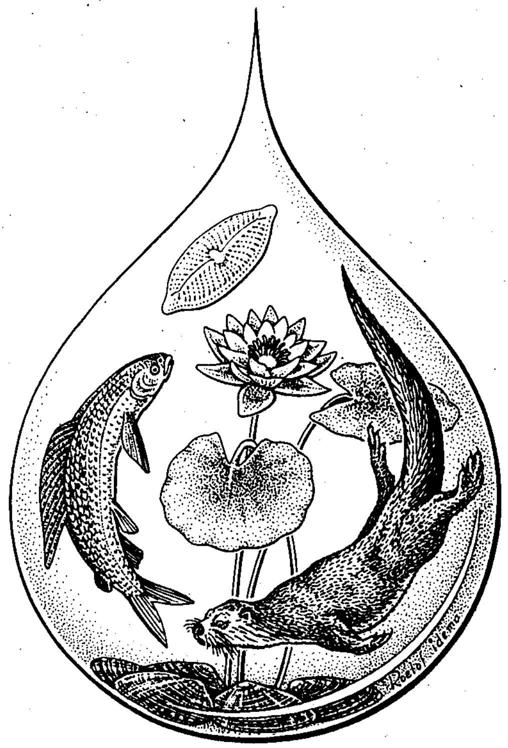
Toward harmony of humankind, the sea and its life

SEA WIND

BULLETIN OF OCEAN VOICE INTERNATIONAL



SPECIAL ISSUE:

Global Freshwater Biodiversity:
Striving for the integrity of freshwater ecosystems

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Ocean Voice International encourages harmony between people, marine life and environment. It is environmental, humanitarian, and global in its concerns. It is non-profit Charitable Organization, Business Registration Number 11897-0789-RR0001. It works through education, research, economic and technical co-operation.

Ocean Voice's goals and means are:

* To conserve the diversity of marine life
* To protect and restore marine ecosystems & ecological services
* To enhance the quality of life of and equity of benefits for coastal fisher peoples
* To promote the ecologically sustainable harvest of marine resources
* By providing education towards these ends
* By partnerships to train people to use environmentally sound marine resource harvesting methods
* By engaging in and sharing results of marine life scientific research, indigenous and traditional knowledge
* By fostering the participation of marine harvesters in environ-mental decision making, management & mutual co-operation
* By writing, soliciting, publishing and communicating relevant articles, periodicals, manuals and books

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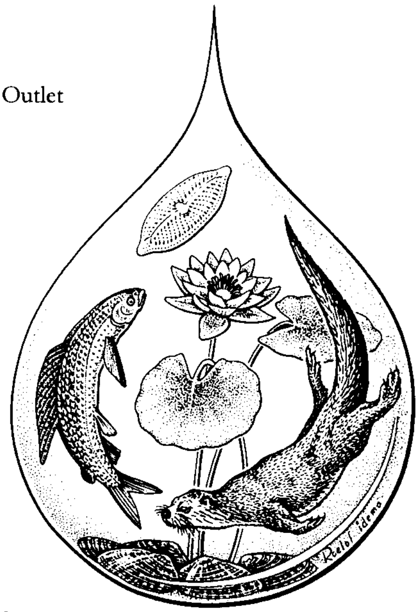
Global Freshwater Biodiversity:

Striving for the integrity of freshwater ecosystems



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QUOTATIONS

An evening breeze across the reedy banks;
Ripples around the blue-grey heron's shanks. **Buson**

Everything has changed but for our way of thinking. **Albert Einstein** paraphrased

The Bird of Time has but a little way to fly
- And Lo! The Bird is on the Wing.
Edward Fitzgerald, The Rubaiyat of Omar Khayyam.

The frog does not drink up the pond in which he lives.
First Nations, North American proverb

The world is but a single dewdrop, set
Trembling upon a stem;
and yet .... and yet .... **Issa**

The holy wars of the twenty-first century will be fought over water.
James R. Karr, 1995, Clean water is not enough

The economy did not collapse when we abolished slavery, allowed women to vote, prevented industrial sweatshops from exploiting child labor, controlled strip mining, limited grazing on public lands, or began protecting old-growth forests and watersheds in the Pacific Northwest. In fact, despite curtailment of logging in federal forests in Oregon, the state has posted its lowest unemployment rate in a generation.
James R. Karr. 1994.
Restoring salmon: We must do better.

Has the Earth, then, no room for them?
Who does the wind seek? For whom is the wet glistening of streams?

Is there by the banks of the pond's deep dreaming nowhere they can see their faces reflected?

They need only, as a tree does,
a little space to grow.
Ranier Maria Rilke,
Ralke's Book of Hours

The health of our waterways is an index of the health of our environment as a whole.
Sci. Council of Canada, 1988, p. 9, Water 2020.

Water scarcity is likely to be the next major natural resource crisis.
Alex de Sherbinin, IUCN.

Everything is water, water is all.
Thales (ca. 624- ca. 546 B.C.)

1.0 EXECUTIVE SUMMARY

This paper provides an overview of global freshwater biodiversity with an emphasis on fishes, ponders which human activities most imperil that biodiversity, and asks what are the key options, gaps and players in sustaining the freshwater realm. The intent is to provide a paper which will stimulate discussion and lead to constructive action.

The water resource. Most of the planet's water is marine, some 97.5%, and of the fresh water much is locked up in ice and snow and as groundwater, leaving only a tiny fraction on the surface and liquid, 0.01% . Only 1% of this freshwater has been contained in rivers; the rest was in lakes. Now, dammed reservoirs hold five times five times as much water as in the rivers.

Humankind's and nature's share of freshwater. Surface waters sustain freshwater biodiversity and ecological functions, while serving human needs: agriculture, hydroelectricity, industry, sewage and sanitation, fisheries, aquaculture, transportation, drinking water, recreational and spiritual. About 54% of the planet's accessible surface runoff is used by humans. Human use is now conflicting with the needs of biodiversity needs volume, quality and seasonal rhythm of flows of fresh water. By 2025 AD, human use will conservatively grow to 70% of accessible runoff.

Biodiversity benefits. Freshwater biodiversity benefits humankind. Freshwater wild capture fisheries in 1992 yielded about 12 million tonnes with freshwater aquaculture generating about an equal amount, together about one-quarter of the planet's fishery yields. Some of this is devoted to domestic use, some to export purposes. Other living freshwater resources include rice, aquarium fishes, rushes for baskets and mats, peat for fuel and gardens, cranberries, and sport fishes. A fraction of the Earth's ecological functions are sustained by aquatic species and ecosystems; in the U.S. alone these are valued at several trillion dollars. Medicines like aspirin derived from the water-loving willow, and valuable high tech genetic tools such as PCR, derived from a hotspring bacterium, show some of the promises of future benefits that can be drawn from biodiversity - if we care for it.

Freshwater biodiversity includes about 45,000 scientifically described species and perhaps a million, if undescribed ones are included. Major groups of freshwater organisms include the viruses, bacteria, diatoms, plants, proyozoans, sponges, molluscs, insects, arachnids, crustaceans, molluscs, nematodes, fishes, amphibians, turtles, and mammals like otters. About 25% of the world's phyla, the group just below the kingdom level, are found in fresh waters.

Ecological and geographic distribution. Freshwater fishes comprise 40% of fishes and freshwater molluscs about 25% of all molluscs, a higher proportion than the low relative area of fresh waters , 0.8% of the planet, compared to the seas - 70.8%, or land 28.4%. Most freshwater species occur in rivers, rather than lakes, despite the higher volume of the latter, and more appear to be bottom-dwelling in lakes and rivers than mid-water dwellers. While river systems contain much of fish biodiversity, high numbers of endemic fishes occur in ancient lakes like the Great Rift lakes of Africa and Lake Baikal in Russia. Springs in arid lands, seasonal ponds, and caves may have small populations of unique species easily threatened by human activities. Deep fast-flowing sections of large rivers, like the Amazon, are little explored and are proving to contain dozens of new species; what of the Congo and Mekong rivers?

Freshwater biodiversity is unevenly distributed geographically. It tends to be higher for fish species in the tropics, though invertebrate biodiversity may be more evenly distributed. The three richest areas for fish species are northern South America, central Africa, and southeast Asia. These areas deserve consideration in priorities for conservation and for ecologically harmonious rather than destructive development. Megadiversity (high in absolute species numbers) and densely speciose (high numbers per unit area) country biodiversity assessments, though useful as preliminary steps, were found to be flawed; equal-area grid analyses are promising. Recent studies of deep groundwaters show them to be very rich in unique bacteria, of potential use in biotechnology and bioremediation.

Threats to freshwater biodiversity. The major threats are habitat loss, pollution, introduction of exotic species, and overharvesting.. *Water-based threats* include dams, exotic species, overharvesting, and aquaculture. Dams change running- to stillwater-ecosystems, depriving species of their habitats; block migrations; change seasonality of flow, water temperatures and many other qualities. *Land-based threats* include agricultural practices, forestry, industrial and municipal discharges. Agriculture uses 37% (11% crop, 26% pasture) of the Earth's surface and employs 70% of human uses of fresh water. Runoff from agriculture includes pesticides, fertilizers, manure, and sediments. Clear cutting and deforestation make for swifter runoff, turbidity and sedimentation, while depriving rivers from insect, leaf and other inputs into the food chain, woody debris for habitat, and shade. Industrial and municipal discharges include toxic chemicals and sewage wich promotes eutrophication. Groundwater pollution may threaten the scarcely explored microorganisms in aquifers.

Hydrological threats. The reduction of natural continuous vegetation cover also affects the hydrological cycle. Normally such vegetation would 'drink' much of the rainfall and transpire moisture into the air through the leaves. The transpired moisture forms clouds, which drop rain, repeating the cycle. Landscapes deprived of vegetation may have less rain with more of the water flowing in rivers directly to the sea. Urban areas, like crop land and logged areas, promote faster runoff, often polluted after rain or snow melt, and reduce groundwater recharge. More highly vegetated landscapes will better sustain aquatic ecosystems and species diversity. Healthy freshwater ecosystems have as much to do with what we do on land as what we do in freshwater bodies.

Future threats. Future threats include climate change, population growth, increased per capita consumption. Yielding powers of citizens and governments to international trade organizations and trade agreements diminishes the capacity of government to ensure environmental health and implement measures for the Biodiversity Convention.

Biodiversity losses have been only partly detected and measured. Only a few of the larger organisms are monitored or considered. But over 100 freshwater-associated vertebrates (birds, amphibians, and fishes) became extinct after 1600 AD. This comprises 55% of the extinctions for these three classes. So extinctions are disproportionately high in freshwater animals.

World-wide 20% of freshwater fishes are vulnerable, endangered or extinct; 20% of threatened insects have aquatic larval stages; 57% of freshwater dolphins are vulnerable or endangered; 70% of freshwater otters are vulnerable or endangered. About 75% of freshwater molluscs in the U.S. are rare or imperilled. FAO considers, with the possible exception of North America and parts of Europe, nearly all inland fisheries show symptoms of over-exploitation. Cichlid fisheries in Lake Victoria have been replaced by Nile perch catches, but many of the endemic cichlids are extinct. Many stocks of salmonids in western North America have been lost.

About half of the wetlands of the world have been lost. Ecosystem integrity has declined in about 25 million km of rivers due to the construction of dams. Water quality in lakes in populated areas has declined and many lakes and rivers contain exotic species.

In balance the few rivers whose ecosystems have been restored, like the Thames and the Chesapeake Bay basin, show that freshwater ecosystems can be restored if efforts are made.

Water-based strategies for conservation and sustainable use. Desist from building new dams in areas of high biodiversity (see maps) or productivity. Distinguish natural flooding with tangible riverine and riparian benefits from flooding of anthropogenic origin. Use land-based biological approaches to help solve the latter, rather than relying wholly on river engineering. Utilize indigenous species *ecosystems* whenever possible in aquaculture and use ecosystems-based fisheries management approaches.

Land-based strategies for conservation and sustainable use. About half of the Earth's land surface is used for agriculture and forestry. Ecological approaches to use that land could include the following. Maintain vegetation cover over greater areas and time periods. This reduces rapid runoff and erosion, while enhancing the hydrological cycle and quality of aquatic ecosystems. Utilize polyculture of genetically variable and locally adapted genotypes as much as possible. This reduces need for input of pesticides and fertilizers. Use of several species of native trees in replanting or employ natural regeneration in small cut areas to ensure habitat is maintained in indigenous terrestrial, flood plains and riparian areas, for the benefit of aquatic species.

Municipalities, if they keep toxic chemicals out of sewage systems (and rivers), can use it as a resource, returning nutrients to farmland or aquatic Living Machine culture systems. Smart industry executives are turning environmental costs into economic opportunities and profit. Recycling of chemical reagents, discovering environmentally friendly alternatives to chemical and energy expenditures, can help provide good returns to shareholders, enhance the firm's reputation, and make shares sought after by the growing number of green investment services.

Drainage- and knowledge-based strategies. Knowledge is needed to conserve biodiversity and sustainably use its components. A global hierarchical freshwater ecosystem classification, still lacking, is a needed tool. Better knowledge of taxonomy and geographic distribution is needed to understand and manage biodiversity, to apply drainage basin approaches, and develop new uses. One example of the lack, if not vacuum in knowledge, is that over 3,000 kinds of new bacteria were discovered in groundwater samples drawn from an aquifer just over 500 m deep — while a billion dollars is expended to send a tiny vehicle to Mars.

Rivers, lakes and wetlands are daughters of the land. Hence it is not surprising that ecologically sound and economic practices on land as well as in the water realm, will maintain and restore aquatic ecosystems. The ray of light amidst the gloom, is that ecologically sustainable agriculture, forestry, industry and urban practices will help restore the diversity and functioning of not only the land, but also freshwater and marine ecosystems. Each of these sectorial changes will have a three-fold benefit.

The public, especially with awareness and education programs by NGOs, usually welcomes such changes, as do a few far-sighted corporations. Other corporations and international trade organizations and legal trade instruments, are amongst the most serious road blocks to implementing the goals of the Biodiversity Convention. Environmental restructuring of trade and globalization organizations may be worth including on the work agenda by parties to the Convention.

Aquatic ecosystems can be restored, faltering species populations can be re-invigorated with them. All we need is suitable practices in watersheds and water bodies, and the willingness to share the planet's surface with other species.

2. INTRODUCTION

This paper reviews the status of fresh waters and their biodiversity with an emphasis on fishes, ponders which human activities most imperil that biodiversity, and asks what are the key options, gaps and players in sustaining the freshwater realm. The intent is to provide a paper which will stimulate discussion and lead to constructive action.

Freshwater is the essence of life for all organisms including aquatic species and humankind. The tiny fraction of water that is fresh and on the surface of the Earth sustains a disproportionate number of species, habitats, and ecological services, as well as humans — humans use 54% the geographically and temporally accessible freshwater runoff (Postel, Daily and Erlich 1996). Human activities are destroying freshwater biodiversity at a rapid rate. This loss is of concern in itself — to the food supply, to livelihood and health of rural and urban peoples, and to maintenance of ecological functions. The loss of biodiversity threatens the integrity of aquatic ecosystems. The biodiversity of inland water ecosystems was placed on the programme of work of the Conference of the Parties of the International Convention on Biological Diversity at the third Conference of the Parties held in Buenos Aires.

Ecological integrity: Ecological integrity is essential to the preservation of biodiversity. Integrity can be defined as the capacity to support and maintain an integrated, adaptive community with a biological composition and functional organization comparable to those of natural waters of the region (Winter and Hughes 1997). Biodiversity should not be likened to the often transitory increase in the variety of species through the introduction of alien plants and animals into wild ecosystems (Winter and Hughes 1995), it should focus on **indigenous** biodiversity at the genetic, taxonomic, ecosystem, and ecological function level. Departure up or down from the natural norms indicates degradation of biodiversity.

Carpenter and Cottingham (1997) suggests several potential indicators of a lake's capacity to maintain normal dynamics, i.e. ecological integrity. These include: livestock density in the watershed (a correlate of phosphorus imports), wetland area per unit lake area (capacity to hold water and export humic substances), proportion of riparian zone occupied by forest and grassland (capacity to attenuate nutrient inputs), lake color (and humic content), piscivore growth rates (control of planktivores), partial pressure of carbon dioxide in surface waters (indicator of ecosystem metabolism), hypolimnetic oxygen depletion (index of eutrophication). They indicate that these indicators can be determined fairly simply from land use records, remote sensing (though blind to certain factors), water and plankton/fish sampling methodology. Brazil has using images taken by air force planes to detect illegal logging and is building a radar- and satellite-based Amazon Surveillance System to carry out this work.

According to Karr (1991) and Karr, Fore and Chu (1997), one should not substitute easily measured but reductionist physical and chemical surrogates in biological monitoring. In general terms, Angermeier and Karr (1994) describe *biological integrity* as a system's wholeness, including presence of all appropriate elements and occurrences of all processes at appropriate rates. But Karr (1991) indicates that we should develop operational definitions for "biological integrity," such as the Index of Biotic Integrity (IBI), based on ecological principles. An appropriate IBI would be based on an array of indicators combined into one or more simple indices and could be used to *detect degradation* and identify its cause and to determine if *improvement* results from management actions. An IBI compares the conditions in the sample site to a comparable undisturbed site in the same ecozone or region using standard methods. It can be accompanied by physical, chemical and toxicity monitoring. According to Karr (1997) biological monitoring is less costly than chemical and physical water quality analysis and bioassays. Angermeier and Karr (1994), discuss the differences between, utility and merits of the concepts of biological diversity and biological integrity. They prefer to use integrity for management. Developing IBI's for a number of tropical areas faces the problem of poor baseline information from which to construct indices (Pringle and Scatena 1997.1)

At another scale, that of countries, the notion of "conservation index," can offer guidance in prioritizing investments in biodiversity conservation (Dinnerstein and Wikramanayake 1993). The conservation index is based upon the interaction of the size of terrestrial protected areas, remaining forest habitats, deforestation rates, and biological richness to identify conservation potentials, threats, and strategies. This kind of index could be used to evaluate aquatic environments.

Ecological functions or services can be defined as the processes or products that one species or group of species provides (incidentally) to other species, increasing the recipient's chances of survival (Jarzen and McAllister 1993; Mosquin *et al* 1995), e.g. fixation of nitrogen, creation of three-dimensional habitat, generation of oxygen, and recycling of nutrients.

We provide a preliminary list of useful documents (and references for citations) at the end of the paper. Armantrout (1995), IJC (1994), Carpenter and Cottingham (1997), Goodrich (1997), Karr (1997), Kottelat and Whitten (1996), McCully (1996), Mickelburgh *et al* (1996), Nyman (1991), Philipp *et al* (1995), Ryman *et al* (1994), Stiassny (1996, 1997), and Winter and Hughes (1995) provide good starting points. Nyman's paper contains a useful list of recommendations. Banarescu's (1990-1995) *Zoogeography of fresh waters*, maps and summarizes the distribution of major freshwater animal taxa and discusses freshwater zoogeography in regard to ecology, dispersal and plate tectonics; we refer the reader to his three volumes and make no attempt to summarize his extensive discussions. A paper on the status of the World Ocean and its biodiversity (McAllister 1995), may be of interest because of the parallelisms and contrasts with freshwater biodiversity. The *Comprehensive assessment of freshwater resources of the world* (UN 1997), is available on the internet. It provides a very useful review of the physical water supply and human use. Its coverage of biodiversity is minimal, and the inclusion of resources in its title affirms its human and economic orientation and mandate.

2.1. BENEFITS

Fresh surface and ground waters provide benefits to humanity. These include drinking water for humans and livestock, washing water, irrigation water for agriculture, habitat for aquatic biodiversity and resources, manufacturing, waste disposal and recycling, electric power generation, cooling, transport, recreation, and others.

Fig. 1. Women fish vendors with flood plain fishes, Siem Riep River, Cambodia. A variety of species from wild capture fisheries provide vital fresh protein in the diet of tropical countries. Women play a number of roles in fisheries, from harvesting and preparation to marketing. Photo by Kenneth MacKay.

In inland waters capture fisheries for food have increased fairly steadily over time, from around 5 million tons in 1979 to over 7 million tons in 1989, then dropped back to about 6.5 million tons from 1990-1992 according to FAO (1995.1). But the data are often unreliable and freshwater extraction is probably underestimated. Catches in local sustenance and indigenous peoples fisheries are often ignored in national statistics, yet are vital to those communities. Evidence suggests that actual freshwater capture fisheries may land twice the reported total, some 12 million metric tonnes per year (Groombridge 1997). These fisheries provide full- and part-time employment for millions of men and women. It is worthwhile noting that some 60-80% of the world's marine commercial fisheries rely on estuaries for spawning and habitat of adults or young (Brusca and Brusca 1990). So a strong link between the status of freshwater ecosystems and marine biodiversity may be expected in many regions.

Aquaculture production worldwide expanded during the period 1984-92 at an average annual compounded rate of 9% (FAO 1995.1). Total production in 1992 was 13.9 million tonnes tonnes of fishes and invertebrates and 5.4 million tonnes of plants. While aquaculture is seen by some as a means of supplementing declining wild capture fisheries, it cannot replace natural biodiversity or ecological functions, and when improperly managed, may be destructive of them.

The ornamental fish trade and the need for its conservation is described by Andrews (1990). Sterba (1962) listed some 1,300 species and 86 families in his book on freshwater aquarium fishes of the world (some of those species are rarely in the trade or kept only in public aquaria), and Axelrod *et al* (1993) included over 3,000 species. The estimated global annual retail value of freshwater and marine aquarium fishes is US$3 billion (Bassleer, 1994 in Kottelet and Whitten 1996). If we suppose that freshwater species comprise two-thirds of this value (many more freshwater than marine aquarium fishes are sold, but the average price per fish is lower), then their retail value is $2 billion. Public aquaria are visited by millions of people every year. Hobbyist's and public aquaria provide recreational, educational and economic benefits for a wide variety of people in developed and developing countries, dependent on freshwater biodiversity (Andrews 1990; Andrews, Krussman and Schofield 1995). In return freshwater biodiversity depends on these aquaria, which provide a considerable degree public awareness of and empathy for freshwater organisms.

In North America wild-caught crayfishes are used for human food, fish bait, and food for predacious aquarium fishes (Huner 1997). Aquaculture of crayfishes indigenous to North America (families Astacidae and Cambaridae) and species brought into United States from Australia (Parastacidae) is becoming important. Some are cultured in rotation with rice. Louisiana wild and cultured production exceeded 45,000 metric tonnes in 1995 in weight and US$58 million in value.

Recreational fishing is important in several countries. Recreational fishing brings the angler in closer contact with nature, increases awareness of the natural world, provides relaxation from daily cares, and provides tasty meals. There are often significant economic returns derived from this activity. In Canada, for example, 75 freshwater and marine species are of primary importance to the country's 6.5 million anglers (Coad 1995). Annually those anglers catch an estimated 330 million fishes, spend $2.9 billion on goods and services directly related to fishing and over $5.3 billion for boats, motors, camping gear and other goods. Healthy aquatic ecosystems and contaminant-free fishes benefit this industry.

The farming of rice (*Oryza*), which, unlike most other grains, usually requires standing water, is worth billions of dollars every year, and is the staple diet in many cultures. The genetic diversity in rice gave rise to thousands of land races, high-yield varieties of the Green Revolution, and to varieties resistant to such diseases as the grassy stunt virus.

A variety of other living aquatic resources are harvested from the wild. A small sample of these includes: wild rice (*Zizania)*, rushes for basket and mat weaving and thatching, freshwater pearls, mussel shells for buttons, mangroves for charcoal, furs from muskrats and beaver, waterfowl for food and sport, and aquatic plants such as water lilies for pond horticulture. Bog cranberries, gathered from the wild or cultivated, are one of many minor wetland crops. Cranberry production was worth $21,403,000 in Canada in 1990 (Mosquin, Whiting and McAllister 1995).

The peat- or bog-mosses, genus *Sphagnum*, world-wide in distribution, include many species. Sphagnum moss, because of its sterile absorptive nature, is useful as a surgical dressing. When sphagnum mosses die, they form peat. While peat is an important fuel in some countries and is used as a soil conditioner in more, its most valuable role may be in the ecological functions it provides in wetlands, e.g. acting as a sponge, dampening water level fluctuations.

A number of medical remedies are based on aquatic organisms. Aspirin, worth a billion-dollars a year in sales, is modelled on compounds originally derived from the bark of the water-loving willow tree, *Salix*.

Freshwater biodiversity provides a number of ecological functions or services (Carpenter and Cottingham 1997; Costanza *et al* 1997; Mosquin 1995). These include primary production, provision of three-dimensional habitat, biogeochemical recycling, pollutant remediation, moderation of nutrient pulses, and population moderation. Note that, contrary to Costanza *et al* 1997, we do not include biological products such as food, as ecological functions. Wetlands moderate downstream flow of water and release humic staining that suppresses responses of phytoplankton to nutrient pulses (Carpenter and Cottingham (1997). To illustrate two functions, dragonflies and amphibians moderate populations of insects and microorganisms break down and recycle wastes discharged into waterways — bioremediation. Most of these functions are not included in national accounting but are nonetheless important.

Globally terrestrial and aquatic ecological functions have been calculated to be minimally worth US$33 trillion per year, almost twice the value of the global gross national product, some $18 trillion (Costanza *et al* 1997). Postel and Carpenter (1997) estimate that the total global value of freshwater ecosystem services is several trillion U.S. dollars per year. In the United States, the additional economic benefits of increasing lake water quality standards for boating, fishing and swimming is estimated at US$31 to $55 billion per year, excluding benefits such as flood control, pollution diminution, lowered drinking water purification costs, and the increased utility of cleaner water for irrigation and industry (Carpenter and Cottingham 1997). Healthy lakes represent substantial benefits, degraded lakes substantial economic losses.

Collectively, ecosystem processes may act as resilience mechanisms or buffering systems against fluctuating inputs, natural and human disturbances (Carpenter and Cottingham 1997). But the resilience may be destroyed by continued stresses or extreme perturbations. When that happens, pathological symptoms may develop and there may be a transition, sometimes abrupt, to a new state — one not necessarily desirable, or community structure oscillation. Continued eutrophication and acid precipitationcan cause prolonged changes in ecosytems.

The genetic and biotechnological potential of freshwater biodiversity is scarcely explored. One example may serve. An enzyme was extracted from a bacterium, *Thermus aquaticus,* discovered living in hotsprings in Yellowstone Park. Using this enzyme, the Taq polymerase chain reaction (PCR) was developed. Taq is a powerful genetic tool that cuts and splices DNA and allows examination of gene sequences (Reak-Kudla *et al* 1997). Taq has been used in criminology, identification of the remains of Czar Nicholas II, and censussing microbial biodiversity. Companies are still fighting over the patenting of the Taq polymerase and its annual sales of over $80 million (Pennisi 1997). If the hotsprings had not been protected in a national park, scientists might not have had the opportunity to discover this useful bacterium. Another enzyme called cellulase 103 was taken from a microbe discovered in an alkaline lake (Pennisi 1997). This will be used for a new detergent additive that promises to make cotton clothes look like new through hundreds of washings.

Fresh waters and their varied life form part of the Earth's ecosphere that restores us spiritually, inspires us esthetically, and must be passed on, unimpaired, to future generations. Freshwater organisms, like all life forms, have an intrinsic right to survival and warrant respect as is attested in the Biodiversity Convention and the World Charter of Nature.

Rivers can serve as sentinels or monitors (Karr 1997). As a continent's circulatory system, rivers can provide a measure of not only their own health, but that of their landscapes according to Karr, who provides examples from the Pacific Northwest in the U.S. Changes anywhere on the landscape are likely to influence rivers.

2.2. A GLIMPSE AT THE STATUS OF FRESH WATERS & BIODIVERSITY

A few images, see the box below, illustrate the status of the world's fresh waters and their biodiversity. Those images make it clear that stresses on freshwater biodiversity are profound, pervasive, and complex.

Snapshots of the status of the world's freshwaters and their biodiversity.

- Aquatic bacterial diversity knowledge is undergoing an explosion
- Globally 20% of freshwater fishes are extinct, endangered or vulnerable
- The rich endemic ichthyofauna of Lake Victoria in Africa has been reduced by exotic predatory Nile perch, overfishing and eutrophication
- 54% of the planet's accessible runoff is now used by humans
- The Thames River, polluted for centuries, is now habitable by fishes
- The dominant fish species of the Laurentian Great Lakes have changed
- A spill of highly toxic cyanide mine tailings has recently swept down a Guyanan river from the Omai gold mine
- Groundwaters as deep as 2.8 km may have rich bacterial flora
- Half of the native freshwater fishes of California are endangered/extinct Agricultural embankment construction in Bangladesh floodplains, one of the world's largest deltas, threatens the aquatic environment and fisheries critical to survival of some of the world's poorest people
- 80 countries with 40% of the world's population now have water shortages that could cripple agriculture and industry (World Bank).
- Construction of dams planned for the Mekong River basin, Asia's hotspot in fish diversity (Kottelat & Whitten 1996), threatens fishes adapted to seasonal flooding & unobstructed migratory movements
- Hydroelectric facilities in Brazil have disrupted migration patterns of economically important species, while the Hidrovia channelization project of central South America may threaten wetlands and foster invasions of non-native biota between drainage basins
- Swiss waters, which suffered from fish kills and odors, are now potable
- The number of wild salmon returning to the Columbia River in the U.S. is less than 10% of what it was before the dams were built
- Zebra mussels are paving shallows of the Great Lakes, displacing native mussels and changing ecosystems
- Living Machines offer better waste treatment & ecosystem restoration
- 90% of New Zealand wetlands were lost after European settlement
- The number of prairie ponds in North America has rebounded from below 2 million in 1989 to ca. 4 million in 1996 and the duck population increased from under 8 to nearly 12 million, mostly due to the North American Waterfowl Management Plan (as well as water availability)
- Of 30,000 rivers in Japan only 2 are neither dammed or modified
- Extinction of native crayfish throughout Europe followed introduction of a North American species and its accompanying crayfish plague
- The Aral Sea in central Asia, Sudan's Sudd swamps, and the Ogalla aquifer in western U.S. are all shrinking
- Half of the world's wetlands have been lost this century (Myers 1997.1)
- The Ganges and Bramaputra rivers together carry more than 3 billion metric tons of soil to the Bay of Bengal each year, spreading it over 3 million km^2 of sea bed.

Outright loss of species and ecosystems is a concern. But the slow widespread deterioration of water and habitat quality is just as much a threat, yet less likely to motivate remedial actions. According to Kottelat and Whitten (1996) environmental degradation results in: declines in the number of natives species and those in specialized taxa or guilds; increases in the percentage of exotic species or stocks; declines in the proportion of sensitive to tolerant species; declines in percentage of trophic and habitat specialists and increases in percentage of trophic and habitat generalists over specialists; increases in the incidence of disease and anomalies; increases in large, mature or older individuals (when there is reproductive failure); and increases in spatial or temporal fluctuations.

USE OF FRESH WATERS

↑ Share increasing

BY HUMANS

Agriculture
Hydroelectricity
Industry
Sewage & sanitation
Urban withdrawal
Fisheries & other harvests
Aquaculture
Transportation
Drinking
Recreation
Spiritual

↓ Share decreasing

BY NATURE

Sustains freshwater biodiversity
Underpins ecological functions
Maintain integrity of river/lake beds deltas, & quality of river/lake water masses

Fig. 2. Fresh waters and their biodiversity and resources provide many benefits for humankind. But these uses impinge on the volume, quality and seasonal rhythm of fresh water left for freshwater biodiversity. Since 1940, while human population has doubled, annual global water usage has quadrupled (Stiassny 1996.1). The needs of one-fifth of humankind is unmet. More and more, the water requirements of humans and nature compete.

Reversing losses of aquatic ecosystems is possible, though prevention of loss is preferable. The Thames River in UK, after centuries of pollution, is becoming more habitable for fishes. The levels of some toxic substances in the fresh waters of Europe (Seiges 1995) and North American Great Lakes (SOE 1996) are decreasing. Part of the Danube Delta in Romania and Ukraine has been designated as both a Biosphere Reserve (1990) and a Ramsar site (1991) and in 1995 a management plan was finalized.

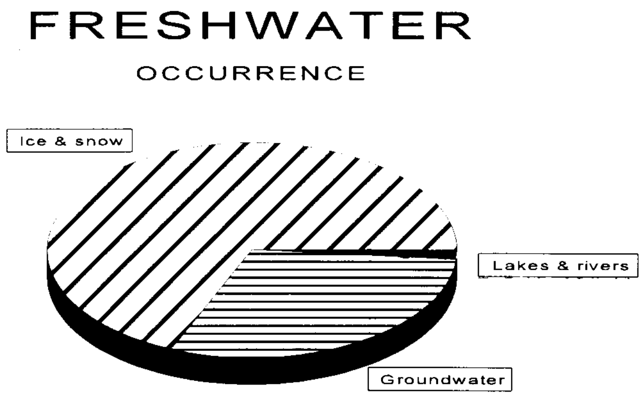


Fig. 3. Of the planet's waters, only 2.5% is freshwater, the rest is marine. Of the portion that is freshwater only 0.3% occurs on the surface as liquid, most of the rest is locked in ice and permanent snow or is groundwater.

The Living Machines approach is a method of using ecologically-based water restoration systems to clean water of wastes. The approach began on Prince Edward Island, was developed through testing in New England, licensing, to national validation in the U.S., and to international validation under the leadership of John Todd of Ocean Arks International. Living Machines are now operational in thirteen states of the U.S. and seven countries. See Josephson *et al* (1996) for a performance report on the Maryland Living Machine. See Higgins (1997) for a variety of aquatic plant wastewater treatment approaches. Over the last two decades the Clean Water Act has reduced annual discharges of toxic chemical and raw sewage into United States lakes and rivers by about a billion pounds and 900 million tons, respectively (Pringle and Scatena 1997.1). Unfortunately there have been efforts to weaken this Act.

At its Second Session in 1994, the United Nations Commission on Sustainable Development (CSD) noted with great concern that many countries were facing a water crisis, with a rapid deterioration of water quality, serious water shortages and reduced availability of freshwater, affecting human health, ecosystems, and economic development. The Session invited governments to cooperate in carrying out a comprehensive assessment of freshwater resources, welcoming the Government of Sweden's offer to prepare a preliminary assessment of freshwater. The Stockholm Environment Institute took on this collaborative task, with financial and technical support from Canada, Denmark, the Netherlands and Norway.

A report was submitted to the Commission and to the General Assembly in 1997, supplemented by background documents with in-depth discussions of the issues discussed in each section (U.N. 1997). The report contains: an executive summary; sections on the supply, availability and use of the world's freshwater resources; water challenges, a 30-year out-look; conclusions; and policy options. The report cites the World Health Organization's estimate that a total of more than five million people die each year from diseases caused by unsafe drinking water, and a lack of sanitation and water for hygiene. The text may be also consulted on the internet (see site under references, UN 1997).

