Introduction

Fish (an estimated 21,723 species) represent approximately half of the estimated 43,173 vertebrates known to science. Of this, approximately 39% of 8,411 species are found in freshwater habitats (Nelson 1984, Cohen 1970). This successful and adaptive group of freshwater fishes are found in an incredible range of diverse habitats from the seasonal pools of the Mojave Desert to the Alpine lakes of South America. Their success is further illustrated by comparing the volume of freshwater habitats to that of the oceans. The oceans account for approximately 97% of all water on earth and an additional 2.09% if tied up in the polar ice caps, groundwater, atmosphere, etc., (Berra 1981). Thus freshwater fishes (39% of all fish species) live in less than .01% of the water on earth (Berra 1981), Unfortunately, the increasing demand placed by human activity, on using these water resources is threatening aquatic species at an alarming rate. Many entire fish faunas currently face the threat of extinction due to over exploitation, environmental degradation, habitat alteration, and the introduction of exotic species (Andrews and Kaufman in press, Andrews 1988). The IUCN's 1990 Red List of Threatened Animals (IUCN, 1990) lists 762 species of fish, which are considered, threatened with extinction, of which the vast majority are freshwater species. Andrews and Kaufman (in press), suggest this figure greatly under represents the magnitude of threats facing fish communities and individual species around the world. Most notable in recent years; the collapse of the Haplochromine cichlid fauna of Lake Victoria due to the introduction of an exotic predator, introduction of exotic species and habitat alteration threaten the desert fishes fauna of northern Mexico and the North American Southwest, and the destruction of aquatic habitat due to deforestation of tropical rainforests in Southeast Asia, Australia, Africa, and South and Central America (Kaufman 1988a). Andrews and Kaufman (in press), reported the percentages of total populations of freshwater fish faunas currently threatened in Europe, Southeast Asia, Australia, and Africa. These include; 315 of the 350+ (90%) species endemic to Lake Victoria as threatened or extinct, 160 of the 500 (32%) species native to Mexico, 19 of 53 (35.8%) of species native to Singapore, and 292 of 1033 (28.3)% native of North America (Andrews and Kaufman, in press).

Whereas these problems seem overwhelming and the hope of reversing many of these situations maybe unrealistic, there are clearly ways in which zoos and aquariums can participate in meaningful and productive conservation (Kaufman 1998a, Andrews 198, Andrews and Kaufman in press). These include ecological research, raising public awareness of aquatic conservation problems, habitat preservation, raising popular and financial support for in situ efforts, and captive maintenance and propagation (Andrews 1988, Kaufman 1988a). Captive breeding program of endangered freshwater fish species, in conjunction with in situ research and conservation efforts preserve valuable options and serve as a hedge against extinction, while population restoration possibilities are being assessed (Kaufman 1988). In addition, they create "living" archives which could be accessed by researchers now and in the future, while providing the general public an opportunity to learn about the conservation of aquatic animals

In recent years, there have been several efforts initiated by AAZPA institutions in an attempt to establish captive propagation efforts for endangered freshwater fish species. These include amongst others; efforts by the Cleveland Zoo to breed the Australian lungfish (Neoceratodus forsteri), propagation efforts by the John G. Shedd Aquarium for the Asian bony tongue (Scleropages formosus) and the "pirarucu" Arapaima gigas , propagation of Lake Victoria Haplochromine cichlids initiated and coordinated by the New England Aquarium, propagation of Mexican desert fishes is being coordinated by the New York and Dallas Aquarium, and propagation of goodieds under the coordination of the Belle Isle Aquarium. In addition, there are a great number of captive breeding programs not involving zoos and aquariums which involve governmental, aquaculture, academic, commercial and amateur hobbyist sectors. Many serious captive propagation efforts and conservation initiatives have been organized by "non-occupational" professional organization such as; the American Cichlid Assoc., the American Killifish Assoc., the Aquatic Conservation Network, the American Livebearer Assoc., the Cyprinodon Study Group, the North American Native Fishes Assoc., and the Australian New Guinea Fish Assoc.

In 1987, the IUCN Captive Breeding Specialist Group (CBSG) identified three fish faunas to serve as pilot captive propagation programs, These are; the Lake Victoria Cichlids, desert fishes, and the Appalachian Stream Fishes. For the purpose of this paper, we will explore the progress, current status, and present goals of these three programs, and offer some preliminary discussion on the processes and ethics of recovery plans, reintroduction, and captive propagation of freshwater fish by zoos and aquariums.

