PROLOGUE: FRESHWATER SYSTEMS

WHAT THEY ARE, WHY THEY MATTER

Freshwater ecosystems in rivers, lakes, and wetlands contain just a fraction—one-hundredth of 1 percent—of the Earth's water and occupy less than 1 percent of the Earth's surface (Watson et al. 1996:329; McAllister et al. 1997:18). Yet these vital systems render services of enormous global value that are on the order of several trillion U.S. dollars, according to some estimates (Postel and Carpenter 1997:210).

The most important goods and services that humans derive from freshwater systems revolve around water supply: providing a sufficient quantity of water for domestic, agriculture, and industrial use; maintaining high water quality; and recharging aquifers that feed groundwater supplies. But freshwater ecosystems provide many other crucial goods and services as well: fish for food and sport, biodiversity, mitigation of floods, assimilation and dilution of wastes, nutrient cycling and restoration of soil fertility, recreational opportunities, aesthetic values, and transportation for both people and goods. Harnessed by dams, these systems also produce hydropower, one of the world's most important renewable energy sources.

Prior to the 20th century, global demand for these goods and services was small compared to what freshwater ecosystems could provide. Historically, human development has favored activities with high economic returns that often maximized single objectives, such as abstracting water for irrigation schemes and urban aqueducts, draining mosquito-ridden swamps, and erecting dams to produce electricity and control seasonal water flows. Conflicts between different users and uses were more frequent in areas with an unreliable water supply. In areas with more reliable runoff patterns, the biggest problems were flood hazards and localized pollution problems when the discharge of human effluent exceeded the waste assimilation capacity of freshwater systems.

With population growth, industrialization, and the expansion of irrigated agriculture, demand for all water-related goods and services has increased dramatically, straining the capacity of freshwater systems. Although many policymakers are aware of the growing problems of water scarcity, there are many other signs of freshwater stress. The total amount and the number of pollutants entering freshwater systems, for example, has grown from a limited amount of organic matter from human and animal wastes and a few metals from mining to large quantities of human effluent and thousands of chemicals, such as pesticides and fertilizers.

The number of large dams (over 15 meters high) has increased sevenfold since 1950, from about 5,750 to more than 41,000 (ICOLD 1998:7, 13), impounding at least 14 percent of the world's annual runoff (L'vovich and White 1990:239). Between 1950 and 2000, annual water availability per person decreased from 16,800 m^3/year to 6,800 m^3/year, calculated on a global basis and assuming 42,700 km^3/yr of global freshwater runoff (Shiklomanov 1997:73). Runoff is defined as the renewable supply of water that flows through the world's rivers after evaporation and infiltration (WMO 1997:7). Water availability per person, therefore, refers to the amount of this renewable supply of water divided by the global population. With global population expected to reach at least 7.8 billion by 2025—the U.N. medium population projection (UNPD 1999:2)—per capita water availability is estimated to fall to 5,400 m^3/year.

As the amount of water available on a per capita basis declines, trade-offs between alternative water uses become more acute in terms of the environmental implications.

In many rivers, ecosystem functions or responses have been lost or impaired to the point at which human values and species diversity are adversely affected and restoration or protection is necessary to sustain natural watershed services. Maximizing one environmental good is no longer possible without significant trade-offs for other goods and services. Resource competition and conflicts are growing, becoming regional and global in scale. Managing freshwater systems increasingly will require integrating multiple objectives and data, using a basin and ecosystem approach to comprehensively assess the impacts on biological, chemical, and hydrological systems. Such an approach is especially important because some key freshwater services, such as water purification, maintenance of biodiversity, and watershed protection, never enter the market and, thus, have no price tag. This makes it harder to assess the trade-offs at stake when different uses of a freshwater resource are proposed.

The example of Africa's Lake Victoria illustrates the profound and unpredictable trade-offs that can occur when management decisions are made without regard to the ecosystem's reaction. In Lake Victoria, maximizing one particular good in concert with increasing resource pressure has caused drastic ecological changes. It also has led to a shift in the distribution of economic benefits from the previously large number of local beneficiaries who obtained a livelihood at a very modest level from the fisheries to a few who could afford to invest or participate in international fish exports.