Postel, Daily and Erlich (1997) further document human appropriation of renewable fresh water. They calculate that 18% of geographically and temporally accessible freshwater runoff is consumed (withdrawals not available for 2 nd or 3rd use), while withdrawals from rivers and streams, combined with in-stream flow requirements add an additional 36% for a total of 54% usage of accessible runoff. With projected population increases they conservatively estimate that human usage will increase to more than 70% of accessible runoff by 2025 AD.

3. FRESH WATERS, THEIR BIODIVERSITY & BIOLOGICAL RESOURCES

3.1. THE FRESHWATER ENVIRONMENT

How much water, where: Lakes and rivers cover about 0.8% of the earth's surface, with seas and oceans (70.8%) and land (28.4%) covering the remainder. In terms of volume, a mere 2.5% of the planet's water is fresh, some 35 million km,^{3} most of which is locked in ice, permafrost, permanent snow, groundwater, and soil moisture, leaving 0.009%, or 0.01% rounded off, of the Earth's water available in rivers, lakes and wetlands (Watson *et al* 1996). Of these surface fresh waters, 99% by volume is in lakes and 1% in rivers (Watson *et al* 1996). The Earth's lake districts contain some 100 million lakes more than 1 hectare but less than 1 km^2 in area, and some one million lakes more than 1 km^2 in area (Wetzel 1990). One should note that different sources give slightly different statistics on the amounts of various forms of freshwater, perhaps suggesting the need for a more precise inventory.

Earth's water supply may have come from outer space.

Until recently the planet's water supply has been thought by most to have been intrinsic and fixed. But Eugene Shoemaker of he U.S. Geological Survey in Flagstaff, Arizona, has revived an earlier hypothesis that much of the planet's water and some of the surface rocky materials were delivered by comets. Study of the Comet Hale-Bopp suggests, if its nucleus was melted, it would yield enough water to fill the Laurentian Great Lakes 35 times over. Early collisions of comets with Earth might have provided the Earth's water supply. So most of our water may have come from outer space. We further hypothesize that the occasional comet arrival maintains the Earth's water supply replacing water vapor lost into space from the upper stratosphere.

It is the tiny fraction, 0.01%, that must serve the human needs including irrigation, industry, hydroelectricity, drinking and waste disposal, demand for which grows with the human population. By 1990, clean drinking water was a concern for 1.23 billion people, a concern that will be magnified when the world's population reaches a projected 10 billion in the year 2050. Yet each of the human uses has an impact on the quality, volume or seasonal rhythm of the aquatic environment which sustains freshwater biodiversity.

Hydrological cycle: Moreover, the hydrological cycle, the evaporation from land and water bodies, transpiration from plants, cloud formation, precipitation, ground water banking and runoff of water, is being modified by anthropogenic changes in vegetation and climate. There are indications that Amazonian and Indian deforestation are affecting the rain/monsoon patterns by decreasing transpiration and increasing runoff. This link in the hydrological cycle deserves closer study. There are deforested areas with extended historical records of precipitation which could provide the necessary data for analyses.

Recent research suggests that deforestation may be linked to mercury contamination of fishes in the Amazon basin (Roulet and Lucotte 1995), though in other areas of the basin contamination results from the use of mercury to extract gold from alluvial deposits.

Solar energy at the water surface is regulated by latitude, altitude, and cloud cover. The received energy affects the water temperature, the amount of dissolved gases and solids, and evaporation. In turn these variables affect which biota, given access, will be present. The solar energy retained at the Earth's surface is modified by amount of greenhouse gases in the atmosphere.

The natural biogeochemical nutrient cycle has been finely tuned by evolution. Nutrients are often swiftly recycled by natural ecosystems, and intact wetlands. Terrestrial and riparian vegetation serve to filter nutrient flow from land to water and may sequester nutrients in vegetation and sediments.

In comparison with terrestrial landscapes, the aquatic environment and aquatic biodiversity are poorly understood. Increased study and understanding of the aquatic realm would strengthen opportunities to soundly manage and conserve this liquid world.

3.2. FRESHWATER BIODIVERSITY

Because of space and time limitations, much of the discussion in this paper will focus on freshwater fishes, although this is a distortion of the wealth of freshwater biota whose diversity and ecological functions are key to sustaining the underwater realm. We discuss ecosystem (microhabitat to ecosphere), taxonomic (species and higher taxonomic groups) and genetic (genes to genome and population) components of biodiversity.

3.21. Ecosystem Level

Freshwater environments are fragmentary, divided into river basins and component lakes and rivers, whereas the World Ocean is one virtually continuous body. Land areas, while broken into more or less continuous continents, nevertheless comprise vast areas compared to the area of water in a basin. Fresh waters, by definition, have a lower salinity than the oceans, posing a greater osmotic challenge to its inhabitants. Both fresh and marine waters have a smaller range of temperatures than terrestrial environments, and never have temperatures much below 0°C. Both aquatic environments are much denser than air, posing hydrodynamic strictures to motion, providing buoyancy and relieving gravitational forces, and having profound consequences for the evaluation of their life forms.

Although water bodies from the poles to the equators share many physical similarities, their biota are mostly quite different, e.g. mangroves and cichlids are tropical while whitefishes (Coregoninae) are boreal and Arctic. As a consequence there is often latitudinal zonation in the families of organisms. Other families, such as the water lilies (Nymphaeaceae) and the minnows (Cyprinidae) are found from the Arctic to the tropics and southwards. At the same time there are biogeographic boundaries separating zones and realms, e.g. Wallace's Line in the eastern Indo-Australian Archipelago divides geographically close but biotically and historically very different freshwater biotas. Thus, of 23 families of primary freshwater fishes in Borneo only one naturally crosses Wallace's Line.

There is a great variety of freshwater ecosystems. These include the still waters of lakes, ponds, and even temporary pools which may contain annual fishes adapted to surviving seasonal droughts by laying dessication resistant eggs. The world's one million lakes (> 1 km^2) vary from deep, cold, and oligotrophic through shallower, warm, mesotrophic, and eutrophic to deep tropical ones with anoxic depths. The world's 10 million ponds (> 1 hectare < 1 km^2), and ephemeral pools (Belk 1997), most smaller, provide an immense range of habitats for a variety of microorganisms, plants, invertebrates, and vertebrates.

Lake zonation can provide a variety of habitats such as the near-shore littoral zone with rooted vegetation, an upper layer or limnetic zone dominated by plankton, both capable of supporting productive fisheries, and a deepwater profundal zone lacking photosynthetic species. Because water replacement times may be lengthy, lakes are subject to nutrient and toxic chemical accumulation. Eutrophication (over-enrichment) can lead to almost lifeless anoxic layers and winter kills in lakes that would normally lack them. Rivers and lakes form a continuum from rivers with continuously flowing currents, to rivers with lake-like bodies in their courses, to lakes where tributaries and outlets contribute a minor quantity compared to the water stored in the lake. Nevertheless the lake concept is useful.

The biogeographic and ecological classifications of fresh waters are less well developed than those for land. Although there are names for a number of freshwater ecosystems, there is no global hierarchical freshwater ecosystem classification. This impedes conservation, ecologically-based management, monitoring and research. Banarescu (1990, 1992, 1995) provides a scheme for partitioning the freshwater zoogeographic zones of the world.

Lammert, Higgins, Grossman and Bryer (1997) provided a classification framework for freshwater communities in North America. They are based on The Nature Conservancy's Aquatic Community Classification Workshop held April 9-11, 1996. It organizes aquatic ecosystems in four hierarchical abiotic levels — Aquatic Province, Aquatic Section, Macrohabitat Type and Habitat Type., and in two hierarchical levels of biological organizations — Alliance and Association. This approach has the advantage of clustering similar habitat types in a hierarchical classification, enabling one to appreciate which habitat sites are distinctive.

An alternative approach to classification has been taken by the World Wildlife Fund (WWF) - U.S. WWF has produced freshwater ecoregion maps for Latin America and Caribbean (117 ecoregions), and North America (76 ecoregions). The ecoregions consist of drainage basins, or portions of basins, characterised by assemblages of species. The ecoregions are not arranged in a hierarchy other than continent of occurrence or Major Habitat Types (for North America: Arctic rivers and lakes; Large temperate lakes; Temperate coastal rivers and lakes; Large temperate rivers; Temperate headwaters and lakes; Endorheic (closed-basin) rivers, lakes, and springs; Xeric region rivers, lakes, and springs). The conservation status of the ecoregions can be evaluated by degree of land cover alteration, water quality degradation, alteration of hydrographic integrity, degree of habitat fragmentation and 'other' losses of original habitat, as well as effects of introduced species and direct species exploitation. These factors can be summarized by weighting conservation status indicators for each major habitat type and calculating a "snapshot total." The likelihood of future threats can also be included in evaluating the ecoregion's conservation status, and to give rankings as Critical, Endangered, Vulnerable, Relatively stable or Relatively intact. This approach enables one to focus on conserving ecological groupings of many species (described and undescribed), rather than attempting to save species one at a time which is less effective.

Measurements of ecological integrity are rare, in part because of the lack of suitable indicators (SOE 1996). A study of 45 major rivers in Nova Scotia showed 19 had impaired ecological integrity. Efforts being made to combat acid rain in Canada, and the Department of Fisheries and Oceans policy of "No Net Loss" of fisheries habitat are important steps forward in protection and restoration of freshwater ecosystems. On the other hand Canada's significant cuts in freshwater research program budgets jeopardize unique work and expertise, some internationally acclaimed. Concern has been expressed that Canada and other countries are losing the capacity to address national, bilateral and international water issues (Bruce and Mitchill 1995; UN 1997).

Habitat complexity and structural diversity are important components for ecosystems and may comprise an overarching component of them (EIFAC 1984; Ryder and Scott 1994). Suitable sized openings amongst aquatic plants, rocks, woody debris, etc. provide shelter from predators and strong currents, or locations for feeding, spawning, and nurseries for larvae and juveniles. Activities that decrease this structural diversity may therefore impact biodiversity.

Wetlands include salt and freshwater marshes, bogs, fens, and mangrove, cypress and other kinds of swamps, many of which are subject to drainage or landfill for farmland and other forms of development. About half of the world's mangrove swamps have been lost, many to aquaculture pond construction. Special Issue 1 of *Intercoast Network* (Naragansett, Rhode Island, March 1997), describes the problems and options for appropriate mangrove management.

The ecology of streams and rivers is substantially covered in Hynes' (1970) while conservation aspects are discussed by Allan and Flecker (1993). These bodies of waters can be divided into a variety of habitats including torrents, pools, riffles, flood plains, oxbows and riverine lakes; rock, boulder, gravel, sand and mud bottoms; clear, cloudy, turbid and 'black' waters; cave waters; first, second, third order streams; cool, warm and hot waters; those with planktonic or macro-plant life — floating, emergent, submergent, and encrusting (periphyton) vegetation, or lacking vegetation. The typical progressive change in rivers from headwaters in highlands, through middle reaches and lowlands to mouths is well studied, though the pattern is not fixed. But the need for research on a second axis, running perpendicular to the first across the floodplain and encompassing the lateral extent of aquatic, semi-aquatic and terrestrial habitats is beginning to be felt (Dudgeon *et al.* 1994).

*Fig. 4. Photo of a stream on Vancouver Island, Canada. Streams like this provide a intricate series of habitats in a unique linear, downstream continuum. They provide homes to American dippers (**Cinclus mexicanus**), coho salmon (**Oncorhynchus kisutch**), cutthroat trout (**Oncorhynchus clarki**), prickly sculpin (**Cottus asper**), caddisflies, fingernail clams (**Sphaerium** spp.), and diatoms. Migrations of the fishes transport nutrients upstream from the ocean. So streams are two-way streets. Photo by D.E.M.*

The groundwater realm, a series of tiny to vast underground lakes, is being further diminished and degraded before it unique biota are fully explored.

Another gap lies in our understanding of groundwater where a great proportion of freshwater is located — 66 times more than in lakes, streams, soil moisture and atmosphere (Watson *et al* 1996, p. 329). (Precipitation enters the surface of the soil to form *soil moisture* in unsaturated soil, or drains down to become *groundwater* in saturated soil or rock where all pore spaces are filled with water.) How much precipitation flows into the groundwater and thence into rivers and lakes? What are/were the natural chemical and physical characteristics of this water? What microbiota live in the groundwater environment? What ecological roles do the microbiota play? Do any have potential in biotechnology?

Some of these underground water bodies are immense and thousands of years old and their species may be ancient. Many of these water bodies are being rapidly depleted to supply water for irrigation, industry and household use. The level of the Ogalla Aquifer which lies under eight of the states of the U.S. Great Plains, is dropping by up to a metre a year, while Bangkok's water table has plunged 25 metres since the late 1950's and saltwater has penetrated its wells (Lean, Hinrichsen and Markham 1990). Many groundwaters are being polluted by toxic chemicals and nutrients, some aquifers in coastal areas by salt water intrusion due to excessive withdrawals. The groundwater realm, a series of tiny to vast underground lakes, is being diminished and degraded before its unique biota are explored.

Deep ground waters have been found to contain rich and unique bacterial floras.

An inkling of the diversity and complexity of the deeper groundwater microbiota was first given by Fliermans and Balkwill (1989). Their drilling of deep aquifers in South Carolina revealed large numbers of peculiar bacteria down to at least 520 metres below the surface. The species changed from one strata or layer to the next, but there was no obvious overall decrease in viable bacterial numbers with increasing depth. More than 3,000 forms, all new to science, were found in the early probes — only about 5,000 species of bacteria have been scientifically described to date. Now the known depth of underground bacteria has been pushed to 2.75 km in northeastern Virginia (Kerr 1997). Some of these bacteria, living at temperatures of up to 75°C, extract energy from ancient organic matter in nearby rock. One can imagine that these may have important ecological functions. One can imagine that some might have potential value in biotechnology. One can imagine that the microbiota in aquifers and groundwaters in the shrinking Ogalla Aquifer, beneath the Sahara Desert, Australia and Japan might be significantly different. But we have no way of knowing without additional research. There is probably a greater diversity of life in the deep aquifers and groundwaters underneath our feet that on Mars. It could be retrieved at a fraction of the cost of Mars probes without affecting Mars exploration. Most of our microbiologists are currently studying the diseases of humans, domestic animals and crops. Why not put more resources into study of 'wild' bacteria? We do not even know how deep microorganisms live in the Earth.

The existence of deep groundwater bacterial floras, differing from strata to strata, and the contamination of groundwaters, poses the question of their conservation. Is groundwater contamination affecting unique groundwater ecosystems?

> ... "the reality of life underground may turn out to be even more fantastic than the dragons, fairy folk, and dwarves of our imagination. Kerr (1997).

The importance of microbial ecology in surface waters is being increasingly appreciated and studied as demonstrated in the International Workshop on Aquatic Microbial Ecology held in 1995 at the University of Konstanz, Germany (Lucas, Créach and Bessières 1997). Microorganisms play important roles in the major cycles of carbon, nitrogen, sulphur, iron and manganese, as well as with their own role in food webs. Microorganisms play a vital role at the water-sediment interface in organic matter metabolism, transport of nutrients and other solutes across the interface, with an oxic surface skin underlain by a deeper anoxic layer.

Also unexplored are the faster and deeper waters of very large river, in part due to lack of sampling, in part due to lack of appropriate gear. Recent deepwater work at 10-50 m depth in the Amazon has revealed upwards of 240 new species plus new genera (Anonymous 1997.2). These are dominated by electric fishes and catfishes, many with eyes reduced or lacking — little light reaches below 10 m of murky water. The opportunity to study deepwater biota in large Asian rivers in undisturbed state is rapidly fading, if not gone (H.B.N. Hynes in Dudgeon 1994), and study of what is left should be given priority.

Although easily accessible, ephemeral pools are poorly studied. In the vernal pools of one region of California 43% of the known crustaceans, some 30 species, were undecribed by science. Such pools contain several endangered species of fairy and tadpole shrimps in the U.S. (Belk 1997). Vernal pool habitat can also contain rare plants like Parish's meadowfoam, *Limnanthes gracilis* var. *parishii*, known from Shrine Pool, California (winter and Higgins 1997).

The appreciation of seasonally flooded areas such as forested wetlands as spawning and nursery habitats increased following publication of Goulding's (1980) book, *The fishes and the forest.* Seasonal flooding contributes to the sustainable benefits which can be drawn from intact river bottom forests. Cambodia's Tonle Sap, or "Great Lake", expands five-fold, thanks to floodwaters from the monsoon-fed Mekong, to 13,000 km^2 (Gráinne Ryder, Mekong Program, Probe International; Ahmed and Tana 1996). With its annual fish catch of 100,000 tons, it is the main protein source for Cambodia's 9.5 million people. It is home to a spectacular abundance of birds, cranes and fishes, that have earned it a nomination for UNESCO World Heritage status. Clearly annual flooding fosters productivity and biodiversity, and changes in the natural annual water rhythm will threaten that biodiversity.

The condition of riparian ecosystems is rightfully recognized as an important influence in the status of streams and rivers. Riparian vegetation filters lateral inflow, shades the water, prevents bank erosion, and provides woody debris, and inputs insects and leaves to stream food chains. But the riparian role should not be overemphasized. Wang *et al* (1997) studied the relationships between watershed land use and habitat quality and between watershed land use and index of biotic integrity (IBI) for 134 sites on 103 streams in Wisconsin. Habitat quality and index of biotic integrity scores were significantly positively correlated with the amount of forested land and negatively correlated with the amount of agricultural land in the entire watershed and in a 100-m-wide buffer strip along the stream. Correlations were generally stronger for the entire watershed than for the buffer. The relationship between forested land, habitat and IBI were generally linear. But with agricultural land use, obvious declines in habitat quality and IBI scores became apparent only when agricultural land use exceeded 50%. High urban land use was associated with poor biotic integrity and was weakly but significantly associated with poor habitat quality. IBI scores were consistently very low when urbanization exceeded between 10% and 20%. Overall, watershed land uses clearly had strong effects on habitat quality and biotic integrity in Wisconsin streams.

The theoretical ecology of large river systems is discussed by Arthington and Welcomme (1995). This included the River Continuum Concept. It is based on an appreciation of the continuous processes in terrestrial-aquatic interactions, especially those governed by the riparian zone and the primary influences of basic geomorphology and physical conditions in river channels on lotic (fast-running water) invertebrate communities, and the Flood Pulse Concept wherein the pulsing flood cycle is considered to maintain the system in dynamic equilibrium. During flooding high habitat diversity in the flood plain is coupled with massive increases in the area of aquatic habitat, nutrient regeneration, and increased primary and secondary productivity. Arthington and Welcomme (1995) also discuss the vertical as well as temporal dimensions of river ecology.

Throughout this paper, the word downstream appears many times as a reflection of the one-way source-to-mouth flow of river systems. Reimchen (1995) showed that the flow was not one-way into the oceans. He described how returning anadromous Pacific salmon transport nutrients into streams and bears, otters, and minks transport salmon prey into the riparian zones where their nutrients fostered growth of trees and other plants. The more we study ecosystems the more complex we appreciate that they are. Pringle (1997) also drew attention to upstream biological processes and to the upstream impacts of alterations to the lower reaches of rivers. The impacts can include phenomena at the genetic, population, community, ecosystem and nutrient levels. This is not so surprising when we consider the upstream migration of many fishes and the upstream flights of adult insects to lay aquatic eggs. Rivers then are two-way streets .

The variety of the remaining aquatic ecosystems can be exemplified as follows. Smaller bodies of waters such as springs sometimes contain endemic species which are especially subject to anthropogenic threats in arid areas. Cave water systems sometimes contain blind unpigmented species uniquely adapted to those systems; some are closely related to surface-dwelling species, others represent ancient phylogenetic relicts. Waters usually or seasonally with low oxygen levels may be inhabited by species capable of breathing air. Epiphytic bromeliids in tropical rain forests contain hold small pools of water used for breeding by insects and amphibians. Artificial freshwater ecosystems include fish ponds and man-made reservoirs, paddy fields, and canals. Discarded coconut shells, cans, bottles and automobile tires may hold enough water for mosquitoes to breed in; the latter have fostered the spread of the tiger mosquito.

Aside from a few ecosystems like wetlands, the conservation status of most of the world's freshwater ecosystems is poorly known. But some estimates will be provided in later sections of this paper of the amount of water locked up globally in reservoirs, with preliminary estimates of the lengths of rivers affected by dams globally, and some national indications of the extent of pollution.

Options: A global freshwater ecosystem classification is desirable. The ecosystem units could be mapped at the global, national and local levels. Biological surveys would provide the grist for this mapping, a geographic information system (GIS) database, and specimens needed for taxonomic and genetic research (see following Sections). Investment in studying the diversity and ecological roles of deep aquifer and groundwater bacterial floras, as well as their potential in industry would be worthwhile.

3.22. Taxonomic Level

Freshwater Phylogenetic Diversity

Despite their relatively small area, fresh waters contain a relatively high variety of higher and lower taxonomic units, from phyla levels down to subspecies. All of the major taxonomic groups (Groombridge 1992) which are likely to contain in excess of 100,000 species occur in freshwater: insects, arachnids, crustaceans, molluscs, nematodes, plants, algae, protozoans, fungi, bacteria and viruses (note that these also occur on land or in the sea, or both). And many other species-rich (annelids, platyhelminths, vertebrates) and minor groups are found in fresh water. About 12 percent of all animal species occur in fresh water (Abramovitz 1996.1).

Higher taxa: Preliminary counts based the *Five Kingdoms* (and Schwartz 1988) shows that at least 25 (27%) of the 92 known phyla recognized, are not infrequently found in fresh water. Of the 33 metazoan phyla May (1994) estimates that 82% are marine, 42% are freshwater, and 33% are terrestrial (and 45% are symbiotic). A survey of information in *Flowering Plants of the World* (Heywood 1993) shows that 7.2% of the angiosperm families are entirely aquatic while 11.4% (probably an underestimate) of the families have some, many or all species aquatic. Phyletic analyses show that the proportion of freshwater phyla or other higher level taxa exceeds the proportion of freshwater areas to marine and terrestrial environments. However, it should be noted that there are no uniquely freshwater metazoan phyla (May 1994).

In recent years it has become evident that bacteria are much more diverse than had previously been thought. The fundamental role of bacteria in planetary cycles is more and more appreciated and their potential in biotechnology, though scarcely investigated, is already being realized. At least 14 of the (then) 17 bacterial phyla have freshwater members (Margulis and Schwartz 1988).

As molecular-phylogenetic analyses begin to unravel the hitherto scarcely known species and evolution of bacteria, we have been surprised at the great richness of taxa. The three major branches or urkingdoms of the tree of life have turned out to be the Archaea, previously lumped with next group, the Bacteria, and the Eucarya - all the rest of life forms (Pace 1997). This fundamental breakthrough by Carl Woese was first stoutly resisted by orthodox scientists, but has now been bolstered by strong evidence from rRNA and other molecular data and is the new orthodoxy. The 12 phylogenetic kingdoms of bacteria (mainly phyla) known in 1987, have now been increased to 25 to 30 distinct kingdom-level groups (Pace 1997).

Freshwater taxa may have different distribution patterns depending on their tolerance to salt water. *Primary* freshwater fishes like the carp family, Cyprinidae, are strictly intolerant of salt water, and are restricted to continents or to islands connected to them during lowered sea levels. *Secondary* freshwater fishes, like the cichlid family, Cichlidae, are generally confined to freshwater but are capable of crossing narrow sea barriers. *Peripheral* fishes, like the sturgeon family Acipenseridae, occur in fresh water but several migrate into coastal waters. Primary freshwater fishes such as the carp family, Cyprinidae, are only found east of Wallace's Line in the Indo-Australian Archipelago.

Species-level taxa: The global number or proportion of species-level biota, animals, plants and microorganisms, that occur in fresh water is not precisely known. But Reaka-Kudla (1997) has made the most recent estimates of the number of known or described species. She estimates that there is a total of 1,868,000 described species, 44,000 of which are aquatic and 35,000 of which are aquatic macrobiota (estimates for the latter are more precise). Her data show that the known aquatic species comprise 2.4% while marine species comprise 14.7%, symbiotic organisms (*sensu lato*) 5.3%, and terrestrial organisms 77.5% of all known living species. These values are shown in Table 1 with the proportion of the Earth's surface that is occupied by each environment. Reaka-Kudla's (1997) estimates show that the number of freshwater species is higher than one would expect on the basis of the relative area that surface fresh waters occupy.

Of the approximately 100,000 species (estimates vary from 80,000-135,000) of molluscs known around the world, about 25% occur in fresh water (IUCN 1996). For estimates of the proportion of freshwater species in certain other groups, see Table 2.

TABLE 1. SPECIES RICHNESS OF EARTH'S MAJOR ENVIRONMENTS

Environment	% Area of Earth's Surface	% of Known Living Species	Relative Species Richness (% Species/ % Area)
Freshwater	0.8%	2.4%	3.0
Terrestrial	28.4%	77.5%	2.7
Marine	70.8%	14.7%	0.2
Symbiotic	N.A.	5.3%	N.A.

Dr. W. G. Franzin of the Freshwater Institute in Winnipeg suggests (*in litt.*) that 44,000 freshwater biota is an underestimate, a point of view shared by Dr. Martine Allard, National Water Research Institute, Burlington. Franzin's preliminary search suggests in North America alone there are 5,000 freshwater Coleoptera, perhaps 20,000 Chironomidae, 4,000 Crustacea, 1,350 Trichoptera. He states that Thorp and Kovich estimate there are between 10,000 and 15,000 freshwater invertebrates in North America, Dave Rosenberg stated that the present estimate of benthic invertebrates in North America was 8,000, while Hedy Kling, the Freshwater Institute's phytoplankton expert, suggests diatoms alone could number in the tens of thousands. The latter estimate is borne out by Poulin, Hamilton and Proulx's, (1995) list of 2,947 species, subspecies, varieties and forms of freshwater algae in the province of Québec, Canada. Of course it is necessary to define whether one is speaking of known or as yet undiscovered or unnamed species, and how to count, for example, insects which may have aquatic larvae but terrestrial-aerial adults. The simplest solution for attributing the latter might be to attribute half the species count to aquatic and half to terrestrial environments.

How many freshwater species are there when those species yet to be scientifically discovered are added? There are currently about 1.8 million described species in all environments and estimates of the total number vary from 5 to 120 million species. If freshwater species comprise the same fraction of the to-be-described species and using Reaka-Kudla's (1997) conservative estimate, than one might expect the total number of freshwater species to lie between 120,000 and 2.9 million, with a midpoint of 1.5 million species. This estimate must be considered approximate because freshwater biota are poorly known in many countries.

For Canada, Mosquin *et al* (1995) estimated that 51% of the species were terrestrial, 23% were freshwater and 25% were marine. The fact that there is more freshwater in Canada than in any other country and that the country is recently deglaciated may skew this relationship from the global pattern seen in Table 1.

Kottlet and Whitten (1996) provide counts for numbers of species of some taxa in Asia: for reptiles: 8 crocodilians, 60 aquatic turtles and 24 species of true water snakes; for amphibians nearly 1000 species which rely on fresh water at some stage of development while freshwater fishes are estimated at 3,500 species. The numbers of prawn and crab species are given for individual countries.

Global species counts and the proportion that are freshwater for selected taxa are presented in Table 2.

TABLE 2. PROPORTION OF FRESHWATER SPECIES FROM AROUND THE WORLD IN SOME MAJOR TAXA

Group	Total Number of Known Species	% in Fresh water	Source
Euglenophyta - euglenas	800	Most	5
Rotifera - rotifers	2,000	97%	5
Diatoms	10,000-12,000	< marine	6
Chlorophyta - gr. algae	16,000	Most	7
Porifera	10,000	1.5%	5
Molluscs - molluscs	100,000	25%	8
Amphipoda - scuds	7,000	24%	2
Ascari - mites & ticks	30,000	10-15%	9
Odonata - dragonflies	5,500	100% larvae 0% adults	3
Osteichthyes - fishes	25,000	41%	1
Cetacea - whales/dolphins	77	9%	4
Otariidae - otters	12	83%	

Sources: 1 = Abramovitz (1996.1), 2 = Dr. E.L. Bousfield (pers.com.) 3 = Brusca & Brusca (1990), 4 = Hoyt (1984), 5 = Margulis & Schwartz (1988), 6 = Michel Poulin (pers. com.), 7 = Margulis *et al* (1989), 8 = IUCN (1996), 9 Brusca & Brusca (1990) & Dr. Ian Smith, Agriculture Canada (pers.comm.)

Data in Table 2 excludes a number of taxa such as Cephalopoda (octopi and squids), Brachiopoda (lampshells), and Chaetognath (arrow worms), which are absent from fresh water. Table 2 demonstrates is the proportion of freshwater species in taxa is highly variable, 1% to 97%, but often disproportionately high.

Fish species and families: Worldwide, 41% of all fish species spend all or part of their lives in fresh water (Abramovtiz 1996), some 8,400 species. Nelson (1994) gave similar figures, 40.4% of 24,618 fish species, dwell in fresh water, while 42.5% used fresh waters. Table 2 shows that the fresh waters are disproportionately rich in species of fishes on the basis of area. That suggests a high sensitivity for fishes to loss of freshwater habitat.

Many of the world's freshwater fish species live in the tropics: at least 2,780 in Africa, 2,400-4,000 in South America, and 2,500 in tropical Asia, with 319 in Europe including the former U.S.S.R., 242 in Central America and 188 in Australia (Stiassny 1996.1) — many more than in temperate and polar regions. Many of those ichthyofaunas center in river basins such as the Zaire, Amazon, Orinoco, Urugai, Parana-Paraguay, Mekong, and Yangtze rivers. In North America the "hottest" spot, richest in species and endemics, is in the Cumberland-Tennessee Plateau drainages of the eastern Mississippi drainage basin, not in the main stem rivers (McAllister *et al* 1986). Alabama alone contains 38% of native freshwater fishes, 43% of native freshwater gill-breathing snails and 60% of mussels, and 52% of native freshwater turtles from U.S. and Canada, and contains relatively high levels of endemism (Lydeard and Mayden 1995).

The number of fish families with freshwater members, 157 (Berra 1981) comprises 33% of the 482 extant fish families (Nelson 1994). More of these families are in the Neotropical (70%), Ethiopian (47%) and Oriental (44%) realms, with fewer families in the Australian (39%), Nearctic (30%), and Palearctic (10%) zones (Berra 1981).

Fish biodiversity hotspots: Biodiversity hotspots are geographic areas rich in species, endemic species, or other taxa. Hotspots are of interest because they are critical if we wish to conserve, manage, or otherwise draw upon these areas where much of biodiversity resides. Conservation International (CI), a international environmental organization, analysed which global areas were important for conservation of terrestrial species, based on the number of endemic species and the degree of threat. Their findings, summarized in their Global Biodiversity Hotspots Map, shows that more than 50% of the Earth's terrestrial biodiversity is contained in less than 2% of the planet's land surface (see web site at: http://www.conservation.org/web/fieldact/hotspots/hot97.htm). CI also recognizes the importance of major tropical wilderness areas such as the Amazon. Comparable analyses are needed for freshwater and marine areas.

Clades: A clade is branch of a phylogenetic tree. Consideration of clades in conservation may be important, because they can represent unique evolutionary lineages (Morrone, Katinas and Crisci 1996). For example, Madagascar contains the most primitive clade of cichlids and another cichlid, *Heterochromis multidens*, found in forest backwaters of the Zaire River, is a sister taxon to the remaining Afro-Neotropical cichlid radiation (Stiassny 1992). Thus presence of clades, especially basal ones, even if low in numbers of species, endemics and genera, should be taken into account in assessing conservation priorities, along with ecological and genetic parameters (Stiassny 1994 *et al.*). Cladistic analysis thus becomes a useful tool in conservation along with other disciplines.

Megadiversity countries. One method of detecting hotspots is by assessing the number of species per country. It is an easy approach because faunal and floral lists and monographs are often prepared for political units such as countries. Countries with especially high counts of species in well-known groups such as tetrapods, angiosperms and swallowtail butterflies, have been called megadiversity countries. McNeeley *et al* (1990) listed the following as megadiversity countries: Brazil, Colombia, Ecuador, Peru, Mexico, Zaire, Madagascar, Australia, China, India, Indonesia and Malaysia and suggest that these countries account for 60-70% of all the world's biodiversity (or perhaps more). Aside from amphibians, predominantly aquatic groups have not been used to gauge which are megadiversity countries. In Table 3, we extract the twelve countries from Appendix 1 with the highest numbers of species of freshwater fishes and the number of species per unit area, plus, from McNeeley *et al* (1990), the number of amphibian species. The megadiversity freshwater fish countries are shown above in Fig. 6. Note that the counts for some countries in the Appendix are incomplete.

TABLE 3. MEGADIVERSITY COUNTRIES — THOSE WITH THE MOST FRESHWATER FISH SPECIES

COUNTRIES RICHEST IN SPECIES	NO. OF FISH SPECIES	SPECIES /1000 KM^2	NO. AMPHIBIAN SP.
1. Brazil	3,000	0.355	516
2. Indonesia	1,300	0.718	270
3. China	1,010	0.108	265
4. Zaire	962	0.424	216
5. Peru	855	0.668	251
6. United States	779	0.085	205
7. India	748	0.252	182
8. Thailand	690	1.351	101
9. Tanzania	682	0.770	127
10. Malaysia	600	1.826	171
11. Venezuela	512	0.580	197
12. Vietnam	450	1.383	72

From the above summary table we note that seven of McNeeley *et al*'s (1990) twelve megadiversity countries are also amongst those with the most freshwater fishes. But the United States, Venezuela, Tanzania, Thailand and Vietnam, rich in freshwater fishes, are excluded in McNeeley's megadiversity list. Exclusion of five or 42% of the fish-rich countries suggests that fishes do not follow terrestrial groupings closely. Below we will see that the number of freshwater fishes and amphibians are highly correlated. This may mean that separate megadiversity categories may have to be established for terrestrial and freshwater species.

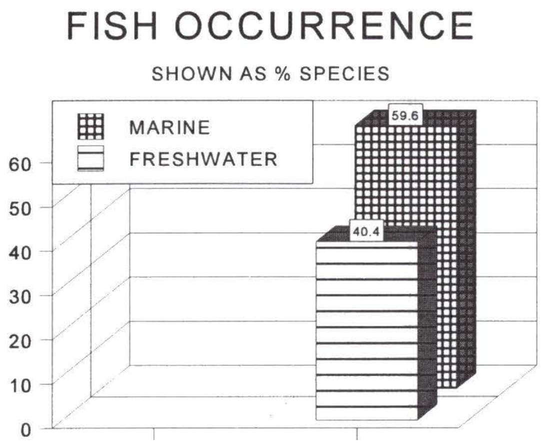


Fig. 5. Although fresh waters cover only 0.8% of the Earth's surface and marine waters 70.8%, still the number of freshwater species is relatively high - 40.4% of all fish species (Nelson 1994).

