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Fish as bioindicators in aquatic environmental pollution assessment: A case study in Lake Victoria wetlands, Uganda

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A B S T R A C T

Growing human population and industrialization have led to the pollution of most aquatic ecosystems and consequent deterioration in environmental water quality. Indicator organisms are needed to improve assessment programmes on the ecological impacts of anthropogenic activities on the aquatic environment. Fish have been widely documented as useful indicators of environmental water quality because of their differential sensitivity to pollution. This study investigated the environmental water quality of selected wetland ecosystems using fish as biological indicators. Fish community structure in relation to water quality was assessed in five wetlands along the shoreline of Lake Victoria from August 2006 to June 2008. Four urban wetlands were variedly impacted by anthropogenic activities while one rural wetland was less impacted, and served as a reference site. Fish species diversity, abundance and richness were assessed, and canonical correspondence analysis (CCA) was used to evaluate the relationship between the fish communities and environmental variables. Results revealed that urban effluent impacted negatively on water quality and consequently the fish community structure. A total of 29 fish species were recorded throughout the study with the lowest number of 15 species recorded in the most impacted site. Shannon diversity and Margalef species richness indices were highest at the references site and lowest at the most impacted site. Wetland haplochromis species dominated the reference site, while *oreochromis* species dominated the most impacted site. The inshore locations registered higher species diversity and low species richness than the offshore locations. Low dissolved oxygen, pH, secchi depth and high electrical conductivity, total phosphorous, and total nitrogen were strongly associated with the effluent-impacted sites and greatly influenced the fish community structure. This study recommends the use of fish as valuable biological indicators in aquatic environmental pollution assessment.

1. Introduction

The Lake Victoria wetlands on the lake's fringes have a fundamental socio-ecological function sustaining the livelihoods of rural and suburban communities while contributing to shore stabilization, flood control, water storage, purification and recharge, nutrient retention and micro-climate regulation (Bakema and Iyango, 2000; NWDR, 2006; Crona et al., 2009; Swallow et al., 2009). The lake's wetlands and coastal shallow bays also play a role in the conservation of fish biodiversity (Chapman et al., 2002, 2003; Balirwa et al., 2003). Particularly, rocky and shallow inshore habitats with fringing macrophyte cover are important refugia for many endangered indigenous fishes of Lake Victoria (Chapman et al., 2002; Balirwa et al., 2003, 2004b; Namulemo, 2004). The authors argue that these heavily vegetated wetlands serve as structural and low-oxygen refugia for fishes that can tolerate such conditions. They also function as barriers to the dispersal of Nile perch, thereby protecting the cichlids from Nile perch predation. However, the wetland socio-ecological functions and the continued survival of the fish species in such habitats are threatened by human impacts in the catchments.

Due to the increasing human population size, wetlands on the Ugandan side of Lake Victoria are being extensively degraded by human activities such as habitat modification for agriculture, urbanization and infrastructure provision, municipal and animal waste disposal, small-scale economic production enterprises such as informal slaughter houses, poultry units, motor garages and car washing facilities (Odada et al., 2004; Mugisha et al., 2007; Banadda et al., 2009; Munabi et al., 2009). These authors argue that these activities serve as point and non-point sources of pollution and lead to increased wastewater discharges that carry potential

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pollutants and cause deterioration of the aquatic environment. This is manifested through alteration of physical and chemical variables beyond safe levels, consequently impacting on biodiversity especially that of fishes (Balirwa et al., 2003; Nzomo, 2005; Carr and Neary, 2006).

There has been a decline of fish stocks and fish species diversity in Lake Victoria (Balirwa et al., 2003; Ogutu-Ohwayo and Balirwa, 2004), due to overexploitation, use of destructive fishing gear and methods, environmental degradation, and ineffective or absent management. The decline has also been attributed to the introduction of the non-indigenous Nile perch. The increase in Nile perch population size coincided with the loss of many populations of indigenous species (Balirwa et al., 2003, 2004a; Ogutu-Ohwayo and Balirwa, 2004; Witte et al., 2007). Long-term recommendations for management of this complex socioecological challenge include putting in place effective research and management programmes, strong policy and legal frameworks and information systems for management of the fisheries and fish habitats (Balirwa et al., 2003; Machiwa, 2003; Ogutu-Ohwayo and Balirwa, 2004). Immediate interventions included control of fishing effort and law enforcement on the use of illegal fishing gear and methods (Ogutu-Ohwayo and Balirwa, 2004) alongside re-stocking programmes and aquaculture which is still on a small scale (FAO, 2006). The environmental changes due to industrial and domestic wastewater effluent may reduce fish access to the wetland refugia in urban waters. Assessment and mitigation of the environmental impacts on water quality and biodiversity have now become necessary.

