4

Sustaining Freshwater Ecosystems

Janet N. Abramovitz

In 1880, a decade before the territory of Washington became a part of the United States, 19,500 tons of salmon and steelhead trout were harvested from the region's most important river, the Columbia. One hundred years later, the harvest was just 50 tons. Fourteen million salmon a year once returned to this river basin to spawn in their ancestral streams; in 1992, only 1.1 million made it back, and most of them had been born in a hatchery. In Idaho, one of the region's five Pacific salmon species—the coho—became extinct in 1986. In 1994, only 400 fall chinook salmon and just one sockeye salmon, nicknamed "Lonesome Larry" by Idaho Governor Cecil Andrus, completed the journey from the Pacific Ocean up the Columbia and Snake Rivers to Idaho's Redfish Lake.[1]

To someone who does not live in the Pacific Northwest, this brief history might seem to be one of those disturbing but unusual environmental disaster reports that occasionally comes out of some far-away and uniquely troubled place. In fact, what has happened to the Columbia River basin is happening to freshwater systems all over the planet—from the Mississippi River to the Mekong, from Lake Erie to Lake Baikal, and in thousands of nameless streams and creeks across every continent. The details vary, and the tragedy may not be as well known, but the causes—and the consequences for human economies and the earth's ecological stability—are much the same.

Most people are unaware of the vulnerability that freshwater environments everywhere share. As biological assets, freshwater systems are both disproportionately rich and disproportionately imperilled. First, 12 percent of all animal species—including 41 percent of all recognized fish species—live in the 1 percent of the earth's surface that is fresh water. (Less than one one-hundredth of 1 percent of the total volume of water on earth is fresh.) At the same time, at least one fifth of all freshwater fish species have become extinct, threatened, or endangered in recent years, and entire freshwater faunas have disappeared.[2]

The plight of Pa
unique. Dramatic
species are seen
world. The Natur
that in North An
oughly studied co
mussels, 64 perce
cent of fish, and
ans are either in
cases—already go
In contrast is th
nized plight of te
17 percent of ma
of birds extinct
high levels of ext
ment are not arti
bations; they are
Ten fish species
America during t
Even more pro
numbers of speci
gered is the fact
species—both ter
are being lost far
extinction rate. N
Stuart Pimm and c
the journal *Science*

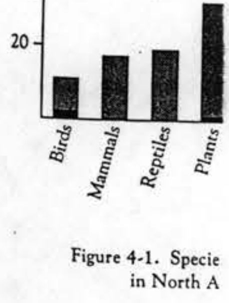

Figure 4-1. Specie
in North A

ater

ı is happening to
over the planet—
River to the Me-
o Lake Baikal, and
eless streams and
ontinent. The de-
;edy may not be as
causes—and the
ıan economies and
cal stability—are

ıaware of the vul-
ater environments
; biological assets,
e both dispropor-
ıroportionately im-
rcent of all animal
percent of all rec-
-live in the 1 per-
ırface that is fresh
· one-hundredth of
volume of water on
same time, at least
ıwater fish species
threatened, or en-
years, and entire
ve disappeared.[2]

The plight of Pacific salmon is far from unique. Dramatic declines in freshwater species are seen in every part of the world. The Nature Conservancy reports that in North America, the most thoroughly studied continent, 67 percent of mussels, 64 percent of crayfish, 36 percent of fish, and 35 percent of amphibians are either in jeopardy or—in some cases—already gone. (See Figure 4-1.) In contrast is the more widely recognized plight of terrestrial animals, with 17 percent of mammals and 11 percent of birds extinct or in jeopardy. These high levels of extinction and endangerment are not artifacts of earlier perturbations; they are recent and increasing. Ten fish species disappeared in North America during the last decade alone.[3]

Even more profound than the actual numbers of species extinct and endangered is the fact that the rate at which species—both terrestrial and aquatic—are being lost far exceeds any natural extinction rate. New calculations by Dr. Stuart Pimm and colleagues published in the journal *Science* indicate that recent extinction rates are 100–1,000 times higher than before humans existed. Further, if now-threatened species become extinct in the next century, rates will continue accelerating to 1,000–10,000 times prehuman levels. Today, we are running what Smithsonian Institution biologist Jonathan Coddington refers to as a "biodiversity deficit": we are destroying species (and ecosystems) faster than nature can create new ones. Such a course is even less sustainable over the long term than a growing financial deficit—since extinction truly is forever.[4]

