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Modeling trophic interactions and the impact of an introduced exotic carp species in the Rift Valley Lake Koka, Ethiopia

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ABSTRACT

The study aims to describe the energy flow and trophic structure, to assess the ecological stage of maturity, the ecosystem impact of the introduced exotic carp species and the current fishery on the Lake Koka ecosystem using a mass-balance trophic model. The Ecopath approach and software were used to represent the lake ecosystem, and input parameters were obtained from in-situ surveys and from published lake specific sources. The model was balanced as per the recommended ecological and thermodynamic constraints. The low ecotrophic efficiency found for adult catfish, primary producers and detritus suggest that these resources are not fully utilized, while other groups have moderate to high values. The annual fishery catch represents only about one sixth of the total fish biomass, and the exploitation rates of target species are well below 0.5 suggesting under-exploitation. The dietary intake of fish-eating birds is 5.8 t km^{-2} $year^{-1}$ almost twice the catch, showing the lake's important role for sustaining the bird populations and hence, caution needs to be taken before implementing any further fisheries development intervention. The mean trophic level of the catch (2.55) is intermediate when compared to other tropical lake systems and reflects the mixed fishery of the lake. Mixed Trophic Impact and Niche Overlap analysis reveals that, contrary to what may be expected, the impact of the introduced exotic carp species on the lake system is less significant than that of the native species. Besides its socio-economic significance, the detritivorous carp seems to fill an unutilized niche and helps the system in recycling organic matter. The *P/R* value (3.2) and other system maturity indices indicate that Lake Koka is as yet an immature, developing system. The model can be used as a reference for exploring ecosystem-based fisheries management scenarios aimed at sustaining fish stocks, ecosystem services as well as ecological integrity.

1. Introduction

The Food web concept has been widely used to elucidate the interactions of the different components of an ecosystem in a predator-prey context and provides a means to understand the role of species in structuring of ecological processes. Knowledge on the various components of an ecosystem and their interrelatedness is therefore essential to optimize resource use and other ecosystem services sustainably, and to conserve and maintain biodiversity. Fisheries management, on the other hand, has been conventionally based on single species surplus production and/or yield per recruit (Y/R) modeling approaches focusing only on a few target species of the fishery. The regular use of these conventional methods is not only due to their relative simplicity and logic, and limited data requirement for assessment, but also because of the applicability of model outputs for management by regulatory bodies. However, many scientists have criticized these methods for lacking to scrutinize and account for recruitment failure and multispecies interactions (*e.g.* Larkin, 1977; Hilborn and Walters, 1992; Trites et al., 1999), which has led to a wide recognition of the need to move towards an ecosystem approach to fisheries (Garcia et al., 2003; Plagányi, 2007; Christensen and Walters, 2011; Grüss et al., 2017). Cury and Christensen (2005) also suggested that exploited fish populations must be considered as integral components of ecosystem function, rather than units that operate independently of their environment as management interventions directed to one target species may have consequences for many other species. As a result, a new approach that includes the different components of the ecosystem called ecosystem approach to fisheries (EAF) termed after Garcia et al. (2003) has emerged based on the pioneer works of ecosystem modelers (*e.g.* Polovina, 1984; Gislason and Helgason, 1985; Christensen and Pauly, 1992). Nonetheless, one has to note that this new approach is an extension of the conventional management approach (Garcia and Cochrane, 2005) and still needs many of its input parameters from individual and population based studies and hence, it rather complements

