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Freshwater Biodiversity in Asia

With Special Reference to Fish



Maurice Kottelat
Tony Whitten

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The World Bank
Washington, D.C.

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Cover photo: The largest freshwater fish in Asia is the giant Mekong catfish *Pangasionodon gigas*. It reportedly migrates along the Mekong between Tonle Sap in Cambodia to upper Laos.
Credit: F. D'Aubenton

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Foreword

Many development projects impact freshwater biodiversity through flow regulation, pollution, siltation, eutrophication, and changes in the vegetation cover, and many of Asia's poorest people depend on freshwater biodiversity for their protein needs. Biodiversity initiatives have hitherto tended to focus on terrestrial systems or, when aquatic systems are targeted, on coral reefs or wetlands (which have not necessarily engaged the requirements of freshwater biodiversity).

Recent ASTEN reviews of major environmental assessments have found that if and when impacts on freshwater biodiversity are investigated, the quality of the available information is sometimes below what is required for informed decision making, and there are few effective mitigation or management provisions incorporated into project designs. This is in part due to acute human resource shortages, the lack of importance given to the work, and the lack of dialogue between specialists. The World Bank's Water Resources Management policy paper recognizes that in order to assist governments in developing strategies and cost-effective mechanisms for ecologically sustainable management, and the protection and restoration of water-dependent ecosystems, more rigorous attention should be given to maintaining biodiversity and protecting ecosystems in the design and implementation of water projects. As a first step, ASTEN has commissioned this report.

The operational implications of this paper are considerable given the frequency with which freshwater ecosystems are affected by development projects. Paying attention to the biological health of freshwater ecosystems can bring economic and health benefits to riparian people, and allow those ecosystems to maximize their beneficial functions such as the improvement of water quality. We hope this report will also make a singular contribution to the meetings prior to and during the Fourth Conference of the Parties to the Biodiversity Convention on Biological Diversity in November 1997 at which a major topic of discussion will be the status and trends of the biodiversity of inland water ecosystems and the identification of options for conservation and sustainable use.

While we are sure this paper will be useful, we are equally sure that the development of concerns relating to freshwater biodiversity would benefit from outside comments and dialogue. Please address those to the Chief, Environment and Natural Resources Division, Asia Technical Department, The World Bank, 1818 H St NW, Washington DC, 20433, USA.

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- Asia is home to some 3500 species of fish, hundreds of other organisms which spend their entire lives in water, and to many types of freshwater habitats. Many of these are of considerable economic value and are an important source of food for many poor people.
- This freshwater biodiversity can be adversely affected by projects related to dams, flood control, water supply, mining, fisheries management, introduction of exotic species, irrigation, bridges, industrial effluent, domestic waste, waterway modification for navigation and other purposes, and forest clearance;
- Current international agreements and World Bank policies support actions to consider and conserve freshwater biodiversity, which has received far less attention than biodiversity in terrestrial and marine ecosystems. Certain freshwater habitats are 'critical' in the sense of the World Bank's OP 4.04 on Natural Habitats;
- Freshwater biodiversity concerns are not always wholly addressed by attention to fisheries management or wetland conservation.
- The countries of Asia differ in their national capacity and expertise in freshwater biodiversity and the related fields of ecology and taxonomy, and in the quantity and quality of relevant and available information. The appropriate remedial strategy is therefore different for each country.
- Straightforward and relatively inexpensive steps to ameliorate a currently serious situation are:
 - * encouraging awareness of and attention to freshwater biodiversity issues;
 - * acknowledging that in order to make appropriate environmental management decisions it is important to collect good and current data;
 - * executing studies to understand the whole economic values of freshwater biodiversity;
 - * preparing field guides and manuals,
 - * nurturing partnerships between engineers and biodiversity specialists to achieve better project designs and more effective mitigation measures; and
 - * encouraging the release of scientific data collected by project proponents as part of environmental assessments.

Concerns

Background

The purpose of this report is to give attention to Asian¹ freshwater biodiversity. It was compiled with limited resources over a limited period and so it has not been able to explore the entire subject. Instead it is intended as a document to initiate discussions and as a basis for future publications and activities on more technical aspects and training. The constraints have forced a concentration on certain species and issues; for example, small algae and invertebrate animals are the most abundant aquatic organisms, but fish are chosen as the focal or 'flagship' group of species in the report because:

- they are conspicuous,
- they are easily identified,
- they are economically valuable,
- they are nutritionally important for many poor communities,
- they are relatively well studied,
- they are disappearing as a result of human-induced impacts,
- they are good indicators of water quality and ecosystem well-being, and
- they are species-rich – out of the approximately 25,000 known fish species over 40% or 10,000 are known exclusively from freshwaters (which constitute just 0.008% of the world's water) and an additional 500 species need freshwater at some stage of their lives (Nelson, 1994: 4-5).

Biodiversity

Biodiversity refers to the abundance and the variety within and among fauna and flora, as well

¹ - Asia is taken to include all countries between Afghanistan and Papua New Guinea, and between Mongolia and Indonesia.

as the ecosystems and ecological processes to which they belong, and is thus usually considered at ecosystem, species, and genetic levels. Ecosystem diversity is concerned with the variety of habitats and species communities, as well as the ecological processes within ecosystems. Species diversity refers to the variety of living organisms, and genetic diversity refers to the total genetic information contained in the genes of an individual species. *'Freshwater biodiversity', in the context of this report, concerns the species and habitats to be found primarily within inland waters.*

Mainstreaming Biodiversity

At the 1995 Conference of the Parties to the Biodiversity Convention, the World Bank launched a significant document entitled *Mainstreaming Biodiversity in Development*. In its foreword it states: *The challenge now is for the Bank to help its developing country partners to mainstream biodiversity conservation in environmentally sustainable development. ... Investment operations in traditional sectors such as agriculture, forestry, energy, tourism, and urban and infrastructure development should gradually become more 'biodiversity friendly'.*

Attention to Freshwater Biodiversity

While threats to charismatic terrestrial organisms such as mammals, birds and orchids, or to disappearing habitats such as rain forests, have attracted much attention, the same cannot be said of the many freshwater habitats that are under very serious threat, or of the very large number of aquatic organisms within them that face imminent extinction (Beverton, 1992; Moyle and Leidy, 1992; Wilcove and Bean, 1994; Abramowitz, 1995; Naimann et al., 1995a,b). The Bank's activities reflect this bias, yet freshwater biodiver-

sity is affected by far more, and a far broader range of, projects than the more 'popular' ecosystems. The effects of development on freshwater biodiversity have been extreme, for in no other comparable set of habitats have complete faunal communities been wiped out so quickly by ill-advised management. For example, an estimated 200 to 400 species of fish disappeared from Lake Victoria after the introduction of a single exotic fish species (Coulter et al., 1986; Barel, 1986). Some 297 (40%) of the roughly 750 freshwater fishes and 213 (72%) of the 297 native mussels known from Canada and the USA are extinct, endangered or threatened (fish data modified from Deacon et al., 1979; Williams et al., 1989; Miller et al., 1989; mussel data from Williams et al., 1992). This undoubtedly reflects the situation elsewhere in the world.

Freshwater biodiversity is a component of 'wetlands' in the sense of the Ramsar Convention² in which 'wetlands' is defined broadly as "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six meters*". However, the popular understanding of wetlands appears to be of land-related ecosystems such as marshes, peatlands, estuaries, floodplains, swamps, and lakes (e.g. Dugan, 1993). Such wetlands are often of ornithological interest but typically have low oxygen concentrations and are inhabited by hardy aquatic organisms which tend to have broad distributions. Other freshwater habitats, such as ubiquitous rivers and streams, are of limited ornithological value, and have therefore attracted relatively little concern. Very few rapids or foothill streams are protected for their intrinsic biodiversity value, although they may be included as part of larger protected areas. Even where wetlands have major conservation value for freshwater biodiversity, ornithological interests have tended to dominate (see Scott, 1989). Today

the wetland conservation lobby is beginning not just to declare a broad definition but to be more actively concerned with a wider range of freshwater species and habitats as well as their respective functions. For example, the recent (March 1996) Brisbane Conference of the Parties to the Convention on Wetlands agreed to include notable fishes, fisheries, and karst areas in the criteria for designating wetlands of international importance (see below). However, the state of concern and knowledge of freshwater biodiversity still lags far behind that of 'traditional' wetlands, hampering informed decision making.

Even in wide-ranging reviews of biodiversity, freshwater biodiversity is often largely ignored. For example, except for a few brief lines in the fish chapter, there is no mention of freshwater biodiversity in the World Conservation Monitoring Centre's *Global Biodiversity* (Groombridge, 1992). The value of fish in the pet trade³ is not even mentioned, whereas there are five pages on the parrot trade and six lines on reptile trade. This is not representative of the respective values of these trades. Gross retail value of the trade in neotropical parrots between 1982 to 1986 reached an estimated total of US\$1.6 billion (Groombridge, 1992), while the estimated annual retail value of aquarium fishes is US\$3 billion (Bassleer, 1994). Freshwater biodiversity is also scarcely mentioned in UNEP's massive *Global Biodiversity Assessment* (Heywood, 1995).

The conservation of 'flagship' species and habitats has been promoted in the hope that it would benefit less attractive species, and in many cases this has been achieved. In the case of wetlands the flagship group has generally been waterfowl. This is logical because:

- they are conspicuous elements of many wetlands,
- they are readily identified,
- they are censused and studied,

² - The official title is "The Ramsar Convention on Wetlands of International Importance, Especially as Waterfowl Habitat" but the whole title is rarely used and is seen as restricting the broad mandate to integrate the conservation of wetland biodiversity with sustainable development and the health and well-being of people.

³ - Popular aquarium fishes originating in Asia include featherbacks, tiger barbs, flying foxes, silver sharks, red-tailed sharks, scissortails, harlequins, and other rasboras, clown loaches, kuhli loaches, glass catfish, halfbeaks, Sulawesi rainbows, Irian rainbows, scats, bumble bee gobies, pearl and other gouramies, fighting fish, and spiny eels.

- they are long-distance migrants, dependent on wetlands in a number of countries in the course of their annual cycle of movements, and thus demonstrate the need for international collaboration in conservation efforts,
- they are of economic importance as game species, and
- they are near the top of most wetland food chains and thus highly susceptible to wetland contamination and disturbance (Scott, 1989).

If freshwater biodiversity is to become a noted concern then flagship species and habitats need to be identified and promoted - candidates for the former could be the giant Mekong catfish, the Chinese sturgeon, the Asian bonytongue, other attractive aquarium fishes, and freshwater porpoises. Candidates for flagship habitats could be biologically-rich rapids and peat swamps.

Despite common perceptions, freshwater biodiversity is an important issue with tremendous economic, social, and environmental impacts. It impinges on human welfare in terms of food, nutrition, other resources, purification of water, recreation, and control of infectious organisms, and cannot be dealt with adequately as a subsection of fisheries management. In general, however, freshwater biodiversity is often given no more than a few lines in environmental assessments of development projects, or disappears under a 'fisheries' heading, whereas it should be a completely distinct concern.

Human Capacity

Progress in freshwater biodiversity is hampered by inadequate human capacity, especially where it relates to organisms and their identification. For example, there are about 80 zoologists in Southeast Asia occupying official positions, who have training in taxonomy and are active at least occasionally in that field (Table 1)⁴. Thirty two of them conduct primary (i.e. original and innovative) research, while the remainder are engaged in activities such as identification, translation of foreign works, and compilation of local lists. Of

these 32, 13 are actively concerned with freshwater biodiversity:

- one works on amphibians,
- two on fish,
- two on decapod crustaceans (crabs and shrimps),
- two on insects,
- one on midges,
- three on molluscs,
- one on copepod crustaceans (zooplankton),
- one on parasitic worms.

It is clear that the weight of interest is, not surprisingly, on organisms important as food and on vectors of pathogens. Of these 13 primary freshwater taxonomists, only three are of international stature (as gauged by publications in international, peer-reviewed journals and membership of editorial boards). The problem is exacerbated because 11 of the 32 conducting primary research and five of the 13 who actually work with freshwater organisms will be retiring in the next five years.

Academic training alone does not create expert taxonomists; this expertise relies heavily on practice. Experience shows that it is almost impossible to recognize real skill in conducting taxonomic research before students begin practical work. Indeed, the only efficient way to find promising students is to test them and invest in those truly showing the capacity and interest. A recurrent problem is that some researchers are reluctant to leave their office in order to conduct field work because the social norm is that field activities which involve getting wet and handling dead animals do not befit individuals with a high academic degree. This can be extremely prejudicial to the quality of research because opportunities are missed to gain intimate knowledge of aquatic organisms, their habitats, behavior etc. Opportunities are also missed when donors and in-country institutions do not insist that findings are published in peer-reviewed journals. In addition, students trained abroad frequently work on organisms of the host country rather than those indigenous to their home country for sound reasons of cost and speed. Unfortunately, their

⁴ - Similar data for botanists and for the rest of Asia could not be assembled.

Table 1. Approximate numbers of taxonomists in Southeast Asia. Only taxonomists trained, active and with a full-time position are included. Figures in parentheses represent the number of freshwater biodiversity specialists.

	Total	No. conducting primary research	No. due to retire in next five years	No. conducting primary research and due to retire in next five years
Brunei	3	-	-	-
Burma	? 1	-	-	-
Cambodia	-	-	-	-
Indonesia	16	6 (2)	7	2
Laos	-	-	-	-
Malaysia	20	10 (3)	6	4 (2)
Philippines	15	4 (1)	4	1
Singapore	8	6 (4)	3	2 (2)
Thailand	10	6 (3)	4	2 (1)
Vietnam	? 7	-	? 2	-
Total	80	32 (13)	26	11 (5)

experience may not then be relevant to their local setting and the store of knowledge of indigenous biodiversity will not have increased.