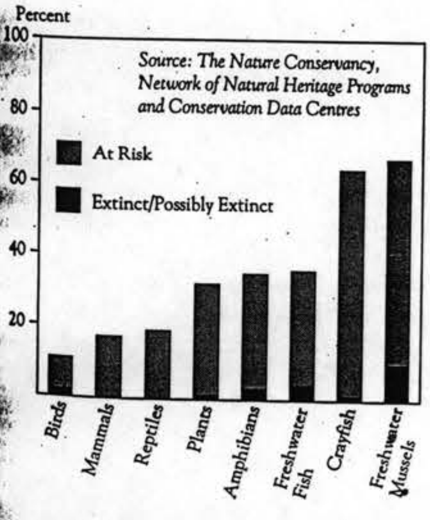

Figure 4-1. Species Extinct and at Risk in North America, 1995

Threats to Freshwater Systems

Around the globe, the integrity and inhabitants of freshwater systems are threatened by the actions and interactions of many human activities. (See Table 4-1.) These threats take the form of habitat degradation and fragmentation, competition for water, introduction of nonnative species, pollution, commercial exploitation, and climate change.[5]

Most losses of freshwater fauna can be attributed to a variety of factors acting together, with physical habitat alteration implicated in 93 percent of the declines, according to an American Fisheries Society (AFS) study of North America. This is hardly surprising, since in the United States only 2 percent of the country's 5.1 million kilometers of rivers and streams remain free-flowing and undeveloped. More than 85 percent of U.S. inland waters are artificially controlled and at least half of the country's original wetlands (excluding those in Alaska) have been drained. The amount of wetlands lost between the 1780s and the 1980s averaged more than 24 hectares (60 acres) an

Table 4-1. Freshwater Fish: Status and Threats in Selected Areas

Area	Known Freshwater Fish Species	Share Extinct	Share Imperilled	Principal Threats
	(number)	(percent)		
Global	9,000+[1]	← 20 →		
Amazon River	3,000+[1]	n.a.	n.a.	Habitat degradation
Asia	1,500+[1]	n.a.	n.a.	Habitat degradation
North America	950	4	36	Habitat degradation; introduced species
Mexico (arid lands)	200	8	60	Competition for water; pollution
Europe	193	n.a.	42	Habitat degradation; pollution
South Africa	94	n.a.	63	Habitat degradation; competition for water; pollution
Lake Victoria	350	57	43	Introduced species

[1]Likely to be higher.
SOURCE: See endnote 5.

hour for every hour of those 200 years.[6]

Logging, mining, grazing, agriculture, industrialization, and urbanization alter terrestrial and aquatic habitats in ways that make them less able to support life or provide valuable ecosystem services. Such activities cause erosion and sedimentation, loss of riparian vegetation, and changes in water flow and temperature. These have profound impacts on the reproductive biology and survivorship of aquatic organisms. Aquatic ecosystems must increasingly compete with humans for the very foundation of their existence—water. In fact, so much water is diverted from rivers around the world that many dry up before reaching the sea. (See Chapter 3.)

But physical changes are not the only form of habitat degradation. Industrial and municipal wastes add chemical pollution and sewage. Pesticides and herbicides enter the waterways through runoff from farms and homes. These nonpoint sources of pollution also add excess organic matter and nutrients (such as nitrogen and phosphorus) that stimulate undesirable plant and algal growth, which robs water of dissolved oxygen needed by aquatic life; silt and sediment that smothers breeding habitat and clogs the gills of fish and mussels; and disease-carrying pathogens such as cryptosporidium that are harmful to humans and aquatic life.

