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The Impact of Evolution and Socio-economics of Commercially Exploited Fish Stock: A Review on *Rastrineobola argentea* in Lake Victoria

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Abstract Fish in Kenya is an important source of food, especially of high quality protein. They provide a good source of income for communities that live around lakes and contributing not only to the social and economic development of these communities but to Kenya's economy. Lake Victoria located in East Africa, is the largest tropical freshwater lake in the world and is currently a habitat to many fish species such as the Nile perch *(Lates niloticus)*, Nile tilapia (*Oreochromis niloticus)* and silver cyprinid known locally as *Omena* (*Rastrineobola argentea)*. During the last two decades the fish population in Lake Victoria has changed significantly primarily due to anthropogenic activities such as introduction of alien species and overfishing. *R. argentea* is the most commercially exploited species of Lake Victoria. It is the main provider of protein for the communities living around the lake and it is also used as a feed, where it is incorporated into feedstock used by both the livestock and poultry farmers. Over the last few years it has become the major prey for *L. niloticus*, an exotic species in the Lake Victoria. This review aims to compile dispersed literature about *R. argentea* in Lake Victoria majoring on its life history changes, threats to existence, its socio-economic value and the dynamic issues facing the management of Lake Victoria fishery.

Keywords: *Genetic diversity, Rastrineobola argentea, Lake Victoria, anthropogenic activities, threats, conservation and management*

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1. Introduction

Globally, freshwater is the most precious human resource essential for both domestic and industrial consumption and is a focal point for human settlement [6]. Lake Victoria is the largest tropical freshwater lake in the world. It is shared by three African countries specifically Tanzania (51%), Uganda (43%) and Kenya (6%) [4]. Lake Victoria is approximately 68,800km^2 and supports one of the world's largest freshwater fishery. The lake is a significant source of food, provision of income, foreign exchange and employment through earnings from exploitation of the fish resources [20]. Recent studies have reported that there are more than 290 species of fish in the Lake [8]. The abundance and distribution of fish in Lake Victoria has changed from the beginning of the 20th century when fisheries development started [25]. This is a result of the interaction among fish and their chemical, physical and biological surrounding taking into account the habitats in which fish live in and the communities in these territories which are continually deviating and evolve progressively in predictable directions, through ecological succession. These deviations include among others, environmental changes, overfishing and the introduction of alien species mainly the Nile perch *(Lates niloticus)* and Nile tilapia (*Oreochromis niloticus)* into the lake [19].

2. A Brief History of Fish in Lake Victoria

By the end of 1940's, fish stocks were under tremendous pressure from the emerging European markets for high quality white fish meat that prompted the development of processing plants along the lake's shore [30]. This led to the development of the transport infrastructure that led fish being conveyed down the railway line to the East African coast and later exported to the European markets. Moreover enhanced fishing technology such as fleet of boats and flaxen gill nets being used to catch fish enhanced the pressure on fish.

To counter this stress, the colonial fisheries authority introduced four exotic tilapia species (*Oreochromis niloticus*, *Oreochromis leucostictus* and *Tilapia zilli)* in the early 1950s which were to supplemented the dwindling stocks of the endemic tilapia species (*Oreochromis esculentus* and *Oreochromis variabilis)* [13]. The more debatable consideration that the colonial fisheries authority had was the enormous amount of *Haplochromis* in the lake which comprised 90% of the lake's fish biomass. Some argued that the lake needed a predator to take advantage of the food source and turn it into an economically more valuable fish meat. The prime candidate as a magnificent predator was the Nile perch (*Lates niloticus*) which has the capacity of growing up to 200kg in weight. In 1954, the Nile perch was secretly introduced, radically transforming the lake both ecologically and economically. After some time the fish began to appear in the mid-1970's. Until the 1970's, the native tilapiine species *Oreochromis esculentus* (Graham) and *Oreochromis variabilis* (Boulenger), *Protopterus aethiopicus* (Heckel), *Bagrus docmak* (Forskåll), *Clarias gariepinus* (Burchell), various *Barbus* species, mormyrids and *Schilbe intermedius* (Rüppell) were the most commercially essential species. However, the Haplochromine cichlids and the native cyprinid, *Rastrineobola argentea*, although abundant, were not originally exploited on a large scale because of their small size. By the 1980's, the Nile perch catches had climbed from 335tons in 1975 to a peak of 380 tons in 1990 this explosion was referred to as the Nile perch 'boom'. The catches of *Haplochromis* had crashed whereas an estimated 200 species were driven into extinction [27]. This was described as one of the greatest mass species extinction events in recent history [15]. Freed from competition for food sources, *R. argentea* population has really thrived from 13,000 tons in 1975 to an all-time high of 546,000 tons in 2006. This however is a challenge since *R. argentea* is currently the main source of food and livelihood of 30 million riparian people found in Lake Victoria region [1]. Currently the fisheries in Lake Victoria include the indigenous Dagaa (*Rastrineobola argentea)* the introduced Nile perch *(Lates niloticus)* and Nile tilapia (*Oreochromis niloticus L.)* While the market has expanded to Middle East, United states and Australia [42].

