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IV. Conservation

Criteria for developing viable underwater natural reserves in Lake Tanganyika

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Abstract

Lake Tanganyika harbours an extraordinary diversity of endemic organisms (well over 500 species of endemic fish, crustaceans and molluscs alone), which presently have little of no legally mandated protection. This complex and unique freshwater ecosystem is currently threatened by resource overexploitation and human population pressure, particularly along its sensitive littoral and sublittoral fringe. Given the complexity and uniqueness of this ecosystem, the creation of one or more underwater parks by the nations adjacent to the lake should be a high priority goal of ecologists concerned with African lakes.

Potential localities of underwater reserves in Lake Tanganyika should meet several criteria in order to gain both governmental and local acceptance and satisfy the goal of preserving ecosystem diversity.

Ecosystem diversity and integrity

Littoral and sublittoral communities in Tanganyika are strongly substrate dependent, with extreme differences between rock, sand and mud bottom faunas. The highest diversity levels for all taxonomic groups occur on topographically complex hard substrates (particularly rocks and algal stromatolite buildups). Reserves should attempt to preserve viable-sized areas of lake bottom in all habitat classes, preferably within a continuous region of lake-margin, but if necessary in separated parcels. Reserve boundaries should incorporate both pelagic zones offshore from the shallow water regions of highest diversity and onshore watersheds (to avoid lake margin disturbance by agriculturally-induced siltation and changes in local nutrient input). Reserves should be large enough to provide adequate buffer zones from areas of intensive agricultural and fishing use (particularly in the more heavily populated northern regions of the lake).

Aesthetic and visitor considerations

An underwater park should incorporate areas of exceptional scenic beauty. To receive full governmental and local support (without which, the "reserve" would likely exist on paper only), an underwater reserve should also be self-supporting financially. The two considerations dictate that an ideal reserve would consist of one or more reaches of steep-rocky habitat which are readily accessible to tourists by boat or road. Spectacular localities with these characteristics exist adjacent to urban centres in all four countries bordering the lake.

Governmental and local support

An ideal Lake Tanganyika reserve would be established in an area which is currently unutilized or lightly utilized for fishing or agriculture to minimize potential usage conflict between local inhabitants and park authorities and visitors. However, long-term protection of an underwater reserve will require more than passive acceptance of the park on the part of nearby residents, since increasing population pressure in areas adjacent to the park could ultimately comporimise its continued protection. Experience in other African parks suggests that long-term local and governmental attitudes towards a Lake Tanganyika underwater park could be shifted from unenthusiastic acceptance to strong support if the park was perceived as a source of employment and income for people in the area. Park development should ideally proceed as part of an international lake-use planning compact between the four bounding nations, in an effort to protect this extraordinary resource.

Introduction

Lake Tanganyika, the largest of the African rift lakes, is one of the most unusual biotic resources on our planet. It harbours over 500 species of endemic animals (primarily fish, crustaceans and molluscs), most of which have evolved in situ within the lake basin during the lake's long and complex history. Many species and genera of the lake's fauna have no close relatives outside the basin, showing an extraordinary degree of morphological derivation for endemic lacustrine organisms. Furthermore, a number of studies have shown that the degree of community complexity and ecological integration observed here is unique among lakes of the world, perhaps the result of a long history of coevolution between its many endemic species (Hecky et al. 1981, Hecky & Kling 1981, West & Cohen 1987). Yet despite the tremendous importance of the lake for both the maintenance of biodiversity on Earth and as an

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economic resource for the people of the region, Lake Tanganyika receives little legally mandated environmental protection. In this paper, I will outline both the opportunities raised by, and the challenges facing the establishment of natural reserves within this lake. Timing is critical for preserving significant portions of this lake in its original state. The basin is faced with extremely rapid population growth, leading to severe overfishing and stream basin erosion (leading to excess littoral siltation). Mineral resource development (particularly of petroleum) may begin in the near future, raising additional concerns for the preservation of this lake. I will also suggest that the establishment of national parks by the nations bordering the lake should be accomplished within an overall environmental framework for the natural resources maintenance of the basin. Without such linkage, fragmented reserves will have little chance for successful long-term preservation.