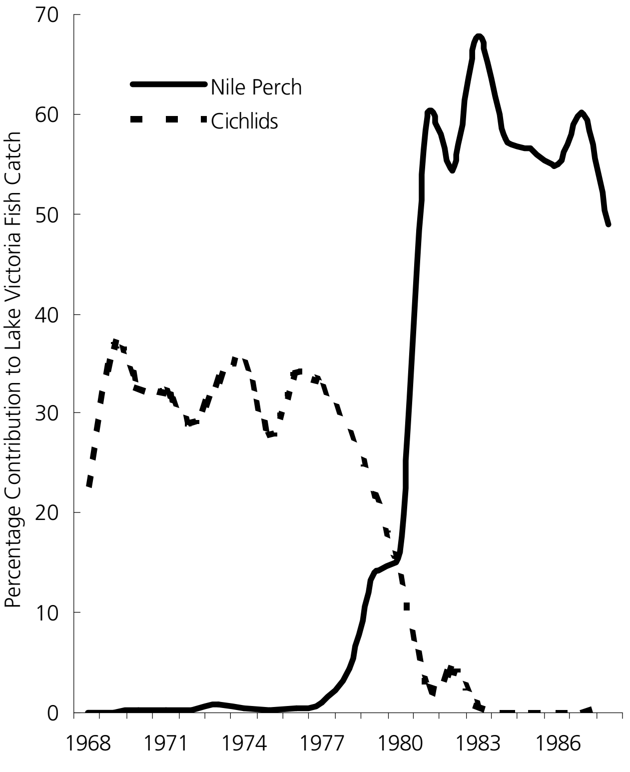
Lake Victoria, bounded by Uganda, Tanzania, and Kenya, is the world's largest tropical lake, and its fish are an important source of food and employment for the region's 30 million people. Before the 1970s, Lake Victoria contained more than 350 species of fish in the cichlid family, of which 90 percent were endemic, giving it one of the most diverse and unique assemblages of fish in the world (Kaufman 1992:846–847, 851). Today, more than half of these species are either extinct or found only in very small populations (Witte et al. 1992:1, 17).

The collapse in the lake's biodiversity was caused primarily by the introduction of two exotic fish species, the Nile perch and Nile tilapia, which fed on and outcompeted the cichlids for food. But other pressures factored in the collapse as well. Overfishing depleted native fish stocks and provided the original motivation for introducing the Nile perch and tilapia in the early 1950s. Land-use changes in the watershed dumped pollution and silt into the lake, increasing nutrient load and causing algal blooms and low oxygen levels in deeper waters—a process called eutrophication. These changes resulted in major shifts in the lake's fish populations. Cichlids once accounted for more than 80 percent of Lake Victoria's biomass and provided much

Figure 1

Trading Biodiversity for Export Earnings: The Changing Lake Victoria Fishery

(Kenya only)



Source: Achieng 1990.

of the fish catch (Kaufman 1992:849). By 1983, Nile perch made up almost 70 percent of the catch, with Nile tilapia and a native species of sardine making up most of the balance (*see Figure 1*) (Achieng 1990:20).

Although the introduced fish devastated the lake's biodiversity, they did not destroy the commercial fishery. In fact, total fish production and its economic value rose considerably. The Nile perch fishery now produces some 300,000 metric tons of fish yearly (FAO 1998), earning US$280 million to US$400 million in the export market—a market that did not even exist before the perch was introduced (Kaufman, personal communication, 2000). Unfortunately, local communities that had depended on the native fish for decades did not benefit from the success of the Nile perch fishery, primarily because Nile perch and tilapia are caught with gear that local fishermen could not afford. And, because most of the Nile perch and tilapia are shipped out of the region, the local availability of fish for consumption has declined. In fact, while tons of perch find their way to restaurants as far away as Israel and Europe, there is evidence of protein malnutrition among the people of the lake basin (Kaufman, personal communication, 2000).

The sustainability of the Nile perch fishery is also a concern. Recent evidence suggests that eutrophication and oxygen depletion in the lake, as well as overfishing in certain areas, are already threatening the long-term sustainability of the Nile perch fishery. The stability of the entire aquatic ecosystem—so radically altered over a 20-year span—is in doubt (Kaufman 1992:850). The ramifications of the species introductions can even be seen in the watershed surrounding Lake Victoria. Drying the perch's oily flesh to preserve it requires firewood, unlike the cichlids, which could be air-dried. This has increased pressure on the area's limited forests, increasing siltation and eutrophication, which, in turn, has further unbalanced the precarious lake ecosystem (Kaufman 1992:849–851; Kaufman, personal communication, 2000).