3. *Rastrineobola argentea* in Lake Victoria

Rastrineobola argentea is a small zooplanktivorous cyprinid fish which is commonly known as the silver cyprinid (Figure 1). Other local names include 'Omena' (Kenya) 'Dagaa' (Tanzania) and 'Mukene' (Uganda) [26]. This small pelagic fish plays a huge role as the source of animal protein for the riverine community. Once the fish is harvested from the lake, it is sun-dried for six to eight hours along the Lake Victoria [8,28]. It is either used as food or transformed into fishmeal and incorporated into livestock and poultry feed thus providing a source of livelihood for the local farmers [20]. The cyprinid population suddenly declined after 1950's which is elucidated by predation from both the Nile perch and fishing [13]. *R. argentea* is the main prey for *L. niloticus* [41]. Initially *R. argentea* was the second most exploited fish of the Lake Victoria with 20% of the total catch in 1989 while the *L. niloticus* formed the larger portion 60% of the total catch in 1989 [20,38]. However, *R. argentea* is now the most commercially exploited species of Lake Victoria with 62.2% of the total catches compared to 29.9% of the *L. niloticus* yet there is a drop in annual yields reported by the Kenyan fisheries [41]. The increase in exploitation of *R. argentea* is attributed to using small mesh or mosquito seine to land the fish [35]. Overfishing, predation and environmental degradation has led to reduced population size of most of the indigenous species of Lake Victoria. Presently *R. argentea* (Figure 1) is the most commercially exploited species of Lake Victoria despite the observed reduction in size at maturity of *R. argentea* on Kenyan beaches of Lake Victoria. Nevertheless, Omena has successfully survived the Nile perch predation and increased fishing pressure which is attributed by the loss of the zooplanktivorous hypochloromines that reduced competition for resources such as food thereby increasing their growth rate [20]. This in turn reduces their age at first maturity thus enduring the disruption of the ecosystem [25].

Figure 1. Dried mature *Rastrineobola argentea* collected from Lake Victoria. Photograph courtesy of https://www.bubblews.com

4. Feeding and Breeding Habits of the *Rastrineobola argentea*

Rastrineobola argentea once considered a pelagic fish mainly fed on macrophytic phytoplankton such as algae and detritus however [14] suggested that the niche invasion by the *R. argentea* has led to dietary shift and morphological modifications of the silver cyprinid. This has been an observed feature of the post Nile-perch Ichthyofauna of the Lake Victoria whose day-time diet is composed of novel prey items such as insects, chaoborus larvae and pupae. Samples collected in 1966 show that *R. argentea* diet consisted of zooplanktons such as copepods, cladocera and rotifers. The morphological adjustments of these contemporary *R. argentea* include shorter and more tightly packed gill rackers. The racker width is larger compared to before the introduction of the alien species while the head and caudal tail have become diminutive [34].

Breeding of *Rastrineobola argentea* takes place all year round with peak time being after the long rains in April-May and after the short rains in August-September [17]. These periods are associated with the lakes turnover where the lake completely or partially mixes with the subsequent high density of zooplankton and insect bloom that provides food for the *R. argentea*. This provides enough food resources to the species encouraging the breeding process. There is increased number of gill filaments which can be directly linked to the recent exploitation of the bottom layer by the Omena [42].

5. Key Threats to Fish Population In Lake Victoria

Rastrineobola argentea is the source of food and livelihood for over 30 million riparian people found around the Lake Victoria region and beyond [23]. This small pelagic fish plays a huge role in food security and poverty alleviation among the Lake Victoria communities [21]. The *R. argentea* fishery in East Africa is currently experiencing high fishing pressure that has led to reduced fish populations. This is an area of concern because human beings are the apical predators of Lake Victoria and their activities determines the ecosystem of the lake. Therefore, the rapid loss of fish stock caused by anthropogenic stress such as over fishing, directly results in the loss of genetic diversity [17]. This anthropogenic stress can impose phenotypic and genotypic changes in natural populations resulting in evolutionary changes in less than a few centuries [32].

