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CONSERVATION AND DEVELOPMENT OF THE LAKE VICTORIA FISHERY: BIODIVERSITY AND GENETICS

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ABSTRACT

Competing factors will determine the future of the Ugandan fisheries. Human population growth places increasing demands on fish species which form potential food resources and raise the threat of species reduction or even extinction within Uganda. A major problem for Uganda in the next twenty years is achieving a balance between the development of commercial fisheries and the conservation of the biodiversity of exploitable aquatic species. This paper highlights genetic approaches to the study of fishes which have potential commercial importance to Uganda, but which are threatened with extinction or severe reduction in numbers. Such fish include the Lake Victoria tilapia, Ngege (*Oreochromis esculentus*), the Ningu (*Labeo victorianus*), the Ssemutundu (*Bagrus docmac*) and the Mamba (*Protopterus aethiopicus*). In addition, the conservation of genetically important but economically ambiguous biodiversity, as represented by the Nkejjes (haplochromine cichlids) of the Lake Victoria basin, will be addressed. Genetic factors that may affect the future of Uganda's exploitable fisheries resources will be examined. How much weight should be placed on the conservation of genetic variation and species diversity? Should steps be taken to encourage or prevent the introduction of exotic species, or the introduction of genetically altered forms of native species? What role will aquaculture and fish hatcheries play in maintaining the harvest size of Ugandan fisheries? How will hybridization between native species, "gene pollution" of native gene pools by introgression from exotic forms, and the potential use of transgenic fish affect future harvests of the Ugandan fisheries? New molecular methods are available to address the genetic constitution of food fishes, assessing the patterns of variation which distinguish individuals, populations and species. These methods have the potential to evaluate the impact of variation in ecology, physiology, morphology, and behavior of extant fish populations and species to the use of these fish as food resources. Will the new molecular tools be useful for the evaluation of fish species diversity and population management in Uganda?

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INTRODUCTION

Uganda is a endowed with vast natural fisheries resources which, if well managed and rationally exploited, are capable of bolstering her economy and fulfilling the protein requirements of her people. Fish protein currently forms the largest part of the average animal protein intake in Uganda. The ever increasing population and the quest for economic growth have greatly increased the pressure on fisheries resources to meet the elevated demand with a consequent increase in fish prices. This threatens to place a once cheap protein source out of reach of many average Ugandans at a time when alternative animal protein sources are relatively expensive. The future ability of this national treasure to continue to provide for the people is endangered.

Many of the problems that will be faced by the Lake Victoria fishery in the next twenty years stem from past management policies for the Ugandan fisheries. At times, unscientific measures were instituted to develop the fisheries, and were accompanied by lax management regulations. This resulted in an unstable fishery for Lake Victoria dominated by introduced species, and with several of the important indigenous food fish species lost.

This paper will deal with the background, and possible recommendations about the problems facing the Lake Victoria fisheries. The paper will consider the need for conservation of fisheries biodiversity in the face of increasing pressure from exploitation, and the necessity of expanding Ugandan expertise in genetics if appropriate changes are to be made to the way that fisheries are studied, managed and preserved.

BACKGROUND - THE AQUATIC BIODIVERSITY CRISIS

Causes of the crisis

The peril to the Ugandan fisheries is attributable to a series of factors. These include:

- Intentional introduction of exotic species including Nile perch and Nile tilapia
- Deregulation of the minimum gillnet mesh size
- Overfishing as demand for fish as a protein source increases
- Increased human activity in the Lake Victoria Basin

Uganda contains approximately 42,000 Km^2 of water surface, with all major water bodies having exploitable fisheries resources. These resources have undergone drastic changes both in size and composition since the inception of the gillnet fishery in the early 1900s. Intentional introduction of several exotic species over the period 1930-1965, and deregulation of the minimum gillnet mesh size requirement during the same period, were intended to address the problem of an increasing demand for fish and a decreasing harvest of fish from the waters of Uganda and East Africa (Fryer and Iles, 1972; Lowe-McConnell, 1993; Ogutu-Ohwayo, 1990). Introductions included the voracious predator, the Nile perch (*Lates niloticus*), and several species of exotic tilapiines, including the ecologically versatile Nile tilapia (*Oreochromis niloticus*). In effect, the introductions were an effort to convert the native fishery biomass into a more easily harvestable form (Nile perch and Nile tilapia). In the short term, these efforts can be viewed as a success. The increases in stock of Nile perch and simultaneous increases in the stocks of the Nile tilapia and the native minnow-like cyprinid (*Rastrineobola argentea*) have greatly improved the commercial fisheries.