Nature of the Lake Tanganyika resource

Biodiversity in Lake Tanganyika can be differentiated into several distinct and major habitat groupings. These include rocky, sandy and muddy substrate littoral communities; rocky, sandy and muddy substrate profundal communities; and a pelagic open-lake community. Assemblages of characteristic organisms (most of which are endemic to the lake) can be recognized for each of these communities, although some species occur

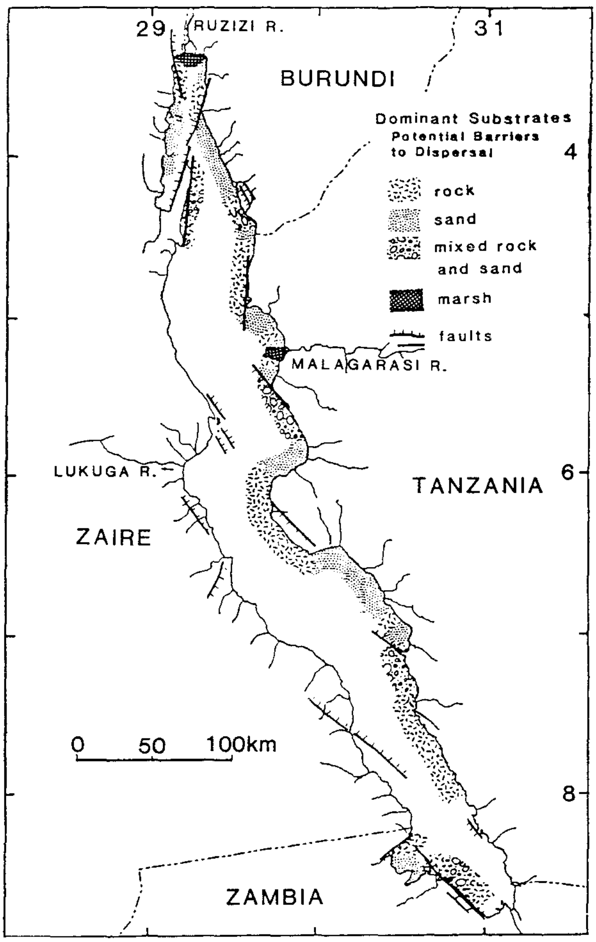

Fig. 1. Littoral substrate map for parts of Lake Tanganyika. Areas without substrate shading patterns have not been visited by the author. Major basin bounding faults are also shown to illustrate the correspondence between these faults and the occurrence of rocky habitat. Fault data from ROSENDAHL (1989).

in multiple habitats (BRICHARD 1978, Anonymous 1981). Furthermore, intralacustrine speciation has led to development of biogeographic privinciality within the lake, most noticeably among the cichlid fish and molluscs (MARLIER 1959, FRYER 1969, COHEN & JOHNSTON 1987, COHEN 1989). Different but closely related (typically congeneric) species or subspecies may occupy the same niche in different parts of the lake basin.

The highest levels of diversity occur on hard substrates at littoral-sublittoral depths (0–30 m). Hard substrates at these depths may consist of rocky outcroppings, rock talus, or algal (stromatolite) reefs. The occurrence of hard substrate habitats in the lake is controlled by the geological structure of the basin (ROSENDAHL et al. 1986, COHEN in press). Most are associated with the presence of major border faults, which occur as long segments (typically 10s of km long) separated by equally long intervals of soft substrate littoral regions (Fig. 1).

Both rock outcroppings and algal reefs provide topographically complex habitat structure (in many ways analogous to coral reefs), which support extremely high levels of fish, gastropod and encrusting organism diversity (BRICHARD 1978, NAKAI & YUMA 1987, YUMA & NAKAI 1987; pers. observ.). Populations of fish and invertebrates on hard bottoms are subdivided into local populations by minor dispersal barriers and the generally poor dispersal capabilities of most hard-substrate dwelling organisms in the lake.

Soft-bottom substrates (sand and mud) support a considerably lower diversity of fish than hard substrates in Tanganyika (MIHIGO 1983). Among molluscs, however, sand and mud substrate diversity is considerably higher than rocky habitat diversity considering both the entire lake (57 sp. vs. 19 sp. respectively) and specific localities (BROWN & MANDAHL-BARTH 1987; pers. observ.). Habitat preferences for Tanganyikan crustaceans are not currently well enough known to compare hard vs. soft substrate diversity levels. However, for single localities, soft bottom diversity is normally higher for this group than on hard bottoms.

