Understanding future ecosystem changes in Lake Victoria basin using participatory local scenarios

Eric O. Odada[1], Washington O. Ochola[2]* and Dan O. Olago[3]

[1]*African Network of Earth System Sciences (AfricanNESS), Department of Geology, University of Nairobi, PO Box 30197, Nairobi, Kenya,* [2]*Department of Agricultural Education and Extension, Egerton University, PO Box 536, Egerton, Njoro, Kenya and* [3]*Department of Geology, University of Nairobi, PO Box 30197, Nairobi, Kenya*

Abstract

Understanding future ecosystem changes is central to sustainable natural resource management especially when coupled with in-depth understanding of impacts of drivers, such as governance, demographic, economic and climate variations and land use policy. This offers comprehensive information for sustainable ecosystem services provision. A foresight process of systematic and presumptive assessment of future state and ecosystem integrity of Lake Victoria basin, as participatory scenario building technique, is presented. Four scenarios have been illustrated as possible future states of the basin over the next twenty years. Using a scenario building model developed in Ventana Simulation (VENSIM®) platform, the paper presents a scenario methodology for tracking changes in lake basin ecosystem status. Plausible trends in land use change, changes in lake levels and contribution of fisheries are presented. This is part of an initial attempt to setup long-term environmental policy planning strategies for Lake Victoria basin. The assumptions, driving forces, impacts and opportunities under each scenario depict major departure and convergence points for an integrated transboundary diagnosis and analysis of regional issues in the basin as well as strategic action planning for long-term interventions. The findings have been presented in terms of temporal, spatial, biophysical and human well-being dimensions. The attempts in this study can be embedded in a policy framework for basin management priority setting and may guide partnerships for environmental management.

Key words: ecosystem, human well-being, Lake Victoria, land use

**Correspondence*: E-mail: babatamara@yahoo.com

Introduction

The need to develop future ecosystem change scenarios stems from the important role that human activities play in environmental integrity. The changes range from ecosystem service, functioning and biodiversity to water resources and greenhouse gas emissions. An understanding of how ecosystems state might evolve is needed in order to project how humans will modify their environment in the future and in turn be affected by the changes. A range of models has been developed to better understand, assess and project changes in ecosystems (Veldkamp & Lambin, 2001; Veldkamp & Verburg, 2004). However, in spite of progress in integrating biophysical and socio-economic drivers of ecosystem change (Veldkamp & Verburg, 2004), projections of future ecosystems conditions remain difficult. Scenario analysis provides an alternative tool to assist in explorations of the future. Scenarios offer a means for examining the forces shaping the world, the uncertainties that lie ahead and the implications for tomorrow of today's actions (Kemp-Benedict, Heaps & Raskin, 2002) and inactions. Scenarios are meant to offer a logical plot and narrative of alternative futures at designated points-in-time explaining clearly any possible future dispersions and taking into account the obvious systems complexity (Toth, Hisznyik & Clark, 1989; Alcamo *et al.*, 2006). The assumption is that the 'current state' of the environment is the outcome of a historical process, which is driven forward by a set of 'driving forces' (Ruskin, 2000) into different future pathways. Scenarios can robustly facilitate understanding of local and global change (Alcamo *et al.*, 2006). Ecosystems 'foresighting' and exploration can reveal possibilities of ecosystems management and help in making choices by showing the consequences of different policy directions.

Much research has been carried out in Lake Victoria basin on its geology, land resources, pollution, wetlands, biodiversity, soil erosion and agricultural production (e.g.

Johnson, Kelts & Odada, 2000; Odada *et al.*, 2004), but it is often of a fragmented nature. The basin was chosen as a suitable case to operationalize a method for exploring ecosystems provision and resource use options for such a well endowed, but fragile ecosystem with problems of land degradation, pollution, resource use conflict, limited opportunities for off-farm employment and food insecurity as well as major environmental and societal issues. This study reports preliminary quantitative, spatially explicit and alternative scenarios of future ecosystem change in the basin, which have been locally constructed to support analyses of the vulnerability of ecosystem services as an attempt to setup long-term environmental policy planning strategies for Lake Victoria basin.

