The Conservation and Management of African Inland Waters

A Synthesis

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Our objectives for this volume were to identify regional issues in the conservation and management of African inland aquatic ecosystems and to develop generalizations as a baseline for decision making in the twenty-first century. To achieve those goals, we drew together a series of papers linking social and natural sciences from diverse environmental and social settings at different scales of analysis (historical, regional, and ecosystem levels). The complexity of the threats to fresh waters is not unique to Africa. It does, however, clearly demonstrate the value of interdisciplinary, multiscale approaches to conservation and management of freshwater systems. In this concluding discussion, we summarize some of the common themes that emerge from the volume with respect to both local and transboundary issues, consider the resilience of African inland waters, and offer a set of generalizations.

The written and sedimentary historical records of African lakes show that Africa is a rather violent and capricious place for aquatic organisms. One of the most poignant examples is Lake Victoria, currently the largest tropical freshwater lake in the world but one that apparently dried up completely only 12,500 years ago (Johnson et al. 1996). However, a lake's drying up is not a unique event; Lake Naivasha in Kenya likely was dry 3,000 years ago (Richardson and Richardson 1972), and Lake Kabaleka, Uganda, was dry approximately 500 years ago (Crisman, Chapman, and Chapman, unpub. data). African lakes are acutely sensitive to climatic change, and the hydrological assumptions of water managers elsewhere in the world may not be generally applicable to African waters (see chapter 1).

On a finer time scale, looking at landscape histories over millennia suggests that African waters have also been subject to environmental change as a result of intensified human use and settlement focusing on agricultural production and iron manufacturing since at least 3000 B.C. (see chapter 2). It is clear that African inland waters cannot be wisely managed under the assumption that they will remain in their current state. Indeed, their current state is an unfortunate one, and efforts must be directed to improving water quality, availability, sustainability, and ecological health just to regain what has already been lost.

The regional and process-oriented perspectives in this volume highlighted both local and transboundary issues in African waters and permitted detection of commonalities among diverse ecological and social settings. Although there are unique regional threats to aquatic systems, some problems are remarkably similar regardless of country or environmental setting. These transcendent issues illustrate clear and enduring linkages between aquatic habitats and human activities.

In general, aquatic ecosystems make up over 70% of the world's biosphere; yet fresh water accounts for less than 3% of the total water in the world, and very little of that fresh water is found in lakes and rivers. Less than 0.009% of the total water supply is found in lakes, and less than 0.0001% is found in rivers (Berner and Berner 1987; chapter 7). Of the challenges currently facing Africa, none is more trenchant than the threat to the continent's supply of fresh water required to sustain human life. Not only is the absolute amount of water limited over large areas of the continent; water quality is also very often a problem (see chapters 4–6). Ethiopia, for example, has limited water resources, and many of these valuable resources are heavily affected by human activities. The most common manifestations of anthropogenic changes in its lakes are reduced water levels, increased salinity, nutrient and sediment loading, altered aquatic biota, and decreased fish catch (chapter 6).

The impacts from water-diversion schemes are even more dramatically manifested in parts of southern Africa suffering from a continual and serious water deficit and ravaged by periodic severe droughts (see chapter 3). In the more arid regions of southern Africa, where population pressures are particularly severe, provision for storage of more than an annual supply of water must be engineered to withstand droughts that may persist for several years. Consequently, large and small dams have been constructed throughout the region, but their impacts on regional hydrology and biodiversity are poorly understood. Interbasin transfers of water also occur, including the impressive Eastern National Water Carrier that is under way in Namibia, an 800-km conduit to transfer water from the Okavango River to Windhoek (see chapters 3 and 17). Water deficits are exacerbated by water quality issues, including industrial and mine effluents, sewage, runoff of nutrients and pesticides, and salinization.

West Africa currently has adequate water resources (chapter 4). However, most of the region's rivers have been impounded to form reservoirs ranging from small farm dams to multimillion-dollar large dams such as the Akosombo Dam on the Volta, one of the world's largest human-made lakes.

