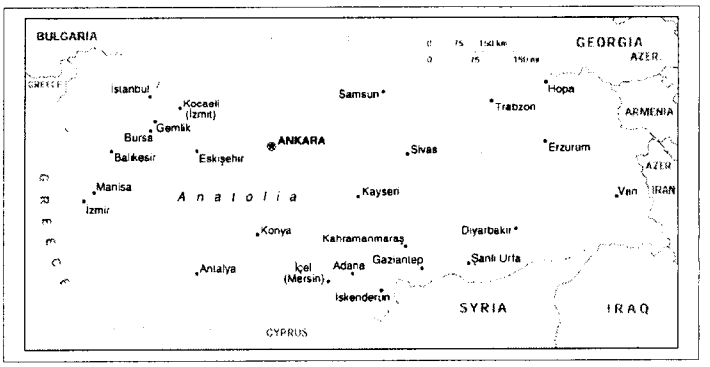
BOX 2
IETC PUBLICATION RELATED TO THE MANAGEMENT OF THE LAKE.



The sluice gates should be so constructed that at least 1.5 metres of water will always be retained within the caldera. This may be increased later after assessment of the effects of flooding. While the construction of a dam is ongoing, water should be retained in the caldera for recovering the similar to that which existed in the caldera 200 years ago. Water available for use by the industries at Cilegon City would be the water that represented the difference between the wet season and dry season levels of the original lake. Box 2 illustrates IETC publication related to the management of this lake.

RELATIONSHIPS BETWEEN HYDROLOGY AND TROPHIC INTERACTIONS OF LAKE MOGAN & LAKE EYMIR FOR AN EFFICIENT WATER QUALITY MANAGEMENT, TURKEY

Author
MERYEM BEKLIOGLU
Biology Department, Middle East Technical University, Ankara, Turkey



Study Area
20 km south of Ankara (39°47'N-32°47'E and 39° 57'N-32°53'E), respectively.

Working Hypothesis
Lake Mogan and Lake Eymir are the part of same hydrological system connected by a sluice. The upstream Lake, Mogan, is a large shallow lake area (6.35 km^2, Z_{max} 3.5 m). The downstream Lake Eymir is a relatively shallow but thermally stratifying (area: 1.25 km^2, Z_{max}: 6 m). The catchment use and the hydrology of the lakes appears to play a prominent role in determining the trophic level dynamics (from algae to fish) through affecting water quality or the load of nutrients, and the water budget. The impact of catchment use (e.g. intensive agriculture, human settlement, water extraction, and recreation) may lead to deterioration ecological value of the lake. Biomanipulation has been attempted in 1998 in Lake Eymir and its effects monitored.

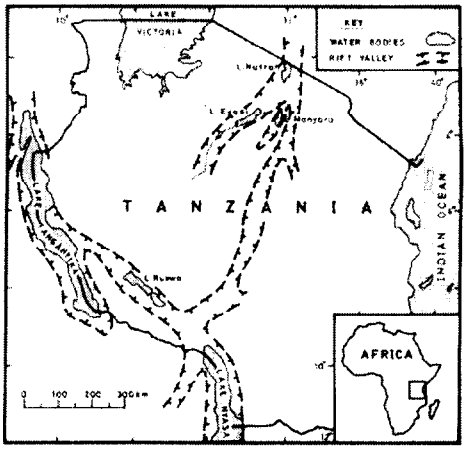
Methods
The sampling of the lakes and the inflows and outflows for physico-chemical and biological parameters have been conducted at regular intervals since March 1997.

Results
A year survey of the lake before biomanipulation showed that the TP concentration was very high (annual mean±SE: 300±24 μg l^{-1}) owing to the external TP loading though the TP concentration fell several fold following a partial sewage effluent diversion in 1995. There was a high spring increase in the chlorophyll-*a* concentration and low summer Secchi. The densities of large-bodied zooplankters, *Daphnia* and *Arcthodiaptomus* remained low (< 1 indv.l^{-1}) in summer. The planktivorous fish-induced control of the water quality appeared to be predominant. The selective removal of tench and carp (33% of the stock 65 tonnes) has been initiated in August 1998. The concentration of chlorophyll *a* and the Secchi depth were significantly different between before and after the fish removal (F: 5.08, P: 0.033, 9.7±2.2 μg l^{-1} and F: 16.88, P<0.001, 285±46 cm, respectively), but the TP concentration did not significantly differ between before and after the fish removal (F: 0.05, P: 0.8) but remained high (292±18.8 μg l^{-1}). The several-fold increase in the density of large-bodied *Daphnia* and *Arcthodiaptomus* following the removal was also recorded throughout this summer. Although the water clarity of the lake has been higher overall in summer 1999 than that of 1998, it had several times collapsed with a short-lasting bloom of blue-green algae *Anabaena* sp. coincident with collapse of the large-bodied grazers. This might be due a high biomass of the fish larvae (YOY).

Ecohydrological Implications of this Study
Lake Mogan has been listed as special site due to being an important wetland hosting 160 bird species. Lake Emyr has potentially extensive development of its littoral zone. There are human settlements (Gölba town and ten small villages giving a population size of 31523), agriculture, small-scale industries, recreational activities and both economical and sportive fishing which are among the widespread uses of the catchment and lakes. There is an urgent need to link the restoration work achieved to date with knowledge of the hydrological regime in order to maximise the use of ecohydrological principles in the formulation of a management plan.