The study area

Lake Victoria basin is located in the upper reaches of the Nile River basin and occupies an area of about 251,000 km^2 of which 69,000 km^2 is the lake area (UNEP, 2006a) and is shared by Kenya, Uganda, Tanzania, Rwanda and Burundi. The basin contains Lake Victoria, which is the largest freshwater lake in Africa and also the second largest freshwater lake of the world. The mean depth is about 40 m with a recorded maximum depth of 84 m and the volume of water stored is estimated at about 2760 km^3 (EAC, 2004).

The lake is at an altitude of 1135 m above the sea level and lies on the equator at 0°30′N–3°00′S and 31°39′W–34°53′E. Knowledge about the history and associated ecological changes of the lake is relatively advanced (Johnson *et al.*, 2000). The growing population, with an average annual growth rate of 3% and an average population density of about 165 persons km^{-2}, is exerting increasingly greater pressures on its natural resources. The utilization of these resources is heavily driven by livelihood needs of the inhabitants of the basin occasioning far reaching ecosystem changes. The socio-cultural and socio-economic image of the lake basin is closely intertwined with the survival activities of the lake region communities, which have ethnic differentials as well as regional universalities.

Methodology

The scenario approach employed replicates the ex-post ecosystem changes over the period 1980–2005. Figure 1 illustrates the methodology of iterating the extended Vensim models used in the scenario framework. Chief economic, social and environmental drivers (see Westhoek, Van De Berg & Bakkes, 2006) have been used as input in the model. The socio-economic and environmental consequences for the basin's ecosystem are calculated and static features showing ecosystems state captured with the

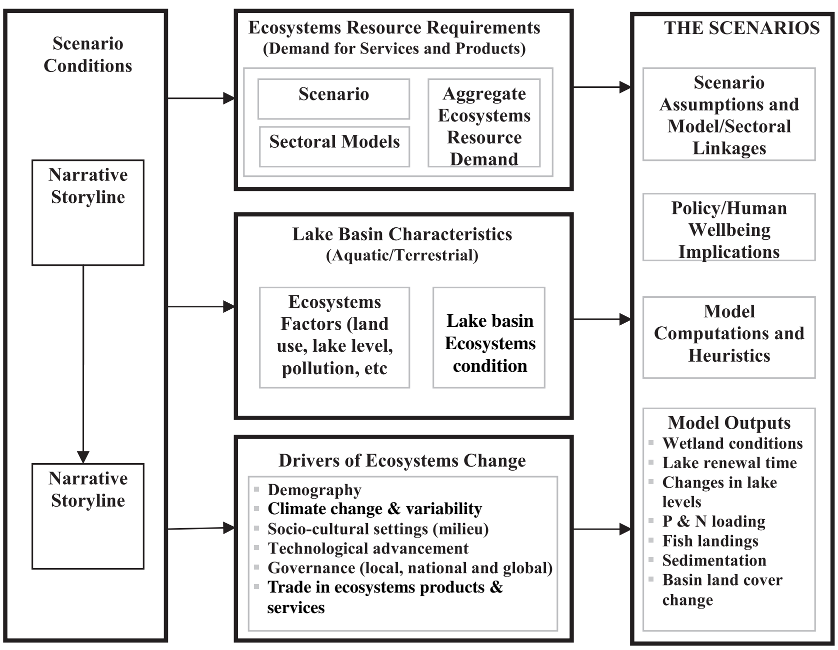

Fig 1 Iterative illustration of the scenario methodology

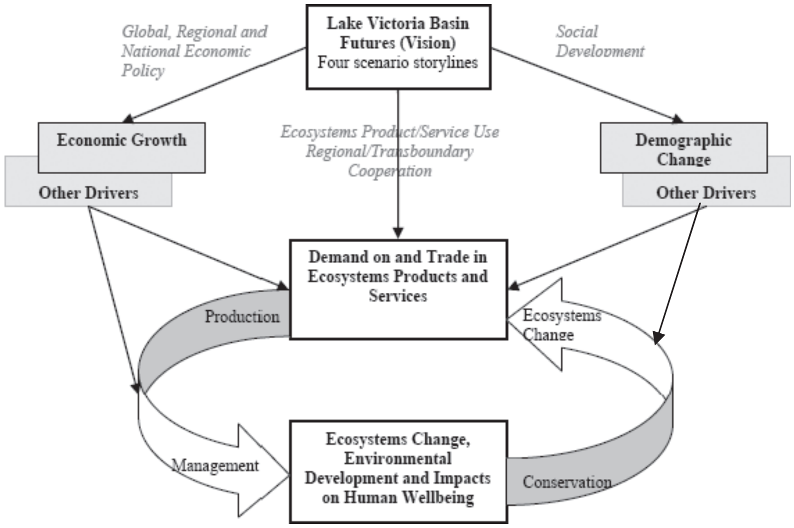

Fig 2 The conceptual framework of Lake Victoria basin ecosystem change scenario development