In all regions of Africa, regardless of availability of surface water, introductions of exotic species threaten the biotic integrity of indigenous communities. Nowhere is this threat better exemplified than in the Lake Victoria basin of East Africa. There, the introduction of Nile perch *(Lates niloticus)* and other nonindigenous fish species has coincided with the disappearance or decline of hundreds of endemic fish species and changes in water quality (see chapters 10 and 12). Management of Lake Victoria is politically, as well as biologically, daunting, owing to the need for transboundary cooperation among the three nations bordering the lake (Uganda, Tanzania, and Kenya), not to mention Burundi and Rwanda, which lie within its catchment. Given the economic importance of Lake Victoria to East Africa, water management solutions must be developed that focus on sustainable utilization of the common resource (chapter 5). This is an extremely difficult task, because management targets are continually changing as the result of species introductions (e.g., Nile perch, water hyacinth *[Eichhornia crassipes]*), changes in the food web, and eutrophication (see chapters 5 and 13). Lake Victoria is a moving system under constant pressure, and woefully complex. In comparison with terrestrial ecosystems, East African fresh waters may be facing even more severe threats to ecosystem integrity because current policies often stress rapid exploitation and the conversion of fish stocks into foreign currency rather than management and conservation for a local and equitable distribution of benefits over the long term.

Certainly, threats to Africa's inland waters are complex and diverse, yet all perturbations to freshwater ecosystems on the continent can be traced to a single factor: human activity. In all of the countries considered, rapidly expanding human populations are putting increasing pressure on aquatic resources by damaging the watershed (e.g., through deforestation and cultural eutrophication) and disrupting aquatic food webs (e.g., through overharvesting and fish introductions).

Nowhere are the effects of human activity clearer than in Madagascar; the entire freshwater system of this huge island and the unique fish community it has spawned are currently threatened by human systems (chapter 7). The Malagasy economy is based on natural resources, and the per capita income had decreased by about 40% from the mid-1970s to about US$235 in 1995. Over 90% of the country's population live in rural areas and rely on subsistence agriculture to survive (chapter 7). Agricultural activities have resulted in a 66% loss of original forest (Green and Sussman 1990), much of which was burned and converted to grassland of invasive grass unpalatable to grazing animals (Gade 1996, Chapman and Peres 2001). The change in the terrestrial system and the introduction of exotic fish species have driven current changes in Madagascar's aquatic systems.

Regardless of the threats to inland waters in Africa, it seems infinitely easier to predict the response of the production base of freshwater systems (e.g., algal communities) to disturbance than to predict the response of the dependent food webs. Information on African freshwater ecosystems is too scant and the systems themselves are far too complex for us to claim that we have anything close to a broad understanding of how the structure and function of food webs are likely to respond to human disturbance. Instead, most management predictions rely on knowledge from the temperate zone. Application of information from temperate waters to the tropics without local verification is ill advised, to say the very least (Crisman and Streever 1996). There is a critical need for a thorough understanding of the structure and function of representative African freshwater ecosystems to serve as a template for long-term management models. For example, inadequate understanding of the structure and function of the food webs has proved a major impediment to predicting the consequences of species introductions. Without such an understanding, one is unlikely to be able to identify critical indigenous species or to predict how their elimination will alter the whole ecosystem.

A historical perspective and an outline of the current plight of aquatic systems in Africa make one thing very clear: If African waters were dynamic before the arrival of humans and their frantic preoccupations, these waters are absolutely boiling with change now that we are here. As a result, managers and conservation biologists must adopt a new paradigm, for they are not managing systems to reach a set goal; rather they are aiming at a ballistic target. Only by using adaptive management approaches (Gunderson et al. 1995) and by continuously monitoring ecosystem health and responses to management interventions and human perturbations can we chase the moving target and add perturbations that might actually be timely and constructive.

A number of countries are taking steps indicating that this new paradigm for managing water resources is being adopted. One of the most innovative pieces of legislation promoting this approach is the National Water Act of South Africa (see chapter 3). From a social point of view, the most significant points of this legislation are that it gives a constitutional right of access to water. In a revolutionary move, it also removes the concept of private water; all water is held in trust by the state. Further, the act provides for a small amount of drinking water to be available to every person every day. Most important for sustainability, the law requires that a significant portion of the water in any river, wetland, or aquifer must be set aside for maintaining the "integrity of the ecosystem" itself. It will be interesting to see if other countries follow South Africa's lead—in the industrialized world, let alone elsewhere in Africa!