TANZANIA'S RIFT VALLEY WETLANDS AND HUMANS: PRIORITIES FOR ACTION

Author
WILFRED SARUNDAY
National Rift Valley Lakes Project Co-ordinator,
National Environment Management Council,
Dar es Salaam, Tanzania



Study Area
Tanzania: area of 945,000 km^2, of which lakes, swamps and other wetlands represents over 7% of the land surface. These includes the Great African Lakes (lake Tanganyika, lake Victoria and lake Nyasa) and associated wetlands covering 5.2 million hectare, riverine freshwater swamps, marshes, and seasonal floodplains covering 2.7 million ha, coastal mangrove swamps covering about 200,000 ha, minor lakes and the lakes of the Eastern and Western arms of the Rift Valley. Over 7 million people live in the Rift valley basin and are dependent on its natural resources.

Working Hypothesis
The existing pattern of local wetland resource utilisation threatens the long-term viability and stability of the fragile wetland ecosystems of the Rift Valley lakes. These threats are driven by the interaction of socio-economic, cultural, institutional and political forces at the local level and beyond the national boundaries. The GEF Rift Valley Lakes initiative seeks to address these critical biodiversity problems.

Methods
The biodiversity values of the Rift Valley system will be understood and promoted by the GEF project. They include *socio-cultural* – lake waters and aquatic resources vital in supporting the social-cultural systems (including beliefs, rituals, folklore, local spirits,) of the local communities; *socio-economic* - large human populations; *ecohydrological* – ground water recharge & discharge function, the local, basin-wide, national and regional hydrological circles, flood control & regulation, sediment retention, maintenance of ecosystem stability, maintenance of the integrity of other ecosystems (the catchment forests serve several important ecological functions including watershed & stream protection); *zoological* – a variety of avifauna, amphibia, ichthyofauna, reptiles, and mammals; *botanical* – many plant species; *limnological* – the chemistry of rift valley lakes is extremely varied and includes features rarely found elsewhere.

Ecohydrological Implications of this Study
The Rift valley lakes are known to harbour significant numbers of endemic species. For example fish species are: Lake Tanganyika (220+), Lake Nyasa (500+) Lake Rukwa (6+), Lake Natron (1+). The endemic water snail species are 32 for Lake Tanganyika and 17 for Lake Nyasa. Lake Natron is the only successfully breeding site for Lesser Flamingos in the world. Lake Eyasi is the focus of an endemic bird area containing 4 species not found outside Tanzania and another that is globally threatened.
To conserve and sustainable use the biodiversity of the Rift Valley the agenda includes the following:

1. Address effectively both proximate and ultimate causes of biodiversity degradation and loss,
2. Adopt multisectoral and multidisciplinary approaches to meet local communities needs and priorities,
3. Adopt a regional approach to conservation planning and management (e.g. the current GEF initiatives),
4. Perform comprehensive inventories of the lakes to document the wealth of flora and fauna,
5. Conduct innovative ecological and sociological study programmes so as to be able to monitor the trends of anthropogenic impacts on the aquatic ecosystems,
6. Create legislative, policy & institutional frameworks,
7. Create special wetland management reserves to protect endemic and endangered species e.g. Lesser Flamingo,
8. Undertake ecological restoration of the degraded landscapes (e.g. tree planting in deforested areas).

CHARACTERISTICS OF SMALL RESERVOIRS IN THE EASTERN RIFT VALLEY, KENYA

Authors
FRANCIS MWAURA
KEN MAVUTI
Department of Zoology,
University of Nairobi, Kenya

Study Area
The catchment area of the basins of lakes Nakuru, Elementeita, Naivasha, Kenya.

Working Hypothesis
Rural reservoirs provide biological resources in addition to the Rift Valley lakes in whose catchment they are situated.

Methods
Morphometric analysis, physico-chemical limnology using standard methods, biological observation and socio-economic assessment using observation and interviews.

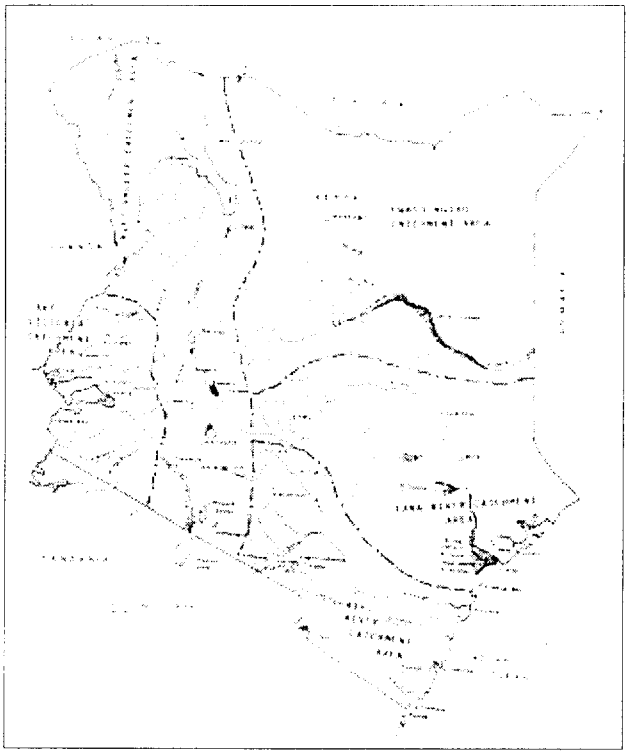
Results
1. All reservoirs were small and shallow – depth 0.8-6 m, area 0.07 – 0.25 km^2. Catchments were up to 57 km^2 and age between 40-48 years. All were polytrophic with turbid water.
2. Phytoplankton blooms were common in the dry season of *Anabaena, Microcystis, Botryococcus* and *Ceratium*. Zooplankton was dominated by *Brachionus, Keratella, Daphnia* and *Diaptomus*. Up to 25 aquatic birds occurred per site, mainly in the dry season.
3. Main community uses were livestock watering and grazing around the edges, by over 50% of the population. The main threats were storage decline, erosion and siltation, algal-toxins leading to cattle deaths, water weeds and bird shooting/egg gathering. There were no fisheries established.