The introduction of nonnative, or exotic, species is the second most common factor in the loss of freshwater species, according to AFS, cited in 68 percent of the cases. Exotics may prey on native fish, compete with them for food and breeding space, and introduce new diseases. The hybridization that often results when an exotic breeds with a native fish can doom the native as a distinct organism. Exotics can also mask ecosystem decline; intentionally introduced exotic sport fish are a kind of fisheries sleight-of-hand. People seeing abundant fish in a stream or lake do not realize these are not native. Many are released regularly from hatcheries or escape from aquaculture operations (see Chapter 6), and some are added to waterways inten-

tionally by recreatio
local streams or l
cleaning out their l
North America, for
400 species of fresh
introduced into sy
natural range; 140 s
not even native to
become established
may constitute 5–1(
fish species; on the
continent, they ofte
than half.[7]

The case of the
trates the interacti
these forces and ho
known. The Amazo
for its vast tropical
digenous peoples.
been given to the
freshwater ecosyste
nourishes both fore
Amazon, flowing 6,
Atlantic Ocean, con
world's freshwate
oceans. During half
the forest up to 20
river are naturally
meters of water. T
constitute at least 1
lion square kilomet
rain forest.[8]

This vast area is
the flooded forest
flora and fauna. Fo
feed only during t
season, surviving th
accumulated fat. Th
more than 3,000 sp
more than any othe
Some of the most
than 200 species t
forest as a source of
forest depends on
persal, and people
forest and the fish.
tons of fish caught
are harvested by sm
ence and local mar

tionally by recreational fishers who stock local streams or by people who are cleaning out their home aquariums. In North America, for example, more than 400 species of freshwater fish have been introduced into systems outside their natural range; 140 species, including 40 not even native to the continent, have become established. In the east, exotics may constitute 5–10 percent of a state's fish species; on the western side of the continent, they often account for more than half.[7]

The case of the Amazon River illustrates the interaction of a number of these forces and how little is commonly known. The Amazon basin is best known for its vast tropical rain forests and indigenous peoples. But little notice has been given to the river itself and the freshwater ecosystem that supports and nourishes both forests and people. The Amazon, flowing 6,500 kilometers to the Atlantic Ocean, contains one fifth of the world's freshwater discharge into oceans. During half the year, portions of the forest up to 20 kilometers from the river are naturally flooded by several meters of water. These flooded forests constitute at least 150,000 of the 5 million square kilometers of the Amazonian rain forest.[8]

This vast area is far from uniform—the flooded forest has its own unique flora and fauna. For example, some fish feed only during the six-month flood season, surviving the rest of the year on accumulated fat. The Amazon is home to more than 3,000 species of fish alone—more than any other river in the world. Some of the most unique are the more than 200 species that use the flooded forest as a source of fruit and seeds. The forest depends on the fish for seed dispersal, and people depend on both the forest and the fish. Most of the 200,000 tons of fish caught each year in the basin are harvested by small fishers for subsistence and local markets.[9]

A variety of activities threaten the integrity of the Amazon River system. As elsewhere, the primary threat is degradation of the watershed through logging, mining, dam construction, and conversion of the floodplain for agriculture and livestock. In the lower third of the Amazon, only 15–20 percent of the flooded forests remain. Some of the most popular food fish, such as the 30-kilogram tambaqui, are already becoming difficult to find. Biologist Michael Goulding, a specialist in Amazonian ecology, warns that if the rates of deforestation of Brazil's tropical rain forest "are directed to the floodplains, as livestock operations suggest they might be, then the flooded forests will be almost entirely eliminated in the next decade. The destruction of the flooded forests may be the single most significant threat to Amazonian biodiversity. [It] could cause the greatest loss of freshwater fish known in human history, [fish that] have been a primary source of animal protein."[10]

What is happening in other large, modified freshwater systems confirms the often unforeseen and irreversible consequences of degrading watersheds, regulating and engineering rivers, polluting waters, and introducing alien species. Their stories also show that the cumulative impacts of individual actions can exact a high toll. Such changes have far-reaching and long-lasting effects on a region's ecological, cultural, and economic well-being. The status of fish and other aquatic organisms are good indicators of this well-being.

Damming Rivers, Damning the Future

Dams have become a major feature on the natural and political landscape.