In addition to the data for fish and amphibian species in Table 3 and area of countries in Appendix 1, we also have data for the number of mammals, birds and reptiles (not shown, but available in McNeeley et al (1990) and Groombridge (1992)). When correlations are made between all pairs of these variables, all of the correlations are positive. Those between number of fish and amphibian species ($r=0.937$) and reptiles and mammals ($r=0.749$) are significant at $p. < 0.01$, those between birds and amphibians ($r=0.663$) and mammals and amphibians ($r=0.640$) are significant at $p< 0.05$. Other correlations, including that with area, are not significant, in part due to the small number of countries. When we examine the relationship between the number of fish species and country area for the 151 countries listed in the appendix, we find that the relationship ($r=0.532$) is significant at $p<0.01$. That relationship is shown in Fig. 6.

McAllister et al (1986) and Currie (1994) may be referred to concerning the relationship of other variables with biodiversity. The former found that aridity was the most important climatic factor in predicting diversity of freshwater fishes.

TABLE 4. DENSELY SPECIOSE COUNTRIES — THOSE WITH THE MOST FISH SPECIES PER UNIT AREA

COUNTRY	NUMBER OF SPECIES	SPECIES/ 1000 KM^2
1. Burundi	209	8.148
2. Malawi	361	3.837
3. Bangladesh	260	1.997
4. Malaysia	600	1.826
5. Sierra Leone	117	1.634
6. Cambodia	260	1.473
7. Viet Nam	450	1.383
8. Thailand	690	1.351
9. Uganda	247	1.238
10. Lao Peop.D.R.	262	1.135
11. Philippines	330	1.107
12. Ghana	224	0.984

Data from Appendix 1 for countries with more than 115 freshwater fish species and more than 1.0 species/1000 km^2

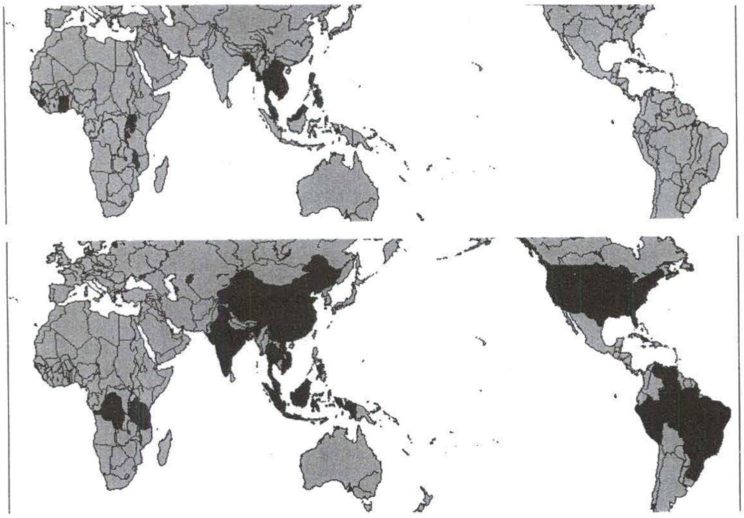


Fig. 6. ***Above:*** *The 12 countries with the most (absolute number) of fish species are dark-colored on this map (from Table 3).*
Below: *The 12 countries with the most species per unit area are darkened (from Table 4).*

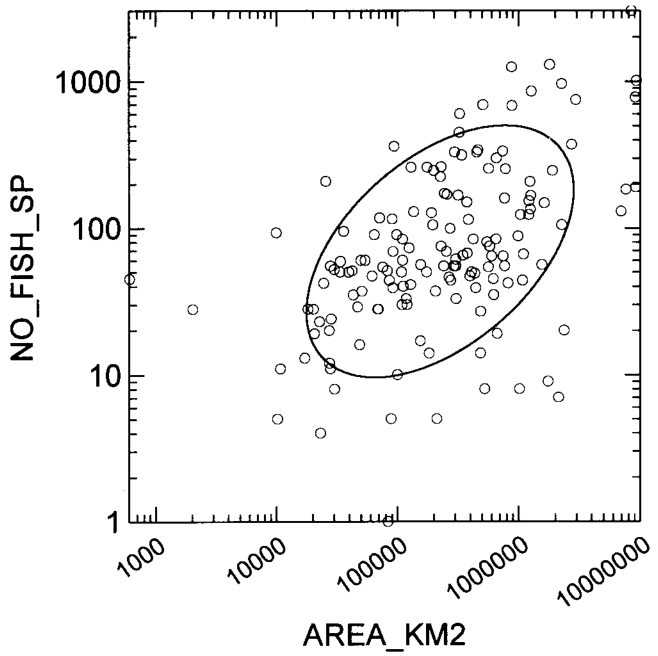


Fig. 7. Relationship between number of freshwater fish species in and area of a country, on log-log axis. Data from 151 countries in Appendix 1 The correlation between species and area (arithmetic values) was 0.532, with a probability of < 0.01. The two countries lacking species were excluded from the graph, but not the correlation calculations

Densely speciose countries. Table 4 ranks the 12 countries with the most freshwater fish species per unit area, excluding those with 115 species or fewer. These countries are shown in the lower half of Fig. 6. The listing is very different from that in the megadiversity table. Firstly there are 9 new countries in Table 4, and secondly even the sequencing of the four common countries is different. This exposes a characteristic of megadiversity rankings; it does not take into account the differing size of countries. Some megadiversity countries are so classified simply because they are larger and have more species according to the well-known species-area curve. For this reason an equal-area global grid has been proposed to reduce the area variable in biodiversity comparisons (McAllister *et al* 1994). However, also to be considered in tetrapod, vascular plant, angiosperm and freshwater fish geographic diversity is proximity to the tropics. Most of the countries in the two lists are tropical or lie on the edge of the subtropics.

Species and area: The data suggest two conclusions. First, common to the two analyses, absolute and species-per-unit-area, are three global regions rich in freshwater fishes: northern South America, central Africa and southeast Asia. These areas then deserve special attention in regard to conservation priorities and development — with precaution. Secondly, although the megadiversity concept is a useful one, we should move towards evaluation which includes number of species per unit area, and per equal-unit areas. Equal-area grid approaches can pinpoint hotspots within countries, or those which are shared by adjacent countries. Ecozones also have the same weakness as countries, unequal areas, when identifying hotspots. Optimally one will have country, ecozone, and equal-area grid overlays in biodiversity information systems, each retained for its particular usefulness.

The number of species present in subtropical and tropical rivers is highly correlated with the area of the river basin; temperate rivers show a similar but less marked pattern and the relationship breaks down in depauperate tundra rivers. Groombridge (1992) showed a virtually straight line log-log relationship between number of fish species and river basin area.

Lake area is also generally positively correlated with freshwater fish species richness (Groombridge 1992). On both a global scale and in a sample of 14 North American lakes, surface area and latitude together account for about one-third of the overall variation in species number (Barbour and Brown 1974). However in a sample of 14 African lakes, surface area, depth and conductivity were the primary factors (Groombridge 1992). Although some species found in both lakes and rivers, others are restricted to lakes. A number of large old lakes are particularly rich in endemic species, including species flocks which have undergone adaptive radiation into vacant ecological niches. Echelle and Kornfield (1984) treat the evolution of species flocks. Table 5 gives the number of species and proportion of endemics in some of these lakes, drawing on data from Banarescu (1990-95), Groombridge (1992), Hocutt and Wiley (1986), and Ogutu-Ohwayo 1996. The figures in Table 5 show that high levels of endemism can occur in lakes.

Lake/river midwater/bottom species richness: About 1,166 species or 12% percent of the world's freshwater fish species occur in the listed lake basins. Other lakes can be expected to contain more species that occur in both lakes and rivers. If the number of lake-restricted species around the world was double that in Table 5, that would mean that one-quarter of of freshwater fish species were lake adapted and that three-quarters lived in rivers and/or lakes. Although a crude estimate, the data nevertheless suggest one thing: rivers have more fish species than lakes, despite the 99 times greater volume of lakes.

TABLE 5. FISH SPECIES RICHNESS & ENDEMISM IN LAKES

REGION - LAKE	NO. FISH SPECIES	DEGREE OF ENDEMISM
AFRICA		
Lake Malawi	250	95%
Lake Tanganyika	200	95%
Lake Victoria	300	99%
ASIA		
Lake Baikal, Russia	50	46%
Lake Biwi, Japan	<63	12%
L. Lanao, Philippines	24	75%
Yunnan upland lakes	65	68%
EUROPE		
Lake Ohrid	17	18%
NORTH AMERICA		
Great Lakes	177	4%
SOUTH AMERICA		
Lake Titicaca	20	70%

Why should rivers have more species than lakes, especially given that lakes have a volume of water 99 times greater than that in rivers? A number of possibilities exist. Many continental areas have no lakes and aside from the Great Rift lakes in Africa there are few large lakes and few clusters of small tropical lakes. Lakes are common in glaciated areas but those are generally young and depauperate. The high lacustrine water volume is clustered in a few great lakes, where given time, there can be adaptive radiation. But the separation of rivers into basins, with occasional basin fusions or fragmentations, and waterfall barriers, has offered a rich potential for geographic speciation in the speciose tropics as well as in the less speciose boreal regions. The surface to volume ratio of rivers is higher, offering more solar energy input and interfacing with diverse terrestrial ecosystems, offering a richer food supply and variety of ecological niches. More important than the surface may be the relative bottom area if we are to judge by what has been found in marine ecosystems — Gray (1997) reported that marine biodiversity is higher in benthic than pelagic systems. The benthic predominance in groups like diatoms, molluscs, insect larvae and scuds appears to reinforce this hypothesis. But more precise figures are needed before this discussion can progress. But this might suggest that particular care be taken of benthic ecosystems.

Invertebrate species richness: While hotspots for freshwater fish species are mostly in the tropics, the same may not be so for invertebrates. According to Allan and Flecker (1993) the invertebrates of the temperate zone running waters are no more diversified than those of tropical environments. They also suggest that the number of invertebrate species in a section of temperate stream may exceed the number of fish species by an order of magnitude.

Plant species richness: Although wetlands occupy only about 5% of the surface area of the conterminous United States, 6,728 plant species or 31% of the U.S. flora occur in wetlands (Wilen 1995). Of these plants, half are restricted to, or usually occur in, wetlands. So even if the number of wetland plant species is halved to 15%, this still means that wetlands have, on the average, more than 3 times the number per unit area of non-wetland areas. The benthic algae are more diverse than the plants, and prominent amongst these are the diatoms (Allan and Flecker 1993). Conservatively, there are 4,000 species of freshwater diatoms in the U.S. (Charles and Kociolek 1995). The Canadian province of Quebec has 2,947 taxa (species, subspecies, varieties and forms) of freshwater algae (Poulin, Hamilton and Proulx 1995).

Bacterial richness: The estimation of the richness of bacterial floras was hitherto restricted to that fraction, about 1% of all bacteria, that could be cultivated by routine techniques (Pace 1997). That suggested that the 5,000 or so culturable bacteria, represented the tip of an iceberg, some 500,000 species. The new molecular sequence-based taxonomic framework may help provide better estimates.

Loss of Freshwater Diversity

Over 100 freshwater associated vertebrates (birds, amphibians and fishes) became extinct following 1600 AD. Freshwater extinctions accounted for 55% of the extinctions in these classes of vertebrates, a disproportionately high number.

The loss of species of freshwater fishes is only partially documented. Of 734 species of globally threatened fishes (critically endangered, endangered, vulnerable), 84% are freshwater (wholly freshwater or anadromous) in the 1996 *Red List* (IUCN 1996). World-wide, it is estimated that over 20% of freshwater fishes are either extinct, endangered or vulnerable (Moyle and Leidy 1992; Moyle and Yoshiyama 1994). But Stiassny (1996.1) believes that a figure of 30-35% would be more accurate. Her estimate is realistic when it is considered that much of the data we base extinctions on is a decade or more out of date. Ninety-two species of freshwater fishes or 1% are extinct in the wild (11 of these survive as captive populations, Groombridge 1997).

At a regional level, 30% of the 979 North American freshwater native fishes are extinct or at risk (endangered, threatened or of special concern; Mayden *et al* 1992). Three genera, twenty-seven species, and 13 subspecies of North American fishes were recorded as extinct. Factors contributing to extinctions are shown in Fig. 8 below. Physical habitat alteration is implicated in 93 percent of the declines — hardly surprising when in the United States only 2% of the nation's 5.1 million km of rivers and streams remain free-flowing and undeveloped and half the wetlands are drained (Abramovitz 1996.1). In the species-rich American state of Alabama, factors contributing to the demise of freshwater biota include habitat destruction from dams, channel modifications, siltation, water quality degradation from point and non-point source pollution and introduction of non-indigenous species (Lydeard and Mayden 1995). About one third of the 193 species of freshwater fishes in Australia are considered threatened and 42% of Europe's freshwater fishes are of concern (11% endangered, 21% vulnerable, and 10% rare; Nyman 1991). Primary threats to survival of North American freshwater mussels were destruction of habitat and expansion of distribution and populations of nonindigenous molluscs such as the Asian clam, *Corbicula fluminea* and zebra mussel, *Dreissena polymorpha.*

Lake endemics can be threatened by human activities. Most of the endemic cyprinid species flock in Lake Lanao became extinct following the introduction of species of a predatory goby, *Glossogobius giurus*, in 1962 from elsewhere in the Philippines (Echelle and Kornfield 1984; Dudgeon *et al.* 1994). The exact number will never be known as the scientific collections on which the species were based, were destroyed during the World War II. Similarly many of the cichlids endemic to Lake Victoria became extinct following the introduction of the Nile perch, eutrophication, and other factors (Ogutu-Ohwayo 1996).

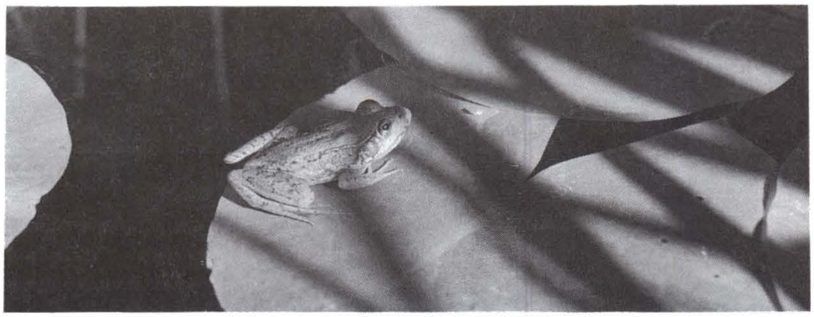
The northern hemisphere lampreys, family Petromyzontidae) provide an interesting case in conservation. Nine (26%) of the 34 nominal species are endangered and one is extinct (Renaud 1997, in press). While some lamprey species at risk are protected by law in Europe, one in Canada, but none are so protected at the national level in the United States. Sea lampreys were killed with lampricides because of their predatory behavior in the Great Lakes of Canada and the U.S. and the Miller Lake lamprey, *Lampetra minima*, was purposely poisoned with ichthycides during the 1950s (because it preyed on introduced trout) and became extinct in 1952 (Miller, Williams and Williams 1989). There seems to be an aversion to protecting lampreys, some members of which are parasitic. Parasitic species generally are seldom considered for protection. Yet these species too are part of the Earth's natural biodiversity. If we are are to exclude from protection species that are harmful to others, where does that put humankind?

Mammals: Of seven freshwater dolphins, 1 is vulnerable, 2 are endangered, and

1 is critically endangered; of 10 freshwater otters, 6 are vulnerable and 1 is endangered (IUCN 1996). Of these freshwater mammals, 59% are at some degree of risk.. Destruction and pollution of wetlands, loss of forests, and lack of public awareness affect otter conservation (de Silva 1996). See IUCN (1996) for other freshwater mammals at risk such as sirenians and freshwater shrews.

Reptiles: Of 23 species of crocodiles, 10 (43%) are threatened, but they have experienced overall improvement in the past 20 years due to conservation measures (IUCN 1996). Of the 143 species of tortoises, turtles and terrapins, 57% are threatened or near threatened; most of these are freshwater turtles (IUCN 1996).

Amphibians: Concern over declining and disappearing amphibian populations has resulted in the creation of the Declining Amphibian Populations Task Force in the IUCN. Amphibian declines are a complex and multifaceted problem. Habitat loss, organochlorine contamination (Russell, Hecnar and Haffner 1995), acid rain and increased UV radiation are four of the factors that have been implicated. According to IUCN (1996) 25% of amphibian species are threatened. An exotic virus in Australia, perhaps introduced through the international trade in ornamental fish, is causing a rapid decline in frog populations in Queensland (IUCN, Gland, press release, 18 September 1996). The Task Force has determined that there are now sufficient scientifically robust studies which demonstrate that the decline or disappearance of amphibian populations from relatively undisturbed habitat is real but not universal (Heyer 1996). More recently, concern has arisen over a possible increase in the number of amphibians with abnormalities such as extra legs, in the U.S. upper mid-west and southern Canada. Ten percent of frogs in an artificial pond in Kitakyushu City Japan have extra legs, possibly due to contamination from ammunition dumps, though ordinary chemical analyses have shown no suspicious chemical substances (*Japan Environment Monitor News Briefs*, November 1996).



Invertebrates: Invertebrates are also being lost. Two-thirds of U.S. crayfish and nearly three-fourths of its freshwater mussel species are now rare or imperiled. Of the 920 terrestrial, freshwater and marine molluscs threatened globally, 18% are snails that occur in springs in the United States, Australia and Europe. The majority of threatened bivalves are freshwater species are at risk due to exotic species, man-made barriers, overharvesting, pollution, and habitat destruction (IUCN 1996). All but 2 of the 407 crustaceans in the 1996 Red List are freshwater. Of the 537 threatened species of insects, 109 or 20% have aquatic larval stages, the rest being terrestrial (IUCN 1996).

One can conclude from all this information that a high proportion of freshwater species are threatened.

Options: Taxonomic knowledge and information could be strengthened by transferring accumulated wisdom of the current retiring generation of taxonomists, educating a new generation, providing jobs for them with special attention to poorly known groups of microorganisms, invertebrates and lower plants, strengthening natural history museum capacity in carrying out field work, scientific specimen storage, collection computerization, genetic laboratories, collection support staff, and in bibliographic resources. The capacity to display taxonomic diversity on equal-area geographic grids would help identify taxonomic hotspots for consideration in planning protected areas.

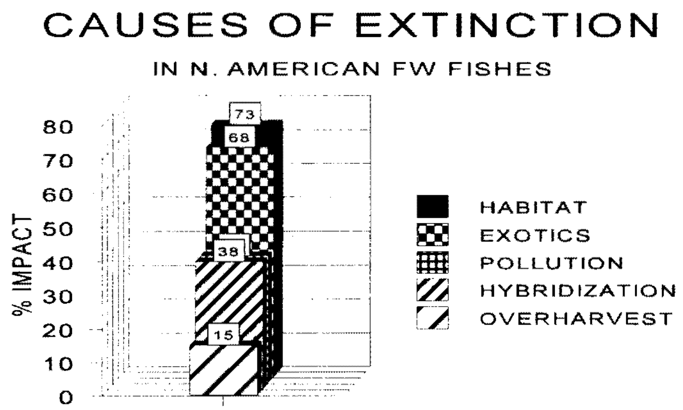


Fig. 8. Causes of and degree of impact on extinctions in North American freshwater fishes. More than one factor may contribute to an extinction. (Data from Miller, Williams & Williams 1989).

3.23. Genetic Level
Several studies show that high heterozygosity is positively related to fitness and is thus beneficial (Nyman 1991). Presumably this is due to a mix of factors. Natural environments are neither spatially or chronologically uniform, so one genetic pattern does not fit all. Furthermore, genetic variability confers resistance to predation, disease and parasites. The relatively high amount of natural genetic diversity found in undisturbed ecosystems is needed to adapt to natural changes, cycles, and biological pests. The conservation of genetic diversity probably becomes more important as natural ecosystems are stressed by toxic chemicals, climate change, habitat degradation, and other factors. Increasing ecosystem variance while decreasing genetic diversity, would seem to be a risky combination, all the more risky since few routinely monitor genetic diversity except in a few commercial species.

The amount of genetic variation within and between populations of freshwater species is poorly documented, though expected to be significant because of the isolation of populations in river drainages and lakes, compounded in some cases by homing to spawning grounds. However, that variability is being increasingly investigated as a means of identifying and managing stocks. Genetic diversity at species and higher levels is also being explored as a tool for distinguishing and classifying species. The existence of multiple, genetically distinct stocks gives rise to special concerns for exploitation, since the overall sustainability of a fishery could be undercut by removing its genetic diversity as individual stocks are depleted or eliminated.

Genetic diversity protection and loss is discussed by Nyman (1991), Ryman, Utter and Laikre (1995) and Waples (1995). Genetic losses/degradation may come from actual loss of species, geographic populations or spawning stocks. Of approximately 1000 historic salmonid stocks in the Pacific Northwest of U.S., only about 100 are considered somewhat healthy (Abramovitz 1996.1).

Fragmentation of habitat may prevent genetic exchange between populations, result in loss of genetic diversity and extirpation of local populations (Pringle 1997). Habitat may be fragmented by degradation areas or by physical barriers such as dams.

Heavily fished populations may lose genetic variability without anyone being aware of it. Over a five year period, under the pressure of an intense and size-selective fishery, the heterozygosity of three populations of the orange roughy, *Hoplostethus atlanticus* (a marine species), decreased significantly (Smith *et al* 1991). This may have resulted from the removal of the largest and most genetically varied large individuals, although other factors may be at work. That possibility gives one pause, when many fisheries are showing declines in larger individuals. So both loss of stocks and genetically diverse individuals from a stock may result in erosion of genetic diversity. But genetic erosion of individual stocks tends to be ignored so long as overall numbers are maintained. Nyman (1991) suggests that a global database be established for population genetic data on freshwater fishes, and, in particular, data from threatened species and populations.

There are numerous studies demonstrating the genetic uniqueness of fish populations to particular river systems, tributaries or lakes or within lakes. We shall mention only one. Inlet and downstream tributaries of Loon Lake, B.C., Canada were shown by studies of C.C. Lindsey and T.G. Northcote to have behaviorally distinct types of rainbow trout, *Oncorhynchus mykiss*. The inlet tributary possessed a stock where the fry, after hatching in the stream, dropped downstream into the lake. The outlet stream possessed a stock where the fry, after hatching, would swim upstream into the lake — those that did not would have been swept downstream over an impassable falls, to be lost from the gene pool. A third stock lived in a tributary of the outlet stream; these had first to drop downstream to the lake outlet, then, cued by warmer temperatures, swim upstream to the lake. Clearly such finely-tuned stocks cannot easily be replaced. Use of inappropriate hatchery stock could result in the loss of the entire planting's progeny over the falls.

Genetic contamination of wild stocks may come about through hybridization with introduced stocks of the same native species, or with transplanted non-native wild stocks of the same species, or with exotic species or subspecies (Ferguson 1990). Such hybridization means that the new stocks are likely to be less well adapted to their environment. Hybrids may be successful in the short term due to hybrid vigor of the F_1s, but the net effect is the dilution of genetic patterns that have evolved over long periods and confer adaptations to local conditions and resiliency to environmental changes.

Genetic impoverishment also results from massive 'enhancement' programs that target the species level only. Examples include restocking programs for Brazilian migratory species; the Japanese chum salmon enhancements program, and many 'successful' North American hatchery programs — in the United States as much as 25-50% of the freshwater fishes caught by anglers are from populations established through introductions (Winter and Hughes 1997). The lower Columbia River coho salmon stock is now dominated by hatchery fish. A species itself may persist, but consist largely of non-native or domesticated stocks.

The dilemma of mobilizing conservation efforts in a "data vacuum" is well illustrated by the above case of Pacific salmon stocks. Despite the obvious decline in returns to the spawning grounds of genetically distinct stocks that make up the Pacific salmon species, there is no "official" listing of stock strengths. Data compiled by the Canadian Department of Fisheries and Oceans compilations are published in varying formats, and a review for the American Fisheries Society was assembled using a variety of published and unpublished sources including government, First Nations and anecdotal records. Another dilemma is posed to management when genetic evidence of a spawning population's distinctiveness is lacking, as in Canadian Pacific herring, *Clupea pallasi* (a marine species), spawning populations. Is genetic evidence for distinct stocks lacking because it is not there (there is only one stock), or just because the stock has not yet been distinguished with appropriate tools or enough resources? Should the Precautionary Principle be applied to such cases, deeming that unique stocks are virtually irreplaceable, or should today's catches be magnified? In other cases the geographic divisions used for fisheries statistics and management may not correspond to genetic stocks. Is Canada's (marine) northern Atlantic cod (*Gadus morhua*) stock, a single genetic stock, or a composite?

Politics and stock conservation may clash when one or more of the countries fishing the marine phase of an anadromous stock takes an undue share of the allowable catch, either to secure a bigger short-term benefits or to drive the other country to the negotiating table. A more statesman-like approach would take into account the irreplacability of unique stocks and the Convention's Precautionary Principle. Unresolved differences would best be taken to adjudication.

Options: Continue genetic research to identify the different stocks in fisheries. Genetic sampling to provide baseline material for current and future research and to build up gene banks are needed. Canadian studies showed that old dried scale samples from scale envelopes can be used for DNA analyses; that would help with stock identification and monitoring of heterozygosity. Apply knowledge to management.

3.3. WILD CAPTURE FISHERIES & HARVESTING

With the possible exception of North America and parts of Europe, nearly all inland resources show symptoms of excessive exploitation (FAO 1995.1). In general, traditional capture fisheries are fully exploited. It should be emphasized that official statistics are inaccurate for freshwater fisheries since many countries have no data collection system for fresh waters, many figures are only estimates, while others lump capture fisheries and aquaculture production. Subsistence fisheries catches tend to be omitted. In the lower Mekong Basin (Thailand, Lao and Vietnam) the reported freshwater catch is 225,000 tons, yet recent estimates suggest the total catch may be as high as 1 million tons.

River food fisheries show the largest loss in fish yields, primarily as a result of channelization and the loss of slow moving areas prone to flooding, as well as from flood control, hydrodams and pollution (FAO 1995.1). Channelization often results in loss of spawning, nursery and other habitats. Overfishing is now leading to seasonal fishing closures in river basins in South America, e.g. in the state of Mato Grosso do Sol, Brazil.

The harvest of wild-caught ornamental fishes in growing. Efforts are being made in Brazil to ensure the sustainability of these practices (Chao 1996; Chao and Prado-Pedreros 1995).

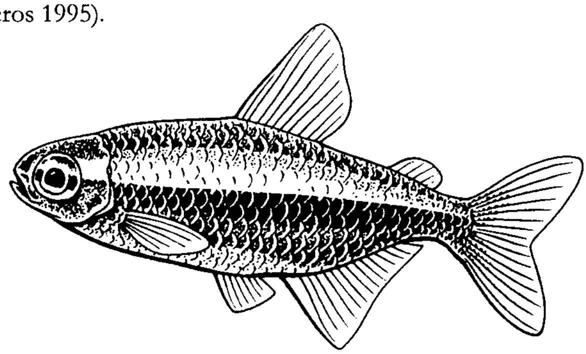


Fig. 9. Wild-caught ornamental fishes provide employment for fishers and sources of hard currency in tropical countries. Up to 21 million colorful cardinal tetra, ***Cheirodon axelrodi****, are harvested each year from the central Amazon. This is one of the unrecognized but significant renewable resources from river flood plains. Drawing by Roelof Idema.*

The biodiversity impacts of freshwater capture fisheries are not as well evaluated as marine capture fisheries. However some freshwater fishing gear, such as gillnets, can produce significant bycatch mortality. Trawls, sometimes used in lake fisheries, can impact benthic habitat and generate significant bycatches. The bycatch in fish traps, checked regularly, is more likely to be released alive.

3.4. AQUACULTURE

Aquaculture currently produces three animal commodity categories: finfish, crustaceans and molluscs. Freshwater fish production grew from over 3 million tonnes in 1984 to about 8 million tonnes in 1992. So freshwater aquaculture production now exceeds catches reported for freshwater capture fisheries by FAO (1995.1), if under reporting of capture fisheries is ignored. Two farmed freshwater species have displaced marine ones amongst the top ten in the world: silver carp (*Hypothalmichthys molitrix*) and grass carp (*Ctenopharyngodon idella*), see Fig. 10, with 1.6 and 1.3 million tonnes respectively per year (Weber 1995). An increasing proportion of freshwater ornamentals is derived from aquaculture, many of them cultured outside of their natural range or country of origin.

Uses of aquatic plants range from water lilies for horticulture, mangroves for charcoal, aquatic plants for aquaria, rushes for weaving, wild and domesticated rice for human food, to food and habitat for wildlife.

Maintaining present per capita fish consumption will, with a projected world population of 7.032 billion by the year 2010, require an additional 19 million tonnes of food fish (FAO 1995.1). Alternatives to increased catches or culture include better management of existing fisheries and habitats, reduction of fish spoilage, and use of fish meal for human food instead of domestic animal or aquaculture feed. Implementing zero population growth policies would also resolve the problem.

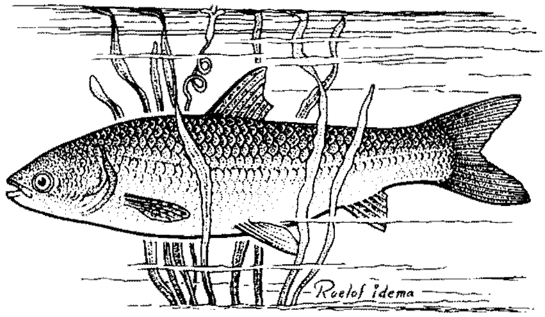


Fig. 10. Aquaculture now produces 1.6 million tonnes of grass carp, ***Ctenopharyngodon idella****, annually.*

The demand for increased aquaculture production and the growing impact of domestic waste on natural ecosystems can be simultaneously resolved in many areas by developing wastewater-fed aquaculture systems. Such systems have been in place in Asia and Europe for some time. Edwards (1996.1) reviews recent literature and develops an action plan to determine the social, environmental, technical and economic aspects of low-cost treatment integrated with fish food production. Edwards (1996.2) describes wastewater use in Vietnamese aquaculture. The chief obstacle to more extensive applications of such approaches seems to be the western taboos about human wastes; the East, with its practical historical use of nightsoil and wastewater, seems to be more open and knowledgeable on this issue. A more challenging issue is preventing the discharge of toxic chemicals into sewage systems.

The major biodiversity impacts of aquaculture are probably the escape of exotic species or stocks, a few of which lead to extinction of native species, contamination of indigenous genomes, or ecological changes; deterioration of water or benthic ecosystem quality; and the conversion of existing natural ecosystems, such as mangrove swamps, for pond construction. Pullin (1994.2) presents ICLARM's position on the use of exotic species and GMOs (genetically modified organisms). The ease of use of exotic (non-native) species in aquaculture may dissuade decision makers from conserving wild stocks. First, the ease with which protein can be produced quickly by importing a species and a ready-made culture system to go with it means that there is little attention paid to local genetic diversity that may be needed for developing future farming systems utilizing local species. Secondly, wild stocks begin to be ignored when aquaculture takes over a significant part of fish production. In Sweden many native river populations of Atlantic salmon are being threatened by large-scale escapes of domestic aquaculture stocks (Gausen and Moen 1991). Furthermore, exotic species tend to be used even when there is no need, e.g. African tilapia in South and Central America where there are dozens of native cichlid species.

The risk of "farm escapes" notwithstanding, the aquaculture industry has invested heavily in the development of technology that, in some cases, has direct application to the maintenance of aquatic diversity. Captive breeding programs have long been adopted as one way to amplify the remaining genetic diversity in threatened populations of terrestrial animals, and a strong case can be made for using analogous fish husbandry techniques where remnant populations of wild fish stocks are being rebuilt. This approach is being used by government and industry partnerships in several countries for rebuilding salmon stocks, and is also being tried in Brazil for the rebuilding of migratory fish stocks.

Hatchery techniques are no substitute for habitat preservation, but in the many cases where populations have already reached critically low numbers, the aquaculture industry has appeared willing to contribute some expertise.

Options: The theory and practice of eco-aquaculture or ecologically benign aquaculture needs to be developed, drawing upon traditional and current technology, existing experience, the lessons in terrestrial agriculture, and ecological principles. Research needs to be conducted using indigenous species for aquaculture. Eight factors appear to be essential for co-aquaculture:

- Use of several species or an ecological assemblage in ponds, instead of a single species;
- Use of heterozygous stocks (instead of a single narrowly focussed genetically uniform variety), or of a more than one genetic variety within ponds, or between adjacent ponds, and use of locally and regionally adapted varieties, as an alterative to widespread use of a genetically uniform stock;
- Use of genetic variability, selection for resistance to pests, diseases and parasites, superior nutrition and living conditions, instead of pesticides, drugs and other control chemicals;
- Use of drugs for disease treatment instead of as a disease

preventative in feeds;

- Use of low-fish-density-stocked, widely-spaced ponds, instead of high-density closely-spaced ponds;
- Use of suitable indigenous species instead of exotic species
- Avoiding off-site impacts of culture;
- Culturing product closer to instead of far from markets, taking into account transportation impacts on environment and freshness of product.

With some exceptions, evolution has endowed natural ecosystems with considerable genetic and taxonomic diversity, a diversity adapted to local and regional conditions. The selected genetic characteristics and the genetic diversity within and between populations confers resistance to predation, parasitism, disease and pests. Holistic natural ecosystems include primary producers, herbivores, detritivores, and nutrient recyclers. Consequently much of the biological and non-biological matter is recycled *in situ*. Learning from the principles of nature and the lessons from agriculture could help foster the development of an eco-aquaculture, environmentally as well as economically sustainable.

4. HUMAN IMPACTS ON FRESHWATER BIODIVERSITY

In this section we consider which human activities are affecting the aquatic environment and in which way. It is convenient to group them under 4.1) Sectorial, 4.2) Legal and Economic, 4.3) Cross-Sectorial, 4.4) Root Causes, 4.5) Impact Interaction, 4.6) Prioritizing Impacts, 4.7) Summary and 4.8) Prognosis of Impacts, providing examples of the kind of impacts which can be expected. The importance of the impacts will differ for each area. At this point it is useful to note that it has been estimated that humans presently use over half of available freshwater runoff, an amount projected to rise to three-quarters by 2025 AD through population increase alone (Postel, Daily and Erlich 1996).

The major threat to aquatic biodiversity is modification of habitat. This includes not only physical modification like draining of wetlands, siltation of spawning sites, and damming of rivers, but also seasonal and chemical changes due to modification of flow rates related to hydroelectric dams and chemical pollution from agricultural, industrial and municipal wastes.