Soft-bottom substrates in Lake Tanganyika occur associated with the outlets of major river deltas and along structural platforms away from major border faults. In addition to clastic sand and mud substrates, continuous blankets of shell debris are also common on these platform areas. Substrate conditions within both delta and platform environments are much more homogenous over long distances than it is the case for hard-bottom environments. Soft-substrate habitats are often interconnected with each other across regions of rock-substrate via sand/mud corridors which form perched on ledges or small shelves. This is in strong contrast with hard-substrate habitat segments, which rarely display well defined corridors across their intermediate habitat barriers. However, despite the greater habitat continuity observed in Tanganyika soft substrate habitats, soft substrate populations of many species still display patchy distribution patterns. For example, the ostracod *Mesocythere irsacae* which inhabits mud substrates in the northern portion of the lake basin is a poorly dispersing, brooding species. Populations of this species show a marked morphological change along the northern Burundi coastline at a point where no physical barrier to migration occurs (see line on inset map, Fig. 2). This may be the result of prior local extinction events accompanied by slow secondary dispersal (and simultaneous morphological divergence) into the unoccupied areas between existing populations (COHEN & JOHNSTON 1987).

Inhabitable hard and soft substrate regions of the lake floor are limited to narrow corridors around the lake margin by the presence of anoxia below 100–150 m. Given the lake's extremely steep margins, this limits most epibenthic animals to a corridor of less than 3 km width (and in many areas < 1 km) from the shoreline around most of the lake.

The pelagic environment of Lake Tanganyika occupies most of the lake's surface area typically beginning within 1 km off shore because of the lake's extremely steep margin. From the standpoint of the conservation biologist it can be considered to extend from the lake's surface down to the lower llimit of oxygenation of the water column. Fish and crustacean diversity within the pelagic zone are low in comparison with the epibenthic environments of the lake. Populations of most pelagic species appear to be much less patchily distributed than is the case for epibenthic species of either hard- or soft-substrate habitats.

Maintenance of ecosystem diversity and integrity in park design

In the establishment of an underwater reserve in Lake Tanganyika, we would ideally like to be able to predict the outcome for the preservation of biodiversity (whether measured as numbers of species or genetic variability within species) of a particular reserve design (size and shape) *prior* to the estab-