Today there are more than 38,000 large dams and countless smaller dams around the world. Over half the large dams are in China, which also leads the world in new dam starts, including the highly controversial Three Gorges Dam project on the Yangtze River. Dams are at once symbols and agents of change. But the problems that they cause can run even deeper than the still waters held in their reservoirs. Many of these problems are surfacing in the Columbia-Snake River basin in North America, a region with a long-standing network of hydropower dam development.[11]

Because of their unusual life history, salmon are good indicators of the health of this region's rivers and forests. They are among the 1 percent of the world's fish species that are anadromous—living in both fresh and salt water. Salmon hatch in streams and rivers, then make their way to the ocean. After several years, they return to their ancestral streams to mate, and often die. Not only are salmon a symbolic link between the land and the sea, they are also an important nutrient link as their carcasses feed terrestrial and aquatic organisms far inland.[12]

Under the best conditions, the odds are just one in 5,000–10,000 that a salmon egg will be fertilized and survive to a reproducing adult. And because these fish pass through a wide range of habitats and conditions, over distances as long as thousands of kilometers, they are vulnerable to the full range of forces that nature and humankind inflict. The Columbia and its main tributary, the Snake River, had more than 24,000 kilometers (15,000 miles) of rivers and streams that were once salmon habitat. The watershed drains 673,400 square kilometers (260,000 square miles) in seven western states in the United States and portions of the Canadian province of British Columbia. Virtually no part has been untouched by the four forces implicated in the salmon's decline—hydropower, habitat, hatcheries, and harvest.[13]

Today, the Pacific salmon's biggest obstacles are the 58 hydropower dams and 78 multipurpose dams in the Columbia-Snake River basin. Most were built during the heyday of hydroelectric development 20–50 years ago. Dams alter the temperature and flow regimes of rivers; they are barriers to migrating organisms such as fish, and to the natural movement of sediments, nutrients, and water—all of which feed the surrounding floodplains and ultimately the sea. In the past, a young salmon's journey to the ocean took two weeks; now it takes two months. Habitat modifications—principally dams and reservoirs—take out an estimated 99 percent of the salmon killed by human activity in the region. A large proportion of the survivors must make an extremely unnatural detour: they are hauled around the dams in trucks and barges. Today, only 71 of the river's 1,996 kilometers run free, without the hindrance of dam or reservoir.[14]

There are other significant obstacles to the salmon's journey as well. Logging, grazing, irrigation withdrawals, agricultural runoff, and wetland conversion have all contributed to the extensive degradation of the freshwater habitats of the Pacific Northwest. Nearly 90 percent of its once extensive primary forests has been lost to logging. Throughout the region, even undammed streams have had their salmon populations drop precipitously, because sedimentation and higher water temperatures caused by logging make the streams unfit for salmon for decades after the operations have ceased. The loss of habitat has become so severe that the coho salmon is being listed as threatened throughout most of its range under the U.S. Endangered Species Act. Across the Canadian border, the effects of overfishing, log-

ging, and mining o
rivers, such as the Fr
have cut salmon pop
20 percent of prev
els.[15]

The serious impa
drawals on freshwat
continue, as agricu
share of water use
signs of abating. (Se
And it is not just mi
as salmon that are
cies that spend the
locale—"resident
threatened with ext

The loss of aqua
happen simply beca
cies dwindles in nu
pears. Much of the
below the species
particular "stocks."
cluding salmon, ar
tinct groups that h
adaptations to thei
These fitness-enha
may govern time an
migration routes, a
biologists see these
stocks as the buildi
vation and rehabilit
in the Pacific North
been sorely deplet
tinct in 55 percent
in 39 percent, and
declining in just 7
and summer chino
percent of their ra
all but 6 percent. A
dromous fish in the
the American Fish
that 214 native,
stocks are in seriou
mately 1,000 histo
are considered so
most all of them ar
tinued habitat de
four populations
given official prot
dangered Species

gest threat to these important and sensitive indicator organisms has been habitat destruction. Unfortunately, the recent spread of nonindigenous organisms such as the zebra mussel may be the fatal blow to the remaining members of the world's most diverse freshwater mussel fauna.[47]

By destroying not only the fauna and flora but the very ecological integrity of the Mississippi River system, we are eliminating valuable current ecological services. We also foreclosing future evolutionary pathways and options for adaptation to climate change. The Mississippi is a geologically old river where species have had a long time to diversify and create complex assemblages. Its richness is reflected in the fact that it is home to almost all the freshwater mussels in the United States and one third of its fish species. It is also home to some of the most ancient lineages of freshwater fish such as gars, sturgeons, and paddlefish. In fact, the entire paddlefish family has only two living species, one in the Mississippi and the other in the troubled Yangtze River in China.[48]

The Mississippi is unique in that its north-south orientation allowed migration to warmer waters during the ice ages. Today it also allows the yearly migration of waterbirds, shorebirds, raptors, and songbirds between northern breeding grounds and winter homes as far as South America. It is this unique north-south orientation that will also play an important role in future evolution and adaptation to climate change.