4.1. SECTORIAL AQUATIC IMPACTS AND OPTIONS

4.11. Agriculture

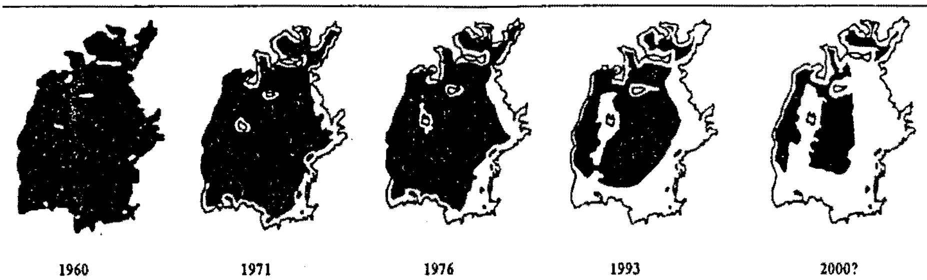
Of the Earth's surface in 1991, 1.4 billion hectares or 11% was used by cropland in 1991 and 3.4 billion hectares or 26% was in permanent pastureland, for an agricultural total of 37% (WRI 1994). More land is used for agriculture than for any other purpose and this land use has a significant impact on aquatic biodiversity. Impacts on aquatic biodiversity: aquatic turbidity; sedimentation; contributing to rapid runoff and flooding; algal blooms from nutrient runoff; increased mortality and reproductive and developmental abnormalities from pesticide runoff (Colborn et at 1996). Water withdrawal for irrigation reduces living space for aquatic organisms. Intense cultivation and grazing in the Loess Plateau of China causes heavy erosion, loading the Yellow River with 1.6 billion tonnes of sediment and making it unsuitable for most biological processes (Heywood 1995). Removal or degradation of natural stream-side vegetation to plant crops or as a result of cattle access to streams can adversely affect water quality (Arthington and Welcomme 1995). The ditching to speed spring runoff and drainage of wetlands, construction of small-scale dikes and dams for irrigation purposes are also important impacts of agriculture.

Fig. 11. Bare soil is bared at intervals on much of the Earth's 1.4 billion acres of cropland. Runoff from this soil exposes streams to turbidity and siltation, pesticides and chemical fertilizers. Drawing by Roelof Idema.

The nutrient levels in lakes and streams are elevated by runoff or discharge from croplands, livestock areas, municipalities, and other sources. This contrasts with natural ecosystems where nutrients are tenuously recycled and much is banked in living organisms (Schueler 1989), e.g. in a Maryland experimental watershed, cropland released 92% of nitrogen and 59% of phosphate inputs, while riparian forests maintained most of their inputs, releasing only 11% and 20%, respectively (Heywood 1995). The health of ecosystems can be measured by the percent retention and loss of nutrients above that found in precipitation. Schueler (1989) proposes that an ombrotrophy or nutrient retention index can be computed based on the major nutrients, nitrogen, phosphorus and potassium in precipitation and stream flow, as a measure of health of landscapes including aquatic ecosystems.

The Swiss have restored their mountain waters to more pristine conditions from lakes and streams which smelled, killed fishes and suffered from overgrowth of algae. The program included education; subsidizing a switch to organic food production; banning all phosphates; taxing garbage and fining evaders; and treating sewage. Fish and otters are now returning; water in every lake is now potable (Grant 1997).

Few agricultural impacts on freshwater are so extreme as those in the Aral Sea basin. The Aral Sea, fed by the Amu Darya and Syr Darya rivers, was the fourth largest inland body of water, ranking just behind Lake Superior. Its slightly saline waters, with 8-9 parts per thousand (PPT) salinity, was home to 24 species of fishes and provided livelihood for 10,000 fishers. To grow cotton on 2.5 million hectares of new farmland, an immense irrigation system was built, diverting water from the rivers. Most of the canals and ditches of the irrigation system were constructed through permeable ground or sand, without waterproof lining. This meant much of the diverted water was lost to irrigation. Heavy applications of pesticides and fertilizers contaminated remaining flows.



'revious and predicted dessication of the Aral Sea. *Reprinted from Karakalpakstan Environmental :enter's informational booklet.*

Fig. 12. Shrinkage of the Aral Sea following diversion of its tributary rivers to irrigate cotton fields. The Aral Sea has shrunk to 25% of its 1960 volume, the salinity has risen four-fold, and its waters are highly polluted, leading to extirpation of most of the fish species and the demise of a fishery that employed 60,000 fishers. (Maps from Karalalpakstan Environmental Center's information booklet.)

The consequence of these activities has meant that no living rivers are connected to the sea, the sea itself has only about 25% of its 1960 volume (see Fig. 12), its salinity has reached at least 40 PPT (higher than the ocean), and the fishery is dead. Studies and discussions under the former Soviet Union and subsequently between Uzbekistan and Turkmenistan have not yet resolved the issues. The United Nations Environment Programme, the World Bank, the United Nations Development Programme and others have provided assistance to address human and environmental health issues. The Aral Sea International Committee (ASIC) involving Americans and activists of the five Central Asian nations in the Aral basin are assisting NGOs of Central Asia to bring about reform of land and water use in the Amu Darya and Syr Darya river basins. (The above material on the Aral Sea basin was drawn from Reznichenko 1992; Heywood 1995; and materials supplied by William T. Davoren of ASIC).

> In late 1986 President Soeharto took a bold step and instituted a number of landmark ecological measures, the most radical of which was the ban on the use of 57 varieties of organophosphate chemicals on rice. (Whitten *et al* 1996).

High-input agriculture is a global aquatic ecosystem problem. One example can suffice. Consumption of fertilizers in Latin America and the Caribbean increased by approximately 97% between 1973 and 1985, contributing substantially to the eutrophication of freshwater ecosystems, resulting in increased biological oxygen demand and algal growth (Pringle and Scatena 1997.1). Pesticide imports have increased by nearly half between 1971-73 and 1983-85. Chemical substances are often employed that are restricted or no longer permitted in countries with more stringent environmental legislation, e.g. the dibromochlorpropane (DBCP) and DDT (Pringle and Scatena 1997.1). FAO estimates that there are more than 100,000 tonnes of obsolete pesticides in developing countries, at risk because they have deteriorated through prolonged storage, or have been banned while in storage (Wodageneh 1997). The stocks include large amounts of highly persistent organochlorine compounds such as DDT, dieldrin and HCH, as well as highly toxic organophos-phorous compounds. Sound disposal systems are lacking in most developing countries.

In Canada virtually no agro-chemical problem were perceived by Harker (1997), who, in a Agriculture and Agri-Food Canada report on non-point agricultural effects on water quality, wrote, "Within the context of the Canadian Water Quality Guidelines, we find no clear evidence on the prairies of the *wide-spread* contamination of surface and ground waters from agricultural activities." But also see views in SOE (1996).

Bio-remediation is an expanding methodology for decontamination of water bodies. One example, the yellow-flowered aquatic iris, *Iris pseudacorus* of Europe, Asia Minor and North Africa, has been found by Rob McKinlay and Charlie

Kasperek of the Scottish Agricultural College, Edinburgh, to help detoxify the broad-spectrum herbicide, atrizine, and the organophosphate pesticides (*Equinox* magazine 16(93): 15, July 1997). Most of the decontamination is carried out by microbes in the plants' exceptionally hardy root systems.

Many traditional practices work with nature, use water or nutrients efficiently, instead of working uphill against ecological principles. For 50 centuries the Egyptians took advantage of the natural flooding of the Nile to water crops and nourish them with nutrient-laden silt. That is sustainability. Elsewhere, terracing, capture of runoff from slopes, micro-catchments, multi-cropping, qanats — groundwater tunnels, and many other small-scale watering and soil retention systems have made traditional agriculture sustainable while keeping neighbouring aquatic ecosystems healthy (McCully 1996). The terraced rice paddies of northern Philippines have sustained cultivation on hill slopes for 2,000 years; unfortunately the new generation is losing the requisite traditional knowledge.

Options: Use more seed varieties and within fields use genetically variable seed and polyculture — different crops in fields (reducing need for pesticides), agro-forestry — mix crops and trees, and other measures to reduce/eliminate pesticide input; switch to organic from chemical fertilizer use; reduce bare soil exposure and tillage; use terracing on slopes or keep slopes in permanent natural vegetation. Maintain permanent riparian vegetation and exclude cattle, to reduce stream pollution (Watson *et al* 1996) and sedimentation. Take into account the hydrological impacts of agriculture (McAllister 1993), as agriculture is the biggest global user of water. Making irrigation more efficient is a top priority in making water use sustainable (Postel 1993). Water-efficient drip irrigation is employed in less than one percent of the world's irrigated area. As much as 10%-50% could be saved, increasing the water volume available for aquatic ecosystems. Find methods for effective disposal of obsolete pesticides.

Reduce use of heavy machinery, increase soil humus levels and enhance soil biota levels to increase soil porosity and foster penetration and retention of water in the soil at the same time as decreasing erosion and flooding (McAllister 1993). Half a million acres in some 15 countries is now irrigated with municipal wastewater, reducing fertilizer demand and water pollution; this necessitates keeping sewage free of harmful substances. In the future, wastewater may well represent the predominant long-term water supply for irrigated agriculture in water-scarce countries; this can free-up water for other uses including the restoration of natural ecosystems (UN 1997).

In Yahagi, near the industrial city of Toyota, there is an exceptionally clean river. Its condition is the result of a twenty-year effort. Farm runoff had badly polluted the river, with a major impact on the fish. So a coalition of fishermen and farmers formed to elect a person to visit all of the discharges into the catchment. Now the river is a model. Suzuki and Oiwa, 1996. ***The Japan we never knew.***

4.12. Forestry

Soil erosion from clearcutting increases turbidity and sedimentation, and rapid runoff; influences the hydrological cycle; induces thermal changes; reduces spawning and rearing habitat. In river basins, removal of stream-side trees eliminates the food source for tropical fructivorous migratory species, and in boreal and tropical regions disrupts the aquatic food chains based on forest leaves and insects, and weakens stream banks held together by a mesh of tree roots. Most of the energy in food chains of small streams is from leaf fall. Hartman and Scrivener (1990) described the complexity of changes, over periods of up to 17 years, following logging of boreal rainforest, changes that were still continuing when the project was closed down.

Maser and Sedell (19940 describe the ecology of wood in streams, rivers, estuaries, and oceans. Woody debris or large organic debris (LOD) is one of the most consistent features of undisturbed streams in temperate rain forests (Hartman and Scrivener 1990) and provides key habitat for invertebrates and fishes. They state that if rotational clearcut harvesting is used as frequently as every 80 years, that LOD will be absent for essentially all time. Lehtinen, Mundahl and Madejczyk (1997) showed that woody snags were important as foraging and shelter in large rivers, not just in small rivers and streams.

The Mekong River system provides the ultimate example of the impacts of deforestation which have resulted in increased runoff, soil erosion, and river lake and swamp siltation, threatening river fisheries and the existence of the Great Lake in Kampuchea, one of the world's most productive fisheries (Arthington and Welcomme 1995). At least 80 percent and perhaps as much as 90 percent of Madagascar's forests are gone (McNeeley *et al* 1990). The freshwater fauna of Madagascar is not rich, but nevertheless contains a considerable proportion of endemics and isolated taxonomic lineages (Banarescu 1992). Deforestation puts at risk Madagascar's river ecosystems, freshwater invertebrates and 75 freshwater fish species. Over 80% of Madagascar's endemic ichthyofauna is restricted to freshwater and of these about 60% were once found int he rivers of eastern coastal forests, precisely the remaining forests which are undergoing the most extensive degradation - many of the species once recorded as abundant are no longer to be found at all (Stiassny and Raminosoa 1994; Stiassny 1997).

In Latin America the most serious non-point source pollution is runoff of sediment, nutrients and pesticides from deforested land and storm water flows from urban areas (Pringle and Scatena 1997.1).

Ives and Messerli (1989) caution about the reliability of data and premature conclusions are sometime drawn concerning deforestation, soil erosion and downstream destruction. Long term studies conducted by Gordon F. Hartman and colleagues on the Carnation Creek basin on Vancouver Island, related the effects of forestry practices on stream ecology (Hartman 1981).

Paper is one of the important products of the forest industry. Amongst many other effects of paper production there has been considerable discussion about the use of chlorine compounds in paper manufacturing and bleaching. There has been a large investment by the paper industry in Canada and other countries in cleaning up these and other effluents. However, only about 20% of North American paper mills have added oxygen delignification (MillWatch 1997). A new environmental concern about paper manufacturing is genetic damage. A study involving Michae Eastman of International Broodstock Technologies, George Kryzynski, Igor Solar and Helen Dye, scientists at the West Vancouver lab of the Department of Fisheries and Oceans, West Vancouver suggests that young chinook salmon, *Oncorhychus tshawytscha*, are genetically damaged when exposed for 30 days to low levels of supposedly non-toxic pulp-mill effluents routinely released into the upper Fraser River near Prince George, the DNA being altered (*Ottawa Citizen*, 14 June 1997, p. A3; February 1997, *Water Science and Technology*). Which of the many compounds in the effluent responsible for the genetic change, is unknown. Easton suggests that testing for genetic impacts should become a standard part of environmental monitoring.

Eco-forestry principles, approaches, examples, and certification, are described by Drengson and Taylor(1997), while Mallet (1997) provides a practical manual of analog forestry for rural communities.

Options: Selective logging or small-patch or narrow contour strip cutting; use of natural regeneration or use of native pest-resistant species where replanting needed; retain trees on steep slopes and stream banks to reduce erosion; and keep harvests within long term regeneration capacity. Take into account the hydrological impacts of forestry. The wider use of solar cookers and solar water heaters, in countries with suitable climates, and the use of more efficient wood stoves can help reduce deforestation spurred by cutting for firewood.

4.13. Hydroelectric and other dams

Dams are constructed for hydroelectric power generation, to provide water for irrigation and for "flood control". By the late 1980s a volume of more than 5,000 km^3 of fresh water was impounded by **large** dams, and 7,500 km^3 will be impounded by the year 2000 (WRI 1994); more than 60% of the world's stream flow will be regulated and many rivers will be reduced to cascades of man-made lakes (Atherington and Welcomme 1995). But large and small reservoirs already have the estimated combined storage of as much as 10,000 km^3 — five times the volume of all the rivers in the world.

Fig. 13. Flooded forest in the Mekong River, Stung Treng Province, Cambodia. Seasonally flooded forests are key habitats in Asia, Africa, South America, that help sustain biodiverse important fisheries that provide dietary protein, at risk when dams are constructed. Photo by Kenneth MacKay.

Worldwide as of 1988 there were 39,000 large dams 15 m or more high (WRI 1994); and more than 100 dams with heights greater than 150 meters, holding 6,000 km^3 (Heywood 1995). Although the overall rate of dam construction is declining, there is a trend towards much larger structures; there are presently more than 28 dams over 200 m high and as many are planned or under const-ruction. In China 90,000 dams were built between 1950 and 1980 (Lean *et al* 1990), and the continental U.S. has 75,000 'sizable' dams, leaving only 2% of the country's 5.1 million km of rivers free-flowing (Myers 1997.1). Of 30,000 rivers in Japan only two have not been either dammed or modified in any way — many are straightened and their banks are lined concrete and rock (Suzuki and Oiwa 1996). The water held in reservoirs has increased more than twenty-fold since 1945; nonetheless, most large rivers systems in Latin America remain unregulated (Pringle and Scatena 1997.1). The Amazon and Orinoco rivers so far lack main-stem dams, though barrages have been placed across some tributaries (Atherinington and Welcomme 1995) and Brazilian hydroelectric planners have 80 dam projects under consideration (Allan and Flecker 1993). Unregulated rivers in Latin America offer a significant opportunity for conservation in this area compared to southern Asia. But this scarcely applies to Mexico, an arid area with high demands for irrigation.

More than 400,000 km^2 have been inundated by reservoirs world wide. Proponents often justify dam/levee construction by arguing that they control flooding. Experience with some river systems, such as the Mississippi, does not validate that postulate.

If the world's dams from small to large total 250,000 and if downstream effects reach, on the average, 100 km, then globally dams impact some 25 million km of river. Egypt's Aswan Dam has serious impacts over 1,000 km downstream, where the delta and its fisheries are shrinking from lack of sediments and nutrients. The construction of the W.A.C. Bennett dam in British Columbia, Canada disrupted the annual flooding of the Athabaska-Peace Delta, 1,200 km downstream, causing conversion of 25% of its wet grasslands to forest habitats (SOE 1991, p. 3-15; Searle 1997).

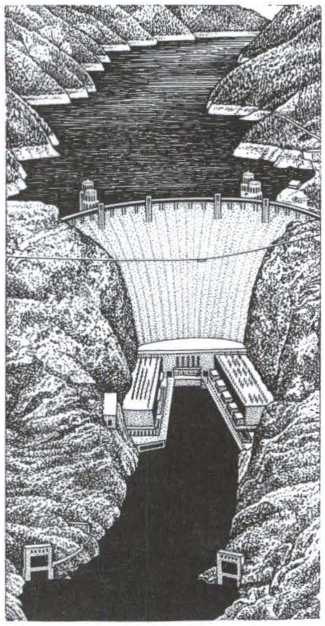


Fig. 14. Worldwide there are more than 40,000 large dams 15 m or more high, and more than 100 m high holding more than 6,000 cubic km of water, and affecting millions of km of downstream plus some upstream ecology, & fragmenting habitat. Drawing by Roelof Idema.

The complete harnessing of mid-European rivers, such as the Danube, Rhine, and Rhône, has led to an overall severe reduction of the species diversity and population dynamics, and the selection of the same small set of resistant species, whatever the initial diversity of different fish communities (Persat, Olivier and Bravard 1995). Degradation can promote weed species.

In Australia studies have shown that river regulation is connected with reduced populations of crayfish, mussels and snails (Gherke *et al* 1995). Gherke *et al*'s study showed that with increasing regulation with weirs and dams in the Murray-Darling river system that the populations of native fish species declined in distribution and abundance. The degree of regulation in reservoirs was measured using the Annual Proportional Flow Deviation (Gherke *et al* 1995, modified in *pers. comm.*). Increasingly, regulated catchments (reservoirs) had reduced species diversity. A lower diversity index in regulated catchments was due to the overwhelming abundance of an exotic species, carp (*Cyprinus carpio*) — desynchronizing environmental and reproductive cycles of native fishes favors the exotics.

At present, about 15% of the world's precipitation on land (after allowing for evaporation) is held in reservoirs of large dams (Stiassny 1996.1). The damming means transformation of running to still water ecosystems; fragmentation of habitats; changes in seasonal flow and temperature cycles; changes in turbidity and sedimentation patterns; barriers to adult migration and fry movement; and release of mercury into the food chain from submerged soils.

Although human fears of floods are often used to argue for dam construction, flooding is a natural phenomenon in many rivers. Fish yields are 1.5 to 4 times greater in natural river-flood plain systems than in equivalent systems with dams and other human interventions (Watson *et al* 1996). And flooding onto plains may trigger or sustain key life history events such as spawning or feeding. Abramovitz (1996.1) suggests that places like the Mekong and Amazon, where there are no dams, offer chances to avoid the costly mistakes made elsewhere. The basis for flood control functions of such dams is weak; the local people, economies, and the fishes are adapted to the normal seasonal flooding. Some 52 million people depend on the Mekong for their food and livelihood. Economic sectors involved in construction or use of electricity favor the development of the Mekong dam network.

Williams and Davis (1996) indicate that floods are necessary in northern rivers ecosystems systems too. Floods may remove sediments from spawning areas, introduce woody debris into stream channels and scour new pool habitats. Restoration of the natural flow regime in the Missouri, they believe, is the key to the rejuvenation of fish and flood plain plant communities in that system.

The rationale for construction of a dam or diversion often ignores flood-plain benefits. Estimates were made for the Kano River Irrigation Project in Nigeria of the irrigation benefits, US$ 0.03-0.04 per 1000 m^3 of annual flood water into wetlands and the flood-plain benefits, US$9.60-14.50 per 1000 m^3 of irrigation water use (Barbier 1996).

Another factor often neglected in water management is evaporation. Evaporative loss from a water body can be increased by high temperatures, high wind speeds and low humidity upwind. Annually, about 10% of the water stored behind the High Aswan Dam evaporates (McCully 1996). In 1989 Canada entered a 100-year agreement with the United States for water supply and flood control in the Souris River Basin, a basin shared by the two countries. Canada was committed to store flood waters and deliver to the U.S. 50% (40% in some wet years) of the natural flow (Gamble 1991). Yet evaporation was not taken into consideration by Canada. For the Rafferty Reservoir subsequent calculations showed about one-half the annual flows would evaporate. This meant much of the Canadian share, including that for aquatic ecosystems, would be lost. Clearly evaporation must be taken into account when planning reservoirs. Long term agreements, like the Souris Basin accord, should consider the effects of climate change which may further reduce available water.

According to McCully (1996) the diversity of fish species in almost all river areas flooded by reservoirs will drop. Welcomme (1995) states that in impounded rivers that many elements of the original riverine faunas disappear soon after the change from lentic to lotic conditions. Most severely affected are migratory species and those requiring flood plains for reproduction and shelter. In the Itaipu reservoir the number of fish species fell 27% from the original 113, following closure of the dam. Miller, Williams and Williams (1989) described the extinction of Amistad Gambusia (*Gambusia amistadensis*) and several other North American freshwater species to which dam construction contributed. Reservoirs with frequent draw-downs may inordinately stress shallow spawning species (Ryder and Scott 1994).

Populations of migratory fish in dammed rivers commonly diminish. The annual run of adult Pacific salmon and steelhead in the Columbia River, U.S.A. has fallen to 1.5 million from 10-16 million fishes before European settlement (McCully 1996). The cost of fisheries losses due to dams for the period 1960 to 1980 was $6.5 billion. This has also lead to increasing competition for stocks in the neighbouring Fraser River, encumbered with few dams. Clearly a number of such externalities should be computed in cost-benefit analyses for planning dams.

Fish catches in new reservoirs usually go through a "boom and bust" cycle (Welcomme 1995). Catches initially increase as nutrient levels rise from decomposition of vegetation and newly inundated lands, only to fall to a more stable regime later. McCully (1996) also indicates that fish production in the impounded area and downstream will usually drop, following a spike in production following initial filling of the reservoir. The average yield per unit area of a tropical floodplain river is 2.5 to 4 time higher than in a reservoir. Calculations in impact assessments of dams should be based on the long term stable catches, rather than the spikes.

The decommissioning (ceasing electric generation or removal of the dam and restoration of the river), is beginning to be considered more and more as dam structures age, they fill up with sediment, or as environmental costs are perceived. Around the world some 5,000 dams are more than 50 years old; the average age of dams in the U.S. is around 40 years (McCully 1996). The 19 metre Grangeville Dam on the Clearwater River, Idaho, was dynamited in 1963 to restore salmon runs. U.S. President Clinton included $32.9 million in his 1998 budget to acquire two dams on the Elwha River, Washington and to begin the removal process, consistent with a law passed in 1992. It may very well be that there is now more opportunity for engineering firms in decommissioning dams, than in constructing new ones. A major challenge will lie in dealing with accumulated sediment.

Engineers, development planners and managers often lack the knowledge, skills and technology to create biodiversity-friendly projects for given goals. A workshop held at White Oak Plantation, Florida by the World Bank brought together 34 people from 14 countries representing a wide variety of disciplines, including engineers and biologists (Anonymous 1997.1). They recommended preparation of two products, a 16-page executive summary for decision makers and managers, and a longer and more technical manual for engineers and other professionals.

Environmentally friendly alternatives to hydroelectric power generation are becoming more and more viable, especially when one takes into account costs hitherto externalized. The World Bank India Alternate Energy project, begun in 1993, seeks to expand the use of environmentally-friendly electricity generation through expanded private sector investments in wind farms and solar photovoltaic systems. Seven wind farms with a capacity of 31MW are estimated to have avoided generation of over 50 million kg of CO^2. In Mexico that Bank has helped fund purchase of 2.4 million compact fluorescent light bulbs for two major cities, which will reduce power consumption.

The cost of photovoltaic systems has fallen from $600 per peak watt generated in the 1960s to approximately $5 per peak watt today (*Appropriate Technology* 22(2): 31, September 1995), still more than direct hydroelectric costs in most places served by power grids. But the external indirect costs of electric power generation should be included when making comparisons with alternate power sources, e.g. loss of farm and forest land, displacement of people, reduction in biodiversity of land ecosystems that will be permanently flooded and riverine species unadapted to reservoir conditions, and loss of delta replenishment.

Options: Construct fish passage structures for existing and new facilities adapted to needs of *local* migratory species; carry out freshwater biodiversity inventories and genetic collection before dam construction; repopulate affected areas using genetically diverse founder stocks. Before hydro dams are constructed, compare the economic benefits of power over the life span of the impoundment (dam impoundments silt up) to fisheries yields in perpetuity. Consider alternatives to hydro power, such as solar power generation, cooking and water heating (Flavin 1995). In river systems where flooding has increased due to human activities, then consider reforestation, protection of wetlands which serve as sponges, and changed agricultural practices and other options before constructing dams and levees. Data on the Mississippi River show that the 1973, 1982 and 1993 floods were substantially higher than they would have been before structural flood control (levees, dams and channelization) began in earnest (Abramovitz 1996.1). Consideration should be given, to removal of some existing dams. Proposals for construction of dams should include life-span and decommissioning cost estimates.

4.14. Inter-basin canals and diversions

Canals are constructed to facilitate boat transportation and to divert water between basins for hydroelectric power generation and other purposes. Canals and other inter-basin water diversions often permit the spread of exotic species or genotypes, including predators, competitors, parasites and diseases. For example, the sea lamprey, *Petromyzon marinus*, spread up the Welland Canal into the upper Great Lakes; canals threatened drainage of wetlands in the plans for the Hidrovia Project in South America.

Options: Carry out environmental impact studies to evaluate canal projects. Use electric fences or 'hot locks' of warm water, 40°C, to block or kill fishes moving between basins; regulate ballast water discharge.

4.15. Industry

Manufacturing, mining, power and other industries discharge toxic substances and oxygen consuming wastes and nutrients; withdraw water; cause thermal pollution; and release acid precipitation-generating, greenhouse and ozone depleting chemicals. Discussions of ways to ameliorate the problem by the International Joint Commission (IJC 1994), have been particularly useful. The IJC defines toxic substance as a substance which causes death, disease, behavioral abnormalities, cancer, genetic mutations (mutagens), physiological and reproductive malfunctions, or deformities (teratogens) in any organism, its offspring, or which can become poisonous after concentration in the food chain or in combination with other substances.

Industries use almost one quarter of the world's freshwater (Postel 1993). Lakes with long water residence times can be sensitive to stress by toxic chemicals. In the Great Lakes, for example, only one percent of the water flows out annually and toxic pollutants from previous decades tend to remain in the water column, the sediments, and the biota (Abramovitz 1996.1; residence times for individual lakes vary from 2.7 years for Lake Erie to 173 years for Lake Superior).

Direct toxicity/carcinogenicity/stress of chemicals in water is complicated by two other phenomena, bioaccumulation in individuals and biomagnification up the food chain (also see Impact Interaction section below). Either direct intake or bioaccumulated intake of some artificial persistent hormone disrupting chemicals such as PCBs, dioxins, atrazine, hexachlorobenzine, as well as other organochlorines and PAHs (polycyclic aromatic hydrocarbons). These may effect development of embryos which are, at certain stages of development, are sensitive to very low concentrations of endocrine disrupters such as xeno-estrogens (Colborn *et al* 1996; EPA 1997) and other chemicals. The EPA study is based on 300 peer-reviewed studies evaluated by their scientists who found compelling evidence that endocrine systems of certain fish and wildlife have been disturbed by chemicals that contaminate their habitats and that endocrine-disrupting chemical have caused "significant population declines" in some species. It may be worth studying whether the 10% toxicity-based reduction in marine production estimated by Patin (1995) should be applied to freshwater production. Patin suggests the threshold levels are being reached in some freshwater Russian ecosystems. Levels of estrogen, testosterone and vitellogenin (an estrogen-controlled protein necessary for egg development) may be affected by contaminants in some U.S. streams, which may impair reproduction (USGS 1997).

Canada has developed a toxic substances management policy (Environment Canada 1997) based on scientific assessment. The management objectives are: 1) virtual elimination from the environment of toxic substances that result predominantly from human activity and that are persistent and bioaccumulative; 2) the management of other toxic substances and substances of concern throughout their entire life cycles, to prevent and minimize their release into the environment. The preliminary list of substances which could be potential candidates for virtual elimination include Aldrin, chlordane, DDT (+DDD + DDE), dieldrin, heptachlor, HCB, Mirex, PCBs, polychlorinated dibenzodioxins and dibenzofurans.

Another phenomenon magnifies chemical concentrations geographically, instead of in organs, or up food chains. Slightly volatile but persistent toxic chemical are transported in gaseous form by winds. When they meet cold temperatures they condense out on the Earth's surface (water or land), or on to solid particles in the air which are then deposited, often as rain or snow (Wania and Mackay 1997).. This condensation process, which one could call geomagnification, tends to concentrate these chemicals in polar regions, such as the Arctic. Transported toxic chemicals include PCBs, pesticides such as DDT, lindane, toxaphene, and α-HCH. Subsequently geomagnified chemicals may biomagnify in the cool condensing area. The contamination can effect fish, birds, marine mammals and, of course, humans — in some cases indigenous peoples or rural populations who rely on wildlife for food. The injustice is that those in warmer climates have mostly 'benefited' from the chemicals, while those who have not used them, in polar regions, receive the impacts.

Mines are sometimes sources of water pollution. The Canadian-owned Omai mine in Guyana suffered a catastrophic breach in its tailings pond in 1995, spilling 3.2 million litres of cyanide-contaminated effluent into the river. The Porgera gold mine in Papua New Guinea has no tailings system and has been dumping its tailings into the Strickland-Fly rivers sytem, leading to loss of fish, crocodiles, turtles and other river life. In placer mining operations it may not be chemicals but simply the turbidity and sedimentation that harms aquatic life. In Ireland 78% of peatlands have been lost: 55% to mining for fuel and electricity, 18% to blankets of conifer monocultures, and 5% into intensely eroded landscapes devoid of plant cover save for a few hardy grasses (IUCN Wetlands Programme 1996).

Monitoring pollution at ground level can be time consuming. Remote sensing offers an alternative. This can be used to monitor discharge of polluted water, thermal effluents, oil spills, sedimentation, vegetation changes. Ryerson (1997) discusses uses, benefits, limitations
and choices. The remote sensing can also be used to monitor changes in water levels above and below dams.

Options: Develop chemical-free processing where possible. Re-use and recycle persistent toxic chemicals, develop new uses for waste products, or better still develop environmentally friendly alternatives to persistent toxic chemicals, especially those which are volatile. Use 'waste' heat as an energy source. Re-cycle water for cooling and other non-contaminating uses. Charge industries the true water costs to encourage efficient use. Apply the Polluter Pays Principle (UN 1997). Legislate Right-to-Know laws like that of the U.S., empowering individuals or groups to summon details of toxic inventories and other records from companies that are storing, manufacturing or using such material and require Toxic Registry Inventories that require companies to file exact details of emissions of over 300 chemicals with an Environmental Protection Agency (Hazarika 1997). Publish names of polluters.

In particular, society must adopt a clear and comprehensive action plan to virtually eliminate persistent toxic substances that are threatening human health and the future of the Great Lakes ecosystem. A consensus-building process is required that will allow all sectors of society (including governments, business corporations and associations, labour unions and professional, consumer and other organizations) to join in making the decisions to effect the required economic and social transition. (IJC 1994).

4.16.

Municipalities

Release of human wastes with consequent eutrophication; discharge of aquatic and atmospheric pollutants; water withdrawal; rapid runoff from paved areas. Marine detritus has received big press, freshwater detritus much less. Yet significant amounts of benthic habitat now consists of metal cans, plastic objects, discarded equipment, etc. The crystal clear, sand-bottomed Walden Pond, site of naturalist, philosopher and author Henry David Thoreau's musings in the 1800s, recently needed cleaning of debris by dedicated divers. A long thread at the Fish-Ecology internet usegroup was devoted to reports of fishes like sturgeons, with rubber bands surrounding and cutting into their bodies. A campaign by the Ministère Environment et Faune for postal delivery persons in Quebec, Canada, to keep in their mail bag all rubber bands for mail delivery rather than throwing them away, was very effective in reducing from 8% to less than 0.5% the number of Atlantic sturgeons with rubber bands

Options: Give high priority to education about and enforcement of regulations against disposal of toxic chemicals into sewage or storm sewer systems. Minimally, construct sewage treatment plants. Optimally, produce safe organic fertilizers from treated sewage, use aquaculture ecosystems, or combined physical and Living Machine biological treatment of wastes to reduce nutrient output. Develop water economy programs. Meter and charge for water use. Increase awareness and education. Involve school classes in stream and beach clean-ups. Teach 'throwing it into the water' does not make it disappear.

4.17. Capture fisheries

Overfishing causes depletion of stocks or shifts in species balances. Causes of fisheries collapse are reviewed by McAllister (1994). Known extinctions of a species due to overfishing are rare; normally extinctions occur as a result of environmental and fishing pressures combined. The decline and extinction of the blue walleye, *Stizostedion vitreum glaucum,* in Lake Erie was probably directly related to over-exploitation by a largely unregulated commercial fishery (Campbell 1987) and overfishing contributed to the extinction of the deepwater cisco, *Coregonus* *johannae* and blackfin cisco, *Coregonus nigripinnis* (Ryder and Scott 1994). Fisheries bycatch depletes natural biodiversity. According to Dr. W.G. Franzin (*in litt.*) bycatch culling is as big a factor in inland as in marine fisheries; one of his students estimated that about 25-30% of the harvest on Lake Winnipeg was culled. But he points out that North Americans cull high value species more than people in other regions. Some fishing methods, trawls, explosives, and poisons destroy habitat and non-target species. Two-cycle boat engines release fuel and oil into the water. However, Shell has developed Nautilus,™ a synthetic biodegradable outboard oil which has less impact than other oils.

Sustainability deals with matters both great and small. When lead fishing weights are lost on the bottom they may be swallowed by ducks, geese and loons (McAllister 1992.2). Absorption of lead from the weight may kill the bird within 4 to 21 days. Use of bismuth, a non-toxic metal, for fishing weights will avoid this problem.