Ecohydrological Implications of this Study
Regular monitoring of water quality and hydroperiodism provides a good indication of the overall health of the catchment land use. They are important foci of biodiversity. The reservoirs play an important role for the community, which could be improved by e.g. fisheries development.
However, in other lakes, e.g. Baringo (see Gichuru and Aloo paper) small reservoirs on the main feeder streams are perceived to affect the quantity of water available to the lake. This conflict needs to be understood and resolved.

SHALLOW WATERS ENVIRONMENTAL EDUCATION AND AWARENESS CREATION IN KENYA

Author
IGNATIUS ABIYA
Kenya Wildlife Service Training Institute,
Naivasha, Kenya

Study Area
The five key drainage basins in Kenya – Rift valley, Lake Victoria, Athi River, Tana River and Ewaso Ngiro basins –and the coastal zone.



THE MAJOR AQUATIC SYSTEMS IN KENYA

Working Hypothesis
In Kenya, as most developing countries, many people do not understand the close links between human activities and the finite nature of environmental resources, including shallow waters. Consequently, shallow water resources and their biodiversity are threatened by unsustainable activities.

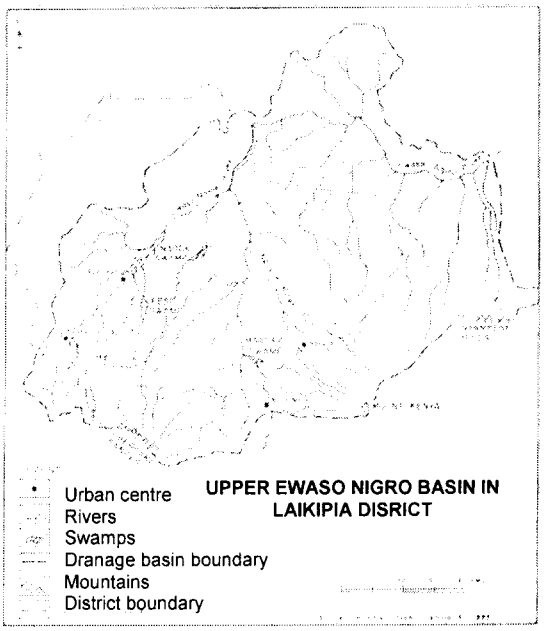
Methods
A holistic multidisciplinary approach to shallow waters environmental education and awareness is pursued, Key players are the National Environment Secretariat, Kenya Wildlife Service (as custodian of the Ramsar Convention), Department of Agriculture, Ministry of Water Resources which organises World Water Day celebrations, WWF and UNEP. Target groups are sectors within the cities as well as indigenous people, farmers and the technical sector.

Results
At policy level the Kenya government has established the need to pursue sustainable resource use and has initiated a National Environmental Action Plan in line with Agenda 21 principles. KWS in its attempts to stimulate multi-sectoral participation in the conservation of shallow waters and awareness-creation has entered into memorabilia of understanding, for example for conservation of catchment forests and mangrove swamps.

Ecohydrological Implications of this Study
Successful ecohydrological management of catchments can only come with the full approval of residents in the catchments, which itself can only be successful once they fully understand the needs and the principles of sustainable development. In developing countries this still has a great deal of progress to make.

CHALLENGES OF CONSERVATION: EWASO NAROK SWAMP, KENYA

Author
THUITA THENYA
Department of Geography,
University of Nairobi, Kenya



Study Area
The 14 km^2 swamp along the Engare Narok river, 0° 15 - 17'N and 36° 34-36' S in the Ewaso Ngiro basin, Laikipia, Kenya.

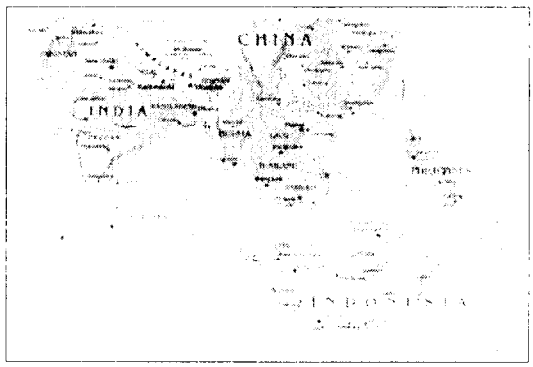
Working Hypothesis
The biological structure of the swamp is not damaged by the human uses made of it.