Great Troubles in Great Lakes

Large lakes can reflect more than the scenery around them. The picture beneath the surface is a much better reflection of human activities on shore. For many large lakes, the truer image is one of pollution, exotic species, and watershed degradation that destabilize these enclosed ecosystems. Large lakes have been viewed as a bottomless sink for whatever humankind has sought to release in its waters.

The world's largest freshwater ecosystem, the Great Lakes of North America, has already felt the full range of anthropogenic stress. Its 520,590-square-kilometer basin is home to more than 38 million people—and to significant portions of North America's industrial and agricultural activity. Over the last 200 years, the Great Lakes basin has lost two thirds of its once extensive wetlands. Barriers, canals, dams, and channels have eliminated vast fish spawning grounds. The Nature Conservancy has identified 100 species and 31 ecological community types within the Great Lakes system that are at risk on a global basis. And nearly half of these exist nowhere else. Today, less than 3 percent of the lakes' 8,661 kilometers (5,382 miles) of U.S. shoreline is suitable for swimming, for supplying drinking water, or even for supporting any aquatic life.[49]

Pollution is a major cause of the plight of the Great Lakes. More than a century of agricultural runoff, human waste, and household detergents have added excess phosphorus to the water, overstimulating algal growth. The resulting eutrophication causes problems such as dangerously depleted oxygen levels. Large quantities of toxic chemicals also enter the lakes every year, despite improvements brought about by decades of regulation in the United States and Canada. And the toxics from previous years tend to remain in the water and bottom sediments because the basin is a relatively closed system—only 1 percent of its water flows out annually. The large surface area of the Great Lakes makes them vulnerable to deposition of airborne pol-

lutants, which
jority of the m
ing the systen
blows all the
and cement pl
Lakes' "airshe
its watershed.
The health
to the health
1993, two thi
fish consumpti
in the Great L
the presence
dane, dioxins
comprehensiv
likely be much
ferent chemica
362 are reliab
The lakes'
causes massive
subtle effects
Many chemica
trated as they
web, with top
mans—receivi
process is kn
and biomagni
person would
water for more
as much PCB
trout would p
Many of th
DDT, PCBs, ag
some compor
plastics—act a
very minute ar
spectrum of m
cal, reproducti
Tumors, defo
normalities, a
are widesprea
and mammals.
human sperm
1940 (when th
ated) has been
many of these
mimic estrog
mone. And en
lated by one

lutants, which today account for the majority of the most toxic substances entering the system. Some of the pollution blows all the way from farms in Mexico and cement plants in Texas. The Great Lakes' "airshed" is thus even larger than its watershed.[50]

The health of lake fish is a good clue to the health of the whole system. In 1993, two thirds of the nation's 1,279 fish consumption advisories were issued in the Great Lakes region, mostly due to the presence of mercury, PCBs, chlordane, dioxins, and DDT. With more comprehensive data, the picture would likely be much worse; of the 30,000 different chemicals entering the lakes, only 362 are reliably monitored.[51]

The lakes' toxic brew sometimes causes massive fish kills, but the more subtle effects may be just as dangerous. Many chemicals become more concentrated as they pass up through the food web, with top predators—such as humans—receiving the highest doses. The process is known as bioaccumulation and biomagnification. For example, a person would need to drink Great Lakes water for more than 1,000 years to ingest as much PCBs as eating a two-pound trout would provide.[52]

Many of the compounds—such as DDT, PCBs, agricultural chemicals, even some components of detergents and plastics—act as endocrine disrupters. In very minute amounts, they alter a whole spectrum of morphological, physiological, reproductive, and life history traits. Tumors, deformities, reproductive abnormalities, and reduced survivorship are widespread in exposed fish, birds, and mammals. A 50-percent decline in human sperm counts worldwide since 1940 (when these chemicals were created) has been attributed to the ability of many of these widespread chemicals to mimic estrogen, the feminizing hormone. And endocrine disrupters assimilated by one generation can produce changes in the next generation. The cognitive, motor, and behavioral development problems noted in children of women who eat contaminated fish do not come from what was eaten just during pregnancy, but from what was consumed by the mother throughout her life.[53]

A person would need to drink Great Lakes water for more than 1,000 years to ingest as much PCBs as eating a two-pound trout would provide.