Fishing can also change the species balance. One example will suffice. In the Laurentian Great Lakes the commercial catch of native salmonids went from 82% of the total catch to 0.2% between 1900 and 1996 (Winter and Hughes 1997), influenced by fishing, predation by sea lampreys, and other factors. Larger individuals and species often disappear early in the overfishing process, shifting the community from large, predominantly K-selected species to small r-selected ones (Atherington and Welcomme 1995). BSAT (1994) state that fishing, in concert with other stresses, reduce "keystone species," often efficient terminal predators to trivial levels in the fishery. These predators, such as lake trout, ciscoes, blue walleye and deepwater sculpins, help retain the community at a steady state. This effect may be more prevalent in North America, where food and recreational fisheries are quite selective. In Europe, Japan and many developing country artisanal fisheries, a wider spectrum of fishes is sought and kept. The diverse fisheries approach is less disruptive of the food web.

Commercial fisheries harvests have declined by at least 80% in the United States since the turn of the century (Karr, Fore and Chu 1997). In 1910 more than 2600 commercial mussel fishers operated in the Illinois River; virtually none remain today. Sturgeon fisheries in Russia, once a source of great wealth, have been closed. These declines represent impacts of overfishing and habitat degradation. Consumption advisories are on the increase in the U.S. and Canada. Fishes that are not fit to eat are not themselves in good health.

Restoring wild salmon fisheries is more than techno-fixes and more than maximizing production for fisheries, according to Karr (1994). Hatcheries exacerbate declines in wild populations, and they waste money. He asserts that ecological restoration is needed - the best approach for protecting and restoring salmon is to maintain quality environment that permit salmon to fulfill their biological potential and maintain viable populations. His pithy comments are refreshing to read.

Karr (1996) indicated biotic integrity of a stream is degraded by human activity via five primary sets of variables:

- Water quality, including excess nutrients, suspended solids, various pollutants;
- Habitat structure, including the physical structure of the stream channel and near channel environment;
- Flow regime, including effects of irrigation or channelization [and we might add dams];
- Energy sources, including excessive anthropogenic input, yet retaining natural inputs like leaves in small streams; and
- Biotic interactions, maintaining natural levels of competition, predation and mutualism, while preventing introduction of exotics or overharvesting.

The ornamental capture fisheries probably have low to moderate impact on species rarity, though local populations can be depleted. Efforts are being made by Dr. Ning Labbish Chao, Bio-Amazonica Conservation International, to make the ornamental fishery in the Rio Negro, Brazil, sustainable (Chao 1996). Few of the species on the IUCN Red List are of interest to the ornamental trade (Andrews 1990).

More ornamental species are being bred on fish farms, including the threatened Indonesian Asian bonytongue, *Scleropages formosus*. The Aquatic Conservation Network links hobbyists and scientists to breed freshwater species at risk and public aquaria are active in captive breeding programs (Andrews and Kaufman 1994). As in all captive breeding programs, there needs to be links to maintaining or restoring the wild habitats so that the species can be re-established in its natural environment.

Probably one of the greatest risks that the ornamental fish trade poses is the release, intentional or accidental, of exotic species or stocks (Andrews 1990; Moyle 1996). Since over one-third of freshwater fish species appear in the trade, the threat is not inconsiderable. Perhaps a dozen ornamental species have been introduced into Mexico (pers. comm. Dr. Salvador Contreras-Baldas, several successfully, and there are numerous freshwater ornamentals established in Florida. The African cichlid, *Oreochromis mossambicus*, has established breeding populations in a variety of water bodies in Queensland and Western Australian river systems (Arthington and Blüdorn 1994). The origin of all introduced stocks is the aquarium trade, including escape from culture facilities, disposal of aquarium fish, escape of fish from ponds during flooding, and possibly deliberate but unauthorized releases. Such introductions have long been a concern to fisheries scientists and conservationists in Australia because of the vulnerability of Australia's unique but species-poor fauna. Australia is also concerned about the importation of aquarium fishes because exotic diseases have already been introduced and parasites might be introduced (Arthington and Blüdorn 1994). Over half of the introduced freshwater fishes in Australia are aquarium fishes (Arthinton 1991).

Andrews (1990) noted that few of the profits generated from the ornamental fish trade are used to provide significant support for conservation activities. However some support is beginning to come from organizations like Ornamental Fish International.

For discussion of capture food fisheries management, see the Resource Management section below.

The introduction of exotic species for food, sport, forage, etc. affects native species and ecosystems. Whittier *et al.* (1997) demonstrated that in lakes in northeastern United States that the number of minnow species (Cyprinidae) was most consistently related to the presence or absence of presence of littoral fish predators. The median number of minnow species in lakes lacking predators was two while zero in lakes with predators. Non-native predators, especially bass of the genus *Micropterus*, have been introduced throughout the Northeast where 69% of the 195 sampled lakes had non-native predators. In lakes where minnows survived with littoral predators, the minnow abundance tended to be suppressed. This indicates that plans considering introduction of predators into lakes as a fisheries enhancement should take into account their potential impact on species which are their prey.

The value of artificial habitats or "fish attractants," created by dumping tires, cars, Christmas trees, etc. into water, has been debated. Some argue that these structures do not produce more fish, but simply concentrate them. Others maintain that the shelter protects the fishes or their young from predators in otherwise barren environments like reservoirs and that Christmas trees may substitute for woody habitat in basins now divested of trees. Some anglers feel that the artificial habitat draws fish, making them easier to locate.

Options: Develop eco-fisheries approaches to management where drainage basins, habitats, and food webs as well as stocks are conserved. Follow the FAO Code for Responsible Fishing (FAO 1995.2), including development/use of gear with low bycatch and habitat impacts. Consider employing sustainable indigenous or other traditional approaches to fishing (Johannes 1981; McGoodwin 1990), e.g.

use of *sasi* principles in Indonesia (Kissya 1995; *sasi* is a traditional Indonesian way of managing fisheries resources); acadja brush parks used by African artisanal fishers (Bernacsek 1987). Utilize participatory planning, community-based management, and TURFs (territorial user rights in fisheries (Spiller 1997). Implement ICES guidelines on species introductions and transfers into national and international legal instruments. Periodic "fallowing" closures of fishing grounds can serve to allow recovery of stocks, forage and habitat. Chao and Prada-Pedreros (1995) suggest that pulse fishing, where fishing areas are periodically left fallow, may be suitable for freshwater aquarium fisheries. The same approach has been suggested for slow growing Arctic charr (*Salvelinus alpinus*) populations in northern Canada.

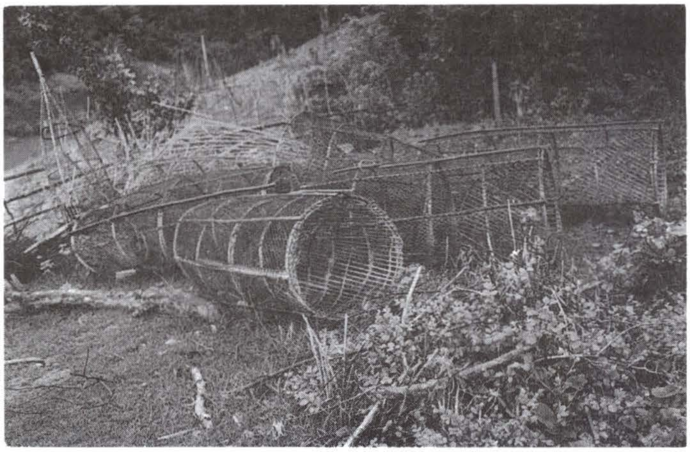


Fig. 15. Bamboo fish traps from Champasak Province in Laos. Some non-mobile traditional fishing gear does not affect habitat, and bycatches can be released alive from them, if the traps are checked regularly. Photo by Kenneth MacKay.

4.18. Aquaculture & exotic introductions

Aquaculture

Modern monocultural aquaculture has been impressively productive. But it has the same narrow underpinnings as modern industrial agriculture, and so is subject to the same predicaments. Those weak underpinnings include genetic uniformity, use of few species (often exotic), crowded conditions, and high external inputs. Pullin (1994.1) estimates that 95% of pisciculture is based on 105 species of finfishes. Consequences include escape of exotic species into the wild or genetic contamination of local stocks, spread of diseases or parasites, and environmental pollution from waste food or aquaculture chemicals. Little use is made of ecosystem models for primary production and recycling of nutrients. Construction of aquaculture ponds may destroy natural ecosystems.

Cultured organisms can have significant effects as disease or parasite vectors. Philipps (1995) described the introduction of the *Gyrodactylus* parasite into none-resistant Norwegian populations of Atlantic salmon (*Salmo salar*) from aquacultured Baltic Sea fish. The introduction resulted in the decimation or extirpation of native salmon populations in 35 river systems.

The use of chemicals to control fouling of fish pens, fish lice or other pests, may pose a problem, because of their toxicity, to species in the adjacent environment. Additionally aquaculture pests may be expected to build up resistance to pesticides, just as they have done in agriculture. In Scotland dichlorvos (a toxic organophosphorus pesticide), then marketed as Nuvan, later as Aquagard, was discharged into the aquatic environment as a sea lice treatment for salmon (Ross 1997). Within five years the prolonged and widespread use rendered it increasingly ineffective as the sea lice developed resistance to it.

Aquaculture provides protein food but not biodiversity or ecological functions. When aquaculture begins to or promises delivery of significant amounts of protein, then decision makers may give lower priority to maintaining or restoring natural aquatic ecosystems. Thus an indirect effect of successful aquaculture may be loss of biodiversity and eco-services.

Thousands of shrimp aquaculture ponds have been abandoned (Stevenson and Burbridge 1997) due to declining environmental quality, prevalence of diseases, release of acid, aluminum and iron from soils, pond failure, poor farming practices, etc. This leaves 3 options: rehabilitate for shrimp; rehabilitate for other uses such as salt production; or restore the area to productive mangrove systems. The latter offers the promise of restoring the environmental, economic and social benefits provided by mangroves, including coastal protection.

Options: Learn lessons from terrestrial agriculture. Develop eco-aquaculture. Use polyculture, fish-rice (Brummett 1995; de la Cruz *et al* 1992; MacKay 1995) and other combinations of aqua-agriculture, and avoid destruction of natural ecosystems. Promote culture systems that ensure containment of exotics, or culture of sterile exotics, but Courtenay and Williams (1992, p. 52) state that experience shows that *all* cultivated aquatic organisms eventually escape. Consider adopting the ICES Protocols and Codes of Practice for quarantine, transfer and introduction of stocks for transplanting in the wild and for aquaculture. Better yet, identify and utilize local stocks of suitable endemic species.

Research is needed to identify alternatives to chemical methods of controlling pests. Costello (1994) reported on the potential of cleaner fishes. He used three species of wrasse to control sea lice on penned salmon in Europe.

Other exotic introductions

Exotic species may be introduced for a variety of other purposes, including for food, sport, forage, mosquito control, or as a means of dumping unwanted stock (aquatic plants, aquarium fishes), or by accident as in ballast water discharge. Effects include displacement or extinctions of native species and degradation of ecosystems through competition, predation, parasitism and diseases, and displacement of valued species in catches (Moyle 1996). The free-floating water hyacinth, *Eichhornia crassipe* and water fern, *Salvinia molesta,* impede water flow and transport on large areas of rivers and lakes, plug paddy fields and reduce fish yields (Atherington and Welcomme 1995). In a single growing season 25 plants produce two million offspring weighing up to 400 tonnes, enough to cover one hectare of water surface (Cook 1991). Styled by some 'the world's worst aquatic weed,' the water hyacinth has spread from its native range in the tropical lowlands of South America to Africa, Asia, Australia, and North America.

Sandlund, Schei and Viken (1996) provide a review of on the spread of alien species and their impacts. The chapter by Moyle in this review concludes:

> *"Unfortunately for the world's aquatic biota, sweeping new policies that would reduce introductions into aquatic systems are very difficult to implement. Exploding human populations and exploding demand for goods and services make effective regulation of introductions unlikely in many, if not most, parts of the world. As a consequence we are likely to see a continued homogenization of the world's freshwater and estuarine biotas, and an increased loss of the many goods and services that intact aquatic ecosystems can provide to humanity. Despite this bleak outlook, efforts at reducing biological invasions into aquatic ecosystems are still worthwhile, even if only a few major invasions are prevented."*

Kottelat and Whitten (1996) list introduced animals and plants known to have a deleterious effect on indigenous biodiversity. The degree to which exotics are influencing freshwater ecosystems can be appreciated from the fact that 139 non-indigenous aquatic organisms have become established in the Laurentian Great Lakes (Ryder and Scott 1994), mostly algae, macrophytes, molluscs and fishes.

In Australia 20 fish species (11% of indigenous ichthyofauna) have been introduced (Arthington 1991). Where exotic species like purple loosestrife and zebra mussels become dominant in aquatic ecosystems it is obvious that they are displacing indigenous biodiversity. Guan and Wiles (1997) reported that introduced western North American crayfish, *Pacifastacus leniusculus,* were displacing native fishes, bullhead (*Cottus gobio*) and stone loach (*Noemacheilus barbatulus*) from shelter in riffles of the River Great Ouse in the U.K. In addition the exotic crayfish preyed upon fishes. The Australian Red Claw shrimp has been introduced into New Caledonia where it is threatening some of the 400 endemic species of freshwater invertebrates (Mermoud Jacky, internet communication, 1 August 1997).

Bianco (1995) develops coefficients for human alteration of aquatic ecosystems and estimates that in Italy at least 65% of the original ichthyofauna was at least partly disturbed by transplantations and exotic introductions. Coates (1995) documents the process undertaken to evaluate fish introductions into the Sepik River Basin, New Guinea. Introductions into one country's portion of an international river basin may spread into a waters of neighbouring country.

The introduction of mosquitofish, *Gambusia affinis,* into springs and other restricted water basins with endemic species, has contributed to extinctions of freshwater fishes. Sport fishery and commercial fishery managers have introduced species to provide new sport fishes, to increase catches by filling a vacant niche, to provide forage for a desirable species, or to provide a harvestable species of high value.

According to Australia's CSIRO there is a need for national systems for detecting and responding to each new invasion occurs before it gets out of hand. New invaders are most vulnerable in the first statges of invasion when only a handful of colonists exists. New methods of control are needed that curb numbers even if not eradicating them - pesticides can't contain an outbreak in the sea as they sometimes do on land. Biological controls and genetic methods of sterilization (as were used to eliminate the screw worm fly on land), are needed, according to Dr. Dick Martin, CSIRO

Options: Develop and promote sustainable aquaculture which utilizes indigenous species, minimizes negative environmental impacts including lessening the destruction of habitat and runoff of harmful chemicals and antibiotics. Increase awareness of impacts of exotic species. Use native species when possible for aquaculture and fisheries. Develop methods of eliminating introductions from ballast water, and systems of early detection and control. Apply biological methods of control. Use ICES/EIFAC (International Council for Exploration of the Sea/ European Inland Fisheries Advisory Commission) Code of Practice and the American Fisheries Society position statements on fish introductions, or better yet write these principles into national legislation and international agreements. Consult with neighbouring states before making introductions into shared waterways.

4.19. Development

Development is a many-factored concept, some of which has been discussed above, e.g. municipalities, agriculture and industry. But it is possible to assemble them into one factor, development. In the minnow diversity study by Whittier *et al.* (1997) cited above under fisheries, the authors examined the effect of watershed -level human disturbance using principle components analyses and the number of minnow species. The first component used five variables, road density (often used as a measure of wilderness-development), % agricultural land, % forest, % urban land, and population density. The first component accounted for 62% of the variance, with all variables loading fairly evenly. This suggests that development as a whole affects minnow diversity and that effects of individual factors tend are cumulative.

Hammond (1997) described how watershed councils in Oregon helped achieve a healthier watershed with higher quality forage for ranchers and higher water quality and riparian ecosystems for agencies and environmental groups in Oregon. Problems involved wildlife and livestock competition, degradation of riparian vegetation, expansion of juniper coverage, drying up of springs, and competition for water resources.

Options: River basin management must consider impacts of new road networks and the consequent multi-sectoral development that follows.

4.2. LEGAL AND ECONOMIC FRAMEWORKS

4.21 Legal frameworks

Legal frameworks and instruments are needed at the international, regional, national and local levels, which can include water basin and ecosystem approaches, especially given the growing potential for conflict over access to water, leaving aquatic biodiversity either dry or exposed to toxins. Law is the primary mechanism that society has to defuse smouldering controversies and mediate disputes. Properly constructed the law can control and even prevent feuds (Karr 1995). The creation by democratic process of legal frameworks and instruments, and the revision of existing ones should be conducted input from scientific, economic, and other sectors. Section 6.1 reviews some of the principle international legal instruments.

Case studies in Puerto Rico and Costa Rica suggest that the formulation of adequate regulations and laws and, even more important, enforcement of laws and regulations that already exist, are key to maintaining water resources (Pringle and Scatena 1997.2).

At the international level, the International Convention on Biological Diversity, was a major step forward in looking at conservation and sustainable development in a holistic manner, and ensuring a broad open consultative process. The World Trade Organization (WTO), on the other hand, has treated trade as an isolated phenomenon, as if it was an island with no connections to the natural world and as if human carrying capacity were infinitely expandable (Rees 1996). WTO's negotiations include input from corporations, but not small businesses, citizens groups, scientific and environmental organizations, or indigenous peoples.

International legal instruments on trade, such as GATT, NAFTA, and MAI (Multilateral Agreement on Investment) need revision in terms of their fundamental philosophies and biases which favor investment and trade over biodiversity. In the rapidly approaching second Millenium, trade and investment agreements are too important to be negotiated solely by officials focussed on commerce. Market forces can deplete or extirpate populations or drive species to extinction, or cause degradation or loss of ecosystems. Negotiating positions and delegations should include biodiversity and biological resource management expertise, as well as small business-representatives, citizens, communities, and NGOs. According to Karr (1995) law should be a thoughtful integration of social, political, and scientific knowledge designed to protect individuals and society as a whole; to this should be added the conservation of biodiversity. Esty (1994) makes a number of forward-looking proposals about greening the GATT. There is wide public support for greening human activities.

In the 145 pages of MAI currently being drafted, there is only one short paragraph on environment, a paragraph that a few countries suggested was unnecessary . Trade and investment, and national, international and transnational corporations all have a powerful influence on the environment. How should that influence be moderated so the articles of the agreement and environmental decisions derived from it are benign?

If MAI is ratified, its application will have to take into account existing and widely supported international instruments like the International Convention on Biological Diversity (CBD), the Law of the Sea (LOS), and Montreal Protocol (MP). The CBD, LOS and MP instruments contain articles respecting the environment. So if trade or investment threatens biodiversity or biological resources, or the fair and equitable sharing of benefits derived from components of biodiversity, then parties may choose to use the CBD, LOS or MP, over MAI or WTO, to settle disputes. That the CBD, LOS, and MP were more openly negotiated, widely supported, and, unlike MAI, have a non-exclusive membership open to all countries, could encourage the use of these environmental instruments.

The International Joint Commission's Great Lakes Water Quality Agreement and other activities, have had a considerable degree of success in restoring and protecting the Great Lakes and their biota (IJC 1994). NAFTA's Council for Environmental Cooperation has already been active and NAFTA's environmental side bar has already been applied.

Options: Review existing trade, investment and other economic agreements which influence aquatic and terrestrial ecosystems, from global to local levels, so as to make the frameworks address serious freshwater and biodiversity issues. Ensure a broad perspective is not lost in serving the immediate human needs - namely that resource species live in healthy biotic communities. Apply the Biodiversity Convention and other environmental instruments to relevant aspects of international trade and investment.

4.22. Economic frameworks

Present financial mechanisms foster loss of biodiversity benefits. Two examples can be considered. Firstly, prices of goods and services do not reflect the costs of lost of biodiversity benefits. Those costs are externalized and passed on to citizens or their governments to remedy, while the manufacturers and producers receive an unfair public subsidies to their operations.

A second example is in national accounting. National accounts presently record financial indebtedness and loss of capital assets. But loss of biodiversity 'interest' (sustainable annual yields) and biodiversity 'indebtedness' (loss of biodiversity capital) is not recorded at all, or not as debits. The depletion of natural capital such as aquatic habitats, fisheries and forests, is currently treated as income. Loss of biodiversity benefits can be variously treated (Mosquin, Whiting and McAllister 1995, Chapter 6). For example lost species, stocks and genes, mostly irredeemable, should be considered capital losses. Severe reduction of stocks of long-living species, such as sturgeons, might be treated as capital losses, while others might be considered as (temporary) loss of revenue. Gross national products (GNP), gross domestic products (GDP) and global products (GP) should reflect biodiversity losses on the debit side of the leger. To do otherwise deceives the public and deprives political leaders of knowledge needed to govern effectively. Failing to respond to biodiversity losses may benefit one industry while penalizing another.

The IUCN Green Accounting Initiative will provide assistance on environmental accounting, encourage international organizations such as the World Bank to support environmental accounting and integrate it into their activities, and encourage the development of standard approaches to environmental accounting (Hecht 1997). Rees (1996) discusses carrying capacity and natural capital in relation to ecological economics. He asks whether the remaining stocks of natural capital are adequate to sustain the anticipated load of the human economy into the next century, based on the ecosystems areas required to support the economy. His approach shows that most so-called "advanced" countries are running massive unaccounted ecological deficits with the rest of the planet. Including costs of ecological structures and functions in accounts will be difficult, according to Rees, even where understanding of the process is clear. A better approach may be the use of ecological footprint analysis (see Box).

Ecological footprint: The corresponding area of productive land and aquatic ecosystems required to produce the resources used, and to assimilate the wastes produced, by a defined population at a specified material standard of living, wherever on Earth that land may be located (Rees 1996).

Options: Trade and investment instruments should be revised to take account of biodiversity and should be negotiated with top level environmental input. Prices of goods and services should include the environmental costs of production. National and global accounts could include biodiversity losses. GNP, GDP and GP should be modified to reflect biodiversity losses as decreases of national or global worth. These should include losses at the gene, species, ecosystem and ecological function level.

4.3. CROSS-SECTORIAL AQUATIC IMPACTS

Climate change and ozone reduction in the thin bubble of air around the planet are influenced by cross-sectorial human activities. Effects of these impacts are discussed by Everett (1995) and Watson *et al* (1996). Climate warming due to increase in greenhouse gas emissions can be expected to increase freshwater temperatures and evaporation, and to change precipitation levels. Over a 20-year period in northwestern Ontario, Canada, air and lake temperatures have already increased by 2°C and the lakes have remained ice-free for three weeks more each year. Thermoclines are deeper; man-made chemical concentrations have increased because of less precipitation and more evaporation; winds have increased; and water is more transparent. In northern latitudes precipitation may increase, permafrost areas may shrink, and some waters may become more turbid because of increased erosion.

Watson *et al* (1996) provides detailed projections of what climate change will do to hydrological systems including precipitation, magnitude and timing of runoff, intensity of floods and droughts, evapotranspiration, changes in turbidity, oxygen and carbon dioxide levels, mobilization and accumulations of contaminants like methyl mercury and pesticides, and thickness and duration of ice cover. The authors have a high level of confidence that climate change will influence freshwater ecosystems through altered flood regimes, water levels and availability, and in the extreme, cause water absence in stream beds and lake basins. Changes in water temperature and thermal structure can directly affect the survival, reproduction and growth of organisms, productivity, the persistence and diversity of species, and the regional distribution of biota. Changes will also alter the input of nutrients and dissolved organic carbon, and influence oxygen availability and the survival of certain organisms. One can expect that water level declines will be greatest in lakes and streams in dry evaporative basins; that effects of severe flood events will be more damaging in drier climates; that increased climate variability, such as floods and droughts, will have significant ecological effects, including the reduction of diversity. Assemblages of biota will tend to move poleward with warming, with range restrictions and local and global extinctions occurring at the lower latitudes of their distributions. Polar and montane species may become extinct as their habitat is "popped-off," while hypolimnion (deep cool-layer) lake species may be "squeezed-out" (McAllister and Dalton 1992).

Climate change is likely to cause extensive and complex perturbations in biodiversity, and not all the perturbations can be predicted with confidence. Further, the effects of climatic change on hydrology and biodiversity will be complicated by other anthropogenic non-climatic impacts such as river impoundment and regulation, land use, water removal, effluent return, and large-scale river diversions.

In 1996, Canada had its wettest year on record in the 49-year period since comparable data were kept (*Ottawa Citizen*, 23 January 1997, p. A3). Most precipitation came in extreme events, and weather-related insurance claims, including flood claims, are above the record set in 1991. Climate change is predicted to produce similar weather and river flow patterns. Extreme flooding can be expected to damage aquatic habitat, increase mortality of eggs, young and adults of animals and rooted aquatic vegetation.

Impacts of droughts should not be ignored — insufficient water, warm summer temperatures and winter freezing of benthic habitats can significantly impact aquatic biodiversity. The storage of water in lakes (where most of the surface water is found) can dampen the effects of short-term droughts. Rodionov (1995) indicates that during previous periods of climatic warming that the levels of the Laurentian Great Lakes and Caspian Sea have tended to fall. The diversity of shallower lakes will be less well protected from droughts.

The potential avenues to migration with climate change vary according to the nature of the water body and the locomotory capacity of the organism. Some aquatic populations or species, restricted to the cool hypolimnion of lakes, may become reduced or extinct as this cool bottom water layer shrinks or disappears. As temperatures increase, species in north-south or low-high altitude rivers may be able to adapt by movement to higher latitudes or altitudes (Everett 1995). Those species confined to east-west tending rivers, to a relatively small river basin, or those rivers with only slight changes in altitude may decrease in numbers or become extinct. Some insects with an aquatic larval stage and a winged adult stage would be better adapted to moving polewards with climate warming.

Ultra-violet B (UV-B) radiation can harm tissues and cause DNA damage in some species. These effects can be expected to increase in surface waters as the ozone layer thins. While less studied in fresh water, nevertheless it might be expected that small, poorly pigmented egg and larval stages in the neuston (thin surface layer of water bodies) or in shallow clear waters will be affected by UV-B increases. Those effects can be expected to be the greatest in fresh waters at higher latitudes, where holes in the ozone layer have been forming, and at higher altitudes.

Options: Reduce emissions of greenhouse gases and chemicals which weaken the ozone layer.. Introduce a broad ecosystem- or watershed-approach to management, involving all stakeholders. Monitor changes in temperatures of rivers, and in thickness of the epilimnion (upper warm layer) and hypolimnion (cool deep layer) of lakes. Identify fish species which would be put at risk by climate warming. As climate warms, transfer species, otherwise unable to migrate, to adjacent poleward water basins. Increase long term research and monitoring. Carry out research on sensitivity of freshwater biota at various life-cycle stages to UV-B radiation increases.

4.4. ROOT CAUSES

Root causes drive biodiversity loss. These causes fall into the political, social and biological spheres. As a result some biologists neglect root causes, choosing to deal with the consequences or symptoms. But even when root causes lie outside their sphere of responsibility, biologists need to be aware of root causes. Otherwise the effects of remedies proposed by biologists may be nullified by the driving forces. The increasing use of terms like Malthusian overfishing suggest that awareness of the root causes is increasing. Fisheries biologists, knowledgeable on the topics, may wish to provide their considered advice to decision makers, along with economists, sociologists, and others. Governments sometimes respond to clear descriptions of problems and to practical and imaginative solutions. The kind of management and licensing system that is recommended may well depend on whether human populations, adjacent to a water body, are stable or rapidly growing, whether they are poor and have few alternative livelihoods, and whether there is a powerful international developing market for a particular high-priced aquatic resource, such as beluga sturgeon caviar. Natural ecosystems no longer dwell in isolation from local and global demographic and market trends.

Addressing root causes raise a number of questions. When resources are at a minimum, what proportion of efforts should be directed to symptoms and what proportion to root causes? Which approach brings early results? Which approach is most cost effective? Root causes, often ignored, should be put on the table for open transparent discussions, establishing strategies and action plans. Some root causes were dealt with in the Canadian Biodiversity Strategy.

Human population growth: Most of the sectorial impacts discussed above increase with human population growth. The fact that population growth rates are exponential reduces the available response time for governments. At present rates the world's population will double in 43 years with 93% of the growth occurring in less well developed countries, increasing demand for fish catches at the same time that the status of aquatic fish stocks, habitat and biodiversity deteriorates.

About one-third of the world's population lives in countries that are experiencing moderate to high water stress partly from increasing demands from a growing population and human activities (UN 1997), despite the International Drinking Water Supply and Sanitation Decade, 1981-1990. By the year 2025, as much as two-thirds of the world population would be under water stress conditions (UN 1997). Over a billion people were estimated to be without access to safe water in 1994 and 3 billion were without adequate sanitation in developing countries. According to Eipper (1995), "Until we have at least stabilized the population, our efforts to manage fisheries are likely to be only stopgap measures." At the same time many national agencies have faced reductions in hydrological observing networks and staffing deficiencies at a time when water demand is rising rapidly in many countries and the need for sustainable water resources in becoming increasingly urgent (UN 1997). Obviously all these human uses affect aquatic biodiversity.

Options: Include population in the decision making process. Enhance efficiency of water use. Improve capacity to track water resources.

Water demands are so high that a number of large rivers decrease in volume as they flow downstream, with the result that downstream users face shortages, and ecosystems suffer, both in rivers and in adjacent coastal areas (UN 1997).

High per capita consumption: High rates of per capita consumption in developed countries, stimulated by market forces (see below) act to deplete and degrade biodiversity and resources.

Options: Foster styles of living that do not rely on high rates of consumption.

Reduce use, re-use, and recycle. Encourage methods of harvesting and fish preservation that minimize loss of the aquatic products. Support better communication capacity in communities adjacent to water bodies. Invest more disposable income in natural capital, e.g. reforestation and restoration of aquatic ecosystems.

Poverty: The poor consume or degrade biodiversity in order to survive, as opposed to others who may draw upon biodiversity to increase their wealth.

Options: Involve poor in decision making about their futures, strengthen their capacity to do so, provide support for developing more sustainable ways of securing food and livelihood. Help diversify the livelihoods in poor communities. Institute programs that increase global and national equity of income.

Market forces: Marketing can increase the demand for products and the capacity to deliver them globally, often to the detriment of the environment. Marketing pressures increase with prices. The depletion of sturgeons in the Caspian Sea has been accelerated because of the high price of caviar. Furthermore, a number of harvesting practices are both more detrimental to biodiversity and less profitable than the alternatives, e.g. the use of cyanide to capture live food and aquarium fishes.

According to French (1997) funds from public sources such as development banks have been largely supplanted by private investments during the 1990's. This calls for new policies by governments and international agencies to steer these funds towards environmentally sound enterprises. The flow of private money to the developing world has surged from $44 billion in 1990 to $244 billion in 1996, according to World Bank estimates. According to Hiliary, "The bulk of this investment is underwriting environmentally destructive forms of development, including mines, coal-fired power plants, and logging projects." These projects may be expected to impinge upon freshwater biodiversity. A glimmer of hope is given by a smaller sums being invested in green ventures.

In many countries the power structure effectively concentrates the vast majority of resources in the hands of a favored few, and leads to a desperate struggle among the dispossessed for the remaining resources (Dudgeon 1994). In some countries governments may be strongly influenced by the market system. Under the business-oriented Canadian governments, 1,500 jobs have been eliminated from the Department of the Environment and the Department of Fisheries and Oceans is losing 70% of its freshwater science budget , in the name of debt reduction and by nominally shifting responsibility to provinces. One province, Ontario, has cut the Ministry of Natural Resources budget by 50%, shut down 45 offices and privatized 15 provincial parks, while itself proposing to shift some environmental responsibilities to municipalities.

Globalization of trade is being promoted by some governments and the corporate sector. Whatever the economic benefits of globalization, there are biodiversity costs (Jenkins 1996). These include introduction of exotics, intentional and accidental, such as the zebra mussel (*Dreissena polymorpha*), Asian tiger mosquito (*Aedes albopictus*), purple loosestrife (*Lythrum salicaria*) , and Eurasian water milfoil (*Myriophyllum spictatum*). The transportation by ships and aircraft boats increases emissions of greenhouse gases. Already in 1991 over 4 billion tons of freight were exported by ship and by air, consuming 8.7 exajules of energy, as much as is used by the entire economies of Brazil, Turkey and the Philippines (Goldsmith 1996). The figure would be much larger if the world's trucking industry was included. Elevated international prices, such as that for Russian caviar, can foster unsustainable harvesting. The global economic system does not yet incorporate ecological economics. The planetary support services, present and future biological resources have to be considered as well as the corporate profit sheets. Decisions on the degree to globalize should be made on the basis of careful analyses of holistic cost-benefit sheets.

Options: Evaluate total cost/benfits of localize vs. globalize economies. Promote environmentally friendly and economically effective practices in the private sector, while educating the private sector and the public about the impacts of harmful practices. Encourage inclusion of ecology courses in business, engineering and political science faculties; provide seminars for today's decision makers in government and industry. Re-think how the environment should be managed in two/three tier federal states. Encourage eco-labelling so consumers can exercise their power of choice. Provide case studies to industry and government showing that green products are more competitive and profitable. Promote the hiring of environmental executives in corporations. Evaluate external costs of globalization.

Military activities

Military activities can impact powerfully on the environment, e.g. drainage of wetlands such as Shatt al Arab, aerial spraying of defoliants, and intentional oil spills. Mangroves in Vietnam have been found to be extremely susceptible to defoliants like Agent Orange (Orians and Pfeiffer 1985). Ease of access to explosives in the military often leads to their illegal use in fishing. Military expenditures reduce government funds available for environment, sustainable use of resources, and education. On the other hand military forces are a potential environmental resource. Canada's Green Plan promoted the idea of using Armed Forces to respond to environmental emergencies, natural or man-made. Armed forces recently helped alleviate flood damage along the Red River in Canada, and along the Oder River between Poland and Germany. Inactive armed forces can help reforest drainage basins and and commanders could reward environmental achievements with suitable decorations.

Options: Consider environmental peace dividends, reduce military aid and military technology promotion programs between countries. Follow the World Bank lead in preferential aid support to those countries with low military expenditures. Use existing military personnel to restore wetlands, reforest clearcut areas, etc. Recognize such achievements by the awarding of suitable decorations. Include environmental training in curricula of officers. Develop principles for an environmental convention governing military activities, comparable to the humanitarian Geneva Convention.

4.5. IMPACT INTERACTION

Cumulative impacts: Environmental impact studies commonly evaluate projects on an individual basis, with the result that cumulative impacts are ignored. Limits to the extent of development are seldom established. But Kingdom of Bhutan decreed that 60% of the country should remain under forest cover in perpetuity (Lean *et al* 1990), a measure that will also conserve aquatic biodiversity.

Options: Include cumulative effects in environmental impact studies to be assessed against established targets, e.g. limit the total amount of water that can be diverted from a river, lake or stream (Postel 1993). Use longterm planning and establish limits to emission/discharge levels of harmful substances and other environmental impacts which accumulate. Establish national targets for percentage of land- and aqua-scapes to be protected or sustainably managed.