A second example is the Lake Victoria Environmental Management Programme (LVEMP), which is currently being implemented by the three countries sharing the shorelines of Lake Victoria: Uganda, Kenya, and Tanzania (see chapter 5). This plan is designed to act as a catalyst for these countries to develop a better understanding of how Lake Victoria functions, to learn how the actions of their respective populations affect the lake, and to work out how to implement a comprehensive approach to managing the lake ecosystem. A significant portion of the funding for this project is geared toward understanding ecosystem processes and developing monitoring strategies (including training) that will allow the three countries to respond to changing conditions in Lake Victoria.

These examples not only represent bold new approaches but also illustrate the importance of three essential elements in any such endeavor: transnational management, aggressive research directly tied to management decision making to ensure accountability, and, most important, patience. Of the world's continents, Africa has the largest percentage of its land (62%) in international river basins (basins shared by two or more countries) (chapter 17). In the Southern Africa Development Community (SADC) alone, there are 52 international river basins. Virtually all southern African states share one or more basins with other states, with the exception of the island states of Mauritius and the Seychelles (chapter 17). Most SADC countries have entered into numerous agreements regarding shared river basins, some even dating back to colonial times (e.g., an agreement between the Republic of South Africa and Portugal "in regard to mutual interest and the Cunene River Scheme"). It is clear that regulations governing international waters are going to have a high profile in the development of new water management policies.

Despite the withering complexities alluded to above, at least some of the dramatic changes to aquatic systems in Africa could have easily have been predicted from experience. For example, as demonstrated repeatedly throughout the world, increasing human populations and the drive to raise standards of living act together to guarantee rapid overexploitation of fisheries (see chapter 8). In Africa, many fisheries have been exploited to levels that have produced substantial degradation in the ecosystems that support them. These changes are termed the "fishing-down" process and involve the successive loss of the largest individuals and species in favor of smaller, faster, and shorter-lived fishes (see chapters 8 and 12). Other changes in African waters are less intuitive and illustrate the difficulties of predicting indirect effects of ecosystem change after human disturbance. For example, Seehausen et al. (chapter 13) demonstrated that eutrophication influences fish vision, thereby affecting their ability to capture prey and distinguish among potential mates. These changes can have cascading effects that appear to alter niche partitioning and promote hybridization among species, leading to species loss. The scaffolding of physiological properties and biotic interactions that supports high biological diversity, touching hundreds of species at once, can collapse by anthropogenic impacts on a single, basic environmental parameter such as turbidity.

Several contributors focused on the human dimensions of aquatic ecosystem change, documenting the complex interactions among health improvement schemes, human settlement patterns, and the economic drivers of aquatic change. It is clear that the breakdown of traditional patterns of land use affects aquatic systems. For example, the Okavango and Nata rivers of southern Africa have both material and symbolic value to the inhabitants of the basins (chapter 17). People depend on them for water and other natural resources, and the rivers have tremendous ideological significance. Traditionally, people in the region practiced rotational hunting, grazing, fishing, and plant collection as a means of ensuring that favored species had time to regenerate. Today, however, many of these traditional stewardship techniques are no longer practiced because of the shift of authority away from the traditional leadership system of chiefs to one in which a civil service oversees the management of land, resources, and local government.

The human dimensions of aquatic ecosystem change can be vexing and tragic in vector-borne disease control programs, which can have both direct and indirect effects on inland waters. Since the mid-1970s, the issue of environmental monitoring has been at the forefront of most major vector-borne disease control programs: e.g., the Onchocerciasis Control Programme (OCP) in Africa (see chapter 21). The traditional focus of these monitoring efforts has been to minimize the impact of pesticide use; far less attention has been directed toward environmental changes set in motion when these programs succeed in reducing disease. Nevertheless, there were clear costs associated with the myopia governing the efforts to control river blindness. The OCP story demonstrates the risks of excluding settlement from a more broad-based model of environmental impact and the overwhelming importance of interdisciplinary models that do incorporate settlement as an active agent of aquatic ecosystem change.