The Great Lakes suffer from a kind of "biological pollution" as well: the spread of exotic species. Two hundred years ago, each of the five Great Lakes had its own thriving aquatic community, with an abundance of members of the salmonid group. In 1900, 82 percent of the commercial catch was still native salmonids; by 1966, natives were only 0.2 percent of the catch. The remaining 99.8 percent were exotic species. And many of the surviving natives are hatchery-bred, not self-sustaining populations.[54]

Some exotics were intentionally introduced, in response to the declines of native fish from overfishing. A hatchery program for sport fish, for instance, supports a \$2-billion sport fishery whose value now eclipses the lakes' remnant \$41-million commercial fishery. But most of the 130-plus exotics have found their own way into the system by moving through canals or hitchhiking in ships. More than one third of the exotics have entered the system in the 30 years since the inauguration of the St. Lawrence Seaway. The canals are thought to have opened the Great Lakes up to the sea lamprey, an ocean-going parasite that devastated the lake fisheries. In Lakes

Michigan and Huron, the lamprey is credited with driving the annual commercial lake trout catch from 5,000 tons in the early forties to less than 91 tons just 15 years later. The first effective intergovernmental cooperation in the region came about to combat the sea lamprey, and resulted in the Great Lakes Fishery Commission. The lamprey remains in the lakes and its control requires constant vigilance.[55]

Prospects for controlling a more recent invader, the zebra mussel, are far less certain. Inadvertently introduced to the lakes in 1988 from ship ballast water, the zebra mussel has already spread to most major rivers and lakes in the east, and has been found as far away as California. The larvae of this prolific Caspian Sea native attach to hard surfaces, such as rocks, boats, pipes, and other mussels. They form dense colonies on substrate used by spawning fish and native mussels and virtually eliminate plankton needed by native fish and mussels. Workers at Detroit's electric power generating plant have found as many as 750,000 mussels per square meter in the plant's water intake canal. The cost to cities and industries of keeping these tenacious invaders from clogging intake pipes and heat exchanges could reach $5 billion by 2000 in the Great Lakes alone. By that time, the zebra mussel is expected to have colonized virtually all freshwater systems in North America, since an effective method for controlling it has yet to be devised.[56]

Attempts to heal the Great Lakes have been limited largely to episodes of crisis management. Early in the century, when epidemics were traced to the release of sewage, outfall pipes were extended farther into the water. When the native fisheries collapsed, heavily stocked exotics took their place. And most pollution control has focused on end-of-the-pipe management of individual chemicals rather than on comprehensive source reductions. Still, some progress has been made, albeit very slowly. Citizen groups in both Canada and the United States have been instrumental in spearheading change. The International Joint Commission, the Great Lakes Fishery Commission, and the Great Lakes Water Quality Agreement (GLWQA) of 1978 have provided forums for bilateral cooperation—on both federal and state levels. Cooperation under the GLWQA has significantly reduced phosphorus levels and eutrophication.[57]

In the United States, regulations by federal and state authorities have substantially reduced inputs of many pollutants, and the agencies have developed flexible guidelines for achieving further reductions. A new five-year strategy developed by federal, state, and nongovernmental agencies and coordinated by the Environmental Protection Agency takes an integrated, ecosystem management approach to problem-solving and decision-making in the region. Although it is too soon to judge its success, the strategy represents an important conceptual leap.[58]

On the other side of the globe, one of Africa's Great Lakes is also suffering from the effects of an introduced species. The Nile perch is conspiring with changing land use, pollution, growing population pressures, and war to rob Lake Victoria of its rich fauna and its people of a valuable source of protein and employment. The three largest lakes in the Rift Valley are not connected to each other, and lie within different river basins. Thus, each one's fauna and ecology are distinct—99 percent of the fish found in each lake are endemic, found only there. Lake Tanganyika is the oldest and deepest, with the most diverse fish fauna of any lake on earth. Bounded by Uganda, Kenya, and Tanzania, the shallower Lake Victoria covers some 62,000 square kilometers. It is the largest of the Rift Valley lakes—and the second largest lake in the world. Individually and together, the lakes, with hundreds of species exhibiting unique behaviors, are a living laboratory for studying trophic radiation and evolutionary processes.[59]