Methods
A survey of the flora, the mammalian and the bird fauna. Quantification of the bio-economic uses of the swamp by observation and conduction of questionnaires.

Results
The swamp is composed of three major vegetation types. A woodland zone, dominated by *Acacia xanthophloea*, an emergent sedge zone, dominated by *Cyperus papyrus* and a drawdown zone, dominated by *Aeschynomena schimperi*. 106 species of plants in 30 families were recorded; 13 herbivore (mammal) species, and 174 bird species, 49 swamp specialists.
Human settlement started in 1975, with a peak between 1986 and 1992. 3480 people currently occupy the area, (which is public land) with up to 6000 cattle and 10000 'shoats' in the dry season.

Ecohydrological Implications of this Study
The current occupation has led to habitat destruction of about 60% of the swamp through clearance of swamp plants, farming, cutting of riparian trees for fuel and heavy grazing during dry seasons. Although there is partial regeneration during the wet season, the swamp has also lost its natural hydrological functions so there is an increase in flash flooding and incidence of parasitic diseases. Community involvement in a process leading to sustainable utilisation is now proposed to try to strike a balance between resource utilisation and conservation.

SUSTAINABLE MANAGEMENT OF CAPTURE FISHERIES AND AQUACULTURE IN ASIAN RESERVOIRS

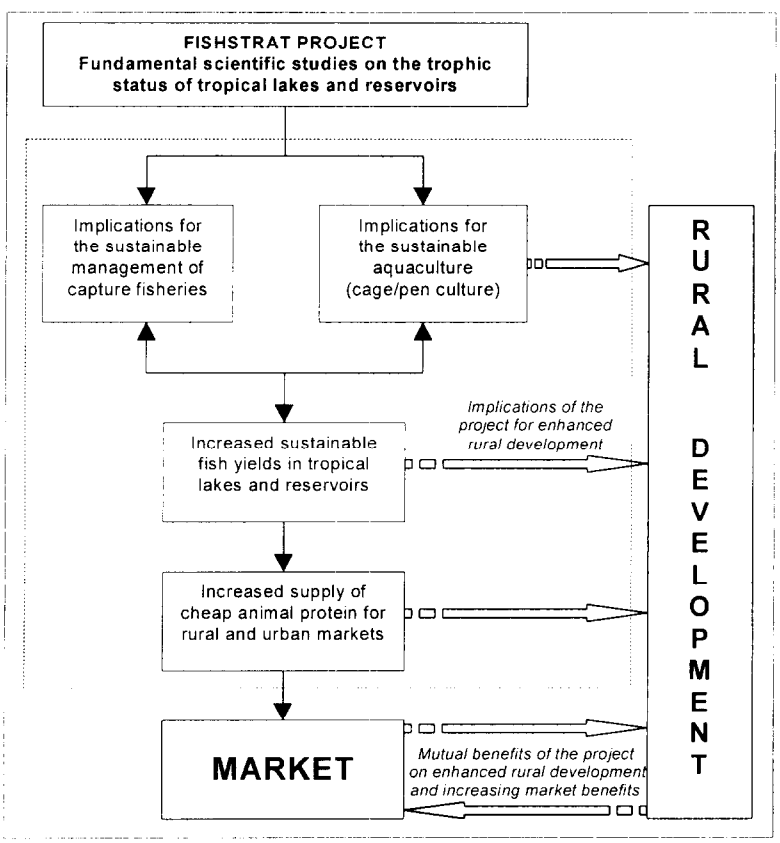


Authors
UPALI AMARASINGHE
Department of Zoology, University of Kelaniya, Sri Lanka
ANNIE DUNCAN
Royal Holloway Institute of Environmental Research, London, UK
JAQUES MOREAU
Institut National Polytechnique de Toulouse, France
FRITZ SCHIEMER
Department of Zoology, University of Vienna, Austria
DAVID SIMON
Department of Geography, Royal Holloway College, London
JACOBUS VIJVERBERG
Netherlands Instate of Ecology, Nieuwersluis, Netherlands

Study Area
Sri Lanka, Thailand and the Phillipines.

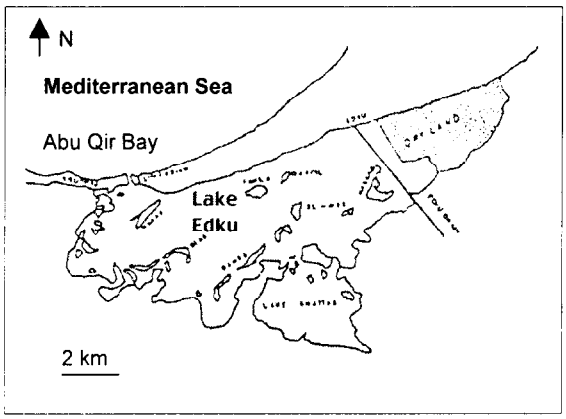
Methods
1. To determine the trophic structure of the water bodies and the capacity to sustain both their existing fisheries and present & future aquaculture.
2. To expand exploitation where appropriate in the local market within the bounds of economic and environmental sustainability.
3. To develop appropriate management procedures in the local socio-economic and cultural conditions.
4. To involve local fisherfolk in such management.