Unfortunately, increased fishing and exotic introductions has also caused increasing declines of many of the species which represented the traditional target of the native fisheries. Accompanying the changes in fish biodiversity, rapid and dramatic changes are also being observed in the aquatic environments of Uganda. This is particularly acute in Lake Victoria, where increased nutrient loading, siltation, and heightened anoxia levels have been noted (Bugenyi and Balirwa, 1989). This has largely affected the nutrient dynamics and the ability of the system to respond to natural changes. Increased human activity in the drainage basin as a result of human population growth and accompanying economic development have contributed greatly to the drastic changes influencing the lake. The Lake Victoria ecosystem has been severely perturbed, leading to what is generally referred to as an ecological disaster (Barel et al., 1992). While commercial fisheries expand, traditional fisheries have been negatively affected, with catches plummeting because of the loss of traditional game. The result has been overfishing, with its associated increasing costs and decreasing return. There is also concern that the enhanced commercial fisheries yields might be only temporary, since the ecological system may have become severely unstable. These changes affect both fisheries yields and the nature of the endemic aquatic community.

As an example, in Lake Victoria up to 50% of the native fish species have been lost or severely depleted.

The entirety of the Lake Victoria cichlid species flock has been listed as endangered by the International Union for the Conservation of Nature (IUCN, 1992), and both local and international efforts are underway to address the increasingly ailing situation. This decline included the extirpation of the two species which once represented the most important economic and food species of the lake, the Ngege, *Oreochromis esculentus* and the related tilapiine *O. variabilis* (Ogutu-Ohwayo, 1992; Kaufman, 1992; Witte et al., 1992).

Results of the crisis

To summarize the effects of changes from 1960 to the present in the ecosystem of the Lake Victoria basin, we observe that the decline of aquatic resources has included:

- deterioration of the environment and water quality of Lake Victoria
- decline of the native fisheries
- loss of traditional endemic food fish species
- extinction of a significant number of endemic Lake Victoria fishes
- increases in the price and decline of the quality of fish related protein
- potential decline of the commercial fisheries and instability of fisheries harvest

POSSIBLE SOLUTIONS

In order to deal with the future needs of Uganda in conserving and managing its fisheries resources, a number of activities must be initiated. These include:

- development of management strategies for commercial and traditional fisheries which combine economic and environmental considerations.
- evaluation of current aquatic biodiversity
- diversification of the Lake Victoria fisheries
- restoration and aquacultural development of native food fish species
- development of the human expertise to plan and evaluate the management of aquatic biodiversity
- development of taxonomic/systematic resources
- development of genetic resources to evaluate aquatic biodiversity and foster aquaculture
- development of a genetics training program in Uganda which would include the study of the genetics of fish

Development of a coordinated fisheries strategy

Mismanagement, coupled with overexploitation and introduction of exotic species, has greatly endangered the fisheries resources, resulting in significant decrease of fisheries biodiversity. Government, industry and scientific efforts must be geared toward improving management of the fisheries resources of Uganda, slowing or preventing loss of native fish species, and developing a local aquaculture industry to supplement the natural harvest. Scientific management policies and governmental programs, together with effective extension services to educate the fishing communities of these programs and policies, and their strict enforcement may give Lake Victoria a second chance. Without these efforts, the natural fisheries will not be able to support Uganda's population in the coming twenty years.

The increasing demand for fisheries products and the quest for national economic development in the next twenty years should include some efforts aimed at the conservation of aquatic biodiversity. The course of the development of the Lake Victoria fishery will greatly depend on what cooperation can be developed between conservation and industry. There is a historical tension between the two approaches. Conservationist projects often aim to understand, restore and preserve the environment, but with an academic approach which often leaves out a consideration of economic and social factors. In contrast, programs for the development of an economically viable fishery industry have a history of fostering exotic species with economic potential but unknown ecological impact. This has resulted in such introductions as that of the Nile perch. The two strategies should be complementary, considering approaches which could combine economic expansion of the fisheries and ecological based management of the fisheries resources.

Evaluation of aquatic biodiversity

Much more is needed to bring the condition of the aquatic fauna of Uganda to the full understanding of even the scientific community. A significant part of the aquatic biodiversity of Lake Victoria appears to have already been lost. However, the true extent of the loss to Uganda is difficult to assess since biological work on the Lake Victoria was very incomplete before the onset of the ecological disaster. For instance, it appears that the majority of the fish species of Lake Victoria have yet to be described, and their role in the ecology of Lake Victoria, and their potential as economic or food resources have not been studied.

