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Prediction of Lake Victoria's response to varied fishing regimes using the Atlantis ecosystem model

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ABSTRACT

Fisheries management of Lake Victoria has evolved from traditional belief systems of local fishing communities to one with formal national and regional institutions. The impact of management interventions utilized so far is difficult to assess. With the advent of whole ecosystem models, management strategy evaluation has taken root elsewhere. The first such model for Lake Victoria ecosystem has been developed to simulate the chemical, biophysical as well fishing processes. We use the Lake Victoria Atlantis model to simulate the ecosystem under alternative fishing scenarios as compared with the current harvest levels. The effects of the different scenarios are tested using six common ecosystem-level indicators. Predictions show that no particular fishing scenario excels in all the six indicators. However, looking at all the indicators simultaneously, the scenario where halting harvesting of the main prey species (haplochromines) results in the best ecosystem performance, the highest yield of commercially important species and possibly has minimal "socioeconomic" cost implications. Findings of this study reinforce the need for an ecosystem approach to fisheries management in Lake Victoria.

1. Introduction

Lake Victoria supports the largest inland fishery and accounts for about 1% of the world's capture production (Kayombo and Jorgensen, 2006; World Bank, 2012). In the last century, it changed from a multi-species fishery to one that is dominated by the introduced Nile perch (*Lates niloticus*), Nile tilapia (*Oreochromis niloticus*) and the native silver cyprinid (*Rastrineobola argentea*). Although, the introduction of alien species was responsible for the destruction of the indigenous multi-species fishery, it transformed it from subsistence to a commercial enterprise (Taabu-Munyaho et al., 2016) giving riparian countries over USD 250 million annually in export earnings (Manyala and Ojuok, 2007; Downing et al., 2014). The apparent lucrative industry attracted new entrants and increased investment in the fishery. Fishing effort has continually increased since the Nile perch boom in the 1980s resulting in decline of the fish stocks (Muhoozi, 2002; Mkumbo and Mlaponi, 2007; Njiru et al., 2014).

Fisheries management in Lake Victoria has undergone different phases utilizing a range of strategies. Before the colonial administration, it was a small scale fishery, managed by traditional belief systems of the fishing communities (Graham, 1929). Afterwards formal institutions (research and management) established in the riparian countries took over the management of the lake (Jackson, 2000). In the more recent times, it was recognized that the trans-boundary resource required a common management policy and hence the establishment of the Lake Victoria Fisheries Organization (LVFO) in 1994 to coordinate and manage fisheries resources of the lake (LVFO, 2007). Over the years several management measures have been introduced in the fishery aimed at sustainable utilization of the resource. Existing measures include mesh sizes limits, ban of beach seining and slot size regulation (only for Nile perch) (Njiru et al., 2014). Almost all of the measures are aimed at regulating the fishing inputs and much less outputs (Downing et al., 2014). However, stocks have continued to decline bringing into question the design, enforcement and compliance with the instituted management measures.

Elsewhere management strategy evaluation (MSE) has taken root (Punt et al., 2016). MSE involves assessing the direct and indirect effects of different management options to determine the most appro-

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priate alternative to meet the operational objectives of the fishery (Punt et al., 2001; Smith et al., 2007). MSE requires an operating model representing the underlying dynamics of the fishery resource with which different management scenarios can be simulated. The first such model (Atlantis) has been developed to simulate the chemical, biophysical and fishing process of the Lake Victoria ecosystem (Nyamweya et al., 2016a). Atlantis is an end to end model that considers all aspects (biophysical, economic and social) of an ecosystem (Fulton et al., 2011). We use this Atlantis model for Lake Victoria to test the effect of different fishing scenarios on the ecosystem function and fisheries production. The scenarios tested include varied fishing pressure for Nile perch (the main predator at the top of the food chain), key prey species (haplochromines) and other species. The effect of fishing pressure on Nile perch is explored because of its commercial significance and concerns of it being over fished as evidenced in the decline of observed biomass and catch rates (Njiru et al., 2014). Fishing pressure on haplochromines is varied to test their impact on the abundance of Nile perch and other predatory fish. For other species whose contribution to catch has been dwindling, a simulation is done with reduced harvest pressure to help decipher the impact of intense fishing on them. The aim is to identify a fishing strategy that: (1) optimizes yield of commercially important species, (2) is easy to implement with minimal alienation of fishing communities and (3) enhances ecosystem function.

2. Materials and methods

The Lake Victoria ecosystem is simulated 20 years into the future assuming different fishing scenarios using the Atlantis modeling framework. The biophysical components and ecosystem functioning of the developed model are described in Nyamweya et al. (2016a). Complete model set up, data and output files used in the simulations are available at https://figshare.com/articles/Lake_Victoria_Atlantis_model_files/4036077. The Lake Victoria Atlantis model has 12 unique spatial areas (Fig. 1) and a total of 34 of biological groups (i.e. 17 fish, 1 bird, 1 reptile, 9 invertebrate and 6 primary producer groups) (Table 1).