Ecohydrological Implications of this Study
The research team consists of a partnership embracing colleagues from three Asian countries and five European countries. They are drawn from universities, government research institutes and ministries. Phase 1 has been completed and Phase 2. The empirical research has just begun to a standard basis to ensure compatibility among the partners, stakeholders and donors. A series of workshops will be held during this phase. The sustainable management and exploitation of small water bodies involves a clear understanding of the hydrological basis of their fisheries production and the extent to which it controls production (see Mwaura & Mavuti, this volume), particularly if the water bodies have no natural catchment. Involvement of local communities will spread these concepts of sustainability as an integral part of rural development.



NUTRIENT CONCENTRATIONS IN LAKE EDKU, A CONTAMINATED EGYPTIAN COASTAL LAKE

Authors
MASSOUD SAAD
A. ABDEL-MOATI
N. ABDEL-ATTI
Oceanography Department,
Alexandra University,
Alexandria, Egypt

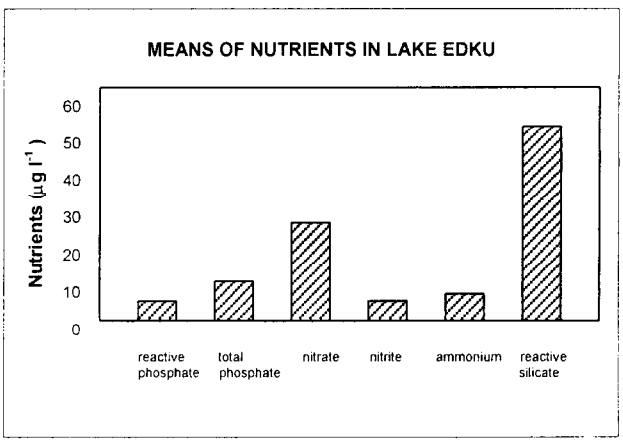


Study Area
Lake Edku and its inflowing drains, east of Alexandria, Egypt.

Working Hypothesis
Nitrogen, phosphorus and silicon forms are higher than previously measured, as a result of intensive agriculture in the area.

Methods
Water samples were collected from lake and inflow drains and nutrients determined using standard methods.

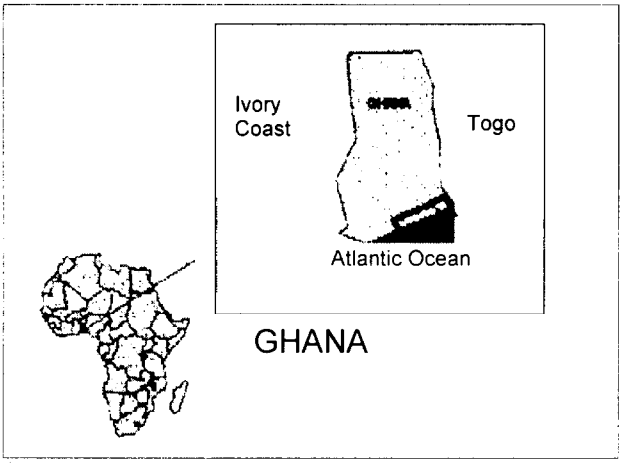
Results
High concentrations of dissolved inorganic phosphorus and nitrate were found in the vicinity of the main drains. Large populations of submerged macrophytes in the mid-lake region regulate phosphorus levels, where 40% of the dissolved phosphorus was in organic form. Dissolved inorganic phosphorus made up 38% of the total phosphorus, particulate between 25 and 49%. Nitrate dominated dissolved inorganic nitrogen, but total dissolved nitrogen was dominated by the organic form to 57%. Nitrogen/phosphorus ratios were high, because of the nitrogen contribution to the drainage water from agricultural fertiliser.



Ecohydrological Implications of this Study
Monthly variations of nutrients were governed by the fluctuations of drainage water discharges and by the loss of drainage water to the sea. Management of the trophic consequences of the drainage waters depends upon the ability to control the retention time in the lake.

WISE USE OF GHANA'S COASTAL WETLANDS

Authors
NICK WILLOUGHBY
ROBIN GRIMBLE
WIM ELLENBOCK
ELIJAH DANSO
JULIUS AMATEKPOR
NRI, University of Greenwich, Kent, UK



Study Area
Coastal Ghana has 5 Ramsar sites making up 500 km^2 of fresh and saline lagoons and 2000km^2 of low-lying catchments. Up to 300,000 migratory birds use them and 600,000 people live there.

Working Hypothesis
The Ramsar Convention demands that sites be used 'wisely'. The key issue is to maintain ecological integrity of the coastal wetlands by involving stakeholders who derive their livelihoods from the system while permitting sustainable developments to continue.