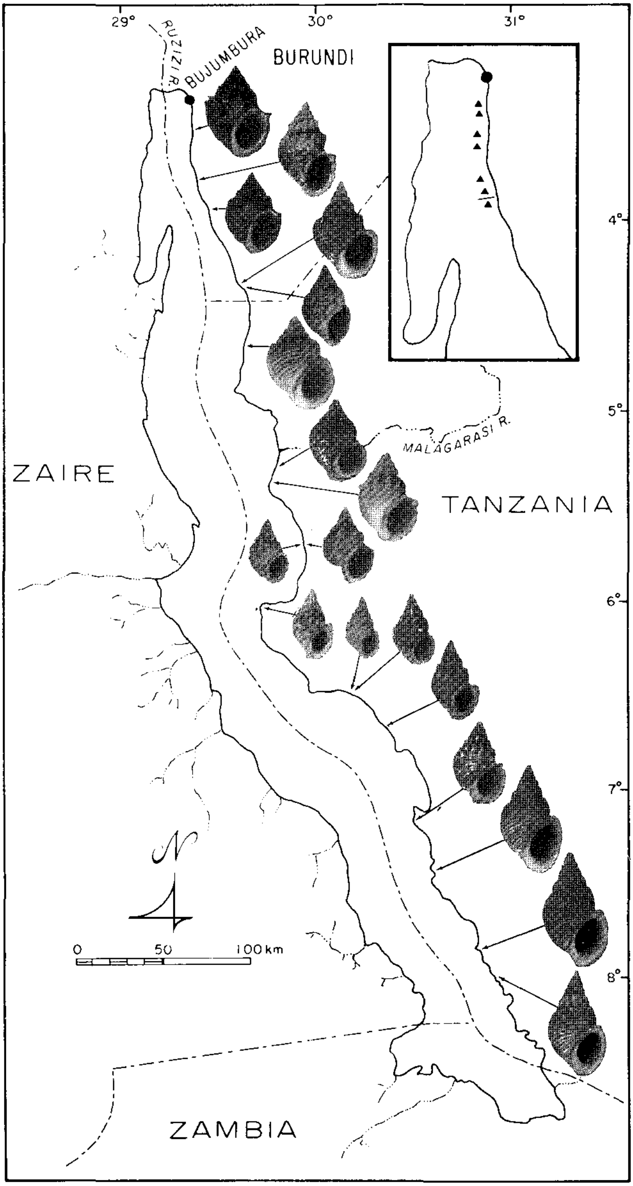

Fig. 2. Map of Lake Tanganyika showing geographic variation *Paramelania* morphs and species along the eastern shoreline. Two localities possess sympatric populations of readily differentiated morphs. Notice the extreme variability exhibited even over relatively short distances.

lishment of the reserve. One approach to this problem taken in other reserve design studies has been to apply principles of island biogeography theory (TERBORGH 1974, DIAMOND 1975, WILSON & WILLIS 1975). In this approach, reserves are treated as 'islands' with predictable immigration and local extinction rates based on their geographic proximity to other populations of the species which are to be protected in the reserve. Although specific recommendations arising from this approach have been criticized on a variety of grounds (see references in BOECKLEN 1986), it has stimulated numerous models for optimal reserve design. Some of the qualitative principles arising from these models are applicable to reserve design in Lake Tanganyika.

Because of the nature of the Tanganyikan ecosystem discussed above, any underwater reserve in the lake designed to initially encompass a large proportion of the lake's biodiversity must consist of an elongate string of shoreline, littoral-sublittoral, habitat segments. Within this arrangement, one or more reaches of hard and/or soft substrate may occur. Regardless of the actual shoreline parallel length of the reserve, the narrowness of the high diversity, littoral-sublittoral zone will make the reserve particularly susceptible to adverse environmental impacts from human activities (in particular, overfishing, agricultural and pollutant discharge) outside of the reserve. Any attempt to preserve the high diversity nearshore environments will be seriously compromised by a failure to also include in the reserve those adjacent areas (both on- and offshore) which directly impact on the nearshore habitats. This implies that reserve boundaries should be drawn to include entire watersheds feeding the proposed coastline 'core' of the reserve. Inclusion of entire watersheds is critical for optimal reserve design in Tanganyika because of the likelihood of excessive sediment, nutrient or pollutant runoff into the core areas as a result of either agricultural or urban land use.

Similarly, an optimally designed reserve should also encompass an adequate width of the pelagic zone to both protect a portion of the pelagic ecosystem and buffer the littoral zone on the lakeward side. Determining an appropriate width of pelagic zone to be included in the reserve is less straightforward than is the case with landward (watershed) boundaries. A minimum of 5 kilometres offshore, however, would probably be necessary to discourage small-scale poaching and other unwanted activities within the reserve.

The other major biological question in optimizing reserve design centres around whether diversity preservation would be best accomplished through a series of disconnected smaller reserves or as one larger continuous reserve. This is probably the most contentious general point of debate among 'applied' biogeographers (DIAMOND 1976, HIGGS & USHER 1980, SIMBERLOFF & ABELE 1982). BOECKLEN (1986) has recently shown that populations which are subdivided but maintain some level of connection through sporadic migration are more likely to preserve both heterozygosity and alleles in the long-term than single large 'intact' populations. Based on this finding he suggests that "archipelagos of refuges with occasional inter refuge-migration appear to be the optimal design strategy for genetic conservation". Similarly, QUINN & HASTINGS (1987) predict that a series of subdivided populations are more 'extinction proof' than a single, larger population (with equal total number of individuals), based upon a series of demographic stochasticity models. This pattern of population organization already exists among both hard and soft substrate epibenthic species in Lake Tanganyika. In order to protect the already tenuous migration corridors (particularly between rocky habitats) an ideal reserve for preserving 'local' genetic and organismal diversity in Tanganyika would, therefore, consist of a string of numerous alternating hard/soft substrate patches. Determining the precise number of such patches needed for long-term diversity maintenance will require data on the level of inter- and intra-population genetic variation (between and within patches) for a variety of species, in addition to accurate censusing information. Such data is not currently available for Lake Tanganyika, and, therefore, should be a high priority as reserve planning moves forward. Support for such research might be solicited from international conservation or environmental authorities as part of a larger basin preservation and development plan.