A critical underpinning of any conservation or management program for aquatic systems is an understanding of the ability of these habitats to recover from human-induced perturbations (see chapter 10). In many cases, it will not be possible to protect aquatic systems from anthropogenic pressures; but as African countries experience economic, political, and social change, it may be possible to restore them, or more realistically, to create conditions conducive to the natural process of ecosystem healing.

Ability of Aquatic Systems to Recover: Aquatic Restoration Ecology

It must be recognized that human interactions with aquatic systems in Africa will likely expand exponentially as a result of rapid population growth and ever more devastatingly efficient harvesting methods. The challenge is to use the past as a template for allowing resilience to return to aquatic ecosystems, or even to directly increase the resistance of ecosystems to change. We can learn to predict whether current and projected disturbances are likely to alter an ecosystem so fundamentally that they will never return to the conditions exhibited during their history (Holling 1973, Deevey 1984).

The ability of an ecosystem to recover from disturbance is a reflection of the intensity of disturbance and associated impacts on system memory (e.g., propagule source, sediments). The importance of system memory varies depending on the type of system considered. The ability of forested watersheds to recover from severe human disturbance is likely a reflection of the number of human disturbance cycles it has experienced and their temporal spacing. After the initial human disturbance, the lag time for forest succession is relatively short, but the loss of system memory (e.g., sediments, nutrients, seedbanks) may be sufficient to hinder recovery. Successive episodes of human disturbance further deplete system memory and promote a downward spiral in ecosystem structure. Whether the ecosystem eventually exceeds the bounds of resistance and resilience and is replaced by a new one depends on the timing between disturbances and their geographical extent.

Human disturbance over broad geographical areas will result in major alterations in both release of nutrients and inorganic sediments from the watershed and the quantity and time of water discharge (see chapters 10 and 11). With regard to the aquatic communities themselves, a massive reduction in the number and abundance of indigenous species, as occurred in Lake Victoria and in Madagascar, is clearly not good for system memory.

Although stream discharge is controlled by processes operating throughout the watershed, structural and functional aspects of the stream food web are strongly influenced by the riparian vegetation (Pringle and Benstead 2001). Most low-order (headwater) streams depend on input from riparian plants (Allan 1995). Streams accumulate little memory of disturbances, since material is removed in floods or more slowly through downstream nutrient spiraling (Webster and Patten 1979). Thus, to prevent serious negative impacts, we must limit intense human interaction with stream systems to activities that do not alter the integrity of riparian vegetation communities. This issue is of particular concern in Africa, where more than 90% of the continent's river course length is composed of rivers less than 9.0 km long (Stiassny 1996).

Isolated wetlands naturally experience intra- and interannual fluctuations in hydrology that often lead to system desiccation and removal of system organic memory through fire and decomposition. Such temporal unpredictability keeps isolated wetlands in a state of arrested development characterized by faunal and floral components extremely tolerant of environmental fluctuation. The long-term impacts of the drainage of such wetlands for short-term agricultural activities can be sharply curtailed, provided that much of the memory (organic sediments) is left intact and hydrology is restored after harvest. On the other hand, the long-term maintenance of agricultural practices, such as altered drainage patterns, can so derange system memory that the ecosystem is irrevocably altered. There is good news, however. Because the biota of fringing wetlands (and of isolated wetlands) have developed in response to the temporal unpredictability of the environment, especially its hydrology, they store little long-term memory and can quickly return to something approaching their status before human disturbance.

Lake responses to human disturbance are strongly controlled by ability to interact with system memory (water depth and sediment type) and the predisturbance structure and function of the ecosystem. Shallow lakes, defined as lacking pronounced thermal stratification of the water column, are characterized by nearly continuous interaction (recycling) with ecosystem memory (sediments) via wind mixing. Shallow lakes display perhaps the most complicated response to disturbance. The ability of fringing wetlands and the littoral zone to transform dissolved nutrients (phosphorus and nitrogen) via photosynthesis into organic carbon (dissolved and particulate) and export it to open waters is critical to the structure and function of the lake. The response of a shallow lake to human disturbance depends on the ability of fringing wetlands and littoral zones to sequester exported nutrients and on the preimpact relative dominance of phytoplankton and macrophytes. Once the absorptive capacity of the littoral zone is exceeded, changes in the structure and function of the pelagic zone become evident.