Lake Victoria

Current data indicates that the Lake Victoria ecological tragedy actually began circa 1930 (Worthington and Beadle, 1932). The subsequent increase in lake turbidity can be related to agricultural development and the increased use of fertilizers. Increases in turbidity due to algal bloom exhibit a high degree of correlation with inadvertent input of nutrients as well as the Nile perch (Lates niloticicus) population (Newell 1960, Talling 1966, Kitaka 1971, Ochumba and Kibaara 1989). Core samples taken from the lake bottom provide evidence that, although portions of the lake have gone anoxic on a seasonal basis before, never has it happened to the extent that we are witnessing today (Kaufman and Sackley, pers. Comm., Kaufman 1991). All indications are that this environmental upheaval is far from over and could result in the complete euthrophication of the lake before it has run its course. A steady increase in turbidity is registered up to a point in time coinciding to the perch population explosion of 1978. From '78 to '80, the population explosion swept across the lake from Uganda at the top, to Tanzania at the bottom, so to, the existing food chain was swallowed wholesale (Witte et. al. in press). The mitigating effect of schools of algae-eating Oreochromis suffered two major blows; fishing, which developed into over fishing, particularly since the arrival and misuse of smaller and smaller monofilament gill nets (Graham 1929, Marten 1979), and secondly the alien introductions which out compete or inhaled the natives. The turbidity responded in kind with an accelerated rate of increase. Industrial airborne pollution seems to be a factor fueling the euthrophication process by providing sulfur or other nutrients, which in their absence, once held the euthrophication process in check (Kaufman 1990, 1991, in press).

Lake Victoria contributes to the sustenance and livelihood of more than 30 million people in Kenya, Uganda, and Tanzania: it is arguably the most important lake in the world (Andrews and Kaufman, in press). It is in the midst of the world's highest rate of human population growth. It is not surprising that the L. Victoria ecosystem has changed with astounding speed and magnitude, especially since the late 1970's (Magers 1991, Witte et. al. in press). The lake's original fauna of about 400 endemic fish species, more than 200 species are extinct or in immediate danger of becoming extinct (Kaufman per. Comm.). The introduced fisheries, particularly for the Nile perch, are more productive than those replaced (Ligtvoet and Mkumbo, 1990). However, even the new fishery is threatened by oxygen depletion in the lake's deeper waters, and the fundamental disturbance to the lake ecosystem that this represents (Barel et. al. 1977, Kaufman and Mallory, 1986).

In 1987, a group of African, North American, and European scientists joined forces as the **Lake Victoria Research Team (LVRT)** to monitor the changing fisheries and environment of the lake, and to build the international support base needed to carry out research, management, and restoration efforts in the lake basin. Species conservation **(Lake Victoria Faunal Rescue Project)** and education **(Kenya National Aquarium and Center for Aquatic Conservation)** projects were added in 1989 to create an umbrella initiative called the **Lake Victoria Research and Conservation Program (LVRCP)**.

Institutional captive maintenance efforts in this country began in earnest at the New England Aquarium in the fall of 1988 with several species being offered from the earlier Selbrink importation of 22 October 1987. Contact was established with our Dutch colleagues who experienced the fall of the Haplochromini first hand while working in the Mwanza Gulf, Tanzania (Witte et. al. in press). To date, the **Victoria Species Survival Plan (VSSP)** is studying, maintaining, and tracking 47 species at 29 institutions in the U.S. alone (appendix 1 & 2). These animals represent a rough cross section of the trophic specializations which have been recovered from the lake. It is important to try and preserve as complete a cross section as possible paying particular attention to those animals which seem most specialized (Kaufman 1988b, 1991, in press). Current priorities within the VSSP are to establish minimum viable populations (MVPs), for each species of two hundred individuals within a single generation, least removed from the wild (Kaufman 1991). Ideally, each species should be represented at at least three institutions. The New England Aquarium continues its leadership role as VSSP

program coordinator with the Toledo Zoo and the Columbus Zoo serving as co-studbook keepers. With the recent addition of the St. Louis Zoo to this group, final efforts are under way to receive formal AAZPA SSP status for the program. Species inventory records are maintained on the software package
Species Inventory Management System (SIMS)
which was developed by the New England Aquarium. Individual species are coordinated by species coordinators which currently include; the John G. Shedd Aquarium, Belle Isle Aquarium, Toledo Zoo, New England Aquarium, Oklahoma City Zoo, St. Louis Zoo, Columbus Zoo, Steinhart Aquarium, Michigan State Univ., Chuck Rambo (Calif), and John Kuhns (Alabama). In addition to institutional participation (appendix 2), the following individuals have participated on a semi-professional basis; Ole Seehausen, Chuck Rambo, Paul Sackley, and Russ McAndrews.