The introduction of the Nile perch to Lake Victoria in 1954—against the prevailing scientific advice of the day—has virtually eliminated the native fish population. (See also Chapter 6.) A 200-kilogram predator more than 2 meters long consumes enormous quantities of little fish: since the perch was introduced, Lake Victoria has lost 200 taxa of endemic cichlids, spectacular species found nowhere else; the remaining 150 or more are listed as endangered. The loss of Lake Victoria's fish is so severe that Boston University biologist Les Kaufman has described it as the "first mass extinction of vertebrates that scientists have had the opportunity to observe."[60]

On shore, there has also been a shift from little fish to big fish. Until recently, the native fish of Lake Victoria were harvested by small-scale fishers and processed and traded by women for local consumption. This kept the nutritional and economic benefits in the lakeside communities. Today, the perch are caught by large, open-water vessels with more destructive gear, then processed and traded by large commercial operations for the export market. Local women are literally left with the scraps—which they must purchase. Deprived of work and unable to afford this higher priced (and less palatable) catch, local people face a serious nutritional predicament. The perch takeover has decimated the primary economic and nutritional resource of 30 million people.[61]

The exact key to its success is uncertain, but the perch is noted for its ability to change its life-style and breeding strategy to suit prevailing conditions. In the late seventies, the lake's water began to lose oxygen through eutrophication, which is deadly for most aquatic life. At the same time, the perch underwent a massive population explosion, and quickly began consuming and displacing native fish. The results are apparent from fishery statistics. Kenya, for example, reported only 0.5 percent of its commercial catch as perch in 1976 but by 1983 the proportion reached 68 percent. While a small portion of that increase may be attributed to larger fishing vessels and so forth, scientific fish surveys also show the demise of native fish and the takeover by introduced fish species. (See Figure 4–2.)[62]

It is unclear whether eutrophication gave the perch an opening, or whether the perch's voracious consumption of native fish "decoupled" the lake's internal recycling and cleansing loop. Either way, there is clear evidence that the structure of the entire system has changed. Ten years ago, Lake Victoria was oxygenated to its bottom—100 meters down. Now it supports life only in the upper 40 meters or less. Regular mixing events, in which the now suffocating, oxygen-depleted bottom waters rise to the surface, cause frequent

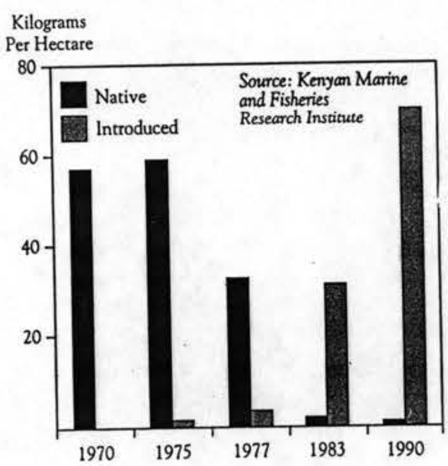

Figure 4-2. The Changing Fish Population of Lake Victoria

fish kills. The perch itself may now be in decline, from overfishing, periodic die-offs, and its own voracious appetite.[63]

There are other pressures on the ecosystem too. Millions of liters of untreated sewage and industrial waste flow into Lake Victoria every day from Kisumu, Kenya's third largest city, and from Mwanza in Tanzania. Watershed degradation and agricultural runoff contribute chemicals, nutrients, and sediment. And from Rwanda came the grisly addition of some 40,000 human corpses—war casualties that floated down the Kagera River in May 1994. Nor is the perch the lake's only alien species problem. Water hyacinth, native to South America, was first found in the lake in 1989. With no predators in Africa, the plant covers waterways quickly, depleting oxygen in the water and clogging intake pipes, irrigation canals, and ports. A single plant can blanket 100 square meters in just a few months. And water hyacinth provides a breeding ground for disease vectors such as bilharzia-carrying snails and malaria mosquitos.[64]

Degraded and simplified, Lake Victoria is no more likely to make a stable "fish ranch" than are the North American Great Lakes. But the institutional challenges of caring for Africa's largest lake are nearly as complex as the ecological ones. A major cooperative effort between all three lakeside countries—Uganda, Kenya, and Tanzania—was recently launched. This Lake Victoria Environmental Management Program will focus on water quality, land use management, restoration of indigenous food fish, control of the Nile perch and water hyacinth, and community-based enforcement. Successful methods developed in pilot zones around the lake during the first few years will then be applied to larger areas. Such cooperation may yet restore Lake Victoria, and could preserve Lakes Malawi and Tanganyika as well—the other jewels of the Rift Valley.