Synergism between impacts: Two or more impacts may neutralize one another, add together (see Cumulative Impacts above), synergistically amplify the impacts (McAllister 1995), or, rarely, produce no net change (two lethal chemicals don't make the organism any "deader."). Neutralization or cancellation of impacts is unlikely, though a broad survey of impact interaction has not been carried out. Amplification or synergism is a likely type of interaction.

A recent example of synergism is that acid rain and global warming together are magnifying the effects of the thinning of the ozone layer by making the surface waters of Canadian lakes much more transparent (*New Scientist*, 24 February 1996, p. 16). Climate warming in this area has resulted in lower precipitation, lower transport of organic carbon into the lakes, and greater lake transparency. Increased acidification also increases transparency. Higher transparency means that harmful UV radiation penetrates more deeply into the water. Lowered river flow, drops in turbulence, and summer evaporation may result in concentration of both nutrients (leading to blooms of toxic blue-green algae) or of toxic substances (Atherington and Welcomme 1995; Pringle and Scatena 1997.1). Under climate warming the loss of streamside vegetation is predicted to increase stream temperature an additional 6°C in summer (Watson *et al* 1996), and would foster sedimentation from bank erosion. The direct impact of exotic fish introductions into California and Australia has been compounded by the transmission of pathogens and parasites (Arthington and Blühdorn 1994).

Options: Support studies on interaction between impacts within and between categories of impacts. Develop practical rules of the thumb to gauge the degree and signficance of synergism.

Global interactions: At the highest ecological level is the ecosphere. Here we find forestry, agriculture, fisheries emissions of greenhouse gases, discharge of toxic compounds, and population growth interacting at the planetary level. The Limits to Growth prepared by Dennis Meadows and others for the Club of Rome was effective in drawing to public attention this level of interactions.

In 1993, the Canadian Club of Rome felt that it was time to take advantage of lessons learned, more advanced computing power now available, and the new science of evolutionary systems. The Club defined a Global Modelling Project in a new conceptual framework, *Concepts for a New Generation of Modelling Tools: Expanding Our Capacity for Perception.* The new approach, now being implemented by Robbert Associates and the Canadian Club of Rome, permits the user to use data sets, establish relationships between variables and vary those relationships or changes in use to seek scenarios where the system would be at greater risk, or more sustainable. More information can be found at the web site: http://www.magmacom.com/~robbert.

4.6. PRIORITIZING IMPACTS

With the multiplicity of human impacts at global and state levels, it is important to find ways of identifying the major impacts so that limited resources are effectively applied. Here are some suggestions for evaluating impacts:

- How much area is involved? This could compare terrestrial source areas of aquatic impacts, e.g. agriculture and forestry, with some measure of intensity. Or it could compare impacted aquatic areas, e.g. number of hectares of an ecosystem, wetland, or lake lost or degraded.

- How much linear distance (or volume of water) is involved? In the U.S. 50% of the 5.8 million km of rivers and streams are polluted to a significant degree and 6.2% are channelized (Myers 1997.1). This kind of measure might be useful for comparing various impacts on river ecosystems, e.g. do hydroelectric dams, agricultural or waste discharges affect the most river habitat. The length of river segments measure could be adjusted for intensity of impact and stream order (position of stream in the hierarchy of tributaries) or annual flow volume. Six hundred km of the Ganges (24% of 2,525 km), are dangerously polluted with human and animal wastes.

- How many species are affected? Identify clusters of threatened and endangered species.

- What hotspot, productivity or other biologically critical areas coincide with high irrigation withdrawal, population growth, etc..

- Mapping impact sites at global, regional, national and local levels helps understand the extent of impacts, especially if impacts are graded, i.e. high, medium and low impacts. Such information can also be entered into geographic information systems (GIS) to help analyse which areas are most heavily impacted and calculate the size of affected areas.

For monitoring purposes, the United Nations report, *Comprehensive assessment of freshwater resources in the world*, recommends that the ratio of water withdrawal to water availability on an annual basis be used as a measure of freshwater stress (UN 1997). This report also states that a critical element in planning is accurate information on the state of water resources — but that assessment capacity has actually declined in some countries.

4.7. SUMMARY OF IMPACTS

Very few of the world's large rivers retain their original functional integrity and many have probably lost much of their capacity to adjust to and recover from severe disturbances (Kyle (1993) in Arthington and Welcomme 1995). This is hardly surprising from the physical point of view when we consider that about 37% of area of the world's drainage basins have been converted to agriculture, many of the world's rivers are blocked by dams, nutrient and toxic chemical levels of rivers have increased, and seasonal flows, turbidity and sedimentation rates in many rivers and estuaries have changed from original conditions. From the biological point of view, a number of fish stocks and other living aquatic resources have diminished or been lost, while exotic plants and animals have been introduced into most major river basins and larger lakes. A few areas have been restored, *viz.* The Chesapeake Bay basin.

Some aquatic species are being saved from extirpation or extinction by captive breeding in public aquaria, hatcheries and hobbyists' aquaria (Andrews and Kaufman 1994). The paddlefish, *Polyodon spathula*, was once extirpated in Texas. State hatcheries and biologists produced and stocked paddlefish fingerlings into areas they once inhabited, habitat was restored and regulation updated (Brett Rowley, in e-mail to sci.bio.fisheries usenet, 7 Oct. 1996).

Assessment of the status of fresh waters and their biodiversity has fallen, like many other ecosystem assessments, into the trap of either compiling narratives of known changes (mostly calamitous) without using any scale (see section on Prioritizing Impacts) or an attempt to summarize the status of all areas, an attempt doomed to failure either by the lack of data or the lack of resources to compile even what is known (the present overview is not immune!). An alternate approach is to use statistical sampling theory and an equal-area grid or water basin sampling system. A series of representative freshwater sites around the globe (in a continent or country) are chosen randomly. The sites are studied to evaluate their current status and monitor future changes. Projections on global status can then be made on the basis of these known samples. This approach is more economic and more likely to produce a realistic picture.

The loss of integrity of freshwater ecosystems has been accompanied by a increase in the number of freshwater fish species at globally risk or extinct (to about 20%), and indications of higher losses in mussels and crayfishes. As the gathering of data for rarity assessment is a slow process and as some areas are poorly monitored, we must consider the 20% figure to be an underestimate.

4.8. PROGNOSIS

The impacts of human water use on freshwater habitat and biodiversity can be expected to grow. Consumption by agriculture, forestry, fisheries, aquaculture, industry, and municipalities will be driven by population growth, which projections show to increase in the mid-term with doubling in about 43 years, and rates of consumption. Hydroelectric, reservoir and canal development is slowing in several areas because fewer sites are available. But larger structures are being built. Mega construction projects are planned or underway in central South America (Hidrovia Project), the Yangtze Kiang (Three Gorges Project), Malaysia (Bakun Dam in Sarawak), and the Mekong River Basin, areas of high aquatic diversity, so there is little hope of respite from river development. The potential for solar power generation could offer some relief from this prospect, if national and international lending institutions build on existing pilot projects and invest in improving solar generation.

Toxic chemical and nutrient levels are reaching or have passed the point of concern in a number of regions. Chemical interaction is poorly understood. Organic farming comprises still only a small proportion of developed world agriculture. High input farming, despite having levelled off with the green revolution in developing countries, continues to be a major factor of input of these substances into aquatic ecosystems and is still increasing in some developed countries like Canada. Climate warming trends and increases in ultra-violet radiation will continue for some time, even if Montreal Protocol targets were met. The spread of exotic species shows no sign of declining. The combined effects of these factors on habitat and biodiversity interactions is poorly understood, although synergism is suspected in some cases.

Given those trends one can only conclude that the prognosis for the state of fresh waters and their biodiversity is poor in the short and medium term. Long term status will depend on to what degree immediate and root causes are addressed. Comparison of our freshwater findings with a similar study on the World Ocean and its biodiversity (McAllister 1995), where problems are numerous and significant, suggests the problems of fresh waters are more serious. In addition, the fresh water problems are impinging on the state of the World Ocean.

5. KEY GAPS, OBSTACLES AND ALTERNATIVES

5.1. STATUS OF SCIENTIFIC KNOWLEDGE & TEK

Global Biodiversity Assessment (Heywood 1995) contains a valuable summary of the theory and principles governing biodiversity. But freshwater biodiversity is scarcely mentioned in the 1,140- page study (Kottelat and Whitten 1996); there are only 7 references to fresh water in the index. An assessment of the present state of freshwater biodiversity knowledge and gaps in it would help prioritize research. Van den Bossche and Bernacsek (1990) provide an excellent source book on inland fishery resources and water bodies for Africa. A comprehensive assessment of the physical fresh waters (freshwater "resources") of the world was undertaken by the Stockholm Environment Institute in cooperation with various international agencies. This assessment was considered by a special session of the UN General Assembly in 1997. These results, focussing on human use and availability, are highly useful to an in depth assessment of a global freshwater biodiversity. That state and needs of international fishery research are treated by World Bank (1993). Amongst other issues this study treats contribution of research, research capabilities in developing countries, human linkages, socio-economics, and policy.

There is no accepted global freshwater ecosystem classification. However, Banarescu (1990-1995) provided a global freshwater zoogeographic scheme. Maxwell *et al* (1995) and Lammert *et al* (1997) provided hierarchical frameworks of aquatic ecological units for North America. An aquatic habitat symposium has been held for the Great Lakes and a (non-hierarchical) freshwater ecoregion map for Latin America and the Caribbean has been developed by the World Wildlife Fund Conservation Support Program for the Biodiversity Support Program and USAID. According to Heywood (1995), "We urgently need a robust classification of the world's ecosystems which can be used to map the distribution of ecological resources...., provide a basis for assessing biological diversity and for setting priorities for conservation." We also need the classification for ecosystem-based management.

About two hundred new species of fishes are discovered, scientifically named and classified each year; about 80 of these could be expected to be from fresh waters. Collette and Vecchione (1995) describe the linkages between fisheries management, conservation, systematics and natural history collections, and Stiassny (1992; 1994; 1996) and Stiassny *et al* (1994) document the role of phylogenetic analysis, cladistic patterns and systematics in conservation of freshwater fishes. Compared to fishes, far more invertebrates, lower plants and microorganisms remain unnamed, unclassified and unmapped.

The ecological linkages, requirements and functions of species are poorly known. The fish species host of the rare riffleshell mussel (*Epioblasma walkeri*) is still unknown (1997, Endangered Species Bulletin 22(2): 29). That knowledge is needed for *in situ* and *ex situ* conservation of the mussel.

The ranges or geographic occurrence of freshwater organisms is weakly documented. The *Atlas of Freshwater Fishes of North America* (Lee *et al* 1980) provides one of the few large-scale reasonably well-mapped fish faunas of the world. Such maps are useful in conservation of individual species or identifying and conserving hotspots — areas rich in species, in managing existing or inaugurating new fisheries.

There is no spot on earth where biologists have inventoried all species of microorganisms, plants and animals, a so-called all taxa biodiversity inventory (ATBI). An ATBI has been planned for land in Costa Rica and in the sea off California, though the former was cancelled. Should one or more fresh water ATBIs, be organized? The most complete catalog of biota for a freshwater site is the two-decade long study of a small German stream, the Breitenbach River. This river is about 1 m wide and flows 4.5 km through meadow and woodland (Peter Zwick *in* Allan and Flecker 1993). Scientists have identified 1,044 invertebrate species in this stream. The three most speciose groups are Insecta (642 species, with 476 Diptera), Nematoda (125), and Rotatoria (106). The Breitenbach River and the ELA area (see next page) could be considered candidates for a freshwater ATBI site.

Persuasive arguments are made that we must study the diversity and ecology of old growth forests, before they disappear before the clearcutter. Equally intricate ecosystems are being lost to dams, pollution and introduction of exotic species in our fresh waters. One can argue that a real push is justified to learn as much as we can about aquatic biodiversity while its complexity and integrity is at least partially intact.

The deep groundwater microbiota are amongst the most poorly known groups of organisms. Research would add to knowledge and might contribute to bioremediation and biotechniology (Fliermans and Balkwill 1989). Pollution and depletion threaten some underground aquifers.

The incomplete understanding of aquatic ecosystems, the lack of a standard freshwater ecosystem classification, and the lack of knowledge of ecological requirements or life history of many species impedes scientific understanding, management, monitoring, and conservation. Long term studies, such as the Canadian Experimental Lake Area (ELA) program (recently cut back), are rare (Schindler 1990). The ELA program has provided significant results concerning eutrophication, acid rain, climate warming and forest fires. Yet such studies are needed to include the spans of natural climatic cycles and to monitor potential impacts of global change, as well as to carry out experiments to test the models that are critical in forecasting the planet's future. Short-term studies will not provide reliable data. The effects of UV-B on freshwater biota needs to be examined more closely.

Basically these problems pose the question how can we conserve, manage and monitor if we do not know what species and ecosystems there are, where they occur and how they function?

But Pringle (1995) suggests that scientist should consider two addition steps. Firstly, within the existing scientific framework, chose research questions considering ecosystem science and landscape ecology, temporal and spatial variability over a range of scales, consideration of humans as part of ecosystems, and draw upon multiple scientific disciplines, when appropriate. Secondly, they should communicate their findings with conservation organizations, listen to them and cooperate with them. Scientific knowledge is crucial to conservation, but will serve little if it sits on the shelf, lost to governments, managers and interested citizens. The latter message is reaffirmed and detailed with examples in Pringle, *et al.* (1993).

Traditional knowledge of freshwater biodiversity is available in abundance from both indigenous and non-native cultures, e.g. knowledge of salmon biodiversity held by native elders in North America and generations of artisanal and sport fishers. The major obstacle to using this information may not be the obvious one of gathering it, but rather the difficulty of convincing professional biologists to accept an authority and point of view other than conventional science.

There is also valuable traditional knowledge in managing water resources for humans and biodiversity. Angarwal and Narain (1997.1 and 1997.2) discuss the decline and revival of traditional water harvesting systems in India. This includes tanks, *johads*, and rooftop water collection. *Johads* are earthen dams thrown across the channels of seasonal streams. But unlike ordinary dams the rainwater is collected during the monsoon and allowed to percolate into the soil around it. Thus it recharges soil moisture and ground water. This approach reduces evaporative loss which occurs in impoundments. In the Thar desert of Rajasthan people developed *kundis* — wells which store runoff from surrounding catchment areas. Social mechanisms to share in maintenance of harvesting systems and equitable access to the water are an important part of traditional water harvesting. This means that local communities have control over the water, their life. Often that is not the case in mega-irrigation projects. Educations systems may wish to find methods to teach such local traditional knowledge in their curricula. Agarwal and Narain point out that greater use of traditional water harvesting methods could, by using less than 2% of India's land area, resolve much of the nation's water shortage. In addition, by accessing rainwater directly, water users could avoid tainted water, ..."the horrendous and growing pollution of India's rivers with industrial contaminants, and fertilizer and pesticide run-offs...."

5.2. RESOURCE MANAGEMENT

Traditional resource management has focussed on stocks of single species, ignoring the status of ecosystems in which they live. The Jakarta Mandate and the Global Biodiversity Forum endorsed an ecosystem approach to management. This means rejecting the single-purpose view of what happens in a body of water (*in litt.* Dr. Frederick W. Schueler) — maximizing trout catches by poisoning out "coarse fishes," ridding streams of snails in the tropics because they are a vector for schistosomiasis. Water resource projects like the Aswan Dam, Gezira Irrigation Project in the Sudan, Lake Volta in Ghana, and Lake Kariba in Zambia may increase the prevalence of schistosomiasis, and demand for molluscicides (shellfish poisons), some of which are also toxic to non-target molluscs and fishes (Tucker 1985). But integrated approaches to schistosomiasis control involving sanitation, provision of save water supplies, environmental modification, and public health education may be less costly and more advantageous to communities than molluscides and chemotherapy (Tucker *opp. cit.*). Hughes and Noss (1992) stress the need for concern about the losses of biological integrity as well as biodiversity.

Some propose introducing individual transferable quotas (ITQs). In Lake Erie ITQs were introduced in 1984, allocating a share of the harvest to fisheries based on historic production (Cowan and Paine 1997). At the same time self-policing of fishers was initiated. Benefits included reduction of fleet size, reduced public costs of enforcement, and better control of the harvest whereby the benefits of good year classes could be spread out for longer periods. Cowan and Paine

(1997) felt that ITQs could not be regarded as a panacea for protecting fish stocks; they cannot deal with uncontrollable events such as the introduction of exotic species. They felt that ITQs did help reduced excessive fishing effort and overfishing resulting from uncontrolled access. The use of ITQs is still being debated.

The territorial use rights in fisheries (TURFs) is another management approach, often used in traditional societies before being displaced by the Western open access approach. It can be re-instituted. The fisher is given rights to fish in a certain area, long enough to encourage taking care of the stock and habitat. Australia uses the TURF approach by licensing marine aquarium fish collectors sole rights to harvest fishes in a given area of reefs; if they care for the fishing area well, then the license may be renewed. The TURF approach warrants pilot trials in other countries. As in all fisheries it has to be decided whether the small-scale or artisanal fisheries or large-scale industrial scale fishing is to be encouraged. McGoodwin (1990) argues for incorporating community-level indigenous style management. There has notable success with co-management with community fishing cooperatives in Japan.

Taylor *et al* (1995) argue for extending the ecosystem concept to a synthesis of the biological, chemical, physical and social processes occurring *within the watershed*, including land-use practices. The watershed approach is a freshwater counterpart of integrated coastal area management (ICAM) and can be called watershed, or generically, ecoscape management as an analogue of landscape, aquascape (freshwater) or seascape (marine and coastal; McAllister 1992.1). The watershed Conservation Authorities in Ontario, Canada were a step in the right direction, but have been cut back by the provincial government. Ecoscape management should also consider the economic aspects of the process, as well as the involvement of local communities and include traditional ecological knowledge (TEK) and scientific knowledge.

Ecosystem management is evolving. From Beyeler and Eger (1997) we extract two definitions:

> *"Ecosystem management integrates scientific knowledge of ecological relationships within a complex sociopolitical and values framework towards the general goal of protecting native ecosystem integrity over the long run."* (Ed Grumbine, *Conservation Biology*, March 1994).
>
> *"The idea of an ecosystem management process is to address large-scale, long-term, complex problems by blending ecological, economic, and social goals, and by acknowledging that people are integral, interacting parts of natures."* (*Keystone National Policy Dialogue on Ecosystem Management*, Final Report, October 1996).

Christensen and Pauly (1996) describe the new ECOPATH 3.0 ecological modelling software which could assist managers in ecosystem approaches. Angelini and Petrere (1996) describe an application in Broa Reservoir, Brazil. The model is robust and can use published data and parameter estimates.

The airshed, defined by trends in strength and direction of atmospheric movements, also needs to be considered. Coal burning power plants in Ohio contribute to acid precipitation in southern Nova Scotia, over 1,200 km to the east, and the decline of the endangered Acadian whitefish, *Coregonus huntsmani*. So airsheds can transcend watershed and national boundaries.

The Biodiversity Convention has focussed increased attention on the Precautionary Principle, whereby ultimate proof is not required before taking conservation action, "Noting also that where there is threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat." This principle is applicable to freshwater environments and biodiversity.

Western management generally operates through scientific research, monitoring, developing management policies and decisions, legislation, and regulations that are often enforced. This involves fisheries managers and policy makers who devise single-species single-stock management programs, and inspection/ enforcement operations. The fishers, relatively well-educated, or companies, use motorized boats equipped with navigational, fish-finding and communications technology. When attempts are made to apply the western-style approach artisanal multi-species fisheries in the tropics, they tend to fail. The approach does not always work even in the northern ecosystems with few species. And it is necessary to admit the quasi-rational approach is exposed to political pressures by various stakeholders.

Alternatives to western style management include management by fishers co-ops, community management, traditional ecological practices, or co-management by fishers and government fisheries managers. Bernacsek (1990) argues that the TURF-like usurfructuary community-based systems of management, often hearkening back to traditional resource tenure, often successfully conserve and manage resources in a cost-effective manner and equitably generate resource rents. These systems, he says, need to be constructed by the local user community itself, out of its own existing political, economic and social structures, rather than being imposed from above.

Middendorp *et al* (1996) describe community fisheries management of 23 freshwater lakes in Bangladesh. This project aims at self-management of oxbow lakes for fishing and fish farming, improving yields through better fisheries practices, and equitable sharing of benefits. NGOs can be helpful in restoring fisheries/ecosystem sustainability at the community and other levels. Community organizers can learn what the community's concerns are, and, building on local knowledge, provide suitable environmental and management education, training in appropriate fishing methods, fish preservation and marketing, help resolve financial issues, establish aquatic reserves, etc. This can be applied in coordination with other government and academic agencies. Haribon (1995) provides instances of fishing approaches by NGO and community partners to sustainable livelihoods and environmental education. Communities also need to be able to monitor their aquatic ecosystems. The International Development Research Centre of Canada has recently developed simple water quality tests using onions, hydra and water fleas that could be used at the community level.

On the pessimistic side, one is tempted to ask whether water bodies with several shifting physical and biological parameters, and growing human pressures, like the Laurentian Great Lakes, can really be managed. Scientific management requires *some* stability amongst its studied components.

On the forward looking side, we suggest looking at the vision of Abramovitz (1996.1):

"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 these 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. .... over the long term, keeping naturally functioning ecosystems healthy will offer the greatest number of benefits for the greatest numbers of people."

If a few of the billions planned for hydroelectric development were instead spent on developing efficient inexpensive solar energy devices, such as photovoltaic cells, we could have relatively clean inexpensive electric power, and more normal river ecosystems with flow and migrations uninterrupted. It should be noted that roofs are **already** ecologically barren and so form an ideal site for solar power sources. In addition they are close to the place of use. Can roof water collectors, mentioned earlier, and roof solar energy collectors be combined?

More ecosystem-oriented versions of aquaculture need to be developed. One pathway is integrating aquaculture with various kinds of agriculture, rice-, pig-, poultry-fish and multi-component integrated resource management systems (Pullin 1994.1). The plant component(s) can then extract and use the nutrients from animal wastes, instead of discharging them into natural ecosystems.

ICES (1995) provides a code to help guide introductions and transfers of marine organisms that should be helpful in regard to freshwater species, though compliance may be difficult to ensure. The transfer of species should not be done exclusively on economic grounds. We should learn the lessons from past transfers and consider their costly legacy in terms of ecosystems, species and eco-services, as well as economic grounds.

Fisheries statistics can be a weak point in management. Without good statistics catch forecasts will be less reliable. Live weight is the basic unit for catch monitoring, quota management and stock assessment. Live weight of catches is often estimated using conversion factors from the landed weight. It has been found that different conversion factors were being used by some members of the European Community. Discussions on harmonizing estimation methods can be found on a web site at:
http://www.ifremer.fr/cofrepeche/. Live weight conversions are also needed to monitor shipments of aquarium fishes. Some persons have mistakenly use the weights of shipments (fishes, containers and water) as live fish weight.

5.3. *IN-SITU* CONSERVATION — PROTECTED AREA MANAGEMENT

Protected areas can play a major role in conserving biodiversity and in sustaining biological benefits in adjacent areas. But protected area networks are only one component in attaining these goals. Williams and Davis (1996) believe that the ecosystem-based approach should be applied to conservation. The species-by-species approach, they feel, has failed in the U.S. Management can usefully involve neighbouring communities and resource users in collaborative- or co-management (Borrini-Feyerabend 1996).

The Brundtland Commission established a target of setting aside 12% of the Earth's surface in protected areas. We have not yet set aside 10% of the Earth in protected areas. But even if we reach the 10% level, according to projections based on species-area curves, this would mean that only about half of the planet's species would be protected (Primack 1993, p. 88). If we want to protect more than 50%, then protected area targets may have to be raised, more diverse areas should be selected for protection, or more ecologically benign methods of agriculture, forestry, fisheries and other kinds of development would need be put into practice outside protected areas. It also assumes that existing and new protected areas are properly managed and guarded and that the protected areas are sufficiently large to minimize harmful edge effects and are not excessively fragmented (Primack 1993, p. 337).

An accurate figure is not available for the total global area of fresh water that is protected by reserves, parks and other measures — there is no freshwater counterpart to the 4-volume *Global Representative System of Marine Protected Areas*, and most freshwater areas are protected simply because they were included within a land-based park. However, if the 7.7 million km^2 or 5.2% of the Earth's land area that is protected (Groombridge 1992) is typical in regards its proportion of fresh water, then about 5.2% of the world's freshwater sites or about 200,000 km^2 are protected in those terrestrial areas. This area, judging by the species-area curve, would be expected to protect less than half of freshwater biodiversity. But a tree-like watershed or buffered upstream area approach is also needed so the drainage basin and upstream activities do not affect the *in-situ* hearts of protected areas.

Establishing new aquatic protected areas faces a particular challenge, many wetlands are already lost or degraded, e.g. more than half of Asia's wetlands have been lost and more than half of the mangroves in the Indo-Malayan realm have been cleared, many for conversion to aquaculture ponds, while many of the surviving Asian wetlands are moderately or severely threatened (Braatz 1992). Hotsprings and arid area cool springs, some with endemic species, are often developed as sources of water, recreation, or thermal energy, and may require spacial attention. Jim's Black Pool hotspring in Yellowstone Park, U.S.A., was found to contain 98 Archael bacterial species (Reaka-Kudla *et al* 1997).

To a considerable degree, freshwater areas are protected either incidentally or intentionally within land-based protected areas. To a degree this is good in that it ensures that part of the adjacent vegetated land is protected from development. But freshwater areas are perhaps best protected intentionally by: a) by selecting particular areas especially for aquatic biodiversity, b) protecting sufficient drainage basin in which the water body occurs, to ensure that land-based development will not detrimentally effect the water body, c) by ensuring a sufficient upriver buffer zone for river parks, and d) by taking into account airsheds which may transport atmospheric pollutants into the water body.

Some lake waters, usually the shallower waters, are included within the protection of adjacent terrestrial parks. Other lakes are better protected as they are wholly surrounded by a terrestrial park which encompasses a portion of its drainage basin. There is space for determined efforts to protect lake ecosystems as desirable entities in themselves, along with drainage basins.

There is also a need to protect the deep water communities of lakes, not just to throw in a narrow band of shallow waters next to the shoreline. For example, in Lake Superior, for example, one should seriously consider designating a profundal (deep) zone of the lake as a protected area. This portion of the lake has its own species including deepwater sculpins, *Myoxocephalus thompsoni*, the siscowet form of lake charr, *Salvelinus namaycush*, and invertebrates such as the crustacean, *Pontoporeia affinis*. To establish deep groundwater protected areas for microbiota, such as those described by Fliermans and Balkwill (1989), would be going against traditional practices. But perhaps it is time to do so now that groundwaters are becoming more polluted. In Lake Victoria, Africa, anthropogenic changes have meant that since 1990 the deeper waters are no longer oxygenated (Stiassny 1996.2). This has wiped out the thriving deep-water cichlid community. Has it also extirpated a unique deep-water aerobic bacterial community?

Two other approaches have been taken. One is exemplified by the 1968 Wild and Scenic Rivers Act of the United States. Rivers selected under this act must be free-flowing with no dams, channelization or similar alterations. Rivers and adjacent landscape must have at least one remarkable feature: scenic, recreational, geological, fish, wildlife, historic, cultural or other. Wild and Scenic rivers fall into three categories: wild, scenic, or recreation. By 1989 0.2% of American river miles were designated by the U.S. Congress as wild and scenic rivers. The Wild and Scenic Rivers Act does put the primary emphasis on the body of water. It may not always offer sufficient protection from human activities in the drainage basin.

A second approach has been protection of freshwater sites under the Ramsar Convention. As of 1992, 520 Ramsar wetlands totalling 323,362 km^2 had been protected (Groombridge 1992); but that figure contains an unknown quantity of marine areas. The Ramsar total includes 40 wetlands in Asia, 12 in the former U.S.S.R., 328 in Europe, 63 in North and Central America, 7 in South America, 45 in Oceania, 43 in Africa and 0 in Antarctica. Ramsar sites do not always include examples of all wetland ecosystems. Canada, has extensive Ramsar site wetland representation and includes 25% of the wetland area designated word-wide under the Convention to date. All of the five class-levels (bog, fen, marsh, swamp and shallow open water) are represented in the Canadian Ramsar network. But only 31 of the 70 wetland forms (Rubec and Kerr-Upal 1996) occurring in the country are represented within the Ramsar Site Network (*forms* are subdivisions of the classes).

Like terrestrial areas, freshwater protected areas are subject to aerial pollution such as acid precipitation. Most freshwater protected areas are also subject to pollution from terrestrial runoff, as well as from upstream sources.

Atherington and Welcomme (1995) point out the need for whole river basin conservation, where feasible. Whereas 'island' biogeographic studies have provided some parameters for calculating the minimal sizes for terrestrial protected areas, the theory is less firm for stream segments, though we have previously noted studies on species-area relationships for river basins and lakes.

Fragmentation of habitat in aquatic ecosystems is also poorly understood. So research is needed to help establish minimal sizes for freshwater protected areas, both for the water bodies and the water basins which feed into them.

Nyman (1991) summarizes the single large vs. the several small reserves debate. He concludes it is neither size nor number, but that fish populations should be retained in lakes or rivers which approximate the ones they live(d) in as much as possible. He goes on to say the more times that criterion is fulfilled for a particular species, the greater the chance of long-term persistence and that, all else being equal, large reserves will support more species than small reserves.

Braatz (1992) underlines the needs for protected areas in the Asia-Pacific region. The needs are: legal frameworks, institutional structures, financial resources, human resources, involvement of NGOs and political commitment. She indicates that this means improving the policy environment, integrating conservation and development and mobilizing financial resources, and outlines the role of the World Bank.

Some freshwater protected areas, at least in North America, face a unique problem: recreational angling is permitted in many of them, subject to licence, catch-limit, and other controls. This contrasts with regulations that forbid visitors from disturbing or killing birds, mammals or flowering plants. In addition some park waters may be stocked with non-native species or genetic stocks of sport fishes. In the past at least, some park waters have had populations of "rough fishes" cleaned with ichthycides (fish poisons) so that sport species could be stocked. Thus recreation goals may conflict with goals of conserving indigenous freshwater fish biodiversity. Some nature reserves, closed to recreational use, have higher levels of protection.

The case for no-take protected areas to conserve biodiversity and to increase harvests in adjacent fishing grounds has been established for marine ecosystems. Is this approach beneficial and effective in freshwater ecosystems?

5.4. *EX-SITU* CONSERVATION

Ex situ conservation of genetic resources is generally accepted as a companion to *in situ* conservation in cases where causes of biodiversity loss cannot be eliminated in time before genetic erosion makes conservation of a species a moot point (Andrews and Kaufman 1994). *Ex situ* conservation is characterized by the Convention on Biological Diversity as a complement to conservation of organisms in their natural surroundings. Clearly genetic resources maintained in a gene bank are of less value without the appropriate habitat into which the species can be restored; equally clearly, there are more and more situations where collection and temporary storage of genetic resources is the only way to prevent their complete disappearance.

Signatories to the Convention on Biological Diversity have undertaken to develop policies governing the collection, storage, transfer, sale and use of genetic material. Recent focussing of attention on the disappearance of aquatic biodiversity has made it imperative that governments also consider the issue of genetic resources, not only for reasons of conservation *per se*, but also for the potential economic value that these resources represent in fisheries and aquaculture (Harvey 1996).

Cryopreservation of sperm is a well-established technology for many species and can now be performed in the field for predictable costs and with excellent results (Harvey 1993). There are a number of collections of cryopreserved sperm of wild freshwater fishes that have arisen in response to the need to conserve genetic variability, which can then be employed in breeding programs aimed at improving production in cultured species, or at rebuilding wild stocks through enhancement. A third application of gene banking, namely the archiving of wild genetic material for its potential value or as an insurance against unexpected population decline, demands indefinite commitment to storage costs and is harder to justify economically. Better cryopreservation techniques for ova, bearers of mitochondrial DNA, need to be developed.

Gene banks for freshwater fishes have been established in Canada, Norway, Finland, United Kingdom, India, Russia, United States, Philippines, Brazil, Colombia, and Venezuela. All operate independently, with little knowledge of, or communication with the others. There is no governmental policy on fish genetic resource conservation in any of the countries that have fish gene banks, and technologies vary. There is an urgent need for discussion and consultation among banks with the aim of standardizing technologies, minimizing redundant efforts, and providing governments with a realistic framework for developing genetic conservation policies. There is also a need for policies to ensure that there is a fair and equitable sharing of benefits derived from such genetic resources, as established under the Biodiversity Convention.

Accessions include salmonids, tilapias, carps, sturgeons, and a variety of South American migratory species. The largest fish gene banks are in Norway, Canada, India and Russia. The Norwegian gene bank, operated by the Ministry of the Environment, is a single-species collection representing approximately 5,500 samples from 160 stocks of Atlantic salmon, *Salmo salar*. The Canadian gene bank, operated by World Fisheries Trust, holds samples from six species, representing approximately 3,000 samples from 38 stocks.

The Aquatic Section of the Captive Breeding Specialist Group (CBSG) of the

World Conservation Union has identified three freshwater fish faunas for initial conservation attention: Lake Victoria fish, desert fish, and Appalachian fish, each with high species richness, high endemism and a large proportion of threatened species. The Aquatic Conservation Network is an international organization linking scientists, aquarium hobbyists and aquarium industry, alerting the conservation community to aquatic conservation issues and establishing captive populations of endangered species. Their present primary focus is on the freshwater fishes of Madagascar.

The World Zoo Organization has established a conservation strategy for zoos and aquaria (IUDZG/CBSG (IUCN/SSC) 1993). The strategy supports goals in the *World Conservation Strategy, Caring for the Earth* and the *Convention on Biological Diversity* through supporting conservation of endangered species and their natural ecosystems, by supporting the increase in scientific knowledge that will benefit conservation, and by promoting an increase in public and political awareness of the pertinent issues. This includes supporting *ex situ* and *in situ* conservation. The National Aquarium in Baltimore, like other public aquaria, supports educational, *in situ* and *ex situ* conservation programs (Andrews, Krussman and Schofield 1995).

5.5. CAPACITY

The declining number of taxonomists, and ecologists and the low degree of support for natural history museums and whole-organism biology in universities is one of the major impediments to understanding aquatic ecosystems. There is an urgent need for accelerated accumulation of knowledge about biodiversity (Savage 1995). The knowledge and experience of aging taxonomists should be passed on to a new generation. The problem, significant in developed countries, is greater in many developing countries. Training people to conduct biological surveys and to integrate knowledge from fishers and indigenous peoples would provide key data for conservation and sustainable use, specimens for taxonomic research and biotechnology, and information for species and ecosystem mapping.