Diversification of fisheries and development of endemic fish resources

In order for Lake Victoria to be able to meet the increasing fish demand in the coming twenty years, the fishery has to diversify. Little consideration has been given to the value of native aquatic species. Value here refers to both the intrinsic value of biodiversity and the economic value of a species to the nation. Some native Ugandan fish species have clear economic potential value. Several species which have been depleted or greatly reduced in numbers ought to be targeted for both economic development and conservation purposes since they originally formed the economic base of the traditional Lake Victoria fishery. Their numbers were already declining before the recent expansion of the commercial fisheries, so they have not represented a significant component of the commercial harvest. Augmentation of these species will not only increase the productive value of the Ugandan fishery, but will also help save these species from extinction. At the forefront should be the preservation and development of Ngege (*Oreochromis esculentus*), which was the most important food and economic species in Lake Victoria before the introductions of exotic species, but is now only extant in some satellite lakes surrounding Lake Victoria, although it still faces competition from the introduced Nile Tilapia in most of these small lakes. Research on Ngege should emphasize factors which could encourage its return to its previous range, as well as approaches which would allow the use of Ngege in Ugandan aquaculture.

A second species of primary interest would be the Ningu (*Labeo victorianus*) which was also extirpated from Lake Victoria, mainly because of extensive harvest of gravid individuals while on their upstream migration for spawning (Ogutu-Ohwayo, 1990). Assessment of existing populations, hatchery culture of the young of this species, reactivation of regulations against upstream fishing and eventual reintroduction, could easily bolster the Ningu to economic levels once again. Several other species, including Ssemutundu (*Bagrus docmac*), and the Mamba (*Protopterus aethiopicus*), currently experiencing severe population reductions, could also be raised to economic status under scientifically viable programs. Each of these native species have clear economic value, and their preservation for future generations also has an innate value to the nation.

Why preserve non-economically important species?

The value of another portion of the aquatic biodiversity of Lake Victoria is more difficult to determine. The most severely affected and most vulnerable group of fish in Lake Victoria is the "haplochromine" species assemblage. These fish, which make up the majority of the fish species in the Lake Victoria basin, have little direct economic value yet form the enormous prey base upon which economically important predatory species like Nile perch directly depend. Nearly 99% of the depleted species of the Lake Victoria waters are haplochromines. Should we be concerned about the decline of these economically "unimportant" forms? Even considering the situation only from an economic perspective, the answer must be yes. Because it directly threatens the food base of the Nile perch, the continued decline of the haplochromine forms could pose a threat to the future of the current commercial Nile perch fishery dominated of Lake Victoria. As mentioned, most of the surviving haplochromine species have been greatly reduced in population size and are regarded as endangered or threatened species (IUCN, 1992).

Development of the human tools to design and guide fisheries management programs

The basis for the conservation and economic development of the Lake Victoria fisheries, given the dramatic ecological changes in the lake, will be a better understanding of those species that remain. We must act to preserve the biological diversity represented by these species, knowing that they may have significant future value. Two factors related to this assessment concern priorities of national strategies of educating Ugandan scientists. It is important to have individuals with the training in fish taxonomy who can identify and study the fish species of Lake Victoria. In addition, at least some of these scientists must be familiar with modern genetic approaches to the study of populations, both natural and domestic. Finally, individuals must be available who have the ability to use genetic approaches to evaluate and assist the development of aquacultural strains of important fish species. This would include the capability of establishing the pattern of the genetic population structure of all the populations of the native and introduced species of concern to the fisheries industry, to assess the amount of variation that exists in these species, and how much of that variation is worthy of protecting or useful for fisheries development in aquaculture or stock enhancement. Finally, training must include an appreciation of the evolutionary effects of the dramatic ecological changes affecting Lake Victoria, in order to be able to

institute measures to prevent loss of genetic variation, by identifying populations or species which contain important genetic traits, and developing management plans which can preserve the species or population genetic variability.

GENETICS AND FISHERIES

The importance of genetic information

An effective approach to the conservation and exploitation of these fisheries resources will require detailed knowledge of the species we are dealing with, and the amount and distribution of both phenotypic and genetic variation in these species. To realize the economic potential of this exploitation of these biological assets, emphasis must be placed on understanding the genetically based variation of each form. Our ability to measure genetic differences between populations of the native food fishes will assist the conservation of important genetic variability which may be required in the future to effectively exploit the aquacultural potential of these forms. It will allow the assessment of environmental influences on morphological and "aquanomic" (aquaculture - economic) traits which might limit the use of phenotypic differences between strains, since such environmentally determined variation may not reflect the true similarity or differences.

It is important to remember that genetic variability is the foundation of a species' evolutionary and agricultural future.