Policy Context

Descriptions and quotes from a number of key documents are presented below in order to demonstrate that freshwater biodiversity is already on the international policy agenda.

Agenda 21. The Convention on Biological Diversity, laid before the UN Conference on Environment and Development in Rio de Janeiro in 1992, has been signed and ratified by most Asian countries. Although freshwater ecosystems are not mentioned specifically, Parties to the Convention are required to develop national biological diversity strategies, plans or policies. One of the most significant outcomes of the Rio Conference is Agenda 21, an action plan for the 1990s and 21st century which elaborates strategies and integrated program measures to halt and reverse the effects of the environmental degradation and to promote environmentally sound and sustainable development in all countries. Chapter 18 deals with 'Freshwater' and includes the following relevant sections:

Protection of water resources, water quality and aquatic ecosystems

Objectives: ...

18.39 (g) To adopt an integrated approach to environmentally sustainable management of water resources, including the protection of aquatic ecosystems and freshwater living resources;

18.39 (h) To put in place strategies for the environmentally sound management of freshwaters and related coastal ecosystems, including consideration of fisheries, aquaculture, animal grazing, agricultural activities and biodiversity.

Activities: ...

All states could implement the following activities: ...

18.40 (e) Protection of aquatic ecosystems

(i) Rehabilitation of polluted and degraded water bodies to restore aquatic habitats and ecosystems;

(ii) Rehabilitation programmes for agricultural lands and for other users, taking into account equivalent action for the protection and use of groundwater resources important for agricultural productivity and for the biodiversity in the tropics;

(iii) Conservation and protection of wetlands (owing to their ecological and habitat importance for many species), taking into account social and economic factors;

(iv) Control of noxious aquatic species that may destroy some other water species;

(f) Protection of freshwater living resources:

(i) Control and monitoring of water quality to allow for the sustainable development of inland fisheries;

(ii) Protection of ecosystems from pollution and degradation for the development of freshwater aquaculture projects;

Water for sustainable food production and rural development

18.76 (h) Inland fisheries:

(i) *Develop the sustainable management of fisheries as part of national water resources planning;*

(iii) *Prevent or mitigate modification of aquatic environments by other users or rehabilitate environments subjected to such modification on behalf of the sustainable use and conservation of biological diversity of living aquatic resources;*

In summary, Chapter 18 is a positive document for the conservation of freshwater biodiversity, although much of the language indicates that freshwater biodiversity is a resource to be harvested. Chapter 35, which deals with 'Science', is also relevant:

Strengthening the scientific basis for sustainable development*Activities*

35.7. *Countries ... should:*

(a) *Prepare an inventory of their natural and social science data holdings relevant to the promotion of sustainable development;*

Enhancing scientific understanding*Activities*

35.12. (e) *Develop the capacity for predicting the responses of terrestrial, freshwater, coastal and marine ecosystems and biodiversity to short- and long-term perturbations of the environment, and develop further restoration ecology;*

(f) *Study the role of biodiversity and the loss of species in the functioning of ecosystems and the global life-support system;*

(g) *Initiate a global observing system of parameters needed for the rational management of coastal and mountain zones and significantly expand freshwater quantity/quality monitoring systems, particularly in developing countries*

Building up scientific capacity and capability*Objectives:*

35.21. (d) *Improving access to relevant information for scientists and decision makers, with the aim of improving public awareness and participation in decision making.*

Activities:

35.22. (b) *Strengthen the scientific infrastructure in schools, universities and research institutions (particularly those in developing countries) by the provision of ... access to current scientific literature ...*

(c) *Develop and expand national scientific and technological databases, processing data in unified formats and systems,*

Ramsar Convention. The Ramsar Convention on Wetlands of International Importance was the first of the modern global inter-governmental treaties on conservation and wise use of natural resources. Concern about declining populations of waterfowl (mainly ducks) was the initial impetus for the Convention, and other concerns were only implicitly indicated, i.e. in the General Criteria 2: *A wetland should be considered internationally important if:*

(a) *it supports an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plant or animal, or an appreciable number of individuals of any one or more of these species;*

or (b) *it is of special value for maintaining the genetic and ecological diversity of a region because of the quality and peculiarities of its flora and fauna;*

or (c) *it is of special value as the habitat of plants or animals at a critical stage of the biological cycle;*

or *it is of special value for one or more endemic plant or animal or communities.*

At the March 1996 Conference of the Parties to the Ramsar Convention a new five-year strategic plan was adopted which sets a clear course for the future, stressing the need to integrate the conservation of wetland biodiversity and sustainable development. With regard to freshwater biodiversity a new Objective is included which recognizes the need to designate wetlands of international importance among types still under-represented in its list. To support this, an additional 'Special Criteria 4' for designating such wetlands based on fish was adopted:

A wetland should be considered internationally important if:

(a) *it supports a significant proportion of indigenous fish subspecies, species or families, life history stages, species interactions and/or values and thereby contributes to global biological diversity;*

or (b) *it is an important source of food for fishes, a spawning ground, nursery and/or migration path on which fish stocks, either within the wetland or elsewhere, depend.*

World Bank Policies. A number of policy documents have been issued in recent years which implicitly support attention to freshwater biodiversity and its conservation.

Operational Policy (OP) 4.04. September 1995.
Natural Habitats:

- Para.1. *The Bank ... supports the protection, maintenance, and rehabilitation of natural habitats and their functions in its economic and sector work, project financing, and policy dialogue. The Bank supports, and expects borrowers to apply, a precautionary approach to natural resource management to ensure opportunities for environmentally sustainable development.*
- Para.4. *The Bank does not support projects that, in the Bank's opinion, involve the significant conversion or degradation of critical natural habitats.*
- Annex A, para 1. *Natural habitats are land and water areas where (i) the ecosystems' biological communities are formed largely by native plant and animal species, and (ii) human activity has not essentially modified the area's primary ecological functions.*

Annex A, para. 2. *Critical natural habitats are existing protected areas and areas officially proposed by governments as protected areas. ...*

and sites that maintain conditions vital for the viability of those protected areas; or sites identified on supplementary lists prepared by the Bank or an authoritative source determined by the Regional Environment Division. Such sites may include ... areas with known high suitability for biodiversity conservation; and sites that are critical for rare, vulnerable, migratory, or endangered species.

Operational Policy (OP) 4.07. July 1993. Water Resources Management

- Para. 2(d). *The Bank will assist borrowers in: Restoring and preserving aquatic ecosystems.*

Operational Directive (OD) 4.00 - Annex B. April 1989. Environmental policy for dam and reservoir projects

- Para. 8 *..an environmental reconnaissance ..., by independent, recognized experts or firms - selected by the borrower and approved by the Bank - is essential.*
- Annex B1. para.10. *Hydroelectric and other developments should preferably be concentrated on the same rivers if hydrological risks and other circumstances permit, in order to preserve elsewhere a representative sample of rivers in the natural state. This should be considered part of the trade-offs.*

Human significance of freshwater biodiversity

Economic Value of the Resources

Human communities depend on freshwater biodiversity for a variety of resources. The various habitats provide a wide range of resources as well as services such as transport, supply of clean water, and energy. Among the organisms, most attention has focused on fish as food because of their overwhelming economic importance, but food fish are not the only freshwater resources and fish are used also for fertilizer, medicine (e.g. see Vincent, 1995), the pet trade, and they are an integral part of a dynamic food chain.

There does not seem to have been an economic analysis of freshwater biodiversity value. The few available data are mostly fisheries statistics, but these are of very limited value for three reasons. First, most statistics do not discriminate between aquaculture and capture fisheries. For example, in FAO fisheries statistics, aquaculture or reservoir production accounts for the entire productivity of inland fisheries of Sri Lanka. Capture fisheries exist in the country, but are not taken into consideration. Second, national statistics for many countries are unreliable. In district fisheries administrations, it is not uncommon to see weekly or monthly statistics for villages in which fisheries officers are rarely, if ever, seen. Statistics may also be falsified where taxes are collected, and there is a vested interest in under-reporting catches.

The third and most salient shortcoming of fisheries statistics is that they represent only catches sold in markets and completely overlook subsistence fisheries, which represent a much larger biomass. Commercial fisheries are usually exclusively represented in official statistics, but these are not necessarily the crucial resource for the majority of the population, especially the impoverished. Almost everywhere along rivers people catch fish; large fish are brought to the market or sold to middlemen, and small fish are eaten

locally. Children catch frogs, tadpoles, snails, mussels, beetles, bugs, etc. in small streams and under stones, and almost everything is eaten. This is probably the main source of animal protein for many of the poorest populations, but it has been completely ignored in official statistical reports. For example, the official fisheries statistics for Laos, Thailand, Cambodia and Vietnam report a total of 360,000 tons for the fisheries catch and aquaculture production in the lower Mekong Basin. These figures, however, underestimate commercial production and often do not include the subsistence fisheries (Mekong River Commission, 1992). The underestimation may be considerable as household consumption studies in N.E. Thailand suggest actual consumption of 32,200 tons, 5.5 times the reported capture and culture (Prapertchob, 1989). This estimate plus recent data emerging from projects undertaken by the Mekong River Commission suggests that the total fisheries catch and aquaculture production may be as high as 1 million tons (J. Jensen, pers. comm.).

Indicative of the dependence of lower income groups on fish, is the fact that the fisheries concept of 'trash fish' does not exist among poor human populations; there being a use for almost every fish. Observations on the fish communities and their exploitation in Danau Sentarum Wildlife Reserve, Indonesia, indicates that of 180 species known from that area, only one species is not used (pers. obs.). There are specific methods for fishing a variety of species, and even species reputed to be poisonous are eaten after the poisonous organs are removed. Species too small for processing are fed to large fish kept in cages (a single fisherman could catch up to 50,000 fish 4-10 cm long per day), along with waste parts of large fishes.

In terms of nutrition, a change of food species can be very significant. Data from Bangladesh show that small capture fish are usually eaten whole by subsistence fisherfolk and provide a rich

source of vitamins and mineral nutrients. Larger, pond-cultured fishes cannot be eaten whole and provide less than one-half the calcium and iron and only 2% of the vitamin content of the smaller and more widely available fishes (Hill and Hanchett, 1995: 37). Also, in some areas of Asia, the larger and commercially more valuable exotic species marketed and consumed primarily in urban centers, have replaced the smaller indigenous species normally sold and consumed in rural areas. The resource thus becomes more valuable, the former common property is privatized and is claimed by wealthy land owners (K. MacKay, pers. comm.). Fisheries planners must therefore consider socio-cultural effects, such as the loss of food diversity and associated traditional knowledge as well as possible reduction in food and life quality.

Besides being used as food, some species are collected for the aquarium fish trade. The main species in this trade in Indonesia is the clown loach *Botia macracanthus*. This is possibly the most important wild-caught pet fish of the world, in terms of biomass, with an estimated 10,000,000 exported per year⁵ (pers. data). Field surveys in Danau Sentarum indicate that some 2,400,000 are caught annually; until 1995 provincial statistics report only about 50,000 to 300,000 individuals. (Aglionby, 1995). Obviously, the economic viability of this massive pet trade depends upon the stability of biodiversity and the integrity of the ecosystem.

There are few studies of the trade in freshwater turtles, but the limited available information indicates significant value. In Vietnam: some 240,000 animals (240,000 kg) are traded annually, representing a value of US\$2.4 million (Centre for Natural Resources Management and Environmental Studies, 1994). In Bangladesh the legal trade in turtles and their eggs was worth nearly US\$1 million in the late 1980s (Das 1990), and it is higher in many S.E. Asian countries where the end point is often the food and medicine markets of China.

Aquatic plants also have many economic uses. For example, out of 237 species of aquatic

plants in Peninsular Malaysia, 61 have a socio-economic value: 15 as human food, 5 as livestock food, 30 as medicine, 3 as fertilizers, 11 for other uses (aquarium trade, ornaments, magic, dyes, baskets, mats, strings) (Nather Khan, 1990). Actually, the number of species collected for the aquarium trade is grossly underestimated. The populations of several species in demand for the aquarium trade have been seriously depleted, especially in Sri Lanka and Malaysia (pers. obs.).

Local Knowledge and Management of Resources

Local knowledge of fish diversity is generally good in communities which depend on fishing activities. Fishermen in Danau Sentarum, Indonesia recognize most fish species, have specific vernacular names for them and know of specific uses or recipes for them (pers. obs.). They have problems, however, with the identification of some of the smaller fishes and occasionally claim that they had never previously seen some of the species caught in small-meshed nets. In fact, they are probably simply not noticed among hauls of small 'trash' fish which are bulk processed to feed cultured fishes. Even so, local knowledge is often biased towards those larger or most valuable species or towards the species collected by their usual gear. For example, after a major pollution event in the Mun River, Thailand, fishermen stated that some of the dead fish washed up were of species they had never seen before (Roberts, 1993b:130).

The local knowledge of fish biology is somewhat less accurate. Fishermen tend to know at which time of the year or day a given species can be caught, what its stomach contents are likely to be, whether the gonads are ripe, and even when the young fish appear, but this knowledge is fragmentary, and there is a tendency to extrapolate generalities from a few specific observations. Their data are also strongly biased; fishermen tend to use different fishing gear at different seasons, and catch fish with different gear in different habitats, so that the data are not comprehensive and must be interpreted carefully.