Three response scenarios are recognized. If phytoplankton was dominant in the preimpact period, it would remain the dominant element after nutrient enrichment. Only when free-floating macrophytes are present would there be a possibility for enhancement of macrophyte communities. If nutrient loading from the watershed lessens, the lake should remain dominated by algae and gradually return to a condition approximating the preimpact period. Algal dominance in shallow lakes both reduces light availability to the bottom and produces sediments that preclude the establishment of rooted plants. In the second scenario, if nutrient loading to a shallow lake dominated by macrophytes does not exceed the assimilative capacity of the plants, the system should remain macrophyte dominated. Under this scenario, the macrophyte community could recover to approximately its preimpact state associated with appropriate sediment conditions and a buried seedbank. The final scenario, a shift from macrophyte to phytoplankton dominance, is the most problematic and the least likely to respond positively to decreased nutrient loading. With phytoplankton dominance, macrophytes (along with benthic algal mats and aufwachs in littoral waters) become light limited; the seedbank is buried; and future macrophyte establishment is hindered by the flocculent nature of the algae-derived sediment. Even with radical reduction in nutrient loading to the lake, internal nutrient cycling from flocculent, fine-grained algal sediments can sustain algae-dominated productivity for decades or centuries. The experience in the temperate zone has taught that only with massive restoration efforts can this trend be reversed (Cooke et al. 1993).

Deep lakes, where the deepest waters may remain permanently stratified and anoxic (Osborne 2000), have the majority of their water farther from their memory than any system discussed previously, and the conditions directly above the memory hinder feedback to surface waters. Thus, deep lakes should display the least sustained negative impact once nutrient loadings from the watershed have been reduced.

Far too often, undue emphasis is placed on land-water interactions as a unidirectional process, and possibilities for feedback loops to terrestrial ecosystems are not recognized. For example, reduction in a nearshore fishery will eliminate a prime economic activity for fishermen. African fishermen typically maintain some level of subsistence farming; thus, the collapse of the fishery will force them to increase the intensity of agricultural effort and to move into marginal land, such as isolated or small fringing wetlands. Here, agricultural production can be maintained for only a short time because of rapid soil oxidation following drainage. The loss of such wetland systems means elimination of an important natural filter system for inorganic sediments and nutrients being exported from highly populated, degraded landscapes. A reduction in the Nile perch fishery in Lake Nabugabo, adjacent to Lake Victoria, has led to intensified forest clearance for charcoal production as a means to earn capital (Chapman and Chapman, pers. obs.). Here, then, is a truly sobering lesson on the complexities we must confront. Serious compromise to populations of an introduced species (the Nile perch), itself responsible for major impacts to the Nabugabo system, can have even more serious affects on the system than did the initial introduction. A similar effect could yet manifest itself in the much larger Lake Victoria, right next door. These are things we badly need to understand.

Generalizations

The history of research on African inland waters is extensive, but still our knowledge of these systems is woefully incomplete. During the exploration period of the late 1800s, the Musée de l'Histoire Naturelle in Paris and the Musée Royale de l'Afrique Centrale in Tervuren in Belgium covered much of the continent with respect to fish collections and identifications (see chapter 8). Studies in the 1920s and 1930s focused more on major lake and river systems, and a few were focused expeditions such as those of Graham (1929) and Worthington (1932, 1933). Welcomme (chapter 8) provides a brief history of the research on rivers in the postwar period when France, Britain, and Belgium initiated intensive research on African fisheries. In the 1970s, Lowe-McConnell (1975) and Welcomme (1975, 1979) produced excellent syntheses of the then-current state of knowledge on fish communities in lakes and rivers that spawned numerous research efforts in both fish biology and applied fisheries. There is a growing resource base on fish and fisheries in Africa. Several key publications have emerged since the 1980s, including taxonomic sources (e.g., the check-lists of freshwater fishes of Africa; Daget et al. 1984, 1986a, 1986b, 1991), guides to freshwater fishes of specific regions (e.g., Eccles 1992, Skelton 1993), and guides to specific taxa (e.g., Greenwood 1980, Trewavas 1983, Teugels 1986). Broader contributions have also emerged, including, for example, Leveque et al., *Biology and Ecology of African Freshwater Fishes* (1988); literature focused on lake and river fisheries (e.g., Welcomme 1985, Witte and van Densen 1995); and contributions on biodiversity conservation and sustainable development, such as Shumway, *Forgotten Waters: Freshwater and Marine Ecosystems in Africa* (1999).