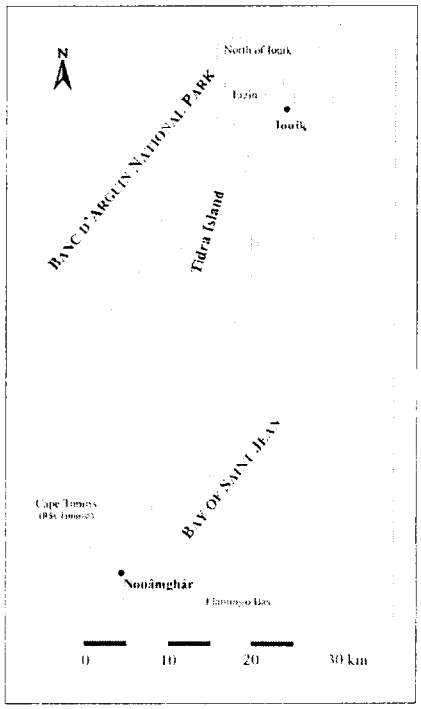
Methods
The approach was to develop and understanding of the complexities and dynamics of the livelihood systems of the local people and their interactions with the biological and physical resources of the wetlands area. Wide consultation with different stakeholders took place to assess their perception of constraints and opportunities and their institutional capacity to participate. Appropriate development options were identified which were technically, socially, environmentally and financially appropriate. A broad analytical planning framework, based on sustainable management, was then prepared and applied in participation with local communities.

Ecohydrological Implications of this Study
The project focuses on assisting stakeholders to develop and manage viable, sustainable, small-scale activities. Formal links were developed with government and non-government agencies. A framework was developed which determined institutional responsibility and arrangements between various stakeholders. Public sector support was encouraged for private sector initiatives, which were in keeping with the sustainable wide-use philosophy. An understanding of the threats to the sites prior to the planning of their sustainable use requires an understanding of their ecohydrology in three states - their 'degrade' state, an ecological 'reference state and their desirable 'sustainable' state.

VIABILITY OF MANGROVES AT THEIR LATITUDINAL LIMITS

Authors
FARID DAHDOUH-GUEBAS
NICO KOEDAM
Laboratory of Botany and Nature Management,
Vrije Universiteit Brussel, Pleinlaan, Belgium

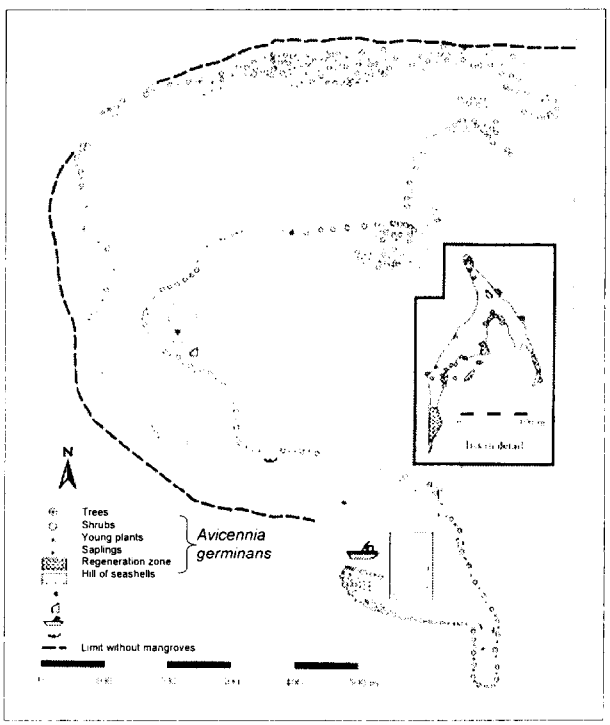
Study Area
Cape Timiris, Bay of St Jean, Iouik and Eizin in the Parc National du Banc d'Arguin, Mauritania.



Working Hypothesis
Avicennia germinans is growing at its northerly limit. Knowledge of its population structure, germination, stress and genetic differentiation will provide a baseline for restoration elsewhere.

Methods
Standard vegetation description, collection of propagules and plantation to assess germination and predation, leaf sampling for genetic differentiation and measurement of environmental variables.

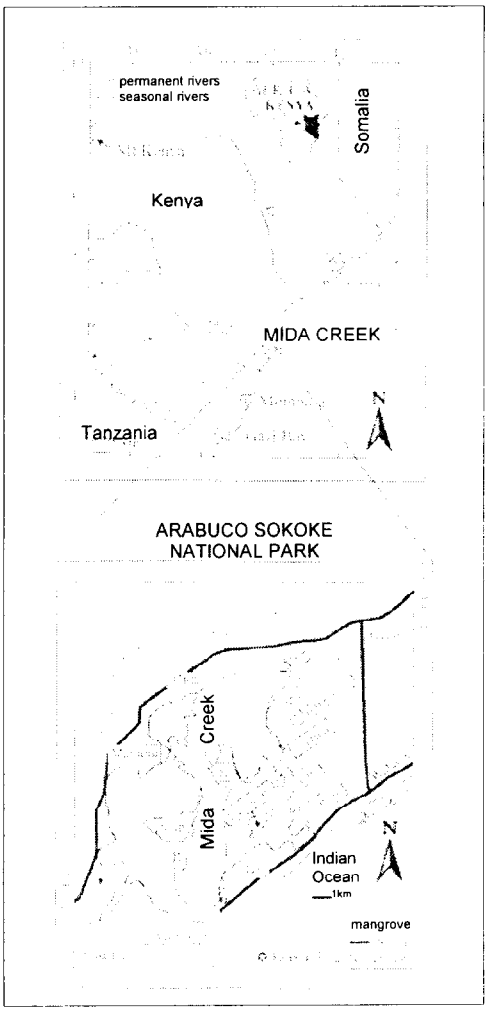
Results
Colonisation of new areas is dependent upon a free flow of hydrodynamics in the bays. There is a genetic distinction between mainland and island populations. Populations flower extensively and have good propagule production but it is irregular within a population. Air and sun exposure of fallen propagules for 24 hours is lethal.