The low number of taxonomists is compounded by their disposition. May (1994) points out that one third of taxonomists work on plants, while the remaining two thirds are roughly equally divided between vertebrate and invertebrate animals, with only 2-3% working on microorganisms. He indicates that the number of vertebrate species is about 40,000, of plants 300,000 while for invertebrates the recorded number is around 1 million although in reality closer to 3 million. Thus for every n taxonomists studying a vertebrate species there are 0.1 n studying a plant species, and around 0.01 n studying both invertebrate species and species of microorganisms. This data argues for priorities to hiring new taxonomists be given to the latter groups.

Resources, research and implementation are needed in developing ecosystem-based approaches to management. World Bank (1992) provides a useful review of international fisheries research. Dudley (1994) states that fisheries scientists in the developing world are facing a crisis. They have few options for managing fisheries, a low level of funding and support. University staff have subsistence salaries, few books, no journals and little research funding.

If fisheries biologists and managers are to move to ecosystem-based fisheries management, then many will require upgrading in their skills and knowledge. Similarly fisherfolk communities on rivers and lakes, will require enhanced awareness and knowledge if co-management is to become a reality. Capacity building in North and South is needed in sustainable fisheries approaches.

5.6. GENDER

Development, capacity building, technology transfer and conservation often underestimates the existing and potential roles and qualifications of women. The traditional ecological knowledge of women is often ignored. The Canadian International Development Agency (CIDA 1993) offers some guidance on a gender relevant approach for fisheries development projects. This includes:

- Ensure that project design and planning include appropriate information on the gender division of labor in the fishing sector;
- Publicity channels and mechanisms should consciously seek to reach men and women equally;
- From early project planning through implementation, project personnel should work with groups in which women as well as men can participate;
- Provide training to those traditionally in the sector, or likely to carry out the work;
- Ensure that credit for investment in the sector is equally available to women;
- Use caution in using income statistics or male incomes to measure family and community benefits;
- Particularly in aquaculture, avoid adding to women's time and responsibility without commensurate increases in income and areas of direct control.

The involvement of women is especially important in regard to policies affecting artisanal fisheries which are community- and family-based, and influence health and nutrition which have a particular significance for women. The periodical, *Women in Resources*, is an good source of information on how women play roles in research and management of resources. When new technologies are introduced in fisheries development projects, women should be involved. Ensuring the equitable involvement of women is often a key to ensure project success.

Ofosu-Amaah (1992) describes a number of success stories involving women and the environment. These include reforestation, erosion prevention, reducing aquatic pollution, and pulse management and conservation of fisheries resources in creeks.

5.7. TECHNOLOGY

A switch to more environmentally friendly but economically practical fishing gear is needed, given the bycatch and habitat-damaging characteristics of some fishing gear. The *Code for Responsible Fishing* (FAO 1995.2) provides many options for environmentally, economically and socially improved ways of fishing. The *ICES/EIFAC Code of Practice on Introductions and Transfers of Marine Organisms* contains clues on reducing the harmful effects of introductions (ICES 1995). Traditionally-based selective fishing methods already exist for some species, but require upgrading and above all, pilot scale participatory demonstrations if they are to be more widely accepted by fishers and fishing industries. Perhaps regional and global workshops could be organized with fishers to exchange low-tech sustainable fishing methods. McGoodwin (1990) believes that it is large-scale mobile industrial fishing that has lead to our current fisheries crises, and that we should consider, amongst other reforms, re-introducing small-scale approaches with indigenous style management. In choosing technologies, local fisherfolk knowledge and traditional ecological knowledge should not be ignored. Many of their technologies have endured over centuries or millennia.

5.8. POLICIES, INSTRUMENTS & PRIORITIES

As can be seen from the section on human impacts, the stresses on fresh water availability, quality and biodiversity are multi-sectorial. Development of policy for biodiversity conservation and sustainable use is fundamental to successful implementation of the Convention on Biological Diversity. For example, Canada and Mexico have developed national strategies on biodiversity and the former is developing a national action plan. Existing legislation and incentives should be made consistent with goals on biodiversity. Policies should foster development of needed new legislation, and production of national strategies, action and monitoring plans on biodiversity conservation and sustainable use, including aquatic biodiversity. Bartley (1995) discusses policy and socioeconomic aspects of aquatic biological diversity conservation. Winter and Hughes (1997) describe the American Fisheries Society position on biodiversity and make recommendations on policy, education, management, monitoring and research.

More forward looking environmental economic thinking needs to be introduced into international trade instruments, to replace what Dr. Bill Rees, Queens University, Kingston, calls "flat earth economics" (Gallon 1997). Denton (1997)'s *Enviro-Management: How Smart Companies Turn Environmental Costs into Profits* and Esty's (1994) *Greening the GATT* of two of the many books now being published on green business and economics, some by hard-nosed business people and experienced economists.

Some trade agreements appear to be in conflict with international instruments on the environment. For example the North American Free Trade Agreement treats water as a "tradable commodity" (Barlow and Robertson 1996), taking no account of commitments under the Biodiversity Convention, nor that water provides habitat for biodiversity. Nor does the draft Multilateral Agreement on Investment take account of the Convention.

There are approximately 300 different regional and national agreements and treaties that relate to fresh water as a resource (UN 1997). Political conflicts in regard to waters crossing national boundaries are not new, but "Water issues will be the next cause for high-level conflicts" was a remark that was often heard among government representatives already at UNCED. That human use of water usually takes priority, leaving aquatic diversity with the remainder, quantity- and quality-wise, compounds this dilemma.

Policies, priorities and implementation in regard to freshwater environment and biodiversity management are often hampered at the national level by the multiplicity of ministries and agencies and interests which are involved in freshwater issues. All of this suggests the need for national water councils to establish common goals, policies and actions.

A basic policy problem is how should water be allocated to meet the human needs and those of nature. Arthington and Pusey (1993) discuss this international problem in the light of Australia's experience - a debate heightened in arid and semi-arid countries like Australia. The recommendations included a moratorium on further off-stream uses in particular systems, the development of national and state policies for environmental water allocation, decide on one or more generic approaches and a package of methods for assessing in-stream flow requirements on the best hydrological, geomorphological, water quality and ecological information available and input from experts. Currently river ecologists in Australia are reluctant to advise on water allocation because theoretical understanding of river communities and ecosystem functioning, especially in relation to flow regimes and flow variability, is poorly developed — thus posing a requirement to support research on which to base sound policy.

Another policy concerns bringing commodities into line with true costs. Often marketplace prices today reflect only part of the costs. For example, the costs of automobile air pollution, some $300 billion in the U.S. is not presently included in the price of gasoline (Myers 1997.2), or it would rise by another $2 tax per gallon. Including other costs, but not global warming, would raise the cost to at least $8 per gallon. Yet a carbon tax on fossil fuels has been shelved by governments, heavily lobbied by interested industries. If these and other prices included costs presently externalized, then this would provide an incentive to producing more environmentally friendly goods and services by investors who presently get a 'free meal'. Happily, in the fossil fuel instance, Shell and BP in June 1997, announced programs to develop solar energy alternatives to fossil fuels. These companies became concerned over the contribution of fossil fuels to greenhouse gas emissions.

However, as conservation is sometimes a 'crisis discipline,' policy development sometimes works against conservation, particularly genetic conservation, by assigning unrealistic economic value to biodiversity and hence placing legislative or policy barriers in the way of genetic collection. In regard to conservation of freshwater genetic diversity, policy makers should be aware that international agreements on plant genetic diversity are still evolving after decades of conservation. One way to facilitate genetic collection while developing policy is to separate collection from management.

5.9. AWARENESS, EDUCATION & ETHICS

Fresh water conservation and management must overcome significant barriers:

- ♦ Low status accorded to aquatic issues and fishing communities;
- ♦ Lack of awareness and knowledge of the diversity;
- ♦ Lack of appreciation of value of aquatic species and ecosystems;
- ♦ Ignorance of the effects of human activities upon aquatic biodiversity.

Awareness of the biological and economic value of freshwater biodiversity is extremely low, not only for the general public, but also for resource user groups (commercial and sport fishing) and for industries that directly affect the resources. Existing awareness is usually narrow, confusing value of biodiversity with biological resources, a small fraction of the living capital.

Public awareness still seems to be ahead of governments as surveys continue to show. A survey of 1,682 Canadians by Insight Canada Research in November 1996 for Environment Canada showed the public is concerned about the effects of climate warming on the environment and that the federal government will not meet its commitment to reduce greenhouse gases to 1990 levels (*Ottawa Citizen*, 5 March 1997, p. A3). The federal government earned an average rating of 4.8 out of 10, on its overall handling of environmental issues; the provinces averaged 4.7. According to the NAFTA Council for Environmental Cooperation, Canadian industries discharged 55 million kg of pollutants into fresh water compared with only 30 million kg for all U.S. industries. Ontario discharged more pollutants than any other province and has recently reduced its environment department's budget by about half.

Children are open to and interested in environmental issues. Water is fascinating for children. Two successful projects may be mentioned that could serve as models. The Girl Guides and Brownies of Canada have adopted the **Storm Drain Marking Program**, jointly sponsored by the Department of Fisheries and Oceans and Trout Unlimited Canada. The volunteers stencil bright yellow fish symbols beside storm sewers along municipal streets. These and the brochures that the Guides give out remind the public that water-dwelling species may die if hazardous wastes are dumped down household or street-side drains. The successful program has been carried out in several cities and towns in Canada. The **Blue Thumb Kit and Pledge,** developed by the American Water Works Association, focuses on drinking water — cleaning up drinking water for humans helps aquatic biodiversity. This kit teaches, amongst many other messages, where drinking water comes from, that lawn/garden pesticides and fertilizers can run off into lakes and rivers or seep into groundwater, that pipes, taps and toilets should be inspected for leaks to conserve water, and how to write letters to government officials on water issues. The kit contains many information leaflets, a bookmark, experiments, a crossword puzzle, and poster. More information can be obtained at the Blue Thumb Web site: http://www.awwa.org/bluethum.htm. Similar children's programs focussing on the relationship for clean water for nature and humans, but adapted to the needs, culture and language of the country or province, are needed.

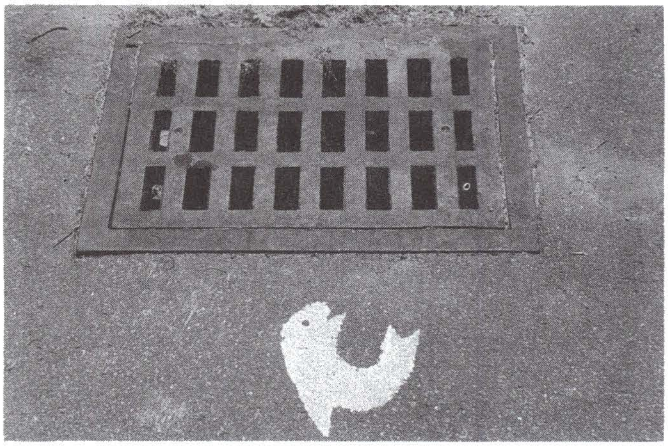


Fig. 16. In the Girl Guides and Brownies of Canada's Storm Drain Marking Program, yellow fish are stencilled beside storm sewers and pamphlets are passed out to remind people not to pour toxic chemicals into storm sewers or down the drain — they empty into rivers & affect fishes..

Invisibility is one of the principle reasons for lack of awareness and appreciation of freshwater biodiversity. Freshwater organisms are largely invisible when viewed from land or boats. Many contaminants dissolve invisibly into the water. Much of the hydrological cycle is invisible. We do not see water being breathed out by plant leaves, expired from evaporating bodies of water, none of the moisture in the air save when it is condensed, and little of the vast amounts of ground water that lie under our feet. Educational programs should aim to make aquatic organisms and ecological processes visible at least in the mind's eye.

In Canada, new environmental non-governmental organizations (ENGOs) have arisen to focus specifically on biodiversity issues. This includes the Canadian Coalition for Biodiversity, a group of ten ENGOs; the Association for Biodiversity Conservation, and the Canadian Biodiversity Institute. The Canadian Coalition for Biodiversity has prepared media packages on biodiversity, published the *Green School Biodiversity Booklet* for secondary schools, held biodiversity poster contests, and urged governments to act more decisively on biodiversity issues, including those involving freshwater biodiversity. Established ENGOs also raise the biodiversity banner. The *Green Teacher*, a quarterly environmental magazine for teachers (ISSN 1192-1285), has published special issues on biodiversity and its Winter 1996-97 issue contains an article on water conservation in Jordan. The World Day for Water, March 22nd, could be used as a vehicle to increase awareness of the need of water for both biodiversity and humankind. The theme for the World Day for Water in 1998 will be, "Groundwater, Invisible Resource." That theme could be used to underline the connection between groundwater, surface water and biota.

Public, hobbyist and school aquaria are one means of stimulating greater awareness and appreciation of aquatic organisms and aquatic conservation problems (Andrews and Kaufman 1994). About 120 million people visit zoos and aquaria each year in North America alone; estimates put the global figure at 1 in 5 people on the planet (Christopher Andrews, *in litt.* November 1996). About 10-20% of European and North American homes keep fish, as part of a multi-billion dollar a year industry. Although some aspects of the industry pose environmental threats, probably no other single activity, scuba diving excepted, increases awareness and appreciation of fresh water biota as much as aquaria. Christopher Andrews, former chair of the IUCN SSC Freshwater Fish Specialist Group wrote (*opp. cit.*) that there is enormous room for support of conservation from the ornamental fish trade, including point of sale education and fund raising. Ornamental Fish International has provided a good example of a freshwater fish industry in raising environmental standards and providing seed funding for conservation activities. The American Zoo and Aquarium Association has signed an agreement with several federal agencies in the U.S. to promote "in your backyard" freshwater conservation.

Many freshwater aquarium fishes are now cultured outside of the country of origin. Mechanisms need to be established to share the benefits derived from these genetic resources as proposed by the Biodiversity Convention.

Well developed senses and codes of individual and corporate environmental ethics can have a beneficial effect on the aquatic environment. Individual ethics, guided by eco-labelling can have a significant effect on the market and the environment. Government and corporate ethical guides and legislation can reduce environmental impacts through choice of materials, manufacturing, and kind of product produced. Corporate codes and government legislation can discourage the use of bribes in circumventing environmental problems. Bribery and corruption are not unknown in water development projects, especially large scale ones (McCully 1996). Transparency International recently published its second annual Corruption Perception Index. This combines the results of surveys of business people whether they had been asked for bribes by politicians and the effectiveness of a country's anti-corruption and bribery laws to arrive at a number between 0 and 10, with 10 being the best. The top countries were: Denmark 9.94, Finland 9.48, Sweden 9.35, New Zealand 9.23, Canada 9.10, Netherlands 9.03, Norway 8.92, Australia 8.86, Singapore 8.66, Luxembourg 8.61, Switzerland 8.61, Ireland 8.28, Germany 8.23, and U.K. 8.22. Third world and developing countries made up most of the lower half of the index, but the chairperson of Transparency International, Peter Eigen, said that most of the bribes are paid by executives of corporations based in western countries and that they are just as much to blame for corruption in developing countries as the people taking the bribes. Much of the time corporations initiate the bribing according to Jim Lyttle of Canada's Transparency International Chapter.

In May 1997, the OECD released an outline of an anti-corruption law it would like to see adopted by all member nations, which included most developed nations; OECD should consider implementing such a provision in MAI. Transparency legislation and enforcement should foster freshwater biodiversity conservation and sustainable use, as well as effective use of government funds.

Today much of modern humankind lives isolated from nature, sees other species as resources or a source of wealth, with man as the dominant life form, and regards human utility as the ultimate test of value. Nevertheless we understand intellectually that biodiversity shapes the world and sustains its life support systems, soil, air, water, micro- and macroclimate. With species disappearing we are faced with choices. We can enlarge our ethical system to include the right of all species and ecosystems to continue to exist. Kapuscinski (1995) discusses a common conservation ethic. This would include adopting an ecocentric view of the world, valuing the work of nature on equal terms with the work of humans, and advocating sustainability of natural resources and overall biodiversity. We can apply enlightened self interest and conclude that survival of humankind and quality of life is tied to other species. Or we can try to survive in a world of increasing artificiality and diminishing biodiversity. Leopold (1966) wrote, "The land ethic simply enlarges the boundaries of the community to include the soil, waters, plants and animals, or collectively, the land." The Earth Council is developing an Earth Charter which will formulate a universal set of ethics applying to the relationships between man and nature.

6. MAIN PLAYERS IN THE FIELD

6.1. INTERNATIONAL LEGAL INSTRUMENTS

1971. Ramsar. Convention on Wetlands of International Importance Especially as Waterfowl Habitat
1972. WHC. UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage
1973. CITES. Convention on Trade in Endangered Species of Wild Flora and Fauna
1992. Framework Convention on Climate Change
1994. International Convention on Biological Diversity
1994. Draft Global Programme of Action to Protect the Marine Environment from Land-Based Activities
1994. Commission on Sustainable Development

6.2. INTERNATIONAL ORGANIZATIONS

The listings under International and National Organizations below provide a representative sample of organizations involved in water issues related to biodiversity. No attempt is made to be complete.

Aquatic Conservation Network, P.O. Box 67, Ottawa, 011, Westboro RPO, Ontario K2A 4E4, Canada, Tel: (613) 729-4670, Fax: (613) 729-5613, E-mail: rob@acn.ca.

Biodiversity Convention Secretariat, World Trade Centre, 413, St-Jacques Street, Suite 630, Montreal, Quebec H2Y 1N9, Canada, Tel: (514) 288-2220, Fax: (514) 288-6588, E-mail: biodiv@mtl.net

Desert Fishes Council, P.O. Box 337, Bishop, California, U.S.A. 93514, Tel: (619) 872-8751. Formed in 1976 to preserve the biological integrity of North American desert aquatic ecosystems and their interrelated faunas and floras.

Ducks Unlimited, Inc., 1 Waterfowl Way, Memphis, Tennessee, U.S.A. 38120, Tel: (901) 754-4666, Fax: (901) 753-2613. Aims to develop, preserve and maintain waterfowl habitat throughout North America and educate the public on waterfowl management and wetlands conservation.

FISH - Fishermen Involved in Saving Habitat in United States and Canada. Contact: Les Stanfield, Ontario Ministry of Natural Resources. Tel. (613) 476-3255.

Food and Agriculture Organization (FAO), Fisheries Division, Viale delle Terme di Caracalla, 00100 Rome, Italy.

Global Rivers Environmental Education Network (GREEN), 216 South State Street, Ann Arbor, Michigan, USA 48104, Tel. (313) 761-8142, Fax: (313) 761-4951. Aims to a means for exchange of data, information and ideas between people, schools and communities interested in studying and improving local and global water quality through hands-on monitoring and local problem solving.

ICES, International Council for the Exploration of the Sea, Palaegade 2-4, DK-1261, Copenhagen K, Denmark, tel: +45 33 154225, e-mail: ices.info@ices.dk, URL: http://www.ices.dk. ICES is a leading forum for the exchange of information on the sea and its living resources, and for the coordination of research by scientists in its 19 member countries.

International Center for Aquatic Resource Management (ICLARM), MCPO Box 1501, 1200 Makati, Metro Manila, Philippines.

International Network on Water, Environment and Health (INWEH), United Nations University, c/o McMaster University, Hamilton, Ontario L8S 4M1, Canada.

International Union for Conservation of Nature (IUCN) — The World Conservation Union, rue Mauverney, 28 Gland, Switzerland, Tel. +41-22-999-00-01, Telefax: +41-22-999-00-02. Includes Wetlands Programme of Ecosystem Management Group and Species Survival Specialist Groups such as: Hippo, Otter, Sirenia, Crane, Flamingo, Grebe, Heron, Pelican, Crocodile, Tortoise and Freshwater Turtle, Freshwater Fish, Sturgeon, Water Beetle, Mollusc, Inland Water Crustacean, Odonata, and Interdisciplinary groups such as Trade and Task Forces such as: the Red List group and the Declining Amphibian Populations group.

IUCN-World Bank Large Dams Interim Working Group, 1400 16th Street NW, Suite 502, Washington, D.C. 20036, U.S.A., Tel. (202) 797-5454, Fax: (202) 797-5461, e-mail: borlando@iucnus.org or asteiner@iucnus.org. This working group is to coordinate and facilitate the establishment of a global commission to assess experience on large dams, develop criteria for assessing alternatives for energy and water resource development, evaluate large dam effectiveness, promote sound standards, and other goals. The Commission is to be launched in November 1997.

International Water Resources Association,.IWRA Executive Office, The University of New Mexico, 1915 Roma NE, Albuquerque, New Mexico 87131-1436, U.S.A. Tel: (505) 277-9400, Fax: (505) 277-9405, E-mail: iwra@unm.edu.

International Water Supply Association, 1 Queen Anne's Gate, London, UK SW1H 9BT, Fax: +44 (171) 222-7243. Attn. Michael J. Slipper, Secretary General.

National Water Research Centre, Shoubra El Kheima, 13411, Egypt, Tel: +20-2-220-4360, Fax: +20-2-220-8219, Attn. Dr. Mahmoud Abu-Zeid, also Chair of Founding Committee of World Water Council.

The Nature Conservancy, 1815 North Lynn Street, Arlington, Virginia, U.S.A. 22209, Tel: (703) 841-5300. Aims to preserve plants, animals and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive.

Strategy for International Fisheries Research (SIFR), c/o IDRC, P.O. Box 8500, Ottawa, ON K1G 3H9, Canada.

UNESCO, 7, Place de Fontenoy, 75007 Paris, France.

United Nations Commission on Sustainable Development (CSD)

United Nations Environment Programme, Coastal and Marine Affairs and Aquatic Biodiversity, Water Branch, P.O. Box 30552, Nairobi, Kenya, Tel. (2542) 6222-022, Fax: (2542) 622-788, E-mail: ian.dight@unep.no.

United Nations Environment Programme Global Environment Monitoring System (GEMS) Collaborating Centre for Freshwater Monitoring and Assessment, National Water Research Institute, 867 Lakeshore Road, Burlington, Ontario L7R 4A6, Canada, e-mail: GEMS@cciw.ca. The GEMS/Water programme is a multi-faceted water science programme oriented towards understanding freshwater quality issues throughout the world. Major activities include monitoring, assessment and capacity building. Implementation involves several United Nations agencies active in the water sector as well as a number of organizations around the world. GEMS has produced a Water Triennial Report for 1988-1990, an electronic document on Water Quality of World River Basins on 82 major watersheds of the world, and an Annotated Digital Atlas of Global Water Quality for country data from 1976-1990.

Wetlands International, 7 Hinton Avenue North, Suite 200, Ottawa, Ontario K1Y 4P1, Canada, Tel: (613) 722-2090, Fax: (613) 722-3318, E-mail: davidson@wetlands.org, WWW: http://www.quickweb.com/wetnet/index.html. Aims to sustain and restore wetlands, their resources and biodiversity for future generations. Has 23 Specialist groups organized around taxonomic or thematic issues.

World Bank, Water Resources Section, 1818 H Street, N.W., Washington, D.C. 20433, USA, Tel: +1 (202) 473-0342, Fax: +1 (202) 334-0568, Attn. John Briscoe, Senior Advisor.

World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge, CB3 0DL, UK, Tel: +44-1223-2777314, Fax: +44-1223-277136. WWW: http://www.wcmc.org.uk. WCMC works with many collaborators, provides information services on conservation and sustainable use of natural resources, and helps build information management capacity in developing countries. The 1997 Red List is available at the WCMC web site.

World Water Council, Les Docks de la Joliette, 10 Place de la Joliette, Atrium 103, 13304 Marseille Cedex 02, France. Tel: 33(4) 91 99 41 00, Fax: 33(4) 91 99 41 01. Guy Lemoigne is the Executive Secretary - Directeur général. Its first international initiative was to co-organize the First World Water Forum held in Marrakesh, Morocco in March 1997. Membership is open to national and international institutions, government agencies, private and publica organizations and firms, as well as to non-governmental, academic and scientific organizations. **World Wildlife Fund** with numerous national offices.

6.3. NATIONAL ORGANIZATIONS

American Groundwater Trust, 6375 Riverside Drive, Dublin, Ohio, USA 43017, Tel: (614) 761-2215, Fax: (614) 761-3446. Aims to initiate and promote public education programs and information activities that lead to optimal utilization and protection of America's groundwater resources.

American Zoo and Aquarium Association (AZA),

Aral Sea Information Committee, 1055 Forth Cronkhite, Sausalito, California, USA 94965, Tel: (415) 331-5122, Fax: (415) 331-2722. Aims to assist the NGOs of Central Asia change existing water use of the Amu Darya and Syr Darya rivers to give priority to water for people, and to restore damaged fish and wildlife environments, including the Aral Sea.

Canadian Club of Rome and Robbert Associates, Robert Hoffman, 340 MacLaren Street, Ottawa, Ontario K2P 0M6, Canada, tel/fax: (613) 232-5613, e-mail: rhoffman@robbert.ca. Are developing a Global Sustainable Development Demonstration Framework, GSDDF using whatIf?® software tools, enabling what-if variation of processes including population, consumption, materials transformations, agriculture, forestry, and mining, tracking the stocks and flows of materials and energy throughout the system.

Canadian Water and Wastewater Association, 45 Rideau Street, Suite 402, Ottawa, Ontario K1N 5W8, Tel: (613) 241-5692, Fax: (613) 241-5193. T. Duncan Ellison, Executive Director.

Canadian Water Quality Association, 151 Frobisher Drive, Suite A-201, Waterloo, Ontario, Canada N2V 2C9, Tel: (519) 885-3854, Fax: (519) 747-9124. Aims to promote the individual right to quality water, educate water quality professionals, promote the growth of water quality improvement industry, serve as a unified voice in government and public relations, and provide a role in educating consumers on water quality.

Cooperative Research Centre for Freshwater Ecology, University of Canberra, P.O. Box 1, Belconnen, ACT 2616, Australia. Director's e-mail: cullen@lake.canberra.edu.au. Established in 1993 under the Federal Government's Cooperative Research Centres Program, the CRC brings together a unique mix of scientific expertise including microbial, algal, zooplankton, aquatic plants, invertebrates, fish and flood-plain ecologists into a centre with strong chemistry, physics, and computing resources, with strong links to hydrological expertise for catchment hydrology.

Department of Fisheries and Oceans of Canada, 200 Kent Street, Ottawa, Ontario K1A 0E6, Canada, Tel: (613) 990-0999, Fax: (613) 996-9055, URL: http://www.ncr.dfo.ca/.

Freshwater Institute, Department of Fisheries and Oceans, University of

Manitoba, Winnipeg, Manitoba R3T 2N6, Canada, Contact: Dr. J. Cooley, Regional Director of Science, Tel: (204) 983-2420, URL: http://www.cisti.nrc.ca/programs/indcan/fedlabs/text/111.html.

National Water Research Institute, Canada Centre for Inland Waters, Environment Canada, P.O. Box 5050, Burlington, Ontario L7R 4A6, Canada, Acting Executive Director, Dr. J.H. Carey, Tel: (905) 336-4625, URL: http://www.cciw.ca/. The National Water Research Institute (NWRI) is Canada's larges freshwater research establishment. It conducts a comprehensive program of research and development in the aquatic sciences, in partnership with Canadian and international science communities. Through ecosystem-based research, NWRI creates and disseminates new knowledge and understanding of aquatic ecosystems required for the resolution of environmental issues of regional, national or international significance for Canada.

North American Lake Management Society, 1 Progress Boulevard, Box 27, Alachua, Florida, USA 32615-9536, Tel: (904) 462-2554, Fax: (904) 462-2568. Aims to promote the understanding, protection, restoration, and management of lakes, ponds, and reservoirs.

Rawson Academy of Aquatic Sciences (The), 1 Nicholas Street, Suite 620, Ottawa, Ontario, Canada K1N 7B7, Tel: (613) 563-2636, Fax: (613) 533-4758.

Stockholm Environment Institute, Box 2142, S-103 14 Stockholm, Sweden, Attention Regina Hahlin. Tel: +46-8-723 02 60, Fax: +46-8-723 03 48, E-mail: rhahlin@nordnet.se, URL: http://nn.apc.org/sei.un.water/

Watercan / Eau vive, 323 Chapel Street, Ottawa, Ontario, Canada K1N 7Z2, Tel: (613) 230-5182, Fax: (613) 237-5969. Aims to sensitize Canadians to the need for clean water around the world, and to raise funds to support communities of the developing world in providing themselves with simple low cost water and sanitation systems along with hygiene education. Watercan is a coalition of non-profit organizations.

Water Environment Federation, 601 Wythe Street, Alexandra, Virginia, USA 22314-1994, Tel: (703) 684-2400, Fax: (703) 684-2492. Aims to enhance and preserve water quality worldwide, through the provision of education and technical services. Guides technological developments in water quality and provides members and the public with the latest information on wastewater treatment and water quality protection.

Water Supply and Sanitation Collaborative Council, 20, avenue Appia, CH 1211 Geneva 27, Switzerland, Tel: 41 22 791-3685; Fax: 41 22 791-4847.

7. KEY MEETINGS IN 1997-98

The listing below provides a selected list of key meetings involving water use and living aquatic resources.

5-8 August 1997
Waterpower '97 — An international conference and exposition on hydropower to be held at World Congress Center, Atlanta, Georgia. Contact: Ms. Patricia Dalton, Waterpower '97, Conferences and Conventions Department, American Society of Civil Engineers, 345 East 47th Street, New York, NY 10017 USA, Tel: 800-548-ASCE or (212) 705-7283, Fax: (212) 705-7975.
10-15 August 1997
7th Stockholm Water Symposium, 3 rd International Conference on Environmental Management of Enclosed Coastal Seas (EMECS), to be held in Stockholm, Sweden. Contact: Stockholm Water Symposium/EMECS-Conference 1997, Stockholm Water Company, S-10636, Stockholm, Sweden, Fax: +46 (8) 736-2022, E-mail: sympos@sthwat.se
24-28 August 1997
127th Annual Meeting of the American Fisheries Society to be held in the Monterey Convention Center, Doubletree and Marriott Hotels, Monterey, California, U.S.A. Contact: Paul Brouha, AFS, 5410 Grosvenor Lane, Suite 110, Bethesda, Maryland 20814, USA, Tel: (301) 897-8616, extension 209, Fax: (301) 897-8096, E-mail: pbrouha@fisheries.org.
24-30 August 1997
9th International Congress of the European Society of Ichthyologists to be held in Trieste, Italy. Contact: Pier Giorgio Bianco, Executive Secretary, SEI, Diparmento di Zoologia, Via Mezzocannone, 8, 1-80134 Naples, Italy, Tel: 39 81 5527089, Fax: 39 81 5526452
26-29 August 1997
International Water Resources Association Conference at ENS '91. Contact: The ENS Secretariat, P.O. Box 2553, Ullandhaug, 4004, Stavanger, Norway. Tel: +47-51-870050, Fax: +47-51-550525.
1-6 September 1998
International Water Resources Association, 9th World Water Congress - Water Resources Outlook for the 21st Century: Conflicts and Opportunities. Held in Montréal, Québec, Canada. Contact Aly M. Shady, Tel: (819) 994-4098, Fax: (819) 953-3343.
15-17 September 1997
Hydropower into the Next Century, to be held in Portoroz, Slovenia. Contact: The International Journal on Hydropower and Dams, Aqua-Media International Ltd., Westmead House, Westmead Road, Sutton, Surry, SM1 4JH, UK, Tel: +44 (181) 643-4727 ext. 5133, Fax: +44 (181) 643-8200.
15-19 September 1997
International Commission on Irrigation and Drainage (ICID). 48th IEC Meeting and 18th European Regional Conference on Irrigation and Drainage, to be held in London, Oxford, U.K. Contact: Rachel Coninx, Thomas Telford Services, One Great George Street, London, SW1 3AA, UK.
6-9 October 1997

IDA World Conference on Desalination and Water Reuse, to be held in Madrid, Spain. Contact: Pat Burke, IDA Headquarters, P.O. Box 387, Topsfield, Massachussetts 01983, U.S.A., Tel: +1 (508) 887-0410, Fax: +1 (508) 887-0411, E-mail: ida1pab@ix.netcom.com.

20-23 October 1997

International Conference on Large-scale Water Resources Development in Developing Countries: New Dimensions of Prospects and Problems, to be held in Kathmandu, Nepal. Contact: Kiran K. Bhattarai, D & M Associates, EPC 400, GPA Box 8975, Kathmandu, Nepal, Tel/Fax: +977 (1) 371-249, E-mail: KIRAN@kiranpc.mos.com.np or gnp@bangla.net or adg@ait.ac.th.

17-21 November 1997

Drainage for the 21st Century: With Special Emphasis to the Humid Tropics, to be held in Penang, Malaysia. Contact: Secretary of MANCID, c/o Planning and Evaluation Division, Department of Irrigation and Drainage, Jalan Sultan Salahuddin, 50626, Kula Lumpur, Malaysia, Tel: +603-291-4452, Fax: +603-291-1082 or +603-291-4282.

25 February - 1 March 1998

1st International Conference on Water Quality and its Mangement, to be held in New Delhi, India. Contact: C.V.J. Varma, Central Board of Irrigation and Power, Malcha Marg, Chanakyapuri, New Delhi, 110 021, India, Tel: +91 (11) 301-5984 or +91 (11) 301-6567, Fax: +91 (11) 301-6347, E-mail: cbip@cbipdel.uunet.in.

20-25 July 1998

49th IEC Meeting (ICID) and 10th Afro-Asian Regional Conference (ICID) to be held at Denpasar, Bali, Indonesia. Contact: Indonesian National Committee, Direktrat Jenderal Pengairan, DPU, 20 Jalan Patimura, P.O. Box 6739, Jakarta 12067, Indonesia, Tel: +62 (21) 739-6616 ext. 405/406, Fax: +62 (21) 739-1956.

4 November 1998

66th ICOLD Executive Meeting and Symposium of Rehabilitation of Dams, to be held in Gjoa, India. Contact. C.V.J. Varma, Indian Committee on Large Dams (ICOLD), CBIP Building, Malcha Marg, Chankyapuri, New Delhi, 110 021, India, Tel: +91 (11) 301-5984, Fax: +91 (11) 301-6347, E-mail: cbip@cbipdel.uunet.in.

8. STRATEGIES AND OPTIONS

The following global priority strategies and actions are derived from the forgoing review and analyses. Individuals countries may need to add strategies and actions to meet their particular priorities.

8.1. USE ECOLOGICAL STRATEGIES & ACTIONS

Ecological strategies and actions are divided into *in situ* activities in water bodies, and *ex situ* activities that take place on land. The overall strategy is to maintain natural genetic, taxonomic and ecological diversity of freshwater ecosystems, and their ecological functions. That requires that the physical, chemical, dissolved gases, and seasonal rhythms of rivers, lakes and wetlands be maintained, and that the species be free to undergo their normal daily and life cycle migrations, in a phrase, to maintain the ecological integrity and diversity.