A New Focus: Maintaining Healthy Ecosystems

Unfortunately, the Columbia, Mekong, Mississippi, and Rhine Rivers and the Great Lakes of North America and East Africa are not isolated cases. Virtually nowhere has been spared the loss of freshwater species and ecosystems. Nor has any place been immune to the cascade of unintended and unanticipated economic and social disruptions that follow the loss of healthy ecosystems. At every level of organization, from genes to species to assemblages to ecosystems, there are indications that the ecological integrity of freshwater systems has been simplified, degraded, and jeopardized. And there is clear evidence that the cumulative and synergistic effects of human actions are responsible for the biodiversity deficit that is severe and deepening.

The disappearing and degraded faunas have much to tell us about what we are doing to these ecosystems and to ourselves—if we choose to listen. Changes in the human condition—health problems, loss of sustenance and livelihoods, creation and exacerbation of conflicts—also provide indicators. So do the severe economic losses that result from ecosystem degradation. Freshwater ecosystems are not just a part of the environment; they are a part of our economies as well. The prospects for human well-being today are bound up in their fate, as are future options for evolution and human use.

When we jeopardize an ecosystem's integrity—its physical, chemical, and biological elements and processes—we compromise its ability to support species and provide the products and services we depend on. The services given include controlling floods, purifying water, recharging aquifers, restoring soil fertility, nurturing fisheries, and supporting recreation. When nature can no longer provide, we must either do without or try to substitute, usually much less effectively and at much higher cost.

To date, our exploitation and management of freshwater resources have tended to focus on only one element at a time—whether navigation, irrigation, power generation, sport or commercial fisheries, or even limited measures of water quality—without regard for the entire system. Even the way we define the systems themselves has not been comprehensive enough. A river does not really stop at the water's edge; a healthy wetland is not simply a place with cattails and ducks.

We need to see these ecosystems in their entirety: rivers and lakes, along with their entire watersheds and all the physical, chemical, and biological elements, are all part of complex, integrated systems. Human inhabitants are also part of those systems. And we need to learn to manage such systems in ways that maintain their integrity. In such a flexible ecosystem-based approach, resources would be managed over large enough areas to allow their species and ecological processes to remain intact while allowing human activity. On a social level, all stakeholders would be involved in defining issues, setting priorities, and implementing solutions.[65]

Most attempts at ecosystem-based management have focused on places already badly degraded—such as the Great Lakes of Africa and North America. Often a first step is rehabilitation efforts such as mitigating pollution, controlling exotics, and improving stream flows and quality. An important part of conservation and restoration is halting further habitat loss and protecting undegraded areas—"strongholds of aquatic biodiversity"—as refuges for healthy populations that can repopulate troubled spots once the pressures of degradation are alleviated. Although the cost of restoration can seem high, it is far less than the price of continued mismanagement. An economic analysis of the slated removal of two aging dams on Washington's Elwha River, for example, found that the $100-million price tag was more than justified by the several billion dollars in nonmarket benefits alone that river and wild salmon restoration would bring. And an extensive study by the National Research Council recommended restoration of aquatic ecosystems to solve water quality, wildlife, and flooding problems at minimal cost and disruption. Restoring 50 percent of the wetlands lost in the United States would affect less than 3 percent of the nation's agricultural, forestry, or urban land.[66]

Restoration and rehabilitation are clearly necessary. But alone they will not be enough. A principal goal now and in the future should be to shift from reactive to preventative management. Places like the Mekong and the Amazon offer chances to avoid the costly mistakes made elsewhere. We already know the heavy price that regulated rivers, water diversion, dam construction, alien species, and habitat degradation and fragmentation can exact from a region. The time has come to act on a corollary principle: over the long term, keeping naturally functioning ecosystems healthy will offer the greatest number of benefits for the greatest number of people.[67]