dynamics from exogenous scenario assumptions. The assumptions and driver relations are similar to those used in modelling the scenarios of the first Lake Victoria Environment Outlook report (UNEP, 2006a). This procedure delivers adjustments to the projected changes in the basin characteristics. Through this procedure, comparable ecosystems and human well-being foresights are simulated in the model. Figure 2 shows the conceptual framework of the scenario development process.

In contrast to the Lake Victoria Basin Environment Outlook scenarios (UNEP, 2006a) and the Africa Environment Outlook scenarios (UNEP, 2006b), the current study did not aim at presenting policy options for the basins ecosystems sustainable management objectives. The study provided a procedure for visualizing and exploring different, plausible, developments in the basin's ecosystem states and trends. The scenarios follow the storyline and simulation approach and are structured along two axes yielding four scenarios distinguishing localization (micro- and meso-levels) of ecosystems management from regionalization through transboundary management of ecosystems goods and services; and economic development pursuing narrowly defined economic objectives from more broadly defined economic, social and environmental objectives.

The scenarios have been elaborated for land use issues and environmental policies that are pegged on drivers of ecosystem change (Odada *et al.*, this issue). This resulted in four distinct scenarios distinguished by extent to which the axes parameters are explained by the drivers with the sole divergent points explained by trends towards equity and environmental sustainability (Fig. 3). Scenarios with a relatively low level of regional integration include the No Development Scenario (NDS) and Worst Case Scenario (WCS). The other two scenarios: Current Practices Scenario (CPS) and Best Practices Scenario (BPS) assume a relatively high level of regional integration, including specific social, economic and environmental policies to nurture it.

The study considered key driving forces that may change the state of the environment and trends in ecosystem service in the basin for the next twenty years. These include demography, socio-economic issues, economic development, land use and governance. These drivers have also been described through the causal chain analysis (Odada *et al.*, 2004) that underscore the root causes of key environmental challenges of the basin. The storylines of the scenarios were scaled down to assess the effects on ecosystems patterns by a series of simulation models that account for the heuristic explanations of structural changes in lake level, nutrient loading, fish catch, sedimentation, nonpoint source pollution and land use. For purposes of brevity, only selected ecosystems indicators related to land use change, lake water level and economic contribution of fisheries have been reported in this study.

Results and discussions

The results of the scenario process are presented in this section as summaries of the integration of the qualitative

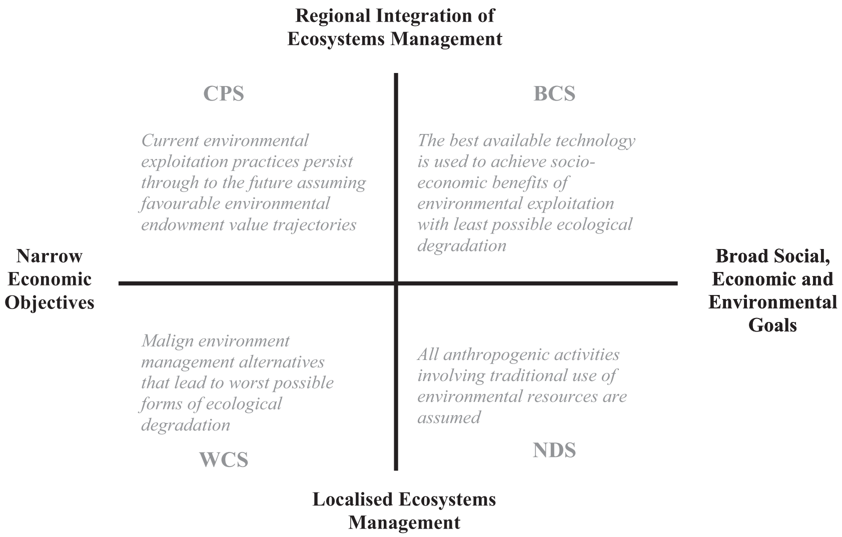

Fig 3 The Lake Victoria basin scenario framework depicting the two critical uncertainties and underlying assumptions in each of the four scenarios

storylines and outputs of model quantification across the four scenarios. All storylines are extended towards 2025 and many drivers are differentiated per country while explicitly taking into account regional context.

