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Exploring Lake Victoria ecosystem functioning using the Atlantis modeling framework

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A B S T R A C T

Lake Victoria has experienced human induced pressures such as overfishing, introduction of alien species, increased eutrophication and climate change impacts. However, there is limited understanding of the system dynamics, major processes, drivers and responses to the changes. To address this challenge, we developed the first end-to-end whole ecosystem model (Atlantis) for the lake. The model is spatially resolved into 12 unique dynamic areas based on depth, species composition, physical-chemical characteristics and fisheries management zones. A total of 38 functional groups constitute the biological model. Four fishing fleets with different targeting options are simulated. Reliability of the model is confirmed by the good fit of simulations output to observational data sets. Herein, we describe the evolution of the biophysical system, illustrating how it responded to the aforementioned induced perturbations since 1958. The constructed virtual Lake Victoria ecosystem model provides a platform for exploring the impact of management interventions before actual implementation.

1. Introduction

Lake Victoria, with a surface area of 68,800 km^2, is the largest tropical and second largest freshwater lake on the planet. The lake's waters straddles three countries (Kenya, Uganda and Tanzania) and supports Africa's largest inland fishery (Geheb et al., 2007). The lake is large enough to create its own weather system as well as influence regional climate (Crul, 1995; Stager and Johnson, 2007). The lake provides ecosystem services such as water for domestic and industrial use, transport, hydro-power generation and food to about 40 million people. Its fisheries provide employment, income and export earnings to the lake-edge communities. Lake Victoria is home to diverse flora and fauna which are intricately connected ecologically.

The lake's ecological health is in jeopardy, and had been for decades, mainly due to a myriad of anthropogenic activities (Hecky et al., 2010). Many riparian towns release raw sewage and municipal waste into the lake on a daily basis. This, together with fertilizer and chemicals from agricultural farms in the catchment, contribute to increased pollution and eutrophication. Invasive species such as water hyacinth (*Eichhornia crassipes*) and Nile perch (*Lates niloticus*) are thought to have been responsible for the manifest of ecological damage in Lake Victoria (Opande et al., 2004; Taabu-Munyaho et al., 2016; Witte et al., 1992). Water hyacinth reproduces rapidly and covers large areas of the lake forming dense mats of plants that block sunlight needed for survival of life below the surface. The introduction of the Nile perch had a major impact on haplochromine cichlids stocks which remain favorite prey, affecting both their abundance and diversity (Witte et al., 1992). Several haplochromine species had gone extinct and their abundance was reduced to less than 1% of their original biomass barely two decades after the introduction of Nile perch. The number of species in demise has only continued to grow and now up to 65% of haplochromine species are thought to have been lost, an event which may well represent the largest species extinction amongst vertebrates in the 20th century (Goldschmidt et al., 1993; Kaufman, 1992; Kaufman and Cohen, 2013; Kitchell et al., 1997). Another challenge is the booming fishing industry that evolved around the

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explosion in biomass of the Nile perch. The lake region is among the most densely populated areas in Africa (Ewald et al., 2004) and demand for fish locally has been increasing rapidly with population growth. This has lead to overexploitation of fish populations, reducing them to dangerously low levels (Taabu-Munyaho et al., 2016).

The complex ecology mixed with adverse human actions on the lake and its catchment (often without prior research of potential impacts) have limited the understanding of the system dynamics, major processes, drivers and responses with no scientific consensus on the subject (Cornelissen et al., 2015; Downing et al., 2014; Odada et al., 2009). Little headway has been made in identifying the major drivers of ecosystem changes that have been witnessed in the last six decades. Work done on the lake usually focuses on one or a few aspects of the system and often falls short of giving “the big picture”. With such a scenario in place, it is quite difficult to predict the implications, both for the ecosystem and the local communities, of any management measures instituted on the lake. In the recent past it has been acknowledged that an ecosystem approach to management is necessary if the lake is to offer ecosystem services in a sustainable way (Cornelissen et al., 2015; Downing et al., 2014; Njiru et al., 2014). This study seeks to describe the Lake Victoria ecosystem functioning, trophic cascade mechanisms as well as complex non-linear system responses. A coupled component modeling approach is employed aiming to describe complex interactions among detailed processes for the purposes of prediction, forecasting and system understanding (Bennett et al., 2013; Kelly et al., 2013). We implement these by developing the first end-to-end (whole of ecosystem) model for Lake Victoria. It is envisaged that the developed model (Atlantis) will be used to predict how the lake might respond to different management measures.