Another consideration for reserve design is the larger scale provinciality observed among species 'flocks' around the lake basin. In this context, a species flock is simply a group of closely related species, which have diverged from a common ancestor within the lake. Fig. 2 illustrates this type of geographic variation for the gastropod genus *Paramelania* around the eastern side of the lake. This variation is almost certainly the result of widespread intralacustrine speciation and is probably a common phenomenon for many fish and invertebrate species in the lake. Because the morphologic variability between populations is expressed over considerable distances (10s to 100s of km), a single reserve could not encompass this type of variation. This suggests that a second element of a reserve design strategy is needed if 'provincial' level diversity is also to be maintained in the lake. A series of reserves around the lake would be needed to preserve biogeographically differentiated species. One possible solution to this problem would be the establishment of one or more reserves in each of the countries bordering the lake. As can be seen from Figs. 1 and 2, Tanzania and Zaire, having longer stretches of coastline, will also contain a greater degree of regional variation within most species flocks than Burundi or Zambia. Thus a strong case could be made for having several well separated reserves in both Tanzania and Zaire.

An additional scientific argument for establishing multiple, spaced reserves around the basin arises from the need to protect the Lake Tanganyika fauna, as a whole, from local encroachment or catastrophic accidents. By establishing multiple, isolated reserves, the impact of serious damage to a single reserve upon the entire ecosystem would be lessened.

Fig. 3 illustrates a composite optimal design strategy for the Tanganyikan fauna based solely on ecological/evolutionary considerations. The lake is shown as a cartoon to defer the many other, alternative considerations (aesthetic, socioeconomic and political) to be discussed below.

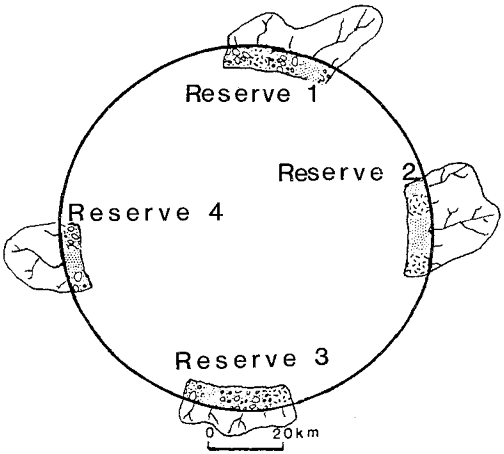

Fig. 3. Generalized reserve design strategy for Lake Tanganyika. In this model, four geographically separated reserves are established. Each parcel contains a mosaic of adjacent, alternating sand and rock substrate habitats. Established corridors facilitate low levels of gene flow between populations within a given parcel. Each reserve segment also encompasses its drainage hinterland, to protect the aquatic reserves from environmental deterioration caused by runoff and siltation. Reserve parcels are of the order of 10s of km in length, and approximately 5 km wide offshore. Four individual parcels are distributed around the basin to ensure the preservation of biodiverisity related to provinciality, and to protect the total resource in case of serious environmental damage in any one parcel. Separation between parcels is of the order of many 10s to 100s of kilometers.

Aesthetic considerations

The Lake Tanganyika basin includes many areas of exceptional beauty which would merit consideration for national park status on their scenic merits alone, even without the presence of the endemic lake fauna. Three areas within the basin (Gombe Stream Reserve and Mahali Mountains National Parks in Tanzania and Sumbu Reserve in Zambia) have already been set aside primarily for protection of their mammalian populations.

Tourism is an important consideration in the establishment of national parks, since most reserves need to raise revenues to support vital maintenance functions. Criteria for the successful attraction of visitors to a reserve, however, may be quite different from those based on strictly preservational grounds (Deshmukh 1986). This means that diversity considerations must be compromised with economic ones. It is imperative, therefore, that the design of reserves in Lake Tanganyika address the concerns of future park administrators who must pay the bills for environmental mitigation, antipoaching patrols, etc. These bills will have to be paid by the visitors.