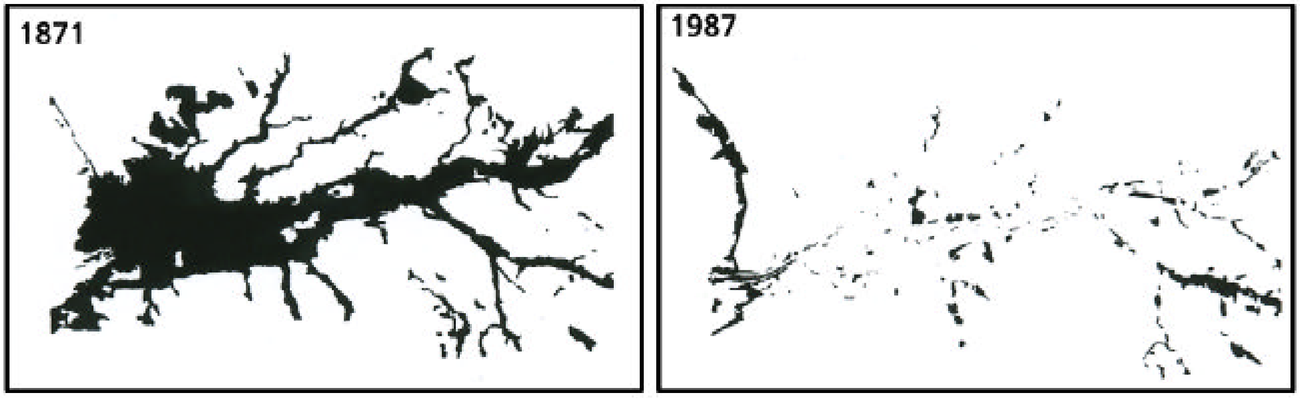
In sum, introducing Nile perch and tilapia to Lake Victoria traded the lake's biodiversity and an important local food source for a significant—although perhaps unsustainable—source of export earnings. When fisheries managers introduced these species, they unknowingly altered the balance of goods and services the lake produced and redistributed the economic benefits flowing from them. Knowing the full dimensions of these trade-offs, would they make the same decision today?

Another very different case that illustrates these trade-offs between environmental goods and services over time and the cost to recover some of these services is the Skjern River floodplain restoration effort in Denmark. The Skjern River is the largest river in Denmark, with a watershed area covering 6 percent of the country. It is the main source of freshwater and nutrients to the Ringkøbing Fjord, which is a coastal, shallow lagoon connected to the North Sea (NFNA 1997:5). The downstream floodplain, where the restoration project is taking place, occupies about 1 percent of the watershed (Riber, personal communication, 2000). Agriculture with extensive animal husbandry is the predominant land use in the watershed. The course of the lower Skjern River has been modified several times since the 18th century, with the greatest change taking place in the 1960s when the lower 20 kilometers of the river were straightened and confined within embankments. This last modification converted 4,000 hectares of wetlands, meadows, and marshlands into farmland, mostly for grain production, reducing the wetland area to only 2 percent of its original extent (*see Figure 2*) (NFNA 1999:6, 7).

One benefit of the river channelization, in addition to providing more land for agriculture, was to reduce the frequency of floods. Although flooding of the floodplain was prevented, a

Figure 2

Skjern River Floodplain: Marshland and Meadow Area in 1871 and 1987



Source: DHI Water and Environment 1999.

new flooding risk in the neighboring towns emerged, but these flooding events were marginal (Riber, personal communication, 2000). Also on the negative side of the ledger, channel modification reduced biodiversity in the watershed. For example, otters disappeared, nesting waterfowl declined, and the salmon population—the last wild salmon population in Denmark—was reduced to a small fraction of its peak (NFNA 1999:4, 24, 25). Draining wetlands caused other environmental changes, including ground subsidence of up to one meter in certain areas, ochre leaching, and waterlogging that reduced the productivity of the reclaimed agricultural land. In addition, the intensive agricultural use brought higher nutrient loadings to the fjord, contributing to its eutrophication (Olesen and Havnø 1998:3; NFNA 1999:12, 13).

The Skjern River floodplain restoration project was motivated by changes in societal values and priorities, notably the decreased economic importance of agriculture in the country, an increased appreciation of nature for recreation and tourism, and the desire to rectify past environmental damage. Work began in 1999 with the aim of restoring the Skjern River to a "natural" river by eliminating embankments, returning the river to its original meandering course, and recreating wetlands. The goal is to bring back salmon, bird, and plant populations. Furthermore, the new wetlands will act as filters, decreasing eutrophication in the fjord and helping to restore its biodiversity. The cost of the restoration project is estimated at US$35 million. It will take 3 years to restore the planned 2,200 hectares of wetlands. The area will be operated as a natural park by the National Forest and Nature Agency, which is also responsible for implementing the project (NFNA 1999).

Restoration projects like the Skjern River floodplain incorporate, albeit retroactively, all the elements that are important for the management of freshwater systems. They rely on scientific data and modeling, integrate multiple objectives, use a basin and ecosystem approach, and look at trade-offs between different goods and services. To avoid costly restoration projects, future assessments of freshwater systems need to include as many of these elements as possible. The level of detail and comprehensiveness will vary with the scale and purpose of the assessment. Assessments at a global level that are used to set priorities and identify key trends will require less detail, but they will ultimately constitute a much needed worldwide integration of more apparent regional patterns.