Genetics and biodiversity

Why worry about genetic variation? Genetic variation provides flexibility and ability to respond to environmental change (Baker and Stebbins, 1965). High genetic diversity has been found to enhance fitness and survival values, and is expected to be related to the ability to rapidly select for favorable traits in an aquacultural situation. Low genetic variability limits the possible responses to selection (either response to natural environmental change or response to artificial selection). Genetic diversity forms the basis for adaptive change. When genetic variability is lost from a species, it is very difficult to restore. Furthermore, it is now clear that many species possess unique rare genetic types, such as genes for resistance to disease, or genes for the production of biologically active compounds. Often these are not even found in relatives of a species. The products of such genes can be very valuable, both economically and "for the good of mankind." Consequently, the preservation of genetic variability and biodiversity can be viewed as having economic profit as one motive.

It is possible that some of the genetic variation or species biodiversity which has already been lost from Lake Victoria can be revived through captive breeding efforts and hatchery husbandry with eventual reintroduction, perhaps in the lake or in satellite lakes around Lake Victoria (Kaufman, 1992). This will be one way of preserving the genetic "resource" that these species represent. McAndrews (1992), views propagation in captivity as the only clear course of action for saving the threatened species of Lake Victoria from the imminent extinction. Genetic studies, and the training of scientists to carry out these studies, are needed to assess the captive populations and monitor the reintroduced species.

Similar methods can be instituted for wild populations whose populations have been severely reduced. So called "supportive populations" will have to be reared in captivity and later released into the lake to augment the existing populations in order to save some species from extinction. However, supportive breeding can actually lead to serious depletion of genetic variability in the population under some conditions (Ryman and Laikre, 1990). Thus, whichever program or project is instituted to bolster the wild populations has to include complementary genetics project as monitoring measures.

The importance of genetics for success in aquaculture

Of increasing interest and economic importance is aquaculture, given the growing demand for fish and depreciating natural fisheries stocks in the wild. Aquaculture, though still on a small scale in Uganda, will become a major fisheries sector within twenty years to come. However, for this industry to flourish, species of high economic value have to be used. How is this value to be determined? Market forces are normally a major determinant of the economics but are highly dependent on natural traits like taste, coloration, growth rate and food utilization efficiency of the fish. These traits vary among populations and species, and can only be fostered through choice of appropriate stock, selective breeding incorporating genetic programs and analysis of the available genetic variation. For instance, Rowan (1992) views aquaculture as a means to boost populations of the Ngege to commercial levels, and as a consequence, preserving this endangered species from extinction.

As Ugandan scientists become better prepared, it is possible that the future of fisheries in Uganda will in-

clude the use of genetically transformed and engineered fish "designed" to overcome the limitations of potential aquaculture species. A single gene or whole set of genes from one fish species have been inserted in other fish to transfer particular traits of interest. This is known as producing "transgenic" fish. As with all the above mentioned fisheries programs, the use of transgenic fish must be genetically evaluated before they can be used in natural systems or aquaculture programs, with continued monitoring programs to safeguard the wild populations.

Genetic monitoring of fisheries

Genetic information should play several roles in the future management of the natural fisheries of the Lake Victoria region. According to Kornfield (1992), successful managed propagation of wild fishes for preservation of germplasm and biological diversity over multiple lifetimes imposes at least three critical genetic demands: 1) identity of representatives of the species must be known with absolute certainty, 2) the gene pools must remain uncontaminated during husbandry, and 3) the species must retain the genetic architectures of their wild progenitors. In principle, contemporary techniques of molecular biology and formulations from population theory can be used to address these requirements. Individuals must be trained in the identification of species, and in the use of genetics for these purposes. At present many techniques that can be exploited for the evaluation of species diversity and population management in Uganda do exist.

New molecular methods which supplement the traditional electrophoretic analysis of proteins have been developed by scientists. These include the study of DNA variation, where particular regions of the genetic material are analyzed directly for variability. Such methods have been used in studies of tilapia and other African cichlids. Various techniques of "DNA fingerprinting" are relatively inexpensive yet robust in action. Such techniques are quite feasible for use in Uganda and could bridge the enormous gap between ecological studies and genetics.

Recommendations for the expansion of genetic training

The application of genetics to encourage the expansion of the Ugandan fisheries while preserving biological diversity is feasible in Uganda if there is a commitment to the training of Uganda nationals in genetics, molecular biology and fish biology (including modern systematic methods). To accomplish these goals, it is our recommendation that a full fledged genetics program should be instituted at Makerere University and other Ugandan Universities to educate Ugandans in these increasingly important fields of biology. It is important to recognize that genetics and molecular biology will have an impact not only in fisheries biology, but have become integral tools for modern terrestrial agriculture. Plant and animal breeding are rapidly moving into a genetic and molecular revolution. For Uganda to exploit these advances, Ugandan nationals must understand and be able to employ these methods in their work.

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