Local communities may traditionally manage aquatic resources, especially when they rely heavily upon them, and the resource is limiting

⁵ - Cardinal tetras are exported in larger numbers from Brazil but these fish are much smaller.

(Roberts 1993a,b; Roberts and Warren, 1994; Ali, 1996). Traditional management often comes in the form of periodic fishing bans (usually the spawning season of some important fish species) and/or in some areas, the return of broodstock, or the total or seasonal ban of certain fishing gear, and is usually decided by the local community. Where the human population is not too high these management regimes have often been sufficient to maintain a sustainable fisheries. The emergence of overfishing may be related to a change in life-style, such as the move from subsistence fishing to a market economy.

In parts of Cambodia there are active fisheries resource management systems dating back to at least the early 19th century which are particularly

interesting because they represent traditional management systems which have made the transition to being the bases of modern regulations: there are closed and open seasons, sanctuaries, allocated fishing lots, and a wide range of licensed gear, all backed up by a fisheries act. There are inspection units belonging to both the Department of Fisheries and the provincial fisheries offices. They have patrol boats, usually armed, and attempts are made to enforce the regulations. In 1994 the DoF collected over US\$100,000 in inland fishing fees, and US\$128,000 in confiscated goods and fines. In one province alone in 1994 the inspection unit charged over 200 fishermen with illegal fishing (K. MacKay, pers. comm.).

Biodiversity aspects

Ecosystem Diversity

Freshwater habitats inhabited by different freshwater animal and plant communities can be classified in different ways, and the classification below is based simply on their gross geomorphological features. The general types of organisms found in each habitat will be similar among the different areas of Asia but the faunal assemblages will be distinct.

Springs, hill streams, headwaters, rapids. These habitats are characterized by high gradient, often high altitude, usually high dissolved oxygen and low temperature (these characters may be less applicable to lowland rapids), and rocky substrate. High shear stress occurs over and around the stones and boulders. There are few if any macrophytes (rooted aquatic plants). Many of the fish and invertebrates living in these streams have adaptations such as suckers, flattened depressed bodies, and laterally expanded fins to resist being swept away by the current. Often the water is clear, and due to the high light penetration, there is abundant algal growth on the rocks, constituting an important food resource for fishes and invertebrates which themselves form the prey of other species. The chaotic nature of these habitats results in a mosaic of microhabitats, and the sampling of a few hundred meters may yield more species than any other freshwater habitats. These communities are usually very specialized and their movements along the river may be very limited. Extensive stretches of other habitats with low gradient, lower oxygen concentration, higher temperatures, sand or mud bottom, high turbidity, and absence of rocks and algae to graze are barriers to dispersal. As a result, the distribution of many species is limited to a set of rapids, a few headwaters, or a single tributary in a large river basin.

For obvious reasons, sampling of these habitats can be difficult and dangerous, and they are

undersampled in most countries. The fauna of rapids is known to have a very high rate of endemism, but it is one of the least well-known habitats and hundreds of species probably still await discovery.

These habitats are threatened by deforestation which increases the temperature and the sediment load, dam construction which eradicates high gradient sectors within the reservoir and alters the flow pattern downriver, or channelization which reduces the heterogeneity of the river bed, and thus the number of available ecological niches.

Freshwater swamp forests and small streams in lowlands and foothills. Freshwater-swamp forests grow where changes in water level are limited⁶, where there is at least some water present at all times of year, and where the water is mineral-rich freshwater of roughly neutral pH. Inundations may originate from rain or from river water backing up in response to high tides. The major physical differences between these forests and peat swamp forest are the lack of deep peat and the source of water being riverine as well as from the rain (Corner, 1978). They harbor similar freshwater biodiversity to the small streams in the lowlands and foot hills of Asia which were originally under forest cover. These streams become very shallow in the dry season and usually run in a succession of pools and riffles, with a considerable amount of wooden debris (logs, branches, leaf litter). The water is usually clear and cool. There is very little light penetration because of the trees above and thus very little underwater plant growth; the majority of the aquatic fauna relies on exogenous material, either vegetable debris or

⁶ - It should be noted that Danau Sentarum and Tonle Sap are strictly riverine or riparian lakes rather than swamp forests, since the range in water level is much greater - up to 16 m - and water is completely missing from the marginal forests for several months. These fringing forests are thus a very hostile habitat for freshwater biodiversity during the 6-9 dry months.

animals (mainly worms and insects), or on other aquatic animals as food sources. In the wet season, such streams flood the riparian forests, and most fish spawn at that time of the year in the flooded forest where food is abundant for both adults and fry. Large fishes enter the small streams from the large rivers for the same reasons. Due to the heterogeneous structure of these habitats, they offer abundant and diverse shelters, food and spawning grounds and can accommodate a great variety of species, many of them small and easily overlooked.

These communities are threatened by deforestation, which increases the water turbidity and temperature, reduces shelter and food resources, and modifies the spawning grounds. They are also adversely affected by water diversion for agriculture, pollution, and overfishing (especially with poisons). This type of habitat has been completely destroyed in many areas. For example it is now missing in Java which is probably one of the main reasons why half of the species reported from the island up to the middle of this century have not been caught in recent surveys (Kottelat, 1995a).

Large rivers, riverine lakes and flood plains. These important fisheries habitats are characterized by very low gradient, low oxygen concentration, higher temperature, high turbidity and high nutrient load, muddy bottom and cyclical floods. Floods are crucial events for many riverine fisheries for during them fish invade the flooded land where food is abundant for the adults and the fry; most fish spawn during floods or immediately before or after (Taki, 1978). The numerous small lakes (e.g. oxbow lakes) found in the floodplains are also included in this category. Some function as buffers, filling with water during high waters and releasing it in the dry season. These are very ephemeral episodes in the life of a large river but they are crucial to maintaining the biodiversity. Their fish fauna is usually the same as in the main river (although relative densities of the different species may differ).

Large rivers usually host rich species assemblages, but do not exhibit much variation between neighboring basins, as movement from one basin to another is occasionally possible during floods,

especially in coastal areas. Large rivers are usually the most productive part of a basin.

The communities of large rivers are threatened by deforestation which results in increased temperature and siltation and degradation of nursery grounds for fry during floods, pollution (most urban communities are located on large rivers), overfishing and flood control. Flow modification (channelization, diversion) and flood control have a significant impact as they reduce or adversely affect the spawning grounds and the possibility of lateral migrations. Threats may have cumulative effects: the reduced run-off resulting from reservoir construction may no longer be enough to flush concentrated urban, agricultural and industrial pollution, leading to extensive anoxic zones.

Estuaries. Estuaries are complex ecosystems due to the variation in the interactions of saline and freshwater habitats according to daily, tidal and yearly cycles. They are a transit area for all the nutrients carried by the rivers and are an important feeding and spawning ground for many marine fishes and invertebrates. They are also a transit area for all the pollution in a river basin as well as for fishes on their migrations between the sea and freshwaters. This is one of the main points of concern in the present context. Overfishing in estuaries and the clearing of mangrove forests (an important nursery ground) are other major threats to these communities.

Lakes. Unlike the ephemeral riverine lakes discussed above, ancient lakes are often of tectonic or volcanic origin, and are geographically isolated. Lakes in limestone areas may also belong to this category although their evolution may be much faster.

Several lakes host particular fish communities with species specialized to occupy the pelagic habitat (Table 2). 'Species flocks' are a particular feature of some ancient lakes. A species flock is an assemblage of very closely-related species occurring within a restricted geographic area; usually members of a species flock occupy niches (food resources, habitats) that related species outside of the flock would never utilize, but which would be utilized by other groups of animals. The most famous flocks are probably the several

Table 2. Asian lakes with exceptional freshwater biodiversity interest.

	Country	Biodiversity features	References
Lakes in Yunnan	China	large numbers of endemic fishes and invertebrates	Li, 1982; Chu and Chen, 1989, 1990; Yang, 1991; Kottelat and Chu, 1988
Malili Lakes (Matano, Towuti, Wawantoa)	Sulawesi, Indonesia	2 endemic fish genera, 26 endemic fish species (including 15 of the 17 known species of <i>Telmatherinidae</i>), in addition to 1 snake, 3 crabs, about 10 shrimps, some 60 molluscs, 1 macrophyte, possibly sponges and water mites	Kottelat, 1990b-c, 1991
Lake Poso	Sulawesi, Indonesia	1 endemic fish genus, 7 endemic fish species, numerous endemic invertebrates	Kottelat, 1990a
Lake Lindu	Sulawesi, Indonesia	1 endemic fish species	Kottelat, 1990a; Whitten et al., 1987b, c
Lake Tondano	Sulawesi, Indonesia	1 endemic fish genus	Collette, 1995
Lake Sentani	Irian Jaya, Indonesia	2 endemic fish species	Allen, 1991
Lake Biwa	Japan	3 endemic fish species, as well as endemic snails, molluscs, and plankton	Kira, 1995: 18
Lake Inle	Burma	9 endemic species and 3 endemic genera of fishes	Annandale, 1918 and pers. obs.
Lake Rara	Nepal	3 endemic fish species	Terashima, 1984
Lake Kutubu	Papua New Guinea	11 endemic fish species	Allen, 1991; Allen and Hoese, 1986
Lake Lanao	Mindanao, Philippines	2 endemic fish genera, 18 endemic fish species	Kornfeld and Carpenter, 1984

hundred species of cichlid fishes in African rift lakes (Malawi, Tanganyika, Victoria) which occupy all habitat types, display many types of reproductive behavior and exploit all manner of food resources (Echelle and Kornfield, 1984).

The major threats to lake communities are introductions of exotic species, pollution, eutrophication, and changes in water level. Lake communities, especially the complex and diverse ones, tend to be sensitive to changes. Fisheries biologists have often regarded lakes as having many vacant ecological niches, sometimes not realizing that several species may occupy the same niche or that a single species may occupy a number of niches dependent on the season, time of day or life stage or sex of the individual; in addition, niches which exist in one lake do not necessarily exist in another. As a result it has been a common practice to 'improve' lake communities with the introduction of exotic species. Few of these introductions resulted in the expected increased productivity; in many instances rehabilitation of the existing fishery could have been just as cost-effective and less likely to have deleteri-

ous effects (Eccles, 1985). Most of these introductions have had damaging effects on the native communities, sometimes bringing to extinction entire 'species flocks'. The introduction of the Nile perch *Lates niloticus* to 'improve' Lake Victoria resulted in the extinction of an estimated 200 to 400 fish species in less than 30 years (the fate of other freshwater organisms in the lake does not seem to have ever been documented) (Coulter et al., 1986; Barel, 1986). In Asia, the cyprinid species flock of Lake Lanao (Philippines) is apparently also extinct (see the relevant country section).

The only more-or-less pristine species flocks left in Asia are to be found in the Malili lakes, Sulawesi. These lakes actually host two parallel flocks. The fauna of Lake Matano has many of the same families and genera as the other lakes, but most species are unique to the lake. The only other documented case of parallel species flocks in the world is in two crater lakes in Cameroon (Stiassny et al., 1992). See the relevant country section for further discussion of the Malili lakes.

Data on abiotic, biotic and socio-economical factors of 64 Asian lakes and wetlands have been compiled by Kira (1995).

Marshes and swamps. Marshes and swamps have a high productivity because of intense light which results in rapid plant development and, as such, can support diverse invertebrate communities. These habitats are characterized by high temperatures and low oxygen concentrations. Most fish present in these habitats belong to families which have developed ways of breathing atmospheric air as the dissolved oxygen is not sufficient (e.g. gouramies, walking catfishes). They are usually very hardy fishes and most have very broad distributions. Many wetland conservation activities have focused on these habitats because they are important for waterbird migrations. They are, however, of limited value as far as fish biodiversity is concerned.

Peat swamps, black water streams, black water lakes. Peat swamp forests are a specialized habitat type of Southeast Asia. They were originally very extensive along the sea-shores immediately behind the mangrove forests. In some areas of Sumatra and Borneo, the peat layer may reach thicknesses of up to 20 meters. Water is retained by the spongy structure of the peat, and is highly acidic with a pH of 3.5-6.0 (Whitten et al. 1987a; Ng et al., 1992, 1994). It is tea-colored when seen against transmitted light, or black when seen in reflected light, hence the common name of 'black waters'. The water has low calcium concentrations and low oxygen levels. In natural conditions peat swamps are part of forest formations with a relative low tree diversity. Lakes may form on the summit of peat domes or along streams or rivers flowing through extensive areas of peat swamps.

Until recently many biologists considered black waters to be low in biodiversity and productivity (e.g., Johnson, 1968). In fact, peat swamps have simply been poorly studied. Ongoing studies now show that in peninsular Malaysia, 10% of the fish species are found only in peat swamps (Ng, 1994a). Unpublished data indicate that this figure is even higher in Borneo. Most of these species are small and have been overlooked by fisheries biologists. They occupy niches which

are also easily overlooked or difficult to sample. Many species are found only in the peat soils, and persist there even when the streams themselves are dry. They include several species of small worm-like fishes (Kottelat and Lim, 1994) and catfishes (Ng and Lim, 1993) known in no other habitat. Such very specialized organisms have very localized distributions and are confined to specific drainages. As a result, peat swamp fauna exhibit an unusually high degree of endemism.

Peat swamps are very sensitive to deforestation which is usually followed by fire. Peat swamp forest seems unable to regrow on burned peat, so restoration does not occur. Peat swamps have been extensively converted into rice, oil palm and pineapple plantations, and today only 10-20% of the original peat swamps of Peninsular Malaysia still remain (Ng, 1994a). The extant swamps are not free of human interference.