Efforts to prevent or reverse aquatic environmental impacts demand efficient and reliable mechanisms of detection, especially of system contamination. Thus, there is a need to establish a biological monitoring system (Balirwa et al., 2003; Nzomo, 2005). Two biomonitoring studies of the Ugandan part of Lake Victoria supported and recommended biomonitoring as a useful tool for monitoring water quality as it integrates responses to combinations of all contaminants thereby describing overall effects on the environment and biodiversity in a water body (Sekiranda, 2006; Birungi et al., 2007). Birungi et al. (2007) monitored selective trace heavy metals using Nile tilapia (*Oreochromis niloticus*) and Sekiranda (2006) employed GIS techniques to assess water quality and invertebrate and fish community structure in three shallow bays. However, Lake Victoria has diverse ecological zones and the impacts of environmental degradation on water quality are complex and their extent is poorly understood.

Fish have been widely documented as indicators of water quality because of their sensitivity to pollution (Mora et al., 2003, 2008; Gratwicke, 2004; Gratwicke and Speight, 2005; Mora and Robertson, 2005; Sekiranda, 2006; Das and Chakrabarty, 2007). Estimating the number of species from a particular area remains a fundamental theme of ecology. Species diversity is related to the functioning of ecological systems and helps understand the mechanisms and effects of environmental disturbances such as pollution (McGill et al., 2007; Tokeshi and Arakaki, 2007; Mora et al., 2008). Estimation of species diversity is also useful for detecting trends, impacts, or recovery of ecosystems, and quantification of extinction risks and thus prioritization of conservation of biodiversity hot-spot areas (Mora et al., 2008). Ideally, complete inventories provide a full account of the species richness and diversity but these are rarely available. In their place, sampling of biota or surveys provide important data.

Fishes are ideal for ecological investigations. They are readily identified and are species-rich. Additionally, warm tropical waters with high visibility are conducive to observations (Gratwicke, 2004). The species flock of endemic haplochromine cichlids in the basin of East Africa is well known as the most diverse and extensive radiation in the evolution of vertebrates (Rosenberger and Chapman, 2000). This makes Lake Victoria and its catchment an important study area for fish community observation. Knowledge on water quality indicator organisms is critical to the conservation of the cichlid fauna and the regulation of biodiversity loss in the lake. However, the relationship between water quality and fish assemblages has been poorly documented in Lake Victoria, despite being important for water management and ecological monitoring. Therefore, this study assessed urban wetland fish biodiversity that is threatened by pollution from industrial and domestic effluent. This research investigated the fish community structure in relation to the water quality, with the aim of exploring the use of fish as biological indicators of water quality deterioration in selected wetlands in Uganda.

2. Materials and methods

2.1. Study area

Data were collected in the bays of five wetland ecotones located in one ecoregion along the Ugandan shoreline of Lake Victoria. These wetland ecotones included Nakivubo, Kirinya, Masese, Winday Bay and Lwanika. The Nakivubo wetland has become severely degraded over recent years and is threatened by industrial activity and residential development (COWI and VKI, 1998; Emerton et al., 1998). The wetland receives secondary treated effluent from the Bugolobi sewerage treatment works and heavily polluted wastewater comprising of runoff and effluent from guesthouses, slum dwellings and industries in Kampala city through the Nakivubo channel, and discharges into Lake Victoria at Murchison Bay (Fig. 1). The Nakivubo channel is a 12.3 km long and traverses highly populated Kampala slums, markets and industrial areas. Point source pollution and landuse-based nonpoint source pollution in the channel have an impact on the water quality and the aquatic life in the inner Murchison Bay (Kansiime et al., 2007; Kayima et al., 2008; Banadda et al., 2009) where sampling for this study was carried out. The bay receives raw sewage, municipal and industrial wastewater discharge from Kampala (Matagi, 2002; Kansiime et al., 2007; Kayima et al., 2008; Banadda et al., 2009). Kirinya wetland is located along the Northern shoreline of Lake Victoria in Jinja municipality, lying to the north east of the Napoleon gulf (Fig. 1). This wetland receives discharges of domestic, municipal and industrial effluent, surface runoff and storm water from Jinja town (Kelderman et al., 2007; Oguttu et al., 2008). Although this wetland is not an official waste dumping site, open waste dumping of both biodegradable and non-biodegradable materials was frequently observed during this study. Kirinya wetland is also home to hotels, industries, factories, metallurgy and Jinja municipality's wastewater treatment oxidation ponds, the Kirinya National Water and Sewerage Corporation Oxidation ponds that discharge municipal secondary treated effluent into Lake Victoria.

Masese wetland is located 2 km from Kirinya wetland (Fig. 1). This wetland is used for open dumping of waste material in Jinja municipality, both biodegradable and non-biodegradable including chemical waste. Masese wetland was gazetted for waste disposal over three decades ago, when the area was relatively inhabited (Jinja District Profile, 2003). Masese wetland receives urban effluent and storm water runoff through a 1.4 km long drainage channel. This channel carries domestic effluent from several residential villages and informal settlements in the outskirts of Jinja Municipality and pours into the Masese wetland before emptying into Lake Victoria. Winday Bay is almost adjacent on the southwest of the Napoleon gulf (Fig. 1). The catchment of Winday Bay is less disturbed than that of Kirinya and Masese. The main activity is crop cultivation, with recent aquaculture. Lwanika wetland, lo-