Desert Fishes

Human activities have severely impacted the fragile ecosystems of the desert through groundwater mining, pollution, and habitat alteration, threatening the survival of desert species (Loiselle, pers. Comm.). In response to this, a formal proposal of collaboration in Desert Fish conservation efforts between the New York Aquarium and the Autonomous University of Nuevo Leon (Mexico) has been signed (Loiselle, 1992a). The Dallas Aquarium has joined the New York Aquarium along with two corporate sponsors (Phythod Products, Milwaukee and Tetra Sales, U.S.A.) In providing support for the University's Desert Fishes Breeding Center in Monterrey, Mexico. The first shipment of endangered Mexican fishes to foreign participants in the Desert Fishes SSP was received in March 1991, logistics having been managed with the invaluable assistance of the Dallas Aquarium (Loiselle, 1992a). Currently, fourteen AAZPA institutions have agreed to participate (appendix 1). Six species of Cyprinodontids and three Xi phophorus sp.
are being managed by the Desert Fishes SSP under the coordination of the New York Aquarium (appendix 3). In addition, the Dallas Aquarium, in conjunction with the Texas Department of Parks and Wildlife, and the Arizona/Sonora Desert Museum are working with Cyprinodon eximius
and
Cyprinodon macularius eremius
respectfully. In a memo to the New York Zoological Society dated 23 March 1992, Dr. Paul

Loiselle reported, “Given the extent of groundwater mining in northern Mexico and the extent of its impact upon the water table, the elimination of approximately 90% of all aquatic habitats in the Chihuahan and Sonoran deserts by the turn of the century appears inevitable. Absent a comprehensive captive breeding program, the extirpation of their associated fish and invertebrate faunas is certain. These extinctions will effectively foreclose any possibility of eventual habitat restoration, for want of anything to reintroduce” (1992b, p.1).

Appalachian Stream Fishes

Stream fishes of the Appalachian mountain watersheds in the southeastern U.S., are unique and diverse. Unfortunately, these fragile streams have suffered the effects of habitat destruction, alteration, pollution, and acid rain. Currently, much of this rich fauna is threatened by man’s activities and faces an uncertain future. The proposed Appalachian Fishes SSP, although still in its forming stages, holds great promise and will involve, amongst others, the newly opened Tennessee State Aquarium (Andrews and Kaufman, in press).

Discussion

Today, we are witnessing the wholesale destruction of out biotic environment as the world’s economic machine surges forward. Acid rain is killing our lakes and streams, while damaging ancient forests. Tropical and temperate forests are leveled to make way for short term agricultural and cattle interests. Life giving topsoil is lost to the sea through erosion. Coral reefs are choked by siltation and pollution. Emission from residential, commercial, and industrial sources clog the air and threaten to artificially warm the planet. The natural landscape is manipulated and remolded several times over. Mighty rivers are dammed, channelized and in some cases reduced to a mere trickle. An exploding human population growth rate continues to put pressure on the world's dwindling resources. In the shadow of these events, species and entire ecosystems are being damaged and lost at an alarming rate.

In an ideal world, we could throw up a fence and place a sign saying "Do Not Disturb", however, this is not practical nor realistic.