Large areas of coastal peat swamps and mangroves have been turned into ponds for prawn culture in Thailand, Malaysia and Indonesia. These prawns are cultivated almost exclusively for export and this type of aquaculture is not sustainable; the ponds can only be used for about five years before pollution, accumulation of faecal matters and blooms of toxic algae take their toll. Adjacent land and water supplies are also polluted by soil and water conditioners, pesticides, fertilizers, antibiotics and disinfectants which are often used heavily (see Wilks, 1995 for discussion of ecological and social impacts). In most cases, the land cannot be used for other agricultural purposes for many years.

Caves and aquifers. Organisms inhabiting subterranean habitats are often overlooked. These include not only animals living in caves, but also those living in aquifers (some species are, for example, known only from artesian wells). These organisms are often characterized by reduced or absent eyes, pigmentation, and sensory organs. The fauna of only a few Asian cave systems has been investigated, but several caves have been found to harbor unique faunas, both aquatic and terrestrial. Most cave aquatic organisms are restricted to a single cave or a single cave system. The vertebrates and macroinvertebrates (such as crabs and shrimps) have usually been reported,

and, contrary to the situation in many surface water habitats, much attention has also been paid to smaller invertebrates. Very little is known of the fauna of aquifers in Asia, although it is known that they are inhabited by invertebrates and fishes. For example, the catfish *Horaglanis krishnai* is known only from aquifers in Kerala, India.

Most cave environments must be considered to be under threat. Threats include surface water pollution, surface waste disposal, water tapping for human, agricultural or industrial use, limestone mining for cement factories, and tourism. For example, a reservoir built in Funing County, Yunnan, China, submerged cave systems in which blind fishes were seen by geologists.

Juberthie et al. (1994) is the first volume of an ongoing encyclopaedia of subterranean biology. The volumes dealing with vertebrates and cave habitats in Asia should appear in late 1996.

Artificial freshwater habitats. Artificial freshwater habitats in the form of man-made lakes and reservoirs have often replaced ecologically diverse and species-rich natural rivers. Artificial habitats have a uniform underwater landscape, and often suffer from various forms of pollution. The most obvious types of these habitats in Asia are reservoirs, paddy fields, and canals and streams in agriculture and plantation areas. Most new reservoirs go through a phase of being anoxic and toxic as a result of the decomposition of flooded terrestrial vegetation, and only very few, generally air-breathing, species tend to survive. Artificial habitats are generally depauperate and the fish fauna is often at least partly exotic with many species stocked artificially.

Reservoirs may be beneficial for the native fauna in arid areas. Dams and effective forest conservation practice in the Chalakkudy River basin, Kerala, India, have contributed significantly to providing a continuous flow of water in the river, even during periods of drought. Most of the other west-flowing rivers of Kerala and almost all their headwater reaches tend to dry up during the dry season, particularly in areas heavily planted with tea. The Chalakkudy River is inhabited by a diverse aquatic community while other basins have a much lower diversity (Pethiyagoda and Kottelat, 1994).

Species Diversity in Freshwater Organisms

As explained in the first chapter, fish are good group to focus on in a discussion of freshwater biodiversity, but they are clearly not the only group which are dependent on freshwater ecosystems.

Mammals. A wide variety of mammals are dependent on freshwater ecosystems. These range from the freshwater dolphins which live wholly within the water column, to otters, fishing cats and other fish-eating mammals. Many of these animals clearly also depend on there being other suitable surrounding habitat for their survival.

There are three species of obligate freshwater dolphins in the area: the baiji or Yangtze River dolphin *Lipotes vexillifer*, the susu or Ganges River dolphin *Platanista gangetica* and the bhulan or Indus River dolphin *Platanista minor*. All three have distribution ranges restricted to a single river basin, have very small global populations and are under serious threat (e.g. Smith et al., in press). The baiji is close to extinction with an estimated 300 individuals left in 1986, and the number still declining and now considered to be below 100 (Reeves and Leatherwood, 1994).

There are also two recognized species of facultative river dolphins in area: the finless porpoise *Neophocaena phocaenoides* and the Irrawaddy dolphin *Orcaella brevirostris*. They are widely distributed along Asian coasts and are known to enter rivers, but their systematics are not clear. For example, the finless porpoise of the Yangtze seems morphologically distinct from those in Chinese coastal marine waters (Zhou, quoted in Leatherwood and Reeves, 1994), indicating that they are possibly distinct species. There are currently no data to show that marine individuals are able to enter freshwaters or that freshwater ones can enter the seas. Other cetacean species occasionally move up rivers, but only for relatively short periods.

Birds. Birds, such as waterfowl, have attracted more attention than any other animal living on or near freshwaters (e.g. Scott, 1989) and it is thanks to this that so many wetlands have received protection. Bird field guides are usually

among the first tools available for animal identification in a country, and this has created an interest in the group. Wetlands may be important as a source of food, nest sites, shelter, or all of these. Some birds live year round in tropical wetland habitats, while others are migratory. However, as was stated at the start of this report their abundance and diversity at any particular site does not necessarily correlate with the abundance or diversity of organisms living within the water itself, and some freshwater habitats are rarely visited by birds.

Reptiles. There are eight species of crocodylians and 60 species of aquatic turtles in Asia (I. Das, pers. comm.). They have been the focus of attention by conservation groups and agencies and so are not addressed in great detail here. Both groups have a significant market value, the crocodiles for their skins (and marginally their meat) and the turtles for their meat, eggs, and as pets. The turtles of South Asia are described in Das (1994), who also provides a key to the species found in insular Southeast Asia (Das, 1995). The conservation of freshwater turtles is dealt with in Pritchard and Rhodin (1994).

There are 24 species of true water snakes in Asia which are permanent inhabitants of freshwater lakes or rivers (e.g. the endemic *Enhydris matannensis* in the Malili lakes). Except for names, descriptions, and raw distribution data, there is little information available on them.

Amphibians. There are nearly 1000 amphibian species in Asia, most of which rely on freshwater at some stage of their larval development. The type of water body needed by the various species is diverse, ranging from fast-moving hill streams to swamps, mud pools, water-filled leaf axils, pitcher plants, etc. (Inger, 1966; Inger and Stuebing, 1992). Some adult amphibians may spend all their life near or in the water, especially salamanders and discoglossid frogs. Frogs seem to be particularly susceptible to pollution and are viewed as excellent indicators of environmental health. Some of the larger species are under severe pressure in some countries for food, both for domestic and export markets.

Fishes. Fishes are the best known group of exclusively aquatic animals. Approximately 25,000 fish species are recognized by scientists of which about 10,000 are found in freshwaters (Nelson, 1994: 3-5). Specialists estimate that some 5000 species still await discovery, most of them in freshwaters. No detailed account has yet been published of Asian freshwater fishes. Unpublished data indicate that some 4500 species are already reported from Eurasia (Europe and Asia combined), at least 3500 of them in the area covered here. The numbers of freshwater species in each Asian country are shown in the country sections. The distributions of some species of freshwater fish are very restricted, leading to small and vulnerable populations. For example a fighting fish *Betta simplex* is known from a single group of spring pools and their outlet in a karstic area in peninsular Thailand.

It is important to realize that while our knowledge of fish in general is better than for other groups, many fish species are known only from a handful of works on descriptive morphology and taxonomy. Many species have been collected only once by scientists, and this is the source of all (if any) data we have on their ecology and habitat requirements. Detailed information on distribution, habitat, feeding habits, population size and reproduction is available for just a handful of species. These data are based on adults, and information is available on fish larvae only for some of the species used in aquaculture or occasionally kept in aquaria in Europe, North America and Japan. In many areas, experts have been simply unable to identify fish larvae even at the family level (Japan is a noteworthy exception). There exist no data on larval ecology despite the crucial importance of this period in the life and development of fishes; larval ecology is often completely different from adult ecology. An effective management of fish resources requires such information.

Fish migrations are well known throughout Asia (e.g. Chevey and le Poulain, 1940; Blache and Goosens, 1954; D'Aubenton and Blanc, 1965; Fily and D'Aubenton, 1965; Roberts, 1993a,b, 1995). There are short, medium and long distance migrations wholly within freshwater, there are primarily freshwater species which breed in marine habitats, and primarily marine species which

breed in freshwater habitats, and there are separate feeding, spawning and dispersal migrations. The most famous fish migration in Asia is probably that of the 3-m long giant Mekong catfish *Pangasianodon gigas* which reportedly migrates along the Mekong between Tonle Sap in Cambodia to Upper Laos (e.g. Pholprasit, 1994). The Chinese seerfish *Scomberomorus sinensis* migrates between Tonle Sap, Cambodia, and the South China Sea. Information on this facet of their ecology is clearly vital to the management of these species (Hill, 1995). In floodplains, mass lateral migrations are usually associated with feeding and spawning (Taki, 1978). Sicydiine goby larvae are also known to be migratory, and they used to be the basis of specific fisheries in Java and Luzon, and perhaps elsewhere.

Crustaceans. Freshwater crustaceans are economically important because they are consumed over their whole range, and have therefore attracted some attention from biologists and parasitologists (Ng, 1988: 15). There are two main groups of freshwater crustaceans in Asia for which reasonably good data are available: prawns and crabs. The number of species in each Asian country are shown in the country sections. These numbers were deduced with the help of Dr. Peter Ng, National University of Singapore, who has studied these animals extensively in Southeast Asia.

While most of the known migrations concern fishes, species of the commercially-important shrimp *Macrobrachium* breed in estuarine areas, and juveniles migrate upstream for several hundred kilometers.

Most freshwater crustaceans are restricted to freshwater; this is especially true for freshwater crabs, many of which have very restricted geographic distributions. Many species are known from a single stream or group of streams, often associated with a single hill or range; some are known from a single waterfall. About 80% are endemic to a single drainage. The presence of true freshwater crayfishes in New Guinea is noteworthy because they are absent in the rest of South and Southeast Asia.

Unpublished data indicate that where freshwater fish communities are naturally depauperate,

the crustacean diversity is higher (e.g. eastern Kalimantan, Philippines). It is likely that the absence of several species or groups of fishes allows crustaceans to occupy ecological niches which they cannot normally occupy when a diverse fish community is present.

Molluscs. Molluscs (snails and mussels) are another significant group of aquatic animals. There are monographic treatments of them available only for a few countries or islands (e.g. Thailand: Brandt, 1974; Java: van Bentham Jutting 1953, 1956). Some groups have attracted attention because they are intermediate hosts to several parasites, especially schistosomiasis (e.g. Davis, 1980; Davis and Greer, 1980). There is reason to believe that many species have become threatened with extinction, or become extinct, in recent decades as a result of declines in water quality, changes in land use, and the introduction of exotic species.

Other invertebrates. No attempt has been made to summarize data on other groups of aquatic invertebrates. Some are permanent freshwater organisms while others inhabit freshwater only during part of their life cycle (e.g. as larvae). Most groups are still very poorly known (for example, it is almost impossible to identify freshwater sponges), while others have attracted much attention, such as several groups of parasitic worms, especially human parasites. Dragonflies and damselflies have also attracted much attention from scientists and collectors, but this has focused on adults; it is still impossible to identify most larvae, despite their important role in benthic communities.

A review of systematics, ecology and distribution of tropical zooplankton has been published by Dussart et al. (1984). This includes references to most then-recent works. They pointed to notable gaps in Burma, Laos and Cambodia. They conclude (p. 85) that "*in Asia a fairly comprehensive knowledge of systematics and distributions is available at least in half the countries of the area*". An examination of some of the cited literature indicates that most of the data has been obtained at very few localities, and it seems that

"fairly comprehensive" is probably somewhat over optimistic.

Macrophytes. Information on the submerged macrophytes of S.E. Asia tends to be scattered in a number of smaller publications, but some family reviews and identification keys are included in the ongoing series *Flora Malesiana* (e.g. van Steenis 1949a,b; Backer 1951; van Oostroom, 1953; den Hartog, 1957a,b; de Wilde, 1962; Bruggen, 1971; van der Plas, 1971; Taylor, 1977). Some groups have attracted more attention because they are popular as aquarium plants (e.g. Araceae of the genera *Cryptocoryne* and *Lagenandra*). References specific to individual countries are given in Chapter 6.

Genetic Diversity

Genetic diversity is the total genetic information contained in the genes of a population. It describes the variation within that population, and is thought to reflect the ability of the population to adapt to change, although there are some well-documented cases of thriving populations with very limited genetic diversity. However, it is generally believed that populations with greater genetic diversity are more likely to be able to adapt to changes in their environment and to be good subjects for selective breeding.

Very little has been published on the genetic diversity of Asian freshwater organisms. Interest has mainly focused on fish, and then on just a few species which are of known commercial value, such as tilapias (not native to Asia) and carps. Current projects on freshwater genetic biodiversity in Asia are also focused on these fishes, despite being exotic to most of the areas where the projects are conducted, and although they are known to be damaging to native faunas.

There are chromosome data for many species of fishes in Japan, Korea and China (e.g. Yu et al.,

1989), but in most instances they are limited to lists of chromosome numbers, and rarely cover intraspecific variability (e.g. Li et al., 1986). Perhaps the only noteworthy study in this context is the research on mitochondrial DNA of the S.E. Asian catfish *Hemibagrus nemurus* (Dodson et al., 1995).