A. Water-based sector ecological strategies & actions

8.11. Dams and river engineering

* Implement energy conservation before construction of new electric power projects
* Halt dam construction in areas of high biodiversity or endemism
* Avoid dam construction in areas of high biological resource productivity, such as natural flood plains, or where seasonal rhythms or migrations are closely tied to life cycles or productivity
* Investigate alternatives to hydroelectric power generation such as *in situ* solar power
* Implement alternatives to high-volume agricultural irrigation, such as drip irrigation, and traditional small-scale affordable methods such as run-off farming, terracing, in-soil clay-pot watering, tanks, *muang faai* systems, small earth dams, mulching, recharging water table with *khadins*, *qanats*, cultivation of xerophytic crops or varieties, and by reducing water leakage from existing pipe/canal delivery systems
* Investigate ecological methods of flood control, reforestation, multi-crop and agroforestry, augmentation of humus levels and soil porosity, to reduce rapidity of runoff and river siltation
* Stop draining wetlands which provide ecological services and habitat for aquatic species. Restore wetlands; each 1% restored wetlands in a basin reduces flood peaks by nearly 4% (McCully 1996).
* Moderate grazing levels to allow vegetation to regenerate and soil to recover from compaction to reduce rapid runoff and river siltation
* Modifying dam water release practices to more closely mimic natural conditions.
* Decommission dams which threaten survival of important species/ ecosystems, or biological resources.

8.12. Exotic species/genes

* Use indigenous species in aquaculture, most exotics eventually escape
* Use habitat restoration, local genotypes and species to enhance commercial and recreational fisheries, rather than exotic forms
* Use regulations, awareness and education campaigns to discourage introduction of exotics in ballast water or by dumping ornamentals or cultured species
* Use biological controls to reduce impacts of harmful exotics
* Conclude agreements with neighbouring states to require unanimous approval

for introduction of exotic species into shared water bodies or basins

8.13. Stock-focussed fishery management

* Develop and phase in ecosystem-based fishery management, giving as much attention to habitat maintenance and ecological webs as to stock maintenance
* Develop integrated water basin resource management
* Establish freshwater protected areas to strengthen fish stocks as well as to conserve freshwater biodiversity and ecological functions
* Restore wetlands

B. Land-based sector ecological strategies & actions

Give more attention to the role of natural terrestrial ecosystems in managing the hydrological cycle and their alternatives to major engineering investment (Ejigu 1997).

8.14. Agricultural runoff

Chemical and soil erosion runoff harms aquatic ecosystems; farming and grazing have increased the annual sediment loads of rivers of the world from 9 to as much as 45 billion tonnes.

* Enhance crop genetic diversity, species mixes, crop pest resistance and other practices in fields to reduce pest infestations and pesticide requirements, hence pesticide runoff into water bodies
* Change tillage, orient furrows cross the slope, enhance soil crop cover, avoid overgrazing, and use other agricultural practices to reduce immediate runoff, erosion, and consequent variability in water levels, water turbidity and sedimentation of aquatic habitats
* Adapt crops or fertilizer practices to minimize fertilizer runoff and eutrophication of water bodies. Leave crop stalks on land and use mycorrhizal fungi and other nutrient piping/recycling ecological functions.
* Adopt appropriate and improved irrigation technology to minimize water withdrawals, or whenever feasible use crops that are less water intensive.

8.15. Forestry runoff

* Selectively log forests or log only small, narrow contoured forest strips to reduce rapid runoff of water, soil erosion with consequent turbidity and sedimentation of aquatic habitats
* Maintain a wide swathe of natural indigenous riparian vegetation along streams, lakes and coasts, and on flood plains to reduce erosion and to provide appropriate habitat and food for life cycle processes during natural flooding
* Manage so as to achieve natural woody debris levels in streams

8.16. Municipal discharges

* Stop discharge of toxics into municipal wastewater

* Use wastewater as a resource rather than degrading aquatic ecosystems. Apply municipal wastewater for water/nutrients on farmlands, in aquaculture, or treat it in biological recycling systems, thus avoiding eutrophication
* Use best management practices to reduce the impact (toxic, siltation) of urban runoff and stormwater discharge to the receiving aquatic environment by using for example stormwater detention ponds and wetlands or Living Machines.
* Alert the public on the effects of dumping toxics in sewers

8.17. Industrial discharges

* Find profitable alternatives to, or re-use and recycle industrial chemicals, to prevent discharge of toxins, carcinogens, mutagens, hormone disrupting compounds, and other harmful chemicals into water bodies, or release of greenhouses gases and ozone depleting chemicals into the atmosphere.

C. Drainage basin protected area strategies & actions

Areas designed to protect freshwater biodiversity need to include not only the desired freshwater bodies, rivers, lakes or wetlands, but also sufficient of the adjacent drainage basin. Wang *et al* (1997) showed the degree to which various land-based activities affected stream ecosystems. Adequate legislation, enforcement and education programs should be implemented, if they are not already. Biological surveys, museum/
biodiversity center data bases, aerial and satellite imagery help provide information useful for selection of protected areas. Rubec and O'Hop (1995) show how GIS can help integrate geographic information for fisheries management.

8.18. Establish hierarchical ecosystem classification

* Establish a global hierarchical freshwater ecosystem classification. Map the units on appropriate base maps, and if possible, in GIS systems. Indicate which ecosystems lack protected areas or adequate protected areas.

8.19. Select and create protected areas

* Establish classes, goals for, and criteria for selection of protected areas. Criteria can, amongst others, degree of threat at various levels (local to global) or ecological intactness; hotspots of species, endemic species, species at risk and higher taxa; and degree of uniqueness (local to global). * Involve local stakeholders in establishment and management of protected areas.
* Select protected areas and establish boundaries, pass necessary legislation, and staff protected area. Implement restoration programs when required.

8.2. ENGAGE ALL OF SOCIETY

8.21. Increase public awareness and knowledge

* Publish popular manuals and technical monographs on aquatic fauna and flora

* Conduct public awareness and education programs
* Introduce children to environmental issues and involve them in projects
* Foster the concept of balance between humans and nature, the need to reserve space for freshwater biodiversity and ecological processes
* Foster ecological approaches to conservation and sustainable use
* Discourage development on natural flood plains
* Develop educational tools
* Ensure that the curricula of engineering and commerce faculties include ecological components
* Engage corporations benefiting from aquatic ecosystem integrity, see Fig. 17.

Fig. 17. *The eco-tourism industry & clientelle are value the integrity of aquatic ecosystems.* *Photo by D.E.M.*

8.22. Develop capacity and strengthen institutions

* Identify and fill gaps in freshwater taxonomic and ecological expertise
* Foster research into lessor known freshwater taxonomic groups & ecosystems.
* Enhance capacity to conduct biological surveys and survey traditional ecological knowledge, collect specimens for taxonomic study, map species & ecosystem data
* Establish biodiversity data centres in museums or other suitable institutions or agencies to provide data, carry out geographic information system analyses
* Identify representative ecosystems and species hotpots as candidates for freshwater protected areas including neighbouring drainage basins
* Develop capacity and programs to carry out ecosystem-based and watershed approaches to conserving and sustainably using aquatic biodiversity
* Hold workshops for fishers and biologists to discuss traditional and modern fishing methods with low habitat impact and low bycatches to transfer technology South-South and South-North.

8.23. Expand equity, multilateral & effective decisions

* Engage all sectors of society in open and transparent processes. Include especially communities adjacent to water bodies, women, fishers, farmers, schools and universities
* Encourage traditional societies and indigenous peoples to contribute traditional ecologically sustainable alternatives to mega-development
* Include nature as a practical cost-effective partner; work with, not against, ecological principles
* Ensure all government agencies and other sectors coordinate efforts
* Establish national water councils to coordinate implementation and harmonize incentives

8.3. ADDRESS ROOT CAUSES

Addressing root causes will make for effective programs. Ground will be lost if only symptoms are addressed. People and trade are not islands independent of the natural world.

* Consider and address effects of trends in population, consumption, poverty, and inappropriate marketing.
* Fundamentally change WTO so that environment and social issues are profoundly considered in coming to decisions on trade; include suitable expertise on delegations; open the decision process to input from environmental and peoples organizations.
* Emend WTO, international trade agreements, GATT, and the draft Multilateral Agreement on Investment to ensure that globalization of trade does not trade off local or planetary support systems or increase the environmental debt, and so that they are brought into conformity with international legal instruments like the International Convention of Biological Diversity and the Law of the Sea.
* Pass legislation penalizing the solicitation, acceptance, offering or payment of bribes to circumvent environmental (or other) laws or moral responsibilities, drawing upon the OECD draft anti-corruption law.

9. OVERVIEW

Freshwater ecosystems are intimately linked to human activities. Throughout human history people have built their communities along the shores of lakes and rivers, and from ancient times cultures and civilizations have evolved and adapted to the annual cycle of renewal of the world's great river systems. The human pressures now being placed on freshwater ecosystems around the world are increasingly complex and increasingly pervasive, and in many instances the capacity of these systems to assimilate wastes and withdrawals have been surpassed as has their capacity to support the sustainable use of freshwater or living freshwater resources. Humans use over half of the available freshwater runoff. The dramatic loss of biodiversity in many freshwater ecosystems is an unmistakable result of the cumulative impact of these stresses.

Surface freshwater found in the world's lakes and rivers makes up a tiny fraction (about one part in ten thousand) of the water on earth. Yet this fraction is the fraction that has provided the "spark" or "stuff of life" that has allowed evolution and speciation to flourish over millennia in geographically isolated and protected freshwater ecosystems. Like oceanic islands, old unglaciated freshwater ecosystems have given rise to countless, endemic species and varieties. Lakes and rivers have been hotbeds of evolution that have resulted in an astonishingly rich, but very vulnerable, biodiversity heritage.

Water is motion. It may have arrived on Earth from outer space as the frozen ice of comets. Here on Earth it ceaselessly moves between many forms: oceans, glaciers, groundwater, lakes, streams, wetlands, soil moisture, living organisms, water vapor, clouds, rain. Rain falls, supplying plants, soil, groundwater, rivers and lakes; some flows to the ocean. Plants transpire moisture, some moisture condenses as clouds, and clouds give birth to life giving rain. And so the natural cycle repeats, unless interrupted by humankind. Understanding this cycle is a key to freshwater biodiversity conservation and living freshwater resource management.

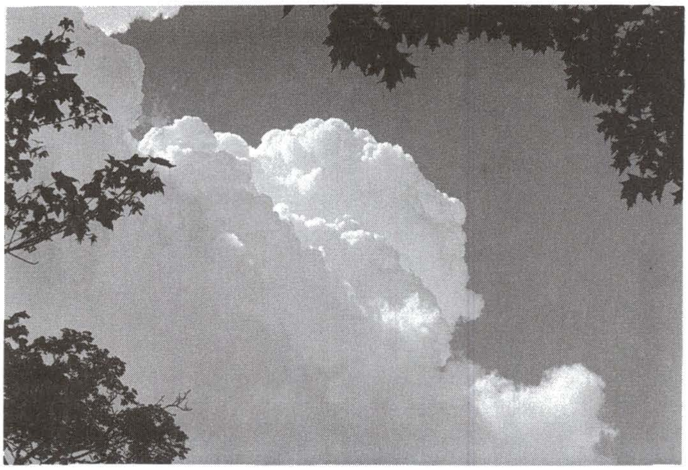


Fig. 18. The trees transpire water vapor and create the clouds; the clouds give birth to rain and water the trees, recharge the groundwaters and rivers. Understanding the hydrological cycle is a key to meeting the needs of humankind and nature for fresh water. When the land becomes bared of vegetation, more rainwater runs directly to the sea. Photo by D.E.M.

Surface water bodies are not islands. Rather they occur in a series of larger interconnected envelopes or "sheds." Lakes, streams, wetlands and underground waters, occur in slowly or rapidly flowing watersheds. Overlying watersheds are airsheds, where prevailing winds transport molecules and particles of human or natural origin, which may drop by themselves or be carried by precipitation into watersheds. Encompassing airsheds is the atmosphere. The atmosphere is permeated with volcanic particles and gases, aeolian soil specks, greenhouse gases, raindrop nuclei (natural and anthropogenic), and global pollutants. These components are condensed (in colder regions) or transported down to watersheds, or they variously reflect/absorb/trap energy/radiation from the sun. The airshed lifts from water bodies, vapor, gases, and (from phytoplankton) water droplet condensation nuclei. Outside is the spaceshed, or outer space which interfaces with the atmosphere. Downwards across that interface, over time, rain tiny to enormous masses of water and mineral as dust, meteors and comets, as well as solar radiation. It is a marvellous, interacting, dynamic system.

Much of what we know and understand about both the richness and the vulnerability of freshwater biodiversity is based on what we know about the freshwater fishes that inhabit — or once inhabited these systems. It is, however, clear that the conditions and circumstances that gave rise to a rich, diverse and vulnerable "fish fauna" also gave rise to other freshwater life forms that are equally rich, diverse and vulnerable. It is discouraging, though not at all surprising, to find that with group after group, it is the freshwater fauna that is the most threatened and endangered. Freshwater mussels, freshwater crayfish, and amphibians are all taxonomic groups that are particularly vulnerable. Of 297 native freshwater mussels (families Margaritiferidae and Unionidae) in the United States and Canada, 71.7% are considered endangered, threatened, or of special concern (Williams *et al* 1993).

The reasons for the extreme vulnerability of freshwater biodiversity are many and varied. Some are obvious. Habitat destruction, invasive alien species, over-exploitation and pollution are powerful factors that are driving the loss of biodiversity globally. They are particularly destructive for the biodiversity of freshwater ecosystems. In part this is because the intensity of human burdens on ecosystems is usually greatest where people live, work, consume, release their wastes, build our cities and our industries — along the shores of lakes and rivers. In a sense, however, these biophysical stresses are themselves the result of the human socioeconomic systems, values, attitudes, and decisions. They must also be addressed if policy makers are to understand and reverse the root causes of biodiversity loss.

The hydrologic system and especially the freshwater portion of this great cycle are integrators of human activity within airsheds and especially within watersheds. Raindrops now contain traces of potent man-made chemicals that impact biota and humans thousands of miles from the sources of pollution. Watersheds and airsheds funnel the stresses — chemicals, invasive alien species, sediments — into ground waters, streams, rivers and lakes. Humans dam, divert, channelize, impound, reclaim and regulate rivers and lakes for energy, industry, agriculture, and municipal uses until there is little or no resemblance to the original ecosystems within which the original life forms (biodiversity) evolved. Often the life forms inhabiting these unique and confined ecosystems simply have no place to go and the result all too often is their elimination.

Globalization is about crossing geographic boundaries or barriers. Many of the barriers that once protected watersheds and their biodiversity-rich ecosystems are not immune from these stresses. Invasive alien species whether brought in accidentally by ocean-going ships or intentionally for aquaculture with accidental escapes into the wild, are linked to the globalization of trade. The spread of exotics and the "boom" in freshwater aquaculture are likely to continue, impacting on the species composition and water quality of natural ecosystems.

A prerequisite for slowing or perhaps even reversing the rate of loss of freshwater biodiversity is to recognize that the conservation of freshwater biodiversity must have higher priority. While experts may appreciate that the biodiversity of freshwater ecosystems is extremely rich, diverse and vulnerable, it hardly matters when in reality the public and politicians are not sufficiently concerned to consider this a priority amongst a host of other more immediate competing priorities. A valuation of aquatic biodiversity including ecological services, fish catch and other harvests from fresh waters, might serve to convince the wider audience of aquatic biodiversity's worth.

If humans are to develop effective responses to the threats posed to freshwater ecosystems and to freshwater biodiversity it will require some fundamental changes in the way people manage their interaction with watersheds. A good start would be to give much greater emphasis on ecosystems and watershed approaches for the conservation, protection, sustainable use and equitable sharing of freshwater biodiversity. The river, lake and wetland ecosystems and their species must be recognized as part of a greater ecoscape which includes the land and human activities upon it.

Perhaps most important and most difficult is the compelling need to understand better the fundamental socioeconomic factors that are driving the loss of biodiversity, and to communicate this understanding in ways that will help to bring about constructive change. It may well mean a much more interdisciplinary approach to the understanding of the linkages between the global macroeconomic and ecological systems and how the current rules of that great global macroeconomic "monopoly game" are impinging on global biodiversity. An important dimension of this challenge is to be able to document clear examples where economic activities and policies are causing loss of biodiversity, while, at

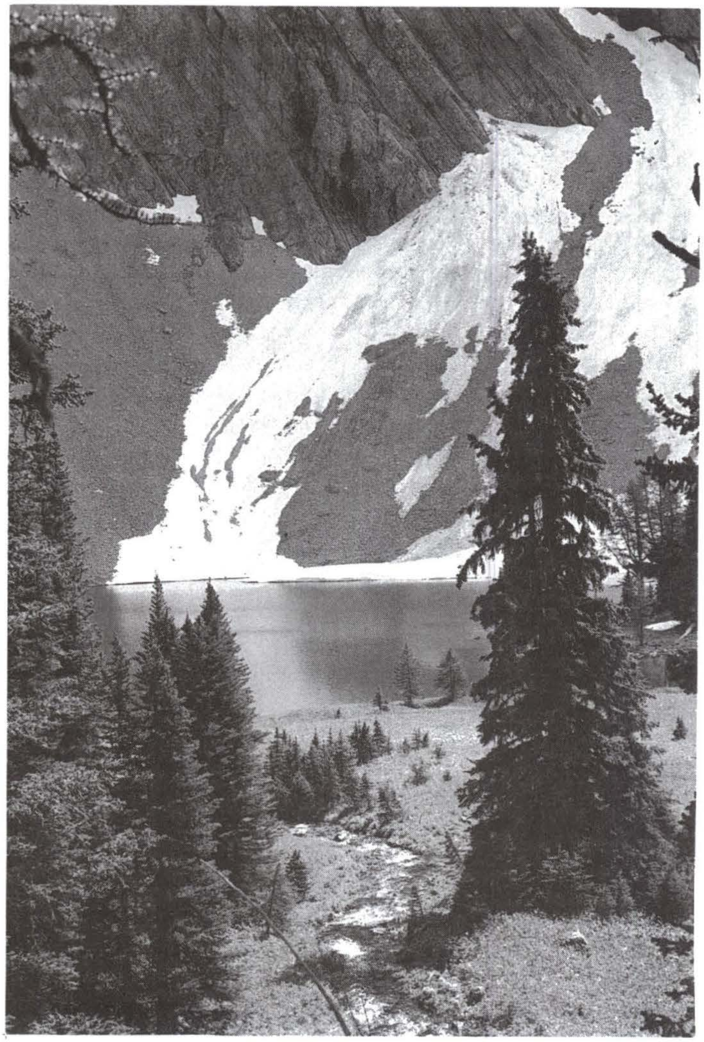


Fig. 19. If humans are to develop effective responses to the threats posed to freshwater ecosystems and to freshwater biodiversity it will require some fundamental changes in the way people manage their interaction with watersheds. A good start would be to give much greater emphasis on ecosystems and watershed approaches for the conservation, protection, sustainable use and equitable sharing of freshwater biodiversity. The river, lake and wetland ecosystems and their species must be recognized as part of a greater ecoscape which includes the land and human activities upon it. Photo by D.E.M.

the same time, being prepared to raise serious questions and offer constructive solutions that could help reverse present trends and teach important lessons for the future.

As part of this learning/adapting process we also cannot overlook the potential for small local, but cumulative initiatives to make a constructive difference. In the long run it seems to many of us that the rules of the "global macroeconomic market approach" will need to be altered — perhaps drastically — so that it becomes more practical and more possible for communities, especially local and indigenous, communities to conserve, protect and sustainably use the biodiversity of local freshwater ecosystems. It is not yet too late to tune the global trade and financial instruments so they are of service to nature and local communities, and not the other way around. These local communities are critical front lines in saving biodiversity. A major challenge of international statesmen as well as national and local politicians now is to provide fresh and innovative international and national contexts that enable the strengthening of the ability of local communities to sustain the biodiversity of the ecosystems on which they depend.

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10. KEY SOURCES OF INFORMATION

10.1. ELECTRONIC SOURCES

Usegroups

AQUA-L — Discussion of aquaculture of all types
BENE —
Biodiv-L — Biodiversity discussion group
Bionet
Fish-Ecology
Fishfolk
rec.aquaria & sci.aquaria — Aquarium hobbyists
sci.bio.fisheries

Web Sites

Aquatic Conservation Network —
http://www.ncf.carleton.ca/freeport/social.services/eco/orgs/aquat-con/menu
Canada Centre for Inland Waters —
http://www.cciw.ca/

Conservation Ecology (journal) —
    nttp://www.consecol.org/vol1/iss/art1
DRWG, OPIRG, Carleton University —
    http://www.
Environment Canada Water Page —
    http://www.ec.gc.ca/water/index.htm
FINS Aquarium Society Page —
    http://www.actwin.com/fish/clubs-national.html
FishBase of ICLARM —
    http://www.fishbase.org
Global Biodiversity —
    http://www.nature.ca/english/gbzine.htm
International Rivers Network —
    http://www.irn.org
Mangrove Action Project
    http://wwwearthisland.org/ei/
Ramsar —
    http://iucn.org/themes/ramsar/
Riparian Ecology Group —
    http://www.ekbot.umu.se/river/ripecol.htm
Sustainable Freshwater Aquaculture —
    http://www.fishace.demon.co.uk
World Fisheries Trust —
    http://vvv.com/~worldfish

CD ROMs

ASFA. **Aquatic biology, aquaculture and fisheries resources**. Biology, fisheries and aquaculture portions of Aquatic Sciences and Fisheries Abstracts (ASFA) with Fisheries Review, FISHLIT, Fish and Wildlife Reference Service, AQUACULTURE, Fish Health News, and Castell's Nutrition Resources, available with annual subscriptions and quarterly updates. Available from National Information Services Corp., Baltimore, Maryland.

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NISC. **Fish and fisheries worldwide** CD ROM by U.S. Fish and Wildlife Service, J.L.B. Smith Institute of Ichthyology and National Fisheries, on fish ecology, distribution and economic aspects.

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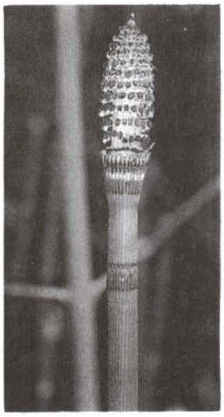

Fig. 20. Horsetails, ***Equisetum****, are one of many moisture-loving plants. Photo by D.E.M..*

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APPENDIX 1. FISH SPECIES DIVERSITY BY COUNTRY

(See Methods below)

COUNTRY	AREA KM^2	NO. FW SPECIES	NO.FW SPECIES/ $1000KM^2$	SOURCE
AFRICA				
Algeria	2,381,740	20	.00840	2
Angola	1,246,700	207	.166	2
Benin	110,620	84	.759	2
Botswana	566,730	54	.0953	2
Burkina Faso	273,800	99	.362	2
Burundi	25,650	209	8.148	2
Cameroon	465,400	342	.735	2
Central African Rep.	622,980	45	.0722	2
Chad	1,259,200	134	.106	2
Congo	341,500	315	.922	2
Cote d'Ivoire	318,000	167	.525	2
Djibouti	23,180	4	.173	2
Egypt	995,450	88	.0884	2
Equatorial Guinea	28,050	55	1.961	2
Ethiopia	1,101,000	66	.0599	2
Gabon	257,670	169	.656	2
Gambia, The	10,000	93	9.300	2
Ghana	227,540	224	.984	2
Guinea	245,860	172	.700	2
Guinea-Bissau	28,120	55	1.956	2
Kenya	569,690	255	.448	2
Lesotho	30,350	8	.264	2
Liberia	90,750	115	1.267	2
Libya	1,759,540	9	.00511	2
Madagascar	581,540	75	.129	2
Malawi	94,080	361	3.837	2
Mali	1,220,190	123	.101	2
Mauritania	1,025,220	8	.00780	2
Mauritius	2,030	28	13.793	2
Morocco	446,300	39	.0874	2
Mozambique	784,090	253	.323	2
Namibia	823,290	42	.0510	2
Niger	1,265,700	166	.131	2
Nigeria	910,770	278	.305	2
Rwanda	24,670	42	1.702	2
Senegal	192,530	127	.660	2
Sierra Leone	71,620	117	1.634	2
Somalia	627,340	35	.0558	2
South Africa	1,221,040	153	.125	2
Sudan	2,276,000	105	.0461	2
Swaziland	17,200	13	.756	2
Tanzania	886,040	682	.770	2
Togo	54,390	60	1.103	2
Tunisia	155,360	17	.109	2
Uganda	199,550	247	1.238	2

Zaire	2,267,600	962	.424	2
Zambia	743,390	335	.451	2
Zimbabwe	386,670	114	.295	2
ASIA				
Afghanistan	652,090	84	.129	3
Bangaladesh	130,170	260	1.997	3
Bhutan +	47,000	29	.617	2
Burma	657,540	300	.456	2
Cambodia	176,520	260	1.473	3
China	9,326,410	1,010	.108	3
India	2,973,190	748	.252	3
Indonesia	1,811,570	1,300	.718	3
Iran	1,636,000	148	.0905	1
Iraq	437,370	49	.112	1
Israel +	20,330	28	1.377	2
Japan	376,520	150	.398	3
Jordan +	88,930	5	.0562	2
Korea, Dem.Peop.Rep.+	120,410	30	.249	3
Korea, Republic	98,730	90	.912	2
Lao Peop. Dem. Rep.	230,800	262	1.135	3
Lebanon +	10,230	5	.489	2
Malaysia	328,550	600	1.826	3
Mongolia	1,566,500	56	.0357	3
Nepal	136,800	129	.943	3
Oman	212,460	5	.0235	1
Pakistan	770,880	159	.206	3
Philippines	298,170	330	1.107	3
Saudi Arabia	2,149,690	7	.00326	1
Singapore	610	45	73.770	3
Sri Lanka	64,630	90	1.393	3
Syrian Arab Rep. +	183,920	14	.0761	2
Taiwan	36,101	95	2.632	3
Thailand	510,890	690	1.351	3
Turkey +	769,630	55	.0715	2
United Arab Em. +	83,600	1	.0120	2
Viet Nam	325,490	450	1.383	3
Yemen	527,970	8	.0152	1
NORTH & CENTRAL AMERICA				
Belize +	22,800	23	1.009	2
Canada	9,220,970	190	.0206	1A
Costa Rica +	51,060	37	.725	2
Cuba +	109,820	30	.273	2
Dominican Rep.+	48,830	16	.328	2
El Salvador +	20,720	19	.917	2
Guatemala +	108,430	50	.461	2
Haiti +	27,560	12	.435	2
Honduras +	111,890	40	.357	2
Jamaica +	10,830	11	1.016	2
Mexico +	1,908,690	480	.251	5
Nicaragua +	118,750	33	.278	2

Panama +	75,990	54	.711	2
Trinidad & Tobago +	50,130	60	1.197	2
United States	9,166,600	779	.0850	2
SOUTH AMERICA				
Argentina +	2,736,690	373	.136	7
Bolivia +	1,084,380	44	.0406	2
Brazil	8,456,510	3000	.355	2
Chile +	748,800	64	.0855	2
Colombia +	1,038,700	123	.118	2
Ecuador +	276,840	44	.159	2
Guiana, French+	378,402	67	.177	2
Guyana +	196,850	105	.533	2
Paraguay +	397,300	47	.118	2
Peru	1,280,000	855	.668	2
Suriname +	156,000	56	.359	2
Uruguay +	174,810	50	.286	2
Venezuela	882,050	512	.580	6
EUROPE				
Albania +	27,400	20	.730	2
Austria +	82,730	51	.616	2
Belgium +	30,230	52	1.720	2
Bulgaria +	110,550	60	.543	2
Czechoslovakia(for.) +	125,360	73	.582	2
Denmark	42,390	51	1.203	2
Finland	304,610	55	.181	2
France	550,100	80	.145	2
Germany	349,310	65	.186	2
Greece +	128,900	41	.318	2
Hungary	92,340	69	.747	2
Iceland +	100,250	10	.0998	2
Ireland +	68,890	28	.406	2
Italy +	294,060	55	.187	2
Netherlands +	33,920	59	1.739	2
Norway +	306,830	33	.108	2
Poland +	304,420	61	.200	2
Portugal	91,950	39	.424	2
Romania +	230,340	75	.326	2
Spain	490,440	27	.0551	2
Sweden +	411,620	50	.121	2
Switzerland +	39,770	50	1.257	2
United Kingdom	241,600	55	.228	2
Yugoslavia (form.) +	255,400	69	.270	2
U.S.S.R. (former)				
Armenia +	28,400	24	.845	2
Azerbaijan +	86,100	44	.511	2
Belarus +	207,600	37	178	2
Estonia +	43,200	35	.810	2
Georgia +	69,700	28	.402	2
Kazakhstan +	669,800	19	.0284	2

Kyrgyzstan +	191,300	0	0.0	2
Latvia +	62,050	47	.757	2
Moldova Republic +	33,700	50	1.484	2
Russian Fed.+	6,995,800	130	.0186	2
Tajikistan +	142,700	0	0.0	2
Turkmenistan +	488,100	14	.0287	2
Ukraine +	603,550	64	.106	2
Uzbekistan +	425,400	84	.197	2
OCEANIA				
Australia +	7,644,440	183	.0239	2
Fiji +	18,270	28	1.533	2
New Zealand	267,990	46	.172	2
Papua New Guinea	452,860	329	.726	3
Solomon Is. +	27,990	11	.393	2

1 = Brian W. Coad (pers. com.), 2 = Coad (1995), 3 - Froese & Pauly 1996, 4 = Kottelat & Whitten 1996, 5 = Salvador Contreras-Balderas, 6 = Mago-Leccia 1970, 7 = Ringuelet & Aramburu 1961. "+s" indicate countries with species counts that are probably significantly underestimated.

Methods: Country biodiversity data for freshwater fish species are presented in Table 1. The country names and geographic areas of each country are from the World Resources Institute report for 1996-97. Most of the fish counts are from Froese and Pauly's (1996) FishBase 96, with some updates by Kottelat and Whitten (1996) and other authors as cited in the table. The FishBase figures were derived as follows: a) where the number was recorded as complete and was not re-estimated, that figure was used; where the number was incomplete, but an estimate of the total number was provided, the latter was used; where the number in FishBase was incomplete and no other figure was presented, then this figure was indicated and those country names are followed by a "+" sign. FishBase freshwater species counts are based on primary, secondary and introduced species (excluding marine visitors). The numbers for most countries are incomplete, research is still turning up new geographic records and new species. Taxonomic research is incomplete and some species will be later found to be synonyms, and new species will be discovered. In addition biological surveys and taxonomic research are in varying states of advancement in different parts of the world. Nevertheless the counts in most cases will represent the relative differences between countries.

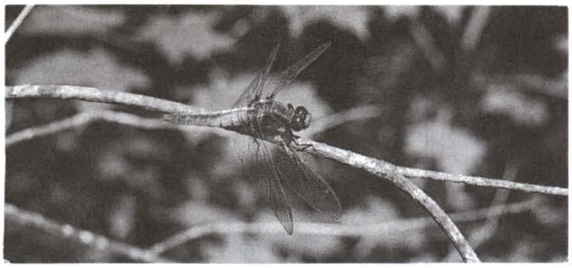

Fig. 21. A dragonfly, a member of the Order Odonata, is one of the fellow beings on this planet with whom we humans share a need for water. The larvae of dragonflies are aquatic while the adults are terrestrial and aerial. Dragon flies benefit humans by consuming mosquitoes. What do humans do for dragonflies? Photo by D.E.M.

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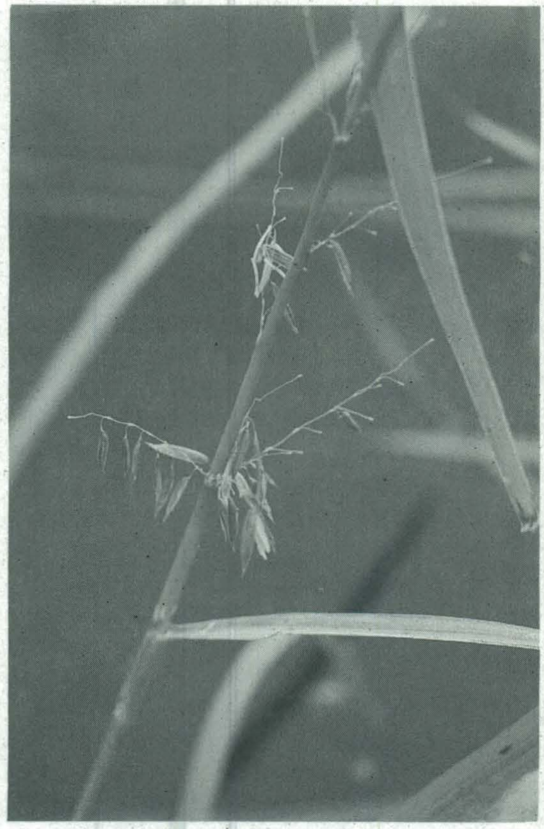

*The use of wild rice (**Zizania**) was taught to European settlers in North America by the First Nations. It is now the basis of a multi-million dollar industry. Wild rice is a favorite food of migrating wild fowl. Photo by D.E.M.*

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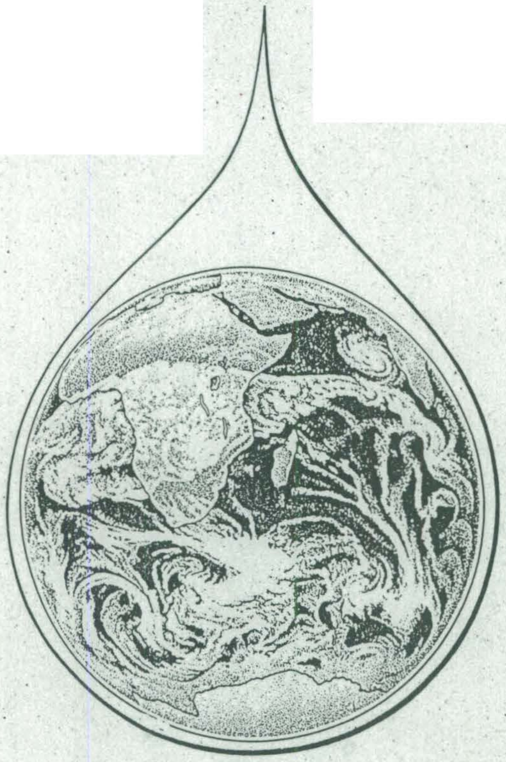

The world is but a single dewdrop, set
Trembling upon a stem;
and yet .... and yet ....

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