Distribution of nutrients, plankton and temperature are driven by an underlying hydrodynamic flow derived from a Regional Oceanographic Model System (ROMS) of the lake (Nyamweya et al., 2016b). Fishing is done with gill nets, long lines, small seines and inshore fleets. Gill nets target most species but the bulk of the catch is Nile perch. Long lines primarily target Nile perch but other fish like the catfishes *Clarias gariepinus, Bagrus docmak, and Synodontis victoriae* are landed by this fleet. Small seines mainly target dagaa (*R. argentea*) when deployed at night using light attraction. When they are deployed without the aggregation lighting or during the day, haplochromines form a significant proportion of the catch. The inshore fleet is an assortment of several gear operating near shore and usually targets all species in such areas. Gill nets and inshore fleets exhibit a normal selection pattern (Eq. (1)) (Millar and Fryer, 1999) whereas long lines and small seine fleets have a size based logistic selectivity (Eq. (2)). In both equations, q_{FX_i} is the selectivity of gear with regard cohort i of vertebrate group FX and

Table 1
Biological groups in the Lake Victoria Atlantis model.

Code	Model group	Group type	Modeled as
LN	Nile perch (*Lates niloticus*)	Fish	Age-structured
CG	African catfish (*Clarias gariepinus*)		
BD	Bagrus (*Bagrus docmak*)		
PA	Lungfish (*Protopterus aethiopicus*)		
HPR	Predatory haplochromines		
HPY	Phytoplantivorous haplochromines		
HBE	Benthivorous haplochromines		
SV	Synodontis (*Synodontis Victoriae*)		
MK	Mormyrus (*Mormyrus kanume*)		
SCH	Schilbe (*Schilbe intermedius*) *sp.*		
RA	Dagaa (*Rastrineobala argentea*)		
ON	Nile tilapia (*Oreochromis niloticus*)		
OT	Other tilapia		
BA	Barbus (*Barbus altinialis*)		
SB	Small Barbus		
LV	Labeo (*Labeo victorianus*)		
ALL	Alestes		
REP	Reptiles	Reptile	
BFE	Birds	Bird	
MIN	Macroinvertebrates	Invertebrate	Biomass pool
BFF	Benthic filter feeder		
BFS	Shallow filter feeder		
BFD	Deep filter feeder		
BG	Benthic grazer		
ZL	Caridina nilotica		
DF	Dinoflagellates		
ZM	Mesozooplankton		
ZS	Microzooplankton		
MB	Microphtybenthos	Primary producer	
MA	Macroalgae		
PL	Large phytoplankton		
PS	Pico-phytoplankton		
PB	Pelagic Bacteria		
BB	Sediment Bacteria		
DL	Labile detritus	Detritus	
DR	Refractory detritus		

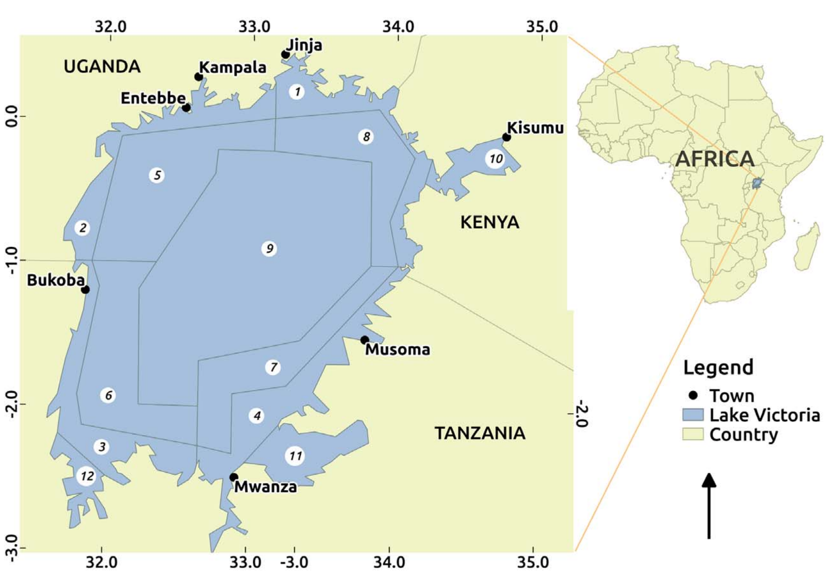

Fig. 1. Lake Victoria in Africa. The numbers indicate the dynamic spatial areas of the Lake Victoria Atlantis model.