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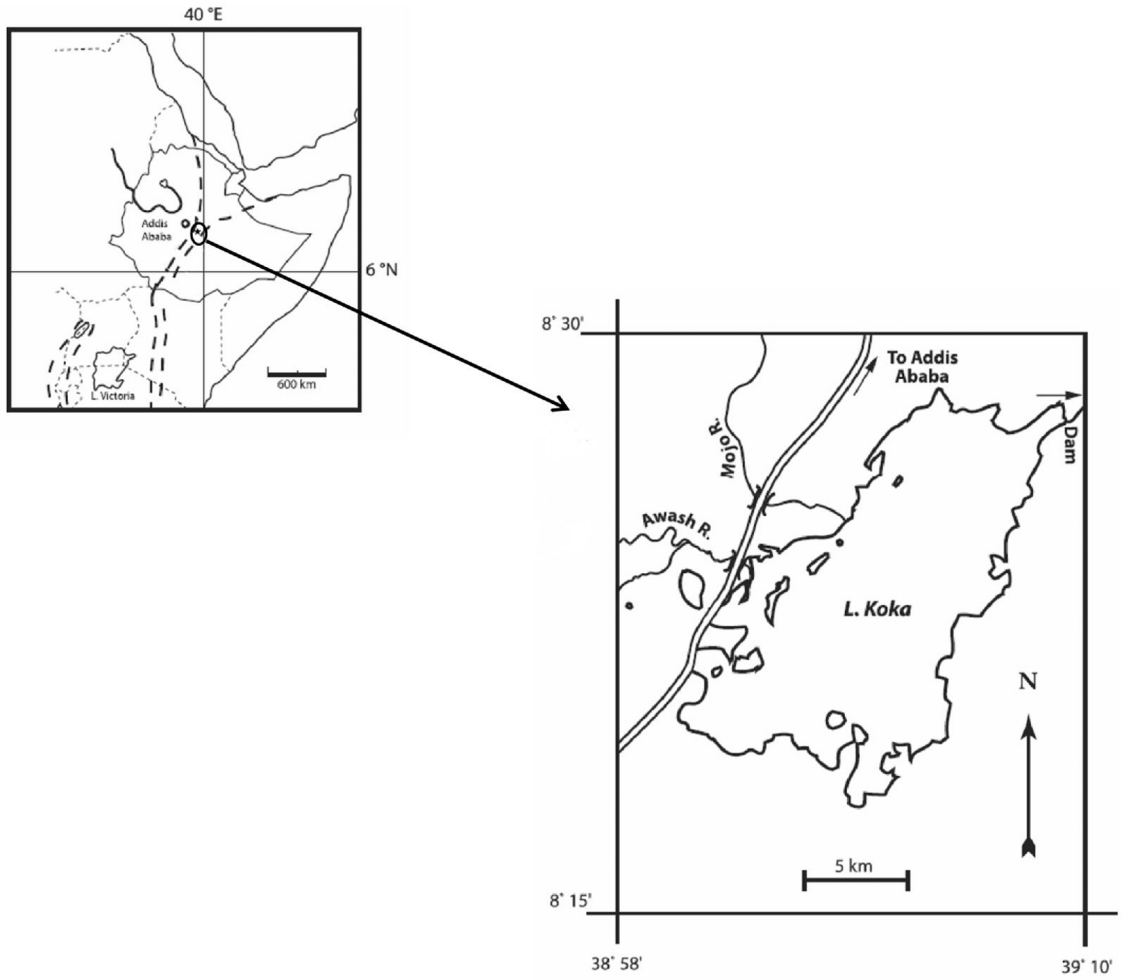

Fig. 1. Map of Ethiopia and the geographical location of Lake Koka.

the EAF.

Food web analysis and multispecies models are gradually leading to a better understanding of the structure and dynamics of ecosystems (Mace, 2001; Colléter et al., 2015). Among the models that consider intra– and interspecies interactions (*e.g.* ATLANTIS, Multispecies trophodynamic model using bioenergetics and allometric approach, ECOPATH with ECOSIM (EwE), Globally applicable Area Disaggregated General Ecosystem Toolbox (GADGET), General Equilibrium Ecosystem Model (GEEM), *etc.*), the trophic modeling approach using EwE developed by Polovina (1984); Christensen and Pauly (1992) and Walters et al. (1997) has gained much popularity and momentum in ecology and fishery science due to its user friendly interface and continuous further development (Plagányi, 2007; Christensen and Walters, 2011). A detailed review on the advantages, disadvantages and limitations of these and other ecosystem models can be found in Plagányi (2007). EwE has also becoming the most widely used and preferred approach for ecosystem-based management of fisheries (Christensen and Walters, 2011; Colléter et al., 2015) for both freshwater and marine ecosystems. However, in Ethiopia, food web studies using EwE have only recently emerged (Fetahi and Mengistou, 2007; Fetahi et al., 2011; Wondie et al., 2012). In Lake Koka, an important lake for Ethiopian fisheries, such an attempt has not yet been tried. Population-based fisheries assessment (Tesfaye and Wolff, 2015), and feed and feeding habit studies on fishery target species are available (Dadebo et al., 2013; Engdaw et al., 2013; Dadebo et al., 2014, 2015) and plankton and other limnological features have also been studied (*e.g.* Mesfin et al., 1988; Kebede and Willén, 1998; Tesfay, 2007; Degefu et al., 2011). However, as yet no attempt has been made to integrate all this available information and describe the structure and function of the different components in an ecosystem context.

Food web analysis is also a useful ecological concept that represents the feeding relationship of the different functional groups within a system. It thus helps to understand/investigate ecological interactions that define the flow of food energy and predator-prey relationships (Chain et al., 2013). This interaction could be simple or complex depending on the developmental stage of the ecosystem (Christensen, 1995; Thapanand et al., 2009). Lake Koka, named after the construction of the dam on River Awash in 1959 and subsequent inundation of the small lake formerly known as Galilea, has been used for different purposes including fishery, irrigation, hydropower generation and water supply. Evidences show that ecosystems change their ecological maturity with time and in response to various uses (Thapanand et al., 2009). The Ecopath with Ecosim approach further allow assessing the maturity stage of the ecosystem using ecological indicators generated from a network analyses. Whether the different interactions and human uses of the lake resulted in some degree of maturity or not has not been investigated yet.

Moreover, EwE has been used to explore the ecological impacts of introduced species in different freshwater systems. Transfers of fish species between lakes as well as introduction of exotic fishes have been going on for decades all over the world (Tesfaye and Wolff, 2014). However, introduction of exotic species becomes unpopular due to unanticipated ecological and socio-economic impacts that this intervention posed. The most frequently cited example is the case of Nile perch (*Latus niloticus*) introduction in Lake Victoria that has believed to cause the loss of many Cichlid species (Kaufman 1992; Witte et al.,