2. Materials and methods

We used the Atlantis ecosystem modelling framework to develop the model. Atlantis provides an opportunity to build a virtual ecosystem which can be used to road test different management regimes before actual implementation (Fulton et al., 2011; Smith et al., 2015). In its fullest form it considers all aspects (parts) of an ecosystem i.e. biophysical, economic and social. The model tracks changes in three dimensional space consisting of horizontal polygons and vertical layers. This 3D structure represents the

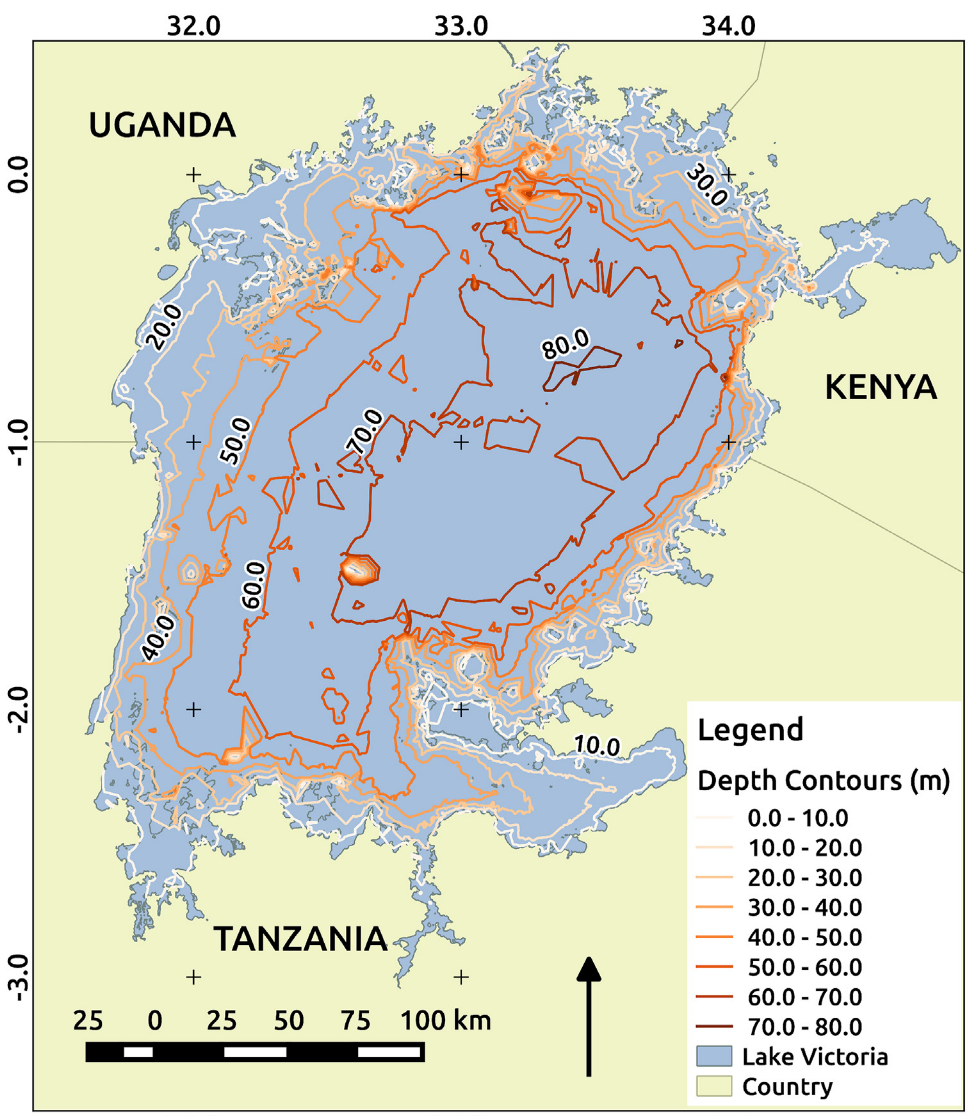

Fig. 1. The topography/bathymetry of Lake Victoria and the three surrounding countries.