Taking a long-term observation on species survival using molecular data such as parentage and kinship, mating systems, dispersal rates, population structure, gene flow and effective population size make genetic studies be recognized as an integral part in understanding the biology of any organism especially when the species environment changes [7,31]. Maintaining high genetic variation is very critical for adaptive evolution, conservation and population persistence to occur [2]. In this case fishing induces evolutionary changes in the life history traits of *R. argentea* as a result of the highly selectivity of the fishing gear that targets fish of a particular age and size. The surviving population is composed of species that mature at a reduced size and age and confer relatively high fitness under fishing pressure but less than optimal under natural selection [37]. Moreover the size of the fishing gear used is 10mm while the average size of *R. argentea* is 40-50mm [25]. This is a form of exploitative selection analogous to artificial selection used by Darwin for the intentional selection of certain characteristics in natural populations [2].

Introduction and colonization of alien species plays a social aspect determining the interaction among individuals of the same or different species [32]. These interactions can either be competition or predation. Generally predation in fish does not eliminate the prey due to replacement by growth but through intraspecific competition of the residual individuals. This results in the survival of the most fit in both the predator and the prey making it an agent of divergent selection driving intraspecific divergence in morphology, life history and behaviour by altering activity level and habitat use especially in the prey taxa [16]. Moreover, the prey adapt to the non-native species by adopting a predator avoidance mechanism resulting in occupation of a different niche inducing phenotypic changes such as increased gill filaments to accommodate the low oxygen levels in the deep waters [35]. They develop shorter caudal fins that enable them to swim faster while avoiding the predator. Consequently, *R. argentea* stretched its habitat, diet including its niche component as a result of competitive release of the *Haplochromis* decrease [10]. Massive emigration may increase growth and survival but may cause a species to lose its niche [42].

Over a period of time this coping mechanism and adaptation to the new superimposed conditions requires genes to differ across individuals that generates variation from selection that retains a deep genetic pool of variants subsequently assist in survival of this species [18]. The dynamics of specific environment are reflected in the continual change within the fish populations that inhabit them therefore evolutionary change or response towards selection depends on the heritability of the trait and strength of the selection [31]. Fishing-induced pressure and biological invasion such as predation are potent forms of novel selection driving plastic and/or evolutionary changes in native prey [33]. Initially *R. argentea* was a pelagic/free swimming fish but with fishing and the introduction of the Nile perch it has shifted its niche to that of a benthic/bottom dweller. This is a form of an adaptation whereby the native prey adopts a predator-avoidance behaviour [16]. Moreover, studies carried out have shown that the mean length of *R. argentea* has significantly reduced in parts of Lake Victoria that experience over-fishing topped up with the presence of Nile perch as compared to unperturbed regions of the lake [34]. Interestingly previously published values for *R. argentea* standard length at 50% age of maturity from the waters of Lake Victoria as 43-44mm (1998), 42 (1996/7), 41 (2002/3), 40 (2004/5) [35]. The mechanism underlying observed changes in these phenotypic traits could represent a genetic/evolutionary response to selection imposed by anthropogenic stressors. The outcomes of these undertakings are due to selective pressure that compromise the long term survival of fish species [2].

According to FAO [29], half of the fish stocks are fully exploited and another 32% are over-exploited, depleted or recovering. The population structure of a fish species is an indicator of its evolutionary stage whether as expanding, stable, or regressing which in turn is determined by the age composition of the population. Population density is a function of time, volume and space and can be described as the number of fish in a lake or weight per unit area or of its volume. Moderate losses or gains in numbers from horizontal migration are normally compensated by corresponding changes in mortality rate. Vertical migration of *R. argentea* lead to concentration of population at specific sites along the Lake Victoria, overharvesting of this species at this particular sites may lead to dramatic loss of fish population density and consequently its genetic diversity [33]. When population size is reduced genetic variation is lost through genetic drift which can supersede the benefits of natural selection resulting in reduced reproductive fitness of individuals [2]. Furthermore, inbreeding occur more frequently in small population leading to further reduction in effective population size and ultimately in population extinction. Therefore the main goal of conservation program is to counteract decrease in effective population size [9].