A comparative analysis of plausible changes in available arable land and aggregated land use change over the scenario period (see Fig. 4) shows increases in agricultural and urban land uses in all scenarios and a decline in forest land in all but the BPS. Agricultural land use witnesses the greatest change occurring under WCS. The result of the large increase in cropland and decline in forest and grassland areas is that great competition exists between land use types. The pressures toward increasing agricultural areas are counterbalanced by policy mechanisms that seek to limit over cultivation of cropland and conservation of protected areas as well as intensification for increased productivity. These pathways are consistent vulnerability of ecosystems to land use change (Metzger *et al.*, 2006; Ochola, 2006; Rounsevell *et al.*, 2006) Deforestation will be heaviest in WCS and lowest in BSC occurring mainly in the frontier highlands of the lake basin while extensive degradation to be witnessed under WCS and CPS will primarily be centred around marginal lands closer to the lake.

Lake Victoria's water level variation, derived from satellite altimeter measurements, shows a negative height variation trend. Current water levels are below normal and the lowest level since 1961. Figure 5 shows the projected variations under each scenario. The basin's and the wider regional energy demands, climate varia-

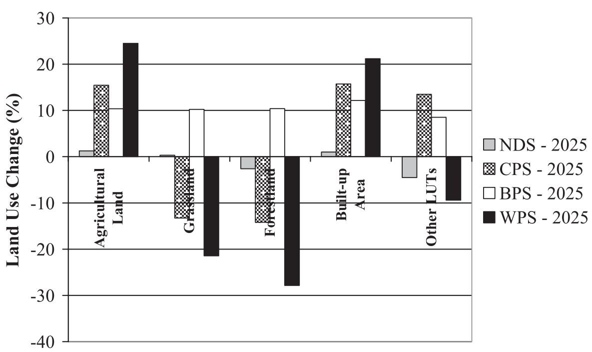

Fig 4 Aggregate land use change trends in 2025 for NDS, CPS, BPS and WPS (the y-axis represents the absolute area as a per cent of the total lake basin area)

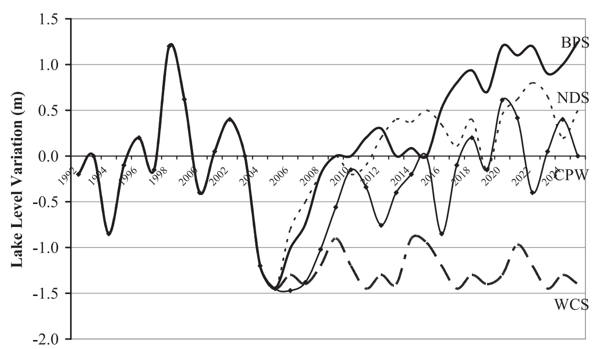

Fig 5 Projected relative variations in Lake Victoria water levels as offshoots from historical data under NDS, CPS, WCS and BPS

tion, land use and associated economic activities will combine to drive the lake water levels in the pathways illustrated.

The changes in the water levels of the lake to 2025 are based on scenario specific assumptions incorporating the theory of runs also used by Karogo & Torfs (2006) to analyse the daily water level time series of the lake after the 1961 2.5 m rise. The key drivers propelling the trends are precipitation and other climate elements, agricultural land use, industrialization along the lake and energy demands. These are projected to affect the hydrological regime of the basin including mean flows from individual tributaries, River Nile flow and overall lake level hydrograghy. The lake levels will continue to fluctuate in response to natural and anthropogenic processes affecting inflow and outflow. None of the scenarios is, however, projected to record lows comparable with the March 1923 drop. The overall balance will depend on ecosystems management strategies that will affect inputs (primarily from rainfall, river inflows and groundwater recharge) as well as outputs through evaporation, Nile outflow and groundwater discharge.