In an effort to help protect resources and wildlife, regional recovery plans have been formed and implemented. Recovery plans for damaged ecosystems and endangered species must be part of a holistic menu of issues in order to be effective and usable (Reading et. al. 1992, Varner and Monroe 1991, Tilt 1989, Culbert and Blair 1989). As Culbert and Glair (1989) point out, recovery plans must consider the biological issues, socioeconomic issues, political issues, and financial and physical limitations. "Many recovery plans are handicapped because they ignore political realities or because they go too far in accommodating them. Recovery is compromised in both cases" (Culbert and Blair, 1989, 10:3). Reintroduction of an extirpated or endangered species is often at the forefront of a recovery plan, but as Griffith et. al. (1989) illustrates, most introduction attempts have failed. Reading et. al. (1991) convincingly argues that reintroduction would be more successful if they were to have a multidisciplinary foundation which incorporates "a systematic, more holistic approach to endangered species reintroduction which explicitly includes socioeconomic, organization, and political (power/authority) aspects, as well as, biological sciences and technical aspects" (Reading et. al. 1991, 11:1). Far too often, the reintroduction issue is seen only from one point of view in which the other side (id: ecological vs. economical) is viewed as a threat rather than as a possible partner. Captive propagation, as well, must be part of a larger holistic effort if reintroduction is its ultimate objective. Varner and Monroe (1991) point out, that captive breeding must be married to habitat preservation efforts if they are to have meaningful, long lasting, and ethical value. They further suggest, that "at least as much" be spent on habitat preservation as is spent on captive breeding (Varner and Monroe 1991, 11:6). Unfortunately, numerous ecosystems are overlooked by present efforts because man is not willing to address the problem of habitat preservation or the problem is on such a large scale it would be impractical for a financial and logistical standpoint. Lake Victoria is such an example. In these cases, faunal rescue operations and captive maintenance are preferable to in situ protection.

In the context of the captive breeding programs of freshwater fishes outlined in this paper, we have a long and arduous road ahead of us. Habitat re-construction, along with research and educational objectives, is hopefully our underlying ultimate goal. The argument can be easily made that the effort needed to be successful, is too overwhelming and impractical for financial, logistical, and space required, not to mention the numerous biological questions that arise. Whereas, we don’t suggest that we have the answers to these questions, we argue that valuable time is lost while debate continues. Extinction of the Haplochromine fauna of Lake Victoria and the desert fishes of Northern Mexico continue at an alarming rate while recovery plans and the resources to carry them out are assembled (Kaufman, pers. Comm., Loiselle, pers. Comm., respectively).

Habitat destruction to the point of extinction is a crisis situation and maintenance in captivity and captive propagation preserve valuable time and options. As Kaufman (1988a) sates, “Obviously it is beyond the reach of zoos and aquariums to solve all these problems at once. It would, however, be a useful exercise to examine one case study of faunal extinction in terms of what we can do about it, and in terms of the role of captive propagation in accomplishing these realizable goals”. Indeed, there are many more Lake Victoria’s on the horizon, and it behooves us to place ourselves in a position from which we can contribute towards meaningful conservation. In an effort to unite a more holistic front, two important meetings have been organized for this year. The U.S. National Science Foundation has funded an international workshop to draw together scientists, conservationists, and government officials to review the status of the Lake, to assess the implications of data gathered by LVRT and others from 1989 - 1992, and to establish guidelines for future research, conservation, and sustainable development in the Lake Victoria basin. The workshop was held August 17-20, 1992, in Uganda, As a compliment to this meeting, the Columbus Zoo and the Ohio State University, College of Biological Sciences will host a symposium titles “ Conservation Genetics and Evolutionary Ecology: A Case Study of the Cichlid Fauna of Lake Victoria” October 30 - November 2, 1992, which will emphasize species conservation and captive management strategies. Similar efforts are being organized by the New York Aquarium, Dallas Aquarium and the Autonomous University of Nuevo Leon, Mexico regarding Mexican Desert Fishes.

The Future, Think and Act Locally

Aside from the three regional efforts outlined in this paper, zoos and aquariums should seek to become involved in local efforts. In 1990. The Columbus Zoo joined with the Ohio Division of Wildlife (ODNR), to institute a ten year recovery plan for the western banded killifish (Fudulus diaphanus menoma
), one of Ohio's endangered species (Ross 1990, Warmolts et. al. elsewhere this conference). Its objectives include; the captive propagation, documentation of life history, determination of habitat populations within its former range, and to acquaint 15,000 school children with this small top minnow. The project is small, relatively inexpensive, and realistically obtainable. Perhaps least emphasized in a recovery plan is the effort given to public education. As Tile (1989., 10:39) points out, "
Perception is reality
… if the general [public] perception runs against an animal or plant's continued survival, all the biological data in the world will be useless against the perception". Strong local support can lead to strong national support. In the end, this may help secure the financial, popular and thus political support to successfully execute larger scale recovery programs.