Megadiversity Countries and Hot Spots

A primary method of identifying the most important areas for conservation has been determining 'megadiversity' countries and hot spots. Megadiversity countries are the few countries which possess the largest fraction of the world's species, while hot spots are regions with high concentrations of endemic species experiencing unusually rapid rates of habitat modifications or loss (Myers, 1988, 1990). Twelve megadiversity countries have been recognized (McNeely et al., 1990): Mexico, Colombia, Ecuador, Peru, Brazil, Zaire, Madagascar, China, India, Malaysia, Indonesia and Australia. This listing was based on terrestrial vertebrates, butterflies and higher plants, and did not take any aquatic organisms into account. The ten countries with the richest freshwater fish fauna world-wide are listed in Table 3. It can be seen that five of these are in Asia, and four are not generally recognized as megadiversity countries. Such analyses are confused, however, by the effect that country size has on species totals. To demonstrate this, Tables 4 and 5 show Asian countries ranked first by the known number of freshwater fish species, and second by their species-to-area ratio. This shows major changes in positions.

The list of the richest countries in terms of the number of freshwater crabs and shrimps mirrors that for fish (Table 6), with the Philippines and Thailand being the highest of those in terms of species-to-area ratio.

Table 3. The top ten countries in terms of numbers of freshwater fish species. Only species actually recorded are included.

	Number of species	Sources
Brazil	3,000	S. O. Kullander, pers. comm.
Indonesia	1,300	Kottelat, unpubl.
Venezuela	1,250	S. O. Kullander, pers. comm.
China	1,010	Kottelat, unpubl.
Peru	855	Chang and Ortega, 1995
Tanzania	800	Eccles, 1992; Kottelat, unpubl.
USA	790	Page and Burr, 1991
India	750	Kottelat, unpubl.
Thailand	690	Kottelat, unpubl.
Malaysia	600	Kottelat, unpubl.

Table 4. Asian countries and other geographical units ranked by their total of freshwater fish species.

	A No. fish species	B Land area (km ²)	A/B x 1000
Indonesia	1,300	1,944,000	0.7
China	1,010	9,560,948	0.1
India	750	3,387,593	0.2
Thailand	690	513,517	1.3
Vietnam	450	329,566	1.4
Borneo	440	535,830	0.8
Philippines	330	299,404	1.1
Png	329	462,000	0.2
Sumatra	300	475,300	0.6
Malaysia penin.	300	131,235	2.3
Burma	300	676,581	0.4
Laos	262	236,798	1.1
Bangladesh	260	144,054	1.8
Cambodia	215	181,035	1.2
Pakistan	159	803,941	0.2
Java	130	132,570	1.0
Nepal	129	147,181	0.9
Taiwan	95	36,179	2.6
Sri lanka	90	65,610	1.4
Korean penin-sula	90	99,143	0.7
Irian jaya	80	414,800	0.2
Sulawesi	70	186,140	0.4
Mongolia	56	1,565,000	0.0
Brunei	55	5,765	9.9
Singapore	45	618	72.9

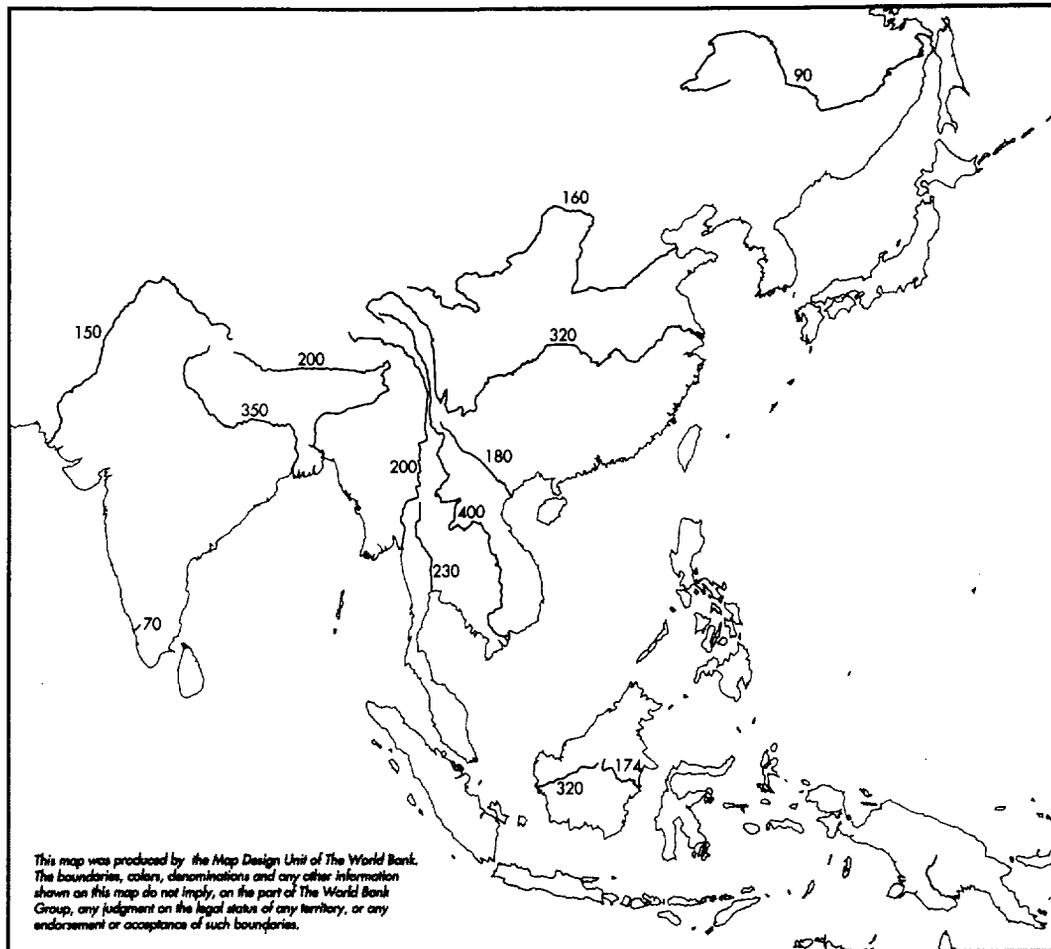
Table 5. Asian countries and other geographical units ranked by their freshwater fish species-to-area ratio.

	A No. fish species	B Land area (km ²)	A/B x 1000
Singapore	45	618	72.9
Brunei	55	5,765	9.9
Taiwan	95	36,179	2.6
Malaysia penin.	300	131,235	2.3
Bangladesh	260	144,054	1.8
Vietnam	450	329,566	1.4
Sri lanka	90	65,610	1.4
Thailand	690	513,517	1.3
Cambodia	215	181,035	1.2
Philippines	330	299,404	1.1
Laos	262	236,798	1.1
Java	130	132,570	1.0
Nepal	129	147,181	0.9
Borneo	440	535,830	0.8
Indonesia	1,300	1,944,000	0.7
Korean penin-sula	90	99,143	0.7
Sumatra	300	475,300	0.6
Burma	300	676,581	0.4
Sulawesi	70	186,140	0.4
India	750	3,387,593	0.2
Png	329	462,000	0.2
Pakistan	159	803,941	0.2
Irian jaya	80	414,800	0.2
China	1,010	9,560,948	0.1
Mongolia	56	1,565,000	0.0

Table 6. The top ten Asian countries in terms of the numbers of crab and shrimp species.

	crabs	shrimps
	No. species recorded in literature	No. species recorded in literature
China	120	50
Indonesia	90	70
India	60	100
Malaysia	88	55
Thailand	63	50
Philippines	41	40
Vietnam	12	30
Burma	20	?
Cambodia	6	15
Laos	7	10

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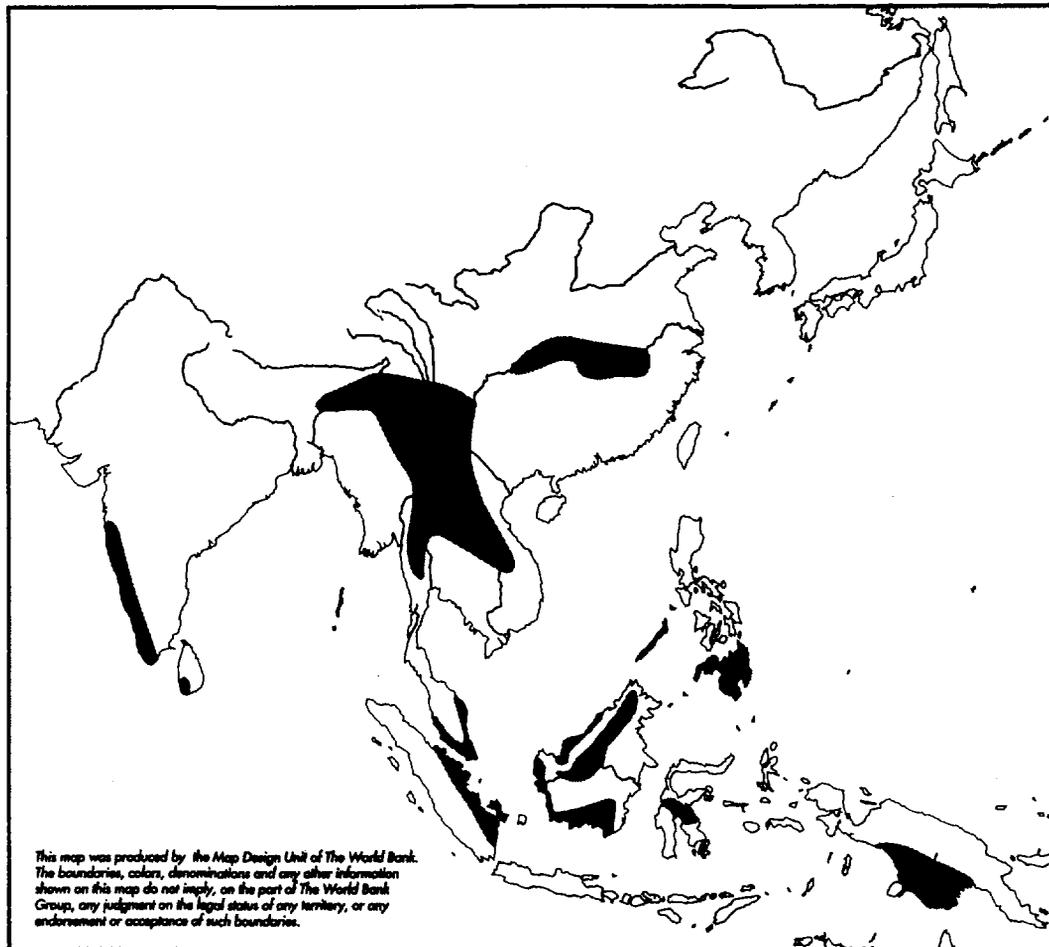
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Figure 1. The total number of fish species known from the major river basins of Asia.

Political units do not, of course, bear much relation to the key determinant in the distribution of freshwater biodiversity, i.e. river basins (Figure 1). Thus the Mekong, Ganges, Kapuas (Kalimantan), and Yangtze basins are the richest in fish species, with the Kapuas the richest in terms of species to length ratio. Lists of biodiversity hot spots of the world have been compiled (Bibby et al., 1992; Groombridge, 1992; Dinerstein and Wikramanayake, 1993), but again these are based on higher plants, terrestrial vertebrates and butterflies and ignore aquatic communities. With speciation and distribution

patterns in freshwater organisms differing from those of terrestrial ones⁷, it is not surprising that many of the terrestrial hot spots, such as oceanic islands, do not contain significant elements of aquatic communities while important regions are entirely missing from existing hot spot distribution maps (e.g. Lake Inle in Burma, Malili lakes in Sulawesi).

⁷ - Terrestrial organisms have two-dimensional distributions whereas aquatic ones have one-dimensional distributions, i.e. upstream and downstream. In that respect the term 'hot rod' might be more appropriate than hot spot.



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Figure 2. The distribution of 'hot spots' for freshwater biodiversity in Asia, based mainly on fishes.

Figure 2 shows the distribution of Asian aquatic 'hot spots' based mainly on freshwater fishes⁸. The Mekong basin is arguably the most important hot spot because of its size and the potential and imminent threats to its integrity. The only published estimate of the number of fish spe-

⁸ - This map is compiled from personal experience in the field, as well as on the literature, and corresponds to a good 'educated guess'. Time and technical limitations did not allow for the more precise procedures used in the production of terrestrial hot spot maps. The technical limitations are mainly a lack of ground surveys over huge areas, the taxonomic uncertainty of a larger number of taxa, and also the larger number of aquatic vertebrate species than terrestrial ones, making surveying more difficult.

cies in the Mekong basin in Vietnam, Cambodia, Laos, Thailand and Burma is 298 (Kottelat, 1989). This list was based on the scientific literature, confirmed by scientists and supported by voucher material. Allowing for species discovered since, the list may now be around 400 and could be expected to reach 500 if the basin were surveyed thoroughly. This is rather less than the unsubstantiated figures of 1000, 1200 or 1500 fish species circulated by some agencies and experts.

Since much conservation planning is now based on hot spot analyses (e.g. Johnson, 1996), it is worth indicating that existing national systems of protected areas across Asia have some positive

benefits for certain elements of freshwater biodiversity. For example, forested protected areas often include species-rich streams, and floodplains may be important as seasonal spawning grounds. There are, however, very few areas which protect the freshwater biodiversity of larger rivers. Exceptions include the Chinese Alligator Reserve on the lower Yangtze River, and the 400 km long National Chambhal (Gharial) Wildlife Sanctuary

on the border between Rajasthan and Madhya Pradesh in India set up to conserve the endangered gharial (*Gavialis gangeticus*) as well as at least eleven species of freshwater turtles and the Ganges dolphin. Both of these focus on large 'flagship' species with presumed benefits for other species. Riverine reserves present a challenge for protected area managers, not least because they tend to be 'lengths' rather than areas.