Over the years, the contribution of fisheries of Lake Victoria to the economies of the riparian states has been significant. According to Abila, Odongkara & Ony Ango (2006), this includes production, contribution to Gross Domestic Product (GDP), employment, foreign exchange earnings, food supply and balance of trade at national levels. At the local and household level, the contribution is in the form of income and food security. As a result of the drivers of change in the three main sub-sectors of Lake Victoria fisheries (fishing, processing and trade), the indicators of the economic distribution and contribution of fisheries to the region under the four scenarios are presented in Table 1.

Although NDS looks impractical, it offers a necessary reference point for the implications of current and future actions or inactions. The CPS would lead to serious ecological consequences of the associated malign upland farming practices, ineffective land and water use policies and pollution. The main challenges associated with WCS which are countered in the BSC and offer opportunities for sustainable transboundary lake ecosystem management include: rapid population explosion; vulnerability to both local and external environmental and economic shocks; unprecedented spread of diseases such as HIV & AlDS (Bishop, Hull & Stock, 2005) and malaria with emergence of new diseases and re-emergence of old ones; and escalating poverty.

The knowledge of the future ecological state of Lake Victoria basin ecosystem as precipitated by various driving forces can enhance avoidance of ecological crises and

Table 1 Distribution of economic benefits of Lake Victoria fisheries under NDS, CPS, BPS and WCS – base year data adopted from Abila *et al.* (2006)

		Production (US$ mill)	Contribution to GDP (%)	Employment of fishermen	Foreign exchange earnings (US$ mill)	Per capita fish consumption	Contribution to animal protein (%)
Kenya	2005	115	0.50	54.16	50	5	10.60
Uganda	2005	150	1.50	41.67	88	12	29.70
Tanzania	2005	I80	1.80	80.05	112	12	32.60
Kenya	NDS	95	0.34	48.23	23	7	16.62
	CPS	121	0.51	62.15	62	6	10.91
	BPS	250	1.50	65.34	75	15	25.50
	WCS	45	0.21	24.51	11	4	8.52
Uganda	NDS	124	1.02	37.11	40	17	46.57
	CPS	158	1.53	47.82	109	14	30.57
	BPS	326	4.50	50.19	132	36	71.45
	WCS	59	0.63	18.86	19	10	23.87
Tanzania	NDS	149	1.22	71.29	52	17	51.11
	CPS	189	1.84	91.86	139	14	33.55
	BPS	391	5.40	96.43	168	36	18.42
	WCS	10	0.76	36.23	25	310	26.20

guide the push towards sustainable environmental management pathways. The scenarios described in this study should assist in the recognition of the ecosystems vision, the identification of paths taken by the respective scenario indicators as well as in development of appropriate steps for redirecting future ecosystems management pathways to the desirable goals. The WCS is characterized by pessimism and apathy, neglect and lack of socio-economic and environment accountability that must be avoided at all costs. The BPS, on the other hand, is heralded by optimism, socio-economic and environmental responsiveness and a natural reaction towards seeking a balance between socio-economic development and environmental sustainability (UNEP, 2006a).

Conclusions and outlook

The scenario approach presented allows the downscaling of coarse scale ecosystem change assessments to the local level. It results in the visualization of the effect of the drivers and policy actions on ecosystems conditions, allows semi-quantitative analysis of effects of ecosystem service demands on aquatic and terrestrial resource status and associated indicators and links transboundary and regional scale assessments. The resultant relationships between the simulated changes and the actual processes of change may not be apparent but is essential in understanding plausible futures of the Lake basin. This could facilitate long-term environmental policy planning strategies for the basin and an integrated transboundary diagnosis and analysis of regional ecosystem change issues in the basin for strategic action planning. The coupling of potential social, economic and environmental processes in the basin for presumptive studies makes it possible to capture future changes in selected features of the basin and adds a temporally and spatially explicit vision of the ecosystem changes projected for the basin consistent with the baseline data as deflected by the interactions between the drivers. Further work should focus on integration of the economic and biophysical approaches in conjunction with elaboration of possible feedbacks on specific environmental attributes of the basin such as phosphorus deposition. Attempts are also being made to incorporate participatory community visioning and scenario building akin to using procedures advanced by Kok *et al.* (2006) and Bishop *et al.* (2005) and creation of specific archetypes as variants of each scenario for more focused policy guidance.

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Conflicts of interest

The authors declare no conflicts of interests.

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