Conclusion

Zoos and aquariums clearly have a role to play in the conservation of aquatic communities and species. These areas include; participation in the funding or ecological research, raising of public awareness, raising popular and financial support for in situ efforts, and captive propagation. Regarding freshwater fishes, currently three regional efforts are being organized and are in varying stages or operation. These are the Cichlids of Lake Victoria, Desert Fishes of Mexico, and the Appalachian Stream Fishes of North America. Many individual and local efforts are at a premium and conservationists must proceed in the face of uncertainty using the best data available". As zoos and aquariums, we must be willing to plunge in while there is still time.

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APPENDIX I

BREEDING PROGRAM PARTICIPANTS

Arizona/Sonora Desert Museum (D) Franklin Park Zoo (V)

Belle Isle Aquarium (D,V) Ft. Wayne Children’s Zoo (V)

Columbus Zoo Aquarium (D,V) Hofstra University (V)

Dallas Aquarium (D) Ohio State University (V)

Ft. Worth Zoo Aquarium (D,V) Michigan State University (V)

Indianpolis Zoo (D,V) Natural Res. Fish Ctr.

National Aquarium in Baltimore (D) (Gainsville, FL) (V)

New England Aquarium (D,V) Laguna Blanca Sch. CA (V)

New York Aquarium (D,V) Old World Exotics, FL (V)

Niagara Falls Aquarium (D) Milwaukee Co. Zoo (V)

St. Louis Zoo (D, V) Museum of Science, MA (V)

San Antonio Zoo Aquarium (D,V) Oklahoma City Zoo (V)

Shedd Aquarium (D,V) Chuck Rambo, CA (V)

Steinhart Aquarium (D,V) Cincinnati Zoo (V)

Tennessee Aquarium (A) Santa Barbara Zoo (V)

Sea World of Ohio (V) Pittsburgh Zoo (V)

John Kuhns, Al. (V) Harvard University (V)

D= Desert Fishes, V=Lake Victoria, A= Appalachian Fishes

APPENDIX II

LAKE VICTORIA BREEDING PROGRAM SPECIES

PISCIVORES

Pyxichromis orthostoma

Prognathochromis perrieri

P. “yellow large mouth” (two stripe brassy)

Harpagochromis “red-eye guiarti”

H. “grey pygmy”

Haplochromis “utajo sp.” (Fred Astaire)

H. “two-stripe white-lip”

H. “frog mouth”

PAEDOPHAGE

Lipochromis maxillaris

ORAL SHELLERS/CRUSHERS

Macropleurodus bicolor

Paralabidochromis plagiodon

Platytaeniodus degeni

Ptyochromis sauvagei

P. xenognathus

P. “dwarf silver crusher”

P. “Hippo Point salmon”

P. “robust xenognathus”

P. “Rusinga oral sheller”

PHARYENGEAL CRUSHERS

Astatoreochromis allaudi

Labrochromis ishmaeli

Haplochromis “Kenya rock-kinesis”

INSECTIVORES

Paralabidochromis chilotes

P. “blue bar”

P. “chromo gyros”

Astatotilapia “aelochephalus-like”

A. “flameback”

A. “grey bar”

A. “gold chest”

A. “macula”

A. “red anal”

A. “red flush”

A. “red little mouth”

A. “spot bar”

A. “thick skin”

Haplochromis “rock kinesis” Uganda

EPILITHIC ALGAL SCRAPERS/PICKERS

Neochromis piceatus

A. “nyereri”

Yssichromis “argens”

Y. “hydrocephalus”

PHYTOPLANKTIVORES

Oreochromis esculentus

APPENDIX III

DESERT FISHES BREEDING PROGRAM SPECIES

Cyprinodon alvarezi Allotoca maculata

Cyprinodon sp. “Charco Axzul” Hubbsina turneri

Cyprinodon sp. “Charco Palma” Characodon lateralis

Cyprinodon fonticola Characodon audax

Cyprinodon nazas Skiffia francesae

Cyprinodon eximus Ataeniobius toweri

Cyprinodon macularius macularius Girardinichthys viviparous

Cyprinodon m. eremius Xenoophorus captivus

Megupsilon aporus Allotoca goslinei

Xiphophorus couchianus Allodontichthys polylepis

Xiphophorus gordoni Xiphophorus meyeri