Visitation considerations include both access and aesthetics. Several urban and semi-urban areas currently exist around the lake which can serve as gateway points for most parts of the lake. However, local road access to most lakeshore localities remains a problem except in Burundi and northern Zaire. Other parts of the lakeshore are currently accessible only through a combination of ferry and water taxi service, with uncertain scheduling. The most practical solution to the access problem would involve a combination of locating one group of reserves in areas which are readily accessible to visitors. Revenues derived from these reserves in turn could be used to administer and protect a second, more remote but possibly more sensitive group of reserves.

Fortunately several areas exist which combine all three attributes of high diversity, aesthetic appeal and access. Semi-continuous rocky shoreline zones 10–30 km south of Uvira, Zaire, in southern Burundi, and along the northern Tanzanian coast, north of Kigoma (adjacent to Gombe Stream) are all prime examples. Basic facilities for visitors could be developed at all of these areas at minimal cost. Examples of other regions of notable biodiversity and aesthetic attraction but which are more remote (falling into the second category) would include the western coast of the Mahali Mountains (Tanzania), the Kipili Islands (Tanzania) and the eastern cost of the Ubware Peninsula (N. Zaire). Because land national parks already exist in Tanzania at Gombe and in the Mahali Mountains, an administrative and visitor system for these areas already exists, making the development of underwater reserves at these sites a simpler proposition than for currently unregulated areas.

Political and economic considerations

The successful preservation of biodiversity at one or more reserves in Lake Tanganyika will require more than passive governmental support from the nations establishing such reserves. A reserve which exists on paper would be worse than useless. Not only would it receive zero financial support for protection, but its designation as a reserve could create a sense of complacency among potential conservation advocacy groups which may be ill informed as to the true level of protection afforded to the designated 'reserve'. It will be vital, therefore, that nations establishing reserves in Lake Tanganyika do so enthusiastically, so that adequate financial resources will be made available to these reserves. Financing for Lake Tanganyikan reserves could be derived from two distinct sources. Internal sources may be available if the reserves are perceived as a source of income and employment for the region and nation. Because the act of setting aside both land and underwater areas for reserve status will inevitably conflict with existing agricultural and fishing activity, it will be important to mitigate this conflict as carefully as possible. Attention should be placed during the initial siting of the reserve boundaries on avoiding (as much as possible) existing areas of already intensive agricultural or fishing use. Such areas likely will already have experienced diversity reductions (as it is the case with the heavily utilized lakeshore margin of northern Burundi). Furthermore, local opposition of the reserve will be immediate and extremely detrimental to its long-term success. Even activities as limited as small scale fish poaching could have a serious negative effect on the sensitive littoral fringe of these reserves. Conversely, for potential reserve areas which are not heavily used at present (particularly those currently experiencing low population pressure), strong local support because of employment opportunities will have a positive effect. As with land-based reserves, visitation can be focused onto a small number of relatively higher impact localities, leaving most of the reserve in a pristine state. Most visitors to an underwater reserve would be SCUBA divers and snorkelers, whose activities can be relatively easily monitored and whose environmental impact could be controlled.

A second potential source of financial support for the development of reserves in Lake Tanganyika are international lending institutions, which have recently shown considerable interest in financing conservation programmes as an integral portion of development aid. The World Bank in particular, has identified the Rift Valley Lakes among its areas of special concern for wildland protection (Goodland 1987).

Ideally, the development of underwater reserves in Lake Tanganyika should proceed as a part of a more comprehensive multinational plan for the resource management of the Lake Tanganyika Basin. This plan might define appropriate industrialization, resource exploitation and land management goals for varying parts of the basin, and set standards for the mitigation of various types of environmental impacts. Without overall planning and subsequent resource management, even very large lake reserves remain permanently threatened by human activities. The industrialization and subsequent extensive pollution of Lake Baikal demonstrates that even the largest lakes are not immune to this type of problem. Such a plan would require the cooperation of all four nations bordering the lake since environmental degradation knows no boundaries. The long-term preservation of this fantastically diverse lake requires that planning begins soon.

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