With respect to limnology, Beadle (1974) provides an entry point for the early exploratory phase of African limnology; Allanson et al. (1990) provide a baseline for southern Africa; and Talling and Lemoalle (1998) discuss recent developments in the understanding of African systems. A blueprint of the status and future of African inland waters was provided by Symoens et al. (1981). Their work was followed by reports on the southern African situation, including Acreman and Hollis (1996) and Davies and Day (1998) and numerous country-specific reports on wetlands from the IUCN. These, along with numerous other contributions from the refereed literature, provide a basic understanding of the structure and function of African inland aquatic ecosystems. They also highlight major gaps that still exist in our knowledge.

Key areas of high biodiversity remain relatively unexplored in some regions, including areas of the Congo basin (see chapter 9). And there is a critical need for sustained research that provides a continuity of observation essential to understanding fluctuating systems, such as floodplain rivers and response to anthropogenic perturbations. It is ironic that the largest continent on the earth, where water problems are the most serious, lacks sufficient basic knowledge in some regions to form sustainable management plans. From periods of landmark accomplishments in the twentieth century, basic and applied research on aquatic systems in Africa have lagged behind research in the rest of the developing world in recent decades because of reduced funding at the international and national levels and far too frequent political instability.

Threats to African inland waters come in several forms, among them eutrophication, deforestation, overexploitation, pollution, introduction of nonindigenous species, and loss of biodiversity. Until recently, government policies in many African countries have emphasized exploitation for development at the expense of conservation and sustainable use. These issues are complicated by the fact that many major freshwater systems in Africa are shared by more than one country, thus requiring management programs that cross political boundaries. It is clear from the many examples presented of conservation and management schemes that policy and management decisions need to be informed by sound scientific research, but they must also be grounded in the appropriate socioeconomic and political context. Despite the multiple dimensions of these complex issues, there seems to be great consensus among regions with respect to the most critical problems, their causes, and the conceptual approaches necessary to minimize impacts and begin resolution. This consensus is encouraging because it suggests both that the development of general principles will be of value to water resource managers throughout the continent and that a continent-wide exchange of knowledge, which is critical to the development of unifying themes, is possible. Several generalizations emerged from the two symposia on African aquatic resources (see Introduction). It is hoped that the following generalizations will set the stage for further exchange of ideas and the development of conservation and management approaches for African aquatic systems:

1. Regardless of geographical region, all participants recognized that crises in water management in Africa are imminent. The nature of the crises differs among regions (e.g., eutrophication and exotic species in Lake Victoria and Southern Madagascar, water deficits in southern Africa, hydrological perturbations in West Africa, land cover change in Madagascar), but there is evidence suggesting that growing concern is warranted. However, it is also recognized that policy makers are sometimes largely unaware of the imminent crises.

2. It was also recognized that research and monitoring have not been able to keep pace with socioeconomic development and environmental change in Africa. Nowhere is this inability more evident than in Lake Victoria, where millions of people and a growing export market now depend on the Nile perch fishery. Yet, we cannot

predict the future of this fishery or the impact of increasing eutrophication and other multidimensional perturbations of the lake and its watershed.

3. There is a pressing need to translate research findings into policy. It is not sufficient to conduct scientific studies; policy makers who will determine and implement changes must embrace the results. Clearly, much of this change must involve local people; thus, programs designed to implement change must involve participatory management schemes. In addition, policy makers must understand that the kind of research required—ongoing environmental and economic assessment, with emphasis on the deciphering of process—is no luxury but rather an essential part of resource management and sustainability.

4. It is clear that water management is typically viewed separately from terrestrial watershed issues. This separation is inappropriate. Integrated management linking terrestrial and aquatic ecosystems is critical for effective conservation and management programs.

5. Finally, the many concerns shared by the different African regions clearly demonstrate the value of a continent-wide exchange of knowledge. There are many similarities in problems and solutions among regions, and the dissemination of knowledge on a continental scale will help identify transboundary issues and provide the common ground to make solid advancement for the conservation and management of African's aquatic systems.

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