Environmental forces that impinge on the lives of fishes are many, complex and interrelated in their effect. Increased deep waters temperatures increased thermal stratification that would encourage organic matter production in the deep water resulting in low oxygen content [14]. Eutrophication has substantially reduced water clarity in Lake Victoria has since 1960’s narrowing the spectrum of light in the Lake [22,27]. Light affect the vision of the fish, colouration of its integuments, migration and movement, reproduction, the rate and pattern of growth of fish. Water clarity causes genetic and ecological differentiation among species [4,23]. Land use changes such as deforestation, soil erosion, desertification, atmospheric pollution has steered the introduction of both organic and inorganic wastes while the loss of vegetation that acted as filters of the lake are contributing factors to the lives of lentic or lotic fishes [6]. Nutrient input from adjoining catchment causes eutrophication through release of fertilizers and sewage that encourages algal bloom that instigate anaerobic conditions leading to toxic tides and associated mass mortality [3]. Besides, Lake Victoria mixes completely owing to its water movements this physical instability tends to trap fish in hypoxic regions killing local fish [15]. Unpolluted water contains saturated oxygen for its given temperature unfortunately use of oxygen by the highly organic bottom deposit or in organic wastes from domestic sewage has resulted in hypoxia or reduced dissolved oxygen required for respiration [23,24].

Major constraints on expanded consumption of fish were identified as lack of infrastructure such as roads, refrigerated storage and transport, freezing and processing plants. Other constraints include low or poor education level, ineffective wealth distribution systems, relatively high prices, low product quality and lack of effective quality control and inspection systems [11,29]. Traditional assessment of fish stock is what is currently being used in the Lake Victoria with the amount being recorded as per the total biomass being used to record as the current stock of the lake [39]. The is poor communication between the fishers and the administrative authority which proves to be a hindrance to the development of fisheries in lake Victoria considering that fish populations change faster than the policy making process [17].

6. Conclusion and Future Directions

Lake Victoria provide valuable natural resources for the exponentially growing human population around it and at large resulting in conflict between the expanding population and the over-exploitation of its resources, biodiversity loss and its implication in the degradation and disruption of natural habitats. This conflict is manifested by increase in price commodity determined by catch levels, diversity and ecosystem health indicators and aggravated by the desire to maintain the ecosystem, ecological and genetic diversity [4,36]. The role of fishery in human nutrition as a concept of food security is vital considering that hunger in sub Saharan Africa remains a huge challenge. Moreover, fishery is a source of protein for many riparian community and this group of people are most vulnerable to price increase resulting from growing demand for fish or decrease in its supply. International forums such as the Convention on Biological Diversity (CBD) tries to resolve these conflicts by ensuring equitable sharing of revenues generated from the exploitation of biodiversity [5]. Therefore understanding dynamic issues facing Lake Victoria is essential in the management of the lake in that it can predict and respond to unforeseen changes for example the recent extinction of Haplochromis as a result of inadequate monitoring and control of the already existing fisheries has led to biodiversity loss [21]. Surveillance is vital in fisheries management through the control of fishing capacity, fishing efforts and the allocation of catch quotas, temporal or spatial access to resources [4]. There is need for the adoption of modern fishery governance, a systemic concept relating to the exercise of economic, social, political and administrative authority which relies on the collection of the basic data on fishers, catches, fishing efforts, prices, values and other related information such as size at capture and length frequencies of the target species. This precision in stock assessment and reliability of Fishery statistics such as fishing vessels is quintessential in policy making, sectoral planning, monitoring and management of fisheries and improving national and regional statistical systems [29]. For successful conservation, institutions should involve the government and community based systems such as the fisher folk in decision making, enforcing restriction access and use, wherewithal to offer incentives to use resources sustainably, have technical capacity to monitor ecological and social conditions and flexibility to cope with changes in the conditions of the resources or its users [5].

The main aim is to increase the supply of fish from the marine sector which may include reducing the fishing to sustainable levels in areas and on stocks currently heavily exploited or overfished. The goal of an ecologically sustainable development is to improve the wellbeing of all people involved directly or indirectly in the fisheries sector as well as the natural productive system full potential of wild fisheries resources is achieved and lost by overfishing [29]. The interaction between the strategic (long term) and the operational (short to medium term scale) involves effective and easy communication between the fishers and the administration which is a major problem in Lake Victoria and a severe obstacle for development.

It is imperative for communication to be transparent between the fishers the management bodies involved. All those involved in fisheries should understand their social and economic importance and partake the use of fishing methods and processes which do not jeopardize economic viability by exhausting resources including protection of aquatic habitat from the effects of pollution including those originating from fisheries themselves. Failure to recognize the contribution of politicians, economists, environmental/wildlife conservational organisation to development of fishery ecology and stock management, fishery declines, environmental degradation and ecosystem alteration places ecological and economically important resources at risk [12]. Therefore the application of evolutionary ecology is imperative in developing routine approaches such as sampling, data analysis and interpretive framework that will enhance the success of fishery resource management in the long term [40]. Global Biodiversity loss is one of the major driver for studies in the life history of a species therefore understanding evolution or life history changes through genetic diversity is prominent to the survival of a species.

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