Threats and the mitigation of impacts

Threats and Effects

The threats faced by freshwater biodiversity in Asia are manifold and pervasive. There are cumulative and synergistic effects, and tolerance to one factor may be lowered by a stress resulting from the presence of another factor. A major problem in managing freshwater ecosystems in the region is the lack of knowledge of how the various human-induced changes affect aquatic life. Ecologists find it hard to define biodiversity precisely in a functional sense or to define the linkages between biodiversity and long-term stability of ecosystems. What is known and beyond doubt, however, is that environmental degradation results in the following biological changes:

- the number of native species, and those in specialized taxa or guilds, declines,
- the percentage of exotic or introduced species or stocks increases,
- the number of generally intolerant or sensitive species declines,
- the percentage of the assemblage comprising generally tolerant or insensitive species increases,
- the percentage of trophic and habitat specialists declines,
- the percentage of trophic and habitat generalists increases,
- the incidence of disease and anomalies increases,
- the percentage of large, mature or older individuals increases,
- reproduction of generally sensitive species decreases,
- spatial or temporal fluctuations are more pronounced (Margalef, 1963).

The most serious result of the losses of biodiversity is that it reduces our future options for sustainable biological resource management.

Pollution. The major source of aquatic pollution in freshwater systems is domestic and industrial organic wastes, although toxic metals are also a concern in some areas. Paper pulp mills and food-processing plants are the main industries causing organic pollution (see Roberts, 1993b: 115, for a description of a molasses spill in Thailand killing fish over 420 km of river). Organic matter is broken down naturally by bacteria in the water, and this decomposition requires oxygen. When a large amount of organic matter is broken down, it consumes a large amount of oxygen, and the oxygen concentration in the water falls. If it falls too low, fish and other aquatic organisms will die. Only a few species are able to survive by breathing atmospheric air or using the oxygen-rich surface layer. Organic pollution is often accompanied by algal blooms which feed on the organic material. Large amounts of decomposing algae then exacerbate the problem..

Inorganic pollutants (including heavy metals, bleaches and dyes) may accumulate in the flesh of fish and adversely affect their survival or reproductive biology, as well as contaminate their predators higher up the food chain including large carnivorous fishes, birds of prey and humans. Agricultural pesticides are increasingly found in freshwaters, and this especially true for areas where irrigated rice culture predominates.

Any one pollutant may be sublethal, but may stress the fish and other organisms so that they are less resistant to diseases and the affects of other pollutants⁹ (Menasveta, 1985; Roberts, 1993b: 108). The toxicology of fishes in temperate regions is quite well known, but this is not the case for fishes from tropical freshwaters. Different

⁹ - Epizootic Ulcerative Syndrome has swept through Asia, affecting mainly carps, and it is suspected that that was associated with pesticide concentrations, low pH and other poor environmental conditions. Although the costs to culture stocks have been calculated, the cost to capture fisheries and to biodiversity have not.

species of fish differ greatly in their sensitivity to chemicals. Besides death, injury, and increased sensitivity to pathogens, pollution may also induce sex changes (Bortone and Davis, 1994).

Increased sediment load. Increased sediment load caused by deforestation, agriculture, mining, and road construction, is one of the most serious threats to freshwater biodiversity in less developed countries. Its economic impacts have been quantified, and it is well recognized that silting-up causes increased flooding, water-logging and navigation problems, (e.g. Meijerink et al., 1988). However, the impacts on biodiversity and fish productivity have been largely ignored, although they are well documented in more developed countries.

Increased sediment loads negatively affects fishes by damaging their gill epithelium, resulting in injuries and death. Silt deposition also modifies the river bed transforming heterogeneous stony substrate into homogeneous sandy substrates and leading to the extinction of many species living in or on the former substrate. Freshly laid eggs are covered and deprived of oxygen and nursery grounds for juveniles destroyed. The resulting water turbidity reduces light penetration and plant survival, thus lowering primary productivity.

Flow alteration and water diversion. The cyclic rise and fall of Asian rivers and lakes are of singular importance because inundated flood plains are the main or exclusive spawning and nursery grounds for many fish species. This cycle also signals and stimulates the breeding and movements of many freshwater species, and any changes in timing and flow rates due to impoundment will have adverse effects on them. A period of zero flow during or following dam construction will clearly be devastating to the aquatic communities downstream. However the deleterious effects of flow regulation and water diversion may be more subtle. Other negative impacts of flow regulation measures and water diversion include habitat destruction and modification, alteration of flood regimes, creation of sterile habitats and barriers to migration. Canals, by connecting different river basins, may allow the entry of invading exotic species and pathogens.

Reservoir construction may result in the destruction of rapids and associated aquatic communities in the reservoir itself as well as downriver. Nature conservation areas are often established around reservoirs to prevent siltation in the basin and to increase the life of a reservoir. This may benefit land animals, but has few benefits for aquatic species, that part of biodiversity most severely imported by reservoir creation. A sharp decline in fish biodiversity in two reservoirs in Thailand is reported by Sontirat (1991).

In the first years after completion of a reservoir some fish species may actually become very abundant, but the local fishermen may be unprepared for this and not be equipped to navigate and fish on a lake for species they are not accustomed to catching. Outsiders rather than locals may have more experience with such conditions and eclipse the local fisherfolk, reducing their food supply (see Roberts, 1993b: 115). The prospect of profitable economic activity may also attract outsiders to the reservoir area, thereby increasing the fishing pressures and other impacts (pollution, deforestation, siltation, etc.).

Introduced species. An introduced species is any species intentionally or accidentally transported and released by man into an environment outside its natural range. Some authors or agencies distinguish between species transported within a country, and those transported across international boundaries. This is based on the idea that the impacts of introductions within a country are less significant, and therefore would not necessitate the same precautions as those across borders. In a biodiversity context, and with large countries to consider, this distinction makes little sense.

For example, the introduction of a fish species within the island of Borneo from Malaysia to Indonesia, with similar faunas would be more significant than an introduction from Sumatra to Irian Jaya, both of which are in Indonesia but possess completely different faunas. Two specific examples from China are also illustrative. The artificial stocking of grass carp in Donghu Lake, Wuhan, caused the virtual disappearance of submerged macrophytes and dramatic blooms of planktonic algae. These conditions favored silver

carp and bighead carp, also native to China but not to the lake. Fish yields trebled but comprised only the few stocked species: most of the 60 fish species native to the lake all but disappeared. In addition, the number of benthic invertebrate species fell from 113 to 26, and zooplankton species fell from 203 to 171. Each summer there are problems with algal blooms which deleteriously affect the quality and supply of drinking water and the living conditions of lakeside residents (Chen 1989). A similar situation has occurred in Lake Honghu, Hubei, where 70 native species of fish were lost as a result of fisheries programs (Chen and Cui, 1993). In biogeographic terms, only introductions within river basins are likely to be less significant.

Animals and plants obviously do not respect political boundaries and the biodiversity in a country with strict prohibitions or controls on introductions may be placed at risk by introductions in a neighboring country which later make their way across the border. Introductions of fishes in Irian Jaya threaten the local endemic aquatic fauna, as well as that of neighboring Papua New Guinea. Fishes introduced in the Mekong basin in China are now appearing in Thailand (Vidthayanon and Kottelat, 1995).

Fisheries departments are charged with increasing fisheries productivity and many of the new candidate species for introduction are exotic and destined for forms of aquaculture. During trials they may be kept in ponds without particular care or sometimes even released into a reservoir, with the argument that if the test is successful, a full environmental assessment will be conducted afterwards for a large scale program. Experience shows that *all* cultivated aquatic organisms eventually escape (Courtenay and Williams, 1992: 52); fish can escape through the normal outlets of the ponds, during floods, as a result of careless ma-

nipulation, or by accidental release of its prey by a fish-eating bird or mammal.

Introductions have been conducted haphazardly in order to strengthen depleted populations or to improve the genetic quality of a population. Here the assumption is made that the introduced stock belongs to a species already present in the target area. With the generally poor quality of available taxonomic data, this is often no more than an assumption. No data are available for Asia, but experience in North America and Europe (Kottelat, ms.) show that stocks assumed to be conspecific, later turned out to represent different species, and that these introductions have resulted in the extinction of native species or the creation of a hybrid stock, an outcome which is little different from extinction.

Examples of the effects of introduced species are shown in Table 7. Many of these introductions were made in the 1970s before there was widespread concern for biodiversity and conservation issues. Even so, there is a single documented case of a fishery agency effectively monitoring the introductions of fish using a pre-introduction assessment (Coates, 1995). Various agencies have proposed clear guidelines and codes of practice (De Silva, 1989: 153; Coates, 1995), which are strongly supported by international agencies. FAO is in the final stages of producing comprehensive guidelines for this purpose (D. Coates, pers. comm.). It is noteworthy that there has never been a serious attempt at assessing the impacts of tilapia *Oreochromis nilotica*. The species has been introduced in at least 68 countries and is generally believed to have had no negative impacts. The truth is that there has simply never been any critical monitoring. Under conditions prevailing in fisheries agencies, impacts on freshwater biodiversity are unlikely to be noted.

Table 7. Some introduced species known to have had deleterious effects on indigenous biodiversity or humans.

Introduced species	Country	Effects	Reference
<i>Ipomaea fistulosa</i>	India	competitor against native species	Cook, 1987
introduced aquarium plants	Thailand	competitors against native species	Piyakarnchana, in De Silva, 1989: 121
snail-contaminated aquarium plants imported from South America	Hong Kong	Introduction of the human pathogen <i>Schistosoma mansoni</i>	Meier-Brook, 1975, cited by De Silva, 1989: 4
golden snail (apparently several species of the genus <i>Pomacea</i>)	Philippines, Indonesia	major pest on rice seedlings and other crops. Displaced native snails, bringing some to local extinction. At the time of introduction it was already known to be a pest in other countries.	Acosta and Pullin, 1991
snail <i>Ampullaria gigas</i>	Thailand	damage rice stems in paddies	Piyakarnchana, in De Silva, 1989: 121
shrimp <i>Macrobrachium nipponense</i>	China. Lake Dianchi, Yunnan	outcompeted the native shrimp <i>Caridina gregoriana</i> which is now very rare or extinct: an endemic loach <i>Yunnanilus nigromaculatus</i> , which feeds on the smaller native shrimp is now very endangered or extinct	Kottelat and Chu, 1988
penaeid shrimps	Philippines	may have introduced diseases to local species	Juliano et al., in De Silva, 1989: 83
American crayfish <i>Procambarus clarkii</i>	Thailand	damage rice stems in paddies.	Piyakarnchana, in De Silva, 1989: 121
American bullfrog <i>Rana catesbiana</i>	Thailand	may be harmful to local amphibian species	Piyakarnchana, in De Silva, 1989: 121
carp <i>Cyprinus carpio</i>	India	species of the native genus <i>Schizothorax</i> have disappeared from waters to which the carp had been introduced	Jhingran and Sehgal, 1978, cited by Welcomme, 1988: 20
Chinese carps	Thailand	responsible for the spread of fish diseases	Piyakarnchana, in De Silva, 1989: 121
<i>Pseudorasbora parva</i>	Lake Lugu, Sichuan	introduced in mistaken belief they were young grass carp; they fed on the eggs of the three endemic fish species causing their virtual or actual extinction	Chen and Ciu, 1993
gambusia <i>Gambusia holbrooki</i> and guppy <i>Poecilia reticulata</i>	Worldwide	introduced for mosquito control but have had rare to non-existent effects on mosquitoes, and negative to perhaps neutral impacts on native fishes	Courtenay and Meffe, 1989; Arthington and Lloyd, 1989
goby <i>Glossogobius giuris</i>	Philippines	extinction of 17 endemic cyprinid species and 3 genera of lake Lanao	De Silva, 1989: 146
grass carp	many places	introduction of the parasitic cestode <i>Bothriocephalus opsarichthydis</i>	De Silva, 1989: 4
Nile tilapia <i>Oreochromis niloticus</i>	at least 68 countries	unrecorded, suspected outcompetition of native species.	Pullin, in press
rainbow trout <i>Oncorhynchus mykiss</i>	Sri Lanka	threatening aquatic organisms, especially the endemic shrimp <i>Cardinia singhalensis</i>	K. De Silva, 1982; P. De Silva and K. De Silva, 1988; Pethiyagoda, 1991: 170
European perch <i>Perca fluviatilis</i>	Lake Bositen, Xinjiang, China	Disappearance of endemic fish <i>Asipiorhynchus laticeps</i>	Chen and Ciu, 1993
tilapia <i>Oreochromis mossambicus</i>	Indonesia, Lake Lindu, Sulawesi	endemic molluscs are extinct and the endemic fish <i>Xenopoeilus sarasinorum</i> is virtually extinct	Whitten et al., 1987; pers. data
tilapia <i>Oreochromis mossambicus</i>	many countries	outcompeted local species	Piyakarnchana, in De Silva, 1989: 121
tilapia <i>Oreochromis mossambicus</i>	Philippines	extinction of local endemic fish <i>Mistichthys luzonensis</i>	
tilapia species	Sri Lanka	endemic and commercially important fish <i>Labeo porcellus</i> has become virtually extinct. Freshwater turtles <i>Lissemys punctata</i> and <i>Melanochelys trijuga</i> have been greatly reduced as a result of the tilapia gill net fishery.	Pethiyagoda, 1994: 195
unknown fishes and their parasites	Indonesia, Lake Poso, Sulawesi	the endemic fish <i>Adrianichthys kruyti</i> and <i>Weberogobius amadi</i> are extinct and <i>X. poptae</i> and <i>Oryzias orthognathus</i> are very seriously threatened. <i>W. amadi</i> was the base of a subsistence fishery which collapsed	Kottelat, 1990a

For example, the introduction of tilapia species into Sri Lanka has usually been presented as a success story. From the environmental point of view it is certainly not, and from a scientific point of view much of the reports and recommendations are flawed by lack of data and superficial statements. *Oreochromis mossambicus* has been proposed to fill what fishery managers perceive as a 'vacant' ecological niche, the open waters of artificial reservoirs. Actually, four species and hybrids have apparently been introduced (Pethiyagoda, 1991); *O. mossambicus* is not a lacustrine but a riverine species (Trewavas, 1983: 311) and administrators do not realize that the classification of niches is anyway artificial and that most species are capable of utilizing different niches in different habitats. Reports that tilapias remained restricted to reservoirs are not supported by field observations (pers. obs. and Pethiyagoda, 1994: 194). While it has been said that indigenous fishes, especially cyprinids, benefited from the presence of tilapias because of increased eutrophication (Fernando, 1991: 27), there is no data to show which species really benefited. To refer to 'cyprinids' and then to generalize conclusions to all native fish is a flawed approach. Actually, the endemic fish *Labeo porcellus* is virtually extinct, although until the 1970s it was sufficiently abundant to warrant a fishery (Pethiyagoda, 1994: 195). The freshwater turtles *Lissemys punctata* and *Melanochelys trijuga* have almost disappeared from reservoirs in which they were previously abundant, as a result of the gill net fishery (Pethiyagoda, 1994: 195).