Ecohydrological Implications of this Study
This work indicates the latitudinal limits of mangrove growth. For the first time it produces high resolution maps of the distribution of the species in the National Park, and it demonstrates the limits of conservation and restoration of mangroves in estuarine/creek situations. It provides a reference for further work.

TRADITIONAL MANGROVE EXPLOITATION IN TROPICAL ESTUARIES

Authors
CHRISTINE MATHENGE
FARID DAHDOUH-GUEBAS
JAMES KAIRO
NICO KOEDAM
Laboratory of Botany and Nature Management
Vrije Universiteit Brussel, Pleinlaan, Belgium



Study Area
Mida Creek, Kenya

Working Hypothesis
The uses of mangroves by local people could, if they understood their impact on the ecosystems, be made sustainable, for the benefit of the people and the ecotone.

Methods
Questionnaires were conducted with 30% of the population of Mida Creek, Kenya (comprising 350 households). In addition observations and records were made on household activities.

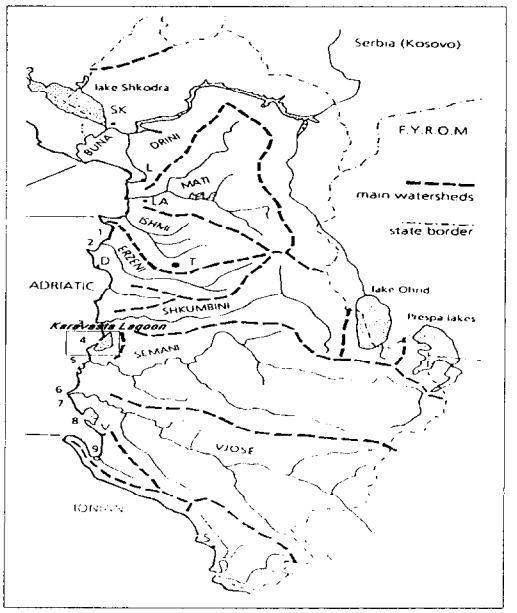
Results
Seventy five percent of the people have an 'expert' or a 'good working' knowledge of the uses of mangroves ('rough idea' and 'no idea' were the other two classes). The traditional uses of the seven species were specific. The most widespread use was poles in house construction, which utilised three species. The majority of people could recognise that the mangrove forest was declining or at least displayed changes.

Ecohydrological Implications of this Study
Local utilisation patterns, rather than a global conclusion, show the exact fate of a natural resource such as the mangrove ecotone. This knowledge is essential for the establishment of community-based conservation schemes with a realistic chance of success. Socio-economics needs to partner ecohydrology in an aquatic environment that is so heavily utilised such as this one (see Kimasop and Cheruiyot, this volume).

THE PROTECTION OF KARAVASTA LAGOON, ALBANIA

Authors
SPASE SHUMKA
Protection and Preservation of Natural Environment in Albania, Str."Asim Vokshi" Pall.33, Shk. 4, Ap. 7, Tirana, Albania
PANDELI MARKU
Agriculture University of Tirana

Study Area
C.4000 ha, Karavasta Lagoon, Divjaka, Albania.



Working Hypothesis
Karavasta lagoon and adjacent region is an internationally important wetland: the quality and peculiarity of flora and fauna which add a genetic and ecological diversity to the area; the wetland community typical of it's bio-geographical region; the presence of 5% of the world's population of pelicans making the lagoon one of five most important sites in the world. The vegetation is characterised by Mediterranean species. Unfortunately illegal over-exploitation as well are overfishing, bird disturbance, hunting, construction. It is proposed that further steps on the frame of nature protection could enhance the biological diversity conservation.

Methods
The 1999 Caracas conference (IUCN) affirmed a widely accepted framework for analyses of protected areas and for the elaboration of policy for their conservation, analyses and management of the resources, for people within the system. For Karavsta Lagoons, the legislation only protects14.55 km^2 of the whole area; 7.80 km^2 as a National Park (the Divjaka Park), and the remaining 6.75 km^2 as a Natural Reserve (the Divjaka reserve). The resource (physical and biological) of this area should be the focus of conservation. Based on the natural values of the region including the sandy littoral belt structure, coastal forest of Divjaka, the lagoon area, living world of this ecosystem we would like to give a new approach towards biodiversity restoration as well as lagoon protection.