Although introductions of exotic species by individuals are forbidden in most countries, they do occur, witness the numerous cases of feral populations of aquarium fishes (Kottelat et al., 1993) whose impact has not yet been assessed in Asia. Introductions for sport fishing, however, are potentially much more dangerous. In many countries, 'fishing ponds' are becoming increasingly widespread. Large native or exotic fishes are released in ponds where anglers pay to catch them. Many large top predators have been released in such ponds, are breeding and will threaten entire aquatic communities if they escape. A recent case is the introduction of the large cichlid *Cichla* sp. in Malaysia. Ideally, governments should control

these activities and conduct an eradication of all exotics introduced in these ponds. Any introduction of piscivorous fishes should be prohibited.

The threats posed by introduced species to freshwater biodiversity are clearly immense, insidious and ever-increasing. In the long term, introduced species may prove to be more damaging to freshwater biodiversity than habitat degradation and reduction because most successful invasions are irreversible. Prevention of further biological invasions is therefore a most urgent priority (Clout, 1995).

Habitat loss. If a habitat is severely degraded or destroyed, then much of the associated biodiversity will be lost. Habitat loss is one of the most important factors in loss of biodiversity in the region, and localized species are especially affected. Land reclamation and the draining of wetlands has a profound impact on freshwater biodiversity. Some 80% of western Malaysia peat swamp forests have already been drained, burned and converted into rice, oil palm or pineapple plantations. This has threatened many rich, diverse, and geographically restricted aquatic communities (Ng, 1994a).

Habitat loss is also an issue when rivers are channelized or impounded, when riparian fringes of vegetation are lost or altered, when silt smothers a bed of larger particles, etc.

Overfishing. Overfishing in oceanic waters is now recognized as extremely widespread and the causative factors, especially the economic factors, are quite well documented (for a recent summary see Fairlie et al., 1995). Overfishing also occurs in many freshwaters but in Asia it has not been the subject of detailed studies or analyses. For a useful analysis of overfishing, data on the productivity and identity of the stocks is essential. For most countries, neither is generally available, and there is an urgent need to gather these basic data.

In some cases, however, overfishing is very easily identified; in many places streams are simply empty. The stream morphology may be normal, the riparian vegetation may be intact, there is no sign of pollution, the water is clear, but there are no fish, no tadpoles, and almost no insects. Investigation usually reveals that the stream is

regularly poisoned, sometimes as frequently as once a week. Under such abuse, most life forms rapidly disappear. Fish poisoning is a traditional way of fishing for some groups of people, who gather and process plants to obtain the poison. The modern trend is towards using pesticides as poison since they are more efficient and easier to obtain, but they are also more damaging to aquatic and human life.

Overfishing is often related to a change in lifestyle. Some groups of people have developed regulatory strategies which seem to avoid overfishing, but communities with excess resources or which have not experienced resource scarcity (such as areas of the Mekong Basin) may not have developed management measures. Where resources are limited, problems may occur where different communities (including ethnic groups, or commercial enterprises) exploiting the same resource come into contact. For example, in West Kalimantan, Indonesia, both the Melayu fisherfolk along the main river and the Iban in more hilly areas, perceive the other community's activity as threatening to their own. The Iban may feel that the Melayu, using sophisticated nets on the main river, will block the migration of fish upriver, while the Melayu are concerned about the abuse of poisons upstream affecting their own fishing success (W. Giesen, pers. comm.). In other cases communities see their fish resources being exploited without restraint by outside interests, and they see no benefit in preserving stocks. Poison abuse is apparently associated with the growing interactions between human communities. Previously fish had to be eaten or processed the same day they were caught, but communication with middlemen creates a market for surplus fish which can be stored in freezers or sent overnight to a city market.

There are, as yet, no published data to indicate that overfishing is responsible for the extinction of any fish species in Asia (which does not mean that it is not the case). But overfishing, usually combined with other threats, is responsible for the drastic reduction of entire communities, especially in densely-populated areas, and of some species of particular economic interest. Examples would include species of *Tor* carp in all south and south-

east Asia, *Wallago* catfish in southeast Asia, and the bonytongue *Scleropages formosus* in Borneo.

Pet trade. The aquarium fish trade has been accused of driving species to extinction because of very selective overfishing, but there is no documented evidence for this. Some species which have been the subject of an important trade have decreased significantly and have disappeared in part of their original range, but this has always been related to other causes (e.g. *Botia sidhimunki* in Thailand). Some species have disappeared also in areas where they had never been collected for the aquarium trade (e.g. the 'silver shark' *Balantiocheilos melanopterus* in the Kapuas basin, west Borneo). On the other hand, some species may be temporarily saved from extinction because of the trade; for example, it is not clear whether the 'red-tailed shark' *Epalzeorhynchus bicolor* (commonly called *Labeo bicolor*) still exists in the wild, but tens of thousands of specimens are exported annually from Thailand, all now captive bred.

Mitigation

Mitigation is theoretically possible against most negative impacts of development projects which influence freshwater biodiversity¹⁰. Despite this, there appears to have been little work in Asia on designing mitigation measures to compensate for the losses to freshwater biodiversity as a result of development project impacts. A common course is to promote aquaculture development, but this addresses loss of protein quantity rather than loss of biodiversity; in many cases, aquaculture actually exacerbates biodiversity losses. Other mitigation measures have been instituted for large dams, but have usually been limited to suggestions for minimum flows below dams to allow the survival of some fishes and fisheries. There is enormous scope for fruitful collaboration between engineers and biodiversity specialists to design innovative features for infrastructure and other projects so that losses to biodiversity can be

¹⁰ - The noteworthy exception is the introduction of exotic species. These are virtually impossible to eradicate once established.

minimized. At the very least, 'standard' mitigation measures should include maintaining shoreline vegetation, maintaining bottom heterogeneity and preserving samples of intact habitats. In this context, point 10 of the World Bank Operational Directive (OD) 4.00 - (Annex B) of April 1989 is important; it requires that a representative sample of rivers be preserved in their natural state.

Fish ladders. At some Asian dam sites, fish ladders (a succession of concrete tanks) have been constructed to allow the passage of migratory fish species, more or less following models used in temperate countries where they are designed primarily for sport and food fishes such as salmon and trout. Transposed to Asian rivers with fish communities which include a large number of migrating or moving species, very few of them able to jump, these systems appear to have completely failed to allow fish, dolphins, shrimps, etc. to pursue their normal movements. Most of the migrating fishes are bottom dwellers and are unable to pass these ladders. Some might adjust their requirements and breed in the habitats to which they are newly confined, but many just die.

Clearly, there is an urgent need to investigate the feasibility of effective fish ladders, fish lifts or swimways adapted to the needs of indigenous aquatic communities. Reeves and Leatherwood (1994) comment that a prototype swimway for river dolphins exists, which, on paper at least, can be designed and built at a reasonable cost (in the context of megaprojects). However, for many species there is currently insufficient knowledge of their biological requirements to enable adequate measures to be taken. An additional problem is that fish may have difficulty finding the entrance of the ladders, lifts or swimways; electric 'fences' have been suggested to direct fishes towards them. It must be borne in mind that if fish migrate in one direction, they or their offspring must return the other way, and not through a turbine or over a spillway. Well-designed fish ladder systems could contribute greatly towards mitigating species loss at dam sites.

Creation of rapids. Mitigation measures for important habitats lost by the creation of a river barrier might include the creation of new rapids situated upriver of the reservoir, stocked by fish

collected before filling and transplanted to the new rapid site. There appears to be no precedent for this but artificial rapids have been created in North America on spillways of power plants in order to compensate for the loss of river stretches used by sport kayakers. If rapids can be constructed for sport, there should be no technical or ethical obstacles to constructing them for maintaining biodiversity.

It has been said that some rapids were preserved at the construction of Pak Mun dam in Thailand, but this refers only to a maintenance of the landscape for tourists. During the tourist season (3 months each year), the water level of the reservoir is lowered during the daytime so that tourists can see the rapids upstream of the dam. Obviously, this will have no benefit for the rapids-inhabiting fishes which will have been eliminated by heavy siltation, stagnant or slow moving waters, and low levels of dissolved oxygen (Roberts, 1993a: 124).

Rapids can also be maintained downstream of dams. Their usefulness depends on permanent water flow in the river bed during and after construction, and the native fishes not being threatened by pollution, explosives or abusive fishing during construction. If rapids are damaged during construction, depending on the sites, they might be restocked by fishes from other submerged rapids at the time of filling. The minimum flow left by most dams is often insufficient to maintain real rapids, especially if the exposed river bed is very wide. The flow must then be restricted to a narrower river bed, to reproduce more closely natural rapid conditions. Depending on the circumstances, such rapids should be kept distinct from spillways which could flush the rapids in the case of flash floods. If they cannot be separated, hydrological devices should be designed to bring the fish back to the 'normal' river bed when the water recedes in order to avoid massive kills in isolated, drying pools.

Creation/restoration of spawning grounds. Many fish species form large, more or less loose, schools which congregate at spawning grounds during the appropriate season. For some species, these spawning grounds are very sharply defined (e.g. a sand bar or stretch of boulders). Once these

are flooded, silt quickly accumulates, covering these places and making spawning impossible. A possible mitigation measure could be the creation (or restoration) of spawning grounds beyond the reach of the reservoir. Clearly the ecological requirements of the species involved need to be researched or at least inferred or extrapolated from other better-known species. New spawning grounds have been successfully created where the modification of water levels in temperate lakes has exposed the original spawning grounds, and there are efforts to do this for the Chinese sturgeon under a collaborative project between the Chinese Institute for Aquaculture Production and the US Department of the Interior (Y.J. Zhu, 1995).

Prevention of unintended movements. Within irrigation and hydropower schemes, canals are sometimes constructed which connect different river basins with different faunas. It is important to prevent invading species from passing from one river basin into another. Their impact would be the same as for deliberately introduced species (see above); these invaders or their parasites and diseases can seriously impact the freshwater biodiversity of the drainages they enter. Such invasions could possibly be prevented either electric barriers or 'hot locks' of warm water - ca. 40 degrees C - strategically placed in the canal system linking to natural waterways (McCauley and Fry, 1986); warm water would be lethal to fish and other freshwater organisms trying to cross the lock.

Species recovery. There are a few on-going attempts to aid the recovery of aquatic species which have experienced serious population depletion. They aim mostly at preserving single charismatic species like dolphins or crocodiles. Where fish are involved, attention is focused on a few species of interest to fisheries, fish of large size (notably the Chinese sturgeon), or those of interest to the aquarium trade. There does not appear to be a recovery program for any aquatic invertebrate within the region. Examples of current interest are given in the country sections. Non-commercial species, whose survival presently seems unlikely without some recovery program

and captive breeding include (but are not restricted to) many of the native species of Lake Poso, Indonesia (see Table 2), those of Lake Lanao, Philippines, some of the endemic species of Lake Dianchi and other Yunnan lakes, China, the species of *Labeo* endemic to Sri Lanka, and soon many rapids-inhabiting fishes from the Mekong and other large rivers.

Any species recovery program must first address the reasons for the initial decline or loss of the species concerned. Appropriate action may include the removal of introduced species and the restoration of habitat. It may also be necessary to address issues of pollution, sedimentation and water flow regimes. It currently seems impossible to restore certain habitats, such as peat swamps and caves. If habitat restoration is not possible, captive breeding programs should be considered, but they are no substitute for naturally maintained biodiversity.