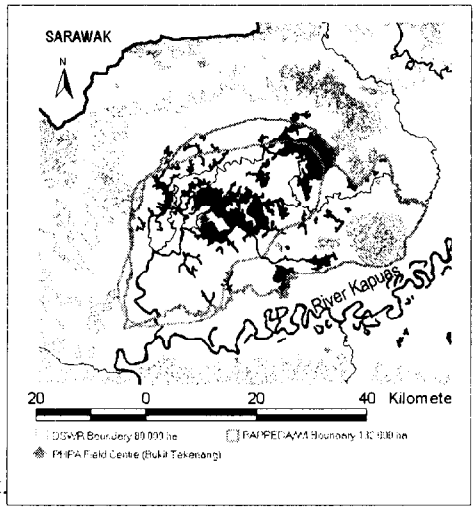
Ecohydrological Implications of this Study
In the spite of its small territory, Albania is a country of a rich biodiversity, due to the very diverse geology and geomorphology, soil conditions and broken topography, hydrology and climate. Karavasta has a legal status of nature protection but needs the institutional strengthening capacity in the frame of national and international low. The 1979 (Berne) Convention of the Conservation of European Wildlife and natural habitats (which Albania signed in 1959 places an obligation on its parties to take such measures as are necessary to maintain populations of all species of animals and plants at levels corresponding to ecological, scientific and cultural requirements.

ALBANIAN LAND USE STATISTICS

Land category	Hectares	Percent total
Forest	1.030.000	36
Agriculture: arable and permanent crops	718.000	25
Agriculture: pastures and meadows	431.000	16
Other land and lakes	696.000	23
Total land area	2.875.000	100

Biological diversity restoration steps include reforestation, wetland restoration, restoration of sand and pebble beaches, removal of the bunkers and their recycling. At the level of the individual site or area requirements first, to define the contribution that site makes to overall national status of the species or habitat, and then to manage the site or area so that this contribution is maintained or enhanced.
Ecohydrology is the holistic management of an aquatic resource taking into account the whole catchment influence. This is a novel approach to conservation in Albania and one, which needs to be encouraged and refined.

COMMUNITY-BASED MANAGEMENT OF FOREST AND LAKE RESOURCES IN DANAU SENTARUM NATIONAL PARK, WEST KALIMANTAN (INDONESIAN BORNEO)



Author
WIM GIESEN
Wetland Consultant, Ulft, The Netherlands

Study Area
Danau Sentarum National Park, West Kalimantan, Indonesia
132,000 ha of floodplain lakes, swamp forest and peat swamp forest.

Working Hypothesis
The integrity of Danau Sentarum NP is threatened by over-fishing, over-exploitation of wood resources and fires. Long-term, sustainable exploitation of these resources is both in interest of conservation lobbyists and the Park's 6,500 human inhabitants, as the latter are much dependent on natural resources. Given the Park administration's chronic lack of funds and the degree of human habitation in the area, community-based management, which builds upon existing traditional management, is considered the most appropriate and effective way forward.

Methods
In 1992-94, an analysis was made of the local economy and use of natural resources, with special emphasis on traditional management approaches. At the same time, an assessment was made of the Park's natural resources, identifying key species and habitats, habitat condition, and threats to the system's integrity. Strengths and weaknesses of existing management were assessed, and opportunities for reinforcing both resource management and the local economy (without threatening the resource base) were identified and implemented on a trial basis from 1993-97.

Results
1. The Park is of considerable significance to conservation, as it supports Borneo's largest Orang Utan Pongo pygmaeus population, the largest inland population of the endemic Proboscis Monkey Nasalis larvatus, three crocodile species, 250 fish species (including many endemics), 30-40 endemic plants and forms an unique ecosystem on the island. However, almost 25% of the Park's swamp forest has been subjected to fires over the past decades, key timber species such as Fagraea fragrans (Loganiaceae) are depleted, and 17 commonly caught fish are over-exploited, including the now rare Asian Arowana Scleropages formosus.
2. The local economy is almost entirely dependent on natural resources of the Park, and more than 80% of all income is derived from fisheries alone. Traditional customary law focuses primarily on fishery resources, which are reasonably well protected, and the main threats (small mesh sizes, funnel nets, poisons) are well understood. In contrast, forest resources have traditionally been open access and loosely regulated. Only recently, as forest resources have come under threat, has customary law been developed to limit the exploitation of produce such as timber, rattan and honey.
3. Existing management was augmented by facilitating regular (conflict resolution) meetings between resource user groups; training in timber mensuration techniques (e.g. thinning) and rattan management (e.g. enrichment planting); awareness raising campaigns (e.g. fires, conservation importance of the Park); boundary demarcation and resource mapping; reducing external party access to resources; and improving communication between Park administration, local government and local community. Efforts to strengthen the local economy included increasing value-added to produce (e.g. honey, beeswax and rattan products), identifying uses for waste material (e.g. fish leather, waterhyacinth paper manufacture) and promotion of new opportunities (e.g. small-scale eco-tourism, lay forest guards).

Ecohydrological Implications of this Study
The results are promising. Local perceptions and attitudes are changing; as expressed by a local villager: "Before we just did activities without thinking about their future impacts, and we experienced resource problems without thinking that we might solve them. The project has shown us that we can think about the future and take actions for ourselves to change the future." The local community is now well aware of the importance of the area to

conservation, and initiatives are being undertaken locally, for example to reduce fire incidence and hunting pressures. Communication lines are evolving, as is the status of the area (e.g. Ramsar Site in April 1994, National Park in February 1999), and economic initiatives first undertaken in 1993/4 are being continued successfully. Community-based management requires a long-term approach and investment of efforts, and display flexibility in order to respond to changes. This approach, which balances the needs of conservation and local resource utilisation, should continue to form the basis of future management initiatives.