Environmental Assessments and Monitoring

Practical considerations for aquatic biodiversity studies in environmental assessments are detailed in Annex B. Careful studies prior to the completion of a project are important because they allow useful and effective monitoring to proceed. Such work should not be restricted to the project site, but should also include areas or rivers which will remain untouched and can be used as a control. This applies to all types of projects, including introductions of exotic species. Unfortunately, with respect to freshwater biodiversity, the general quality of the studies currently conducted is very low, and this hampers discussions and wise decision making.

Noss (1990) identifies five categories of species which warrant intensive monitoring:

- ecological indicators - species that signal the effects of perturbations on a number of other species with similar habitat requirements;
- keystone species upon which the diversity of a large part of the community depends;
- umbrella species with large area requirements which, if given sufficient protected habitat

area, will bring many other species under protection;

- flagship or popular, charismatic species which serve as symbols and rallying points for major conservation initiatives; and
- vulnerable species which are rare, genetically impoverished, of low fecundity, dependent upon patchy or unpredictable resources, extremely variable in population density, or subject to pest control programs.

To these a sixth category could be added (Hill, 1995a):

- nutritionally important species.

Partnerships

At present there is insufficient nurturing of the partnerships necessary between engineers and biodiversity specialists to achieve environmentally sustainable development. There is perhaps too much wringing of hands at the biological damage inflicted by development projects, too much resentment of mitigation being tantamount to clearing up after engineers' mistakes, and too little mutual exploration of measures and designs that would benefit the concerns of both groups. This is a challenge that must be met (Schulze, 1996).

Legal instruments

National Jurisdiction

In many Asian countries the conservation of freshwater biodiversity suffers from being placed under both a conservation agency (often within a forestry department) and a fisheries agency. The interests of conservation and fisheries agencies are often in conflict, and communication between them may be minimal. In the wider context of swamps, floodplains and estuaries many sectors play a role, and the lack of cross-sectoral coordination in planning and development has been and continues to be one of the strongest forces for wetland destruction in Asia.

The fisheries and forestry agencies promulgate very different kinds of laws. Conservation laws usually list protected species whose capture or trade is prohibited, while fisheries laws usually deal with fishing seasons, fishing gear, minimum size, quotas, etc.. The latter may also ban the catch or export of some species and control or ban the introduction of exotics. Conservation agencies, in theory, are interested in numbers of species, whereas fisheries agencies are more concerned with the weight of the fish catch landed. Fisheries agencies often ignore threats to protected species listed by national conservation agencies and international treaties like CITES. For example, in Papua New Guinea the Fisheries Department will issue permits to collect aquarium fishes, but the agency in charge of conservation will not issue export permits for the same fish.

In many developing countries, implementation of nature conservation laws is now generally recognized as a significant problem. The problems include a lack of staff, lack of training and awareness, low motivation associated with low salaries and susceptibility to bribes, lack of community involvement, as well as the inability to identify organisms due to lack of proper identification tools and information. The problems are well publicized when large vertebrates are con-

cerned but the situation is considerably worse for fish and invertebrates.

Nationally Protected Species

Many countries have established lists of nationally-protected species. Very few list freshwater organisms, especially invertebrates. While the reason for listing large mammals and birds is usually clear, this is not the case for freshwater organisms. Where fish are listed, species are often misnamed on legal documents; and where experts are not available in the country to assist in these matters, it seems unlikely that enforcement staff could do better. This general confusion leads to a situation in which protected status is sometimes granted to species which do not exist in the country, which are misidentified, which cannot be identified, or which are not threatened. At the same time, species recognized internationally as seriously threatened species are ignored or overlooked. These problems clearly point to an inadequacy of baseline data and/or incompetent analyses. This leads, at best, to useless conservation laws, and at worst, to regulations that do more harm than good.

Three examples to illustrate the problems are given below.

Cambodia. The Fiat-Law on Fishery Management and Administration No. 33 KRO.CHOR of 19 March 1987 forbids the catch, sale and transportation of three species of fish: *Pangasianodon gigas*, "*probatus jullieni*" (presumably *Probarbus jullieni*) and "*grossochilus latius*". While the identity of the first two is clear, the meaning of the third is not. It appears to be a misspelling of *Crossocheilus latius*, but this fish is not known to occur in Cambodia. It is known only from India (Talwar and Jhingran, 1991: 416), and has never been reported from Cambodia in scientific literature but it sometimes appears in fisheries reports.

It is not possible to determine which species was originally intended and how it has been given that name. Crocodiles are also listed as protected. While the Wildlife Protection Office of the Department of Forestry is responsible for protection of wildlife, the Department of Fisheries is responsible for the protection of aquatic wildlife, including otters, frogs, crocodiles, fish, and dolphins.

Indonesia. Of the six officially protected species of freshwater fishes only the identity of *Scleropages formosus* is indisputable (the Asian bonytongue from Sumatra and Borneo, also known erroneously as arowana), this is not the case with the remaining five:

- *Scleropages leichardti* is a species endemic to Australia (Merrick and Schmida, 1984: 72; Allen 1989: 29); the species occurring in Irian Jaya is *S. jardinii* (Allen, 1991: 37); they have been considered as a single species at some time, but clearly are distinct; the stated English vernacular name 'Dawson River salmon' is never encountered in the literature; available data do not allow a decision on whether listing of this species is justified;
- *Pristis* sp. is a sawfish from Lake Sentani. It is apparently *P. microdon*, a species distributed in freshwaters and upper estuaries of South and Southeast Asia and northern Australia (Last and Stevens, 1994: 364); the status of this species is of concern in its whole distribution and a protection status is apparently justified;
- *Homaloptera gymnogaster* is a loach known from a single specimen from lake Maninjau, Sumatra, described in 1853; additional material has not been reported in the scientific literature since; the original locality data are dubious as members of the genus *Homaloptera* are from hill streams and not from lakes; Kottelat et al. (1993: 52) consider that this species has been described again under 3 different names; the species is widely distributed in hill streams of Sumatra (pers. obs.) and the listing is not justified;
- *Puntius microps* is probably the cave fish reported by Weber and de Beaufort (1916) and

Kottelat et al. (1993) under the same name; preliminary results of on-going research indicate that this fish is misidentified and is either an unnamed cave endemic or a cave population of *P. binotatus*, a species widely distributed in hill streams of Bali, Java and eastern Sumatra; its listing is justified; the status of the material originally described as *P. microps* is not cleared yet; it might be the valid name for a slender fish from lakes of central Java which also seems under threat;

- *Notopterus* sp. is the Javanese population of the commercially important featherback or belida called *N. chitala* by Weber and de Beaufort (1913). Roberts (1992) revised the family and concluded that the Indonesian material should be recognized as *Chitala lopis*. Indonesian belidas actually represent at least two species; unfortunately, no specimen of the Javanese population has yet been found either in the field or in museum holdings to decide its identity (unpubl. data). Verbal accounts by informants who observed it about 30 years ago while still common in Java suggest that it might be a distinct species.

In addition the Trade Department decreed that large (>15 cm) individuals of an otherwise unprotected species, the clown loach *Botia macracanthus*, should not be exported in order to safeguard the breeding stocks for continued capture for the aquarium trade. Despite the volume of the trade in this species (see above), the stocks show no signs of depletion and it is unclear how this regulation can affect the stocks. Fishermen catching a larger individual would eat it or sell it as food fish instead of as an aquarium fish, but are unlikely to release it. The only justification for this regulation is perhaps to ban the export of mature individuals which could be used abroad to establish a breeding stock which would compete with the national trade. However, the fish is already reportedly being bred in Thailand.

Thailand. Four freshwater fishes (*Oreoglanis siamensis*, *Datnioides microlepis*, *Botia sidhimunki*, and *Scleropages formosus*) and two freshwater crabs are officially protected. Neither the migratory giant Mekong catfish *Pangasiano-*

don gigas nor *Probarbus jullieni*, both listed on the Appendices of CITES and Migratory Species Convention, are protected.

National reviews

Afghanistan

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded)

Amphibians: 6

Crocodylians: 0

Turtles: 1

Fish: 84 (?50% of estimated total)

Crabs: 6 (10% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: -

Local skill to identify freshwater fish: -

A checklist of Afghanistan fishes was compiled by Coad (1981). 84 species are recorded from the country; 67 are known from a single river basin. No country-wide survey has ever been conducted, and virtually all the fish samples obtained to date have been chance collections by non-specialists. Our knowledge of this fauna is very fragmentary and many additional species should be expected. Considering the topography of the country, it seems likely that many species could have very restricted distribution ranges.

Bangladesh

Freshwater sites of exceptional biodiversity interest: many of the flood plains; hillstreams on the Bangladesh-Burma border

Freshwater biodiversity (species recorded):

Amphibians: 19

Crocodylians: 2

Turtles: 18

Fish: 260 (90% of estimated total)

Crabs: 5 (70-80% of estimated)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with adequate illustrations: -

Material in local language: -

Material in English: +

Local skill to identify freshwater fish: +

There is a single recent synopsis on the freshwater fishes of Bangladesh, which lists 260

species and includes keys, descriptions, and line drawings of all species, many of which are quite rudimentary (Rahman, 1989). See India, below for general comments on the quality of information.

The freshwater plants of Bangladesh are described by Khan and Halim Mahbuba (1987). The floodplains are discussed by Khan (1994).

Bhutan

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded):

Amphibians: 24

Crocodylians: ?

Turtles: ???

Fish: not known

Crabs: 3 (10-20% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: -

Local skill to identify freshwater fish:

There is apparently no specific publication on the fishes of Bhutan. There are a few scattered references in publications on Indian fishes.

Brunei Darussalam

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded):

Amphibians: 76

Crocodylians: 1 (possibly 3)

Turtles: 4

Fish: 55 (30% of estimated total)

Crabs: not known

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: +

Material in local language: -

Material in English: +

Local skill to identify freshwater fish: -

There is little published information on the freshwater fishes of Brunei. Eden (1984) reported 22 species of aquarium fish, and Choy and Chin (1994) list 44 species from the Belalong-Temburong basin. A checklist by Kottelat and Lim (in press) records 55 species.

Burma

Freshwater sites of exceptional biodiversity interest: Lake Indawngy (#3); Lake Inle (#5) with 9 endemic fish species and 3 endemic genera (Annandale, 1918, and pers. obs.)

Freshwater biodiversity (species recorded):

Amphibians: 75

Crocodylians:

Turtles: ???

Fish: 300 (50% of estimated total)

Crabs: 20 (10% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: -

Local skill to identify freshwater fish: -

Traditionally, monographs on Indian fishes have included Burma although no data after 1940 are available (e.g. Talwar and Jhingran, 1991). A checklist of Burmese fishes has been compiled by Hla Win (1987), listing 250 freshwater species; this list is probably of little use as it is too confused, many names appear several times, the nomenclature is outdated, and several of the listed species are not known to occur in Burma.

Using other published data (Talwar and Jhingran, 1991; Kottelat, 1989) and unpublished sources, there appear to be some 300 fish species already recorded from Burma freshwaters. Our knowledge of them is very superficial and fragmentary.

Cambodia

Freshwater sites of exceptional biodiversity interest: Tonle Sap (#2)¹¹, and the rapids between Khône Falls and Sambor.

Freshwater biodiversity (species recorded):

Amphibians: 28

Crocodylians: 1

Turtles: 1

Fish: 215 (60% of estimated total)

Crabs: 6 (<10% of estimated total)

Shrimps: 15 (75% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: -

Local skill to identify freshwater fish: -

A check list of 215 fish species then known from Cambodia, including a review of the literature and a key to the cyprinid (carp-like) species is available (Kottelat, 1985). This was based on material obtained in the early 1960s and preserved in Muséum national d'Histoire naturelle in Paris, most of which had never been reported. The Mekong River Commission, FAO and DANIDA are publishing an identification guide to the commercial freshwater fishes (Rainboth, in press). The draft which has been circulated includes only 124 species.

All the published information on freshwater crabs dates back to the early 1920s, except for a description of a new species (Ng, 1995).

China

Freshwater sites of exceptional biodiversity interest: Wuhan lakes (#96), Dongting lake (#100), Yunnan lakes (##136, 137, 138, 143)

Freshwater biodiversity (species recorded):

Amphibians: 190

Crocodylians: 1

Turtles: 21

Fish: 1010 (80% of estimated total)

Crabs: 200

Shrimps: 50 (50% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: + (but partial, provincial)

All species with good illustrations: +

Material in local language: +

Material in English: -

Local skill to identify freshwater fish: +

There are two recent synopses of Chinese freshwater fish species. Chen and Zheng (1987) listed about 800 species and S.Q. Zhu (1995) covers 1010. A total of 212 species from that total were first recorded from the country between 1982 and 1992; 156 are new species and 56 new records. Zhu's (1995) book is a set of keys to genera and species, indexes, and line drawings of all but 10 species. The absence of descriptive accounts is a drawback to this book.

In addition to national synopses, there are monographs dealing with the fauna of various

¹¹ - These numbers refer to the *Directory of Asian Wetlands* (Scott, 1989) which provides useful background information.

provinces, basins or islands: Hainan island (Pearl River Fisheries Research Institute et al., 1986), Yunnan (Chu and Chen, 1989, 1990), Sichuan (Ding, 1994), Fujian (Chu, 1984, 1985), Qinling range (Chen et al., 1987), Qinghai and Xizang [Tibet] (Wu and Wu, 1992), Chang Jiang [Yangtze] River (Fisheries Research Institute of Guangxi, 1976), Zhujiang [Pearl] River (Zheng, 1989), Guangdong (Pan et al., 1990), Guangxi (Fisheries Research Institute of Guangxi, 1981) and Heilongjiang (Nikolski, 1960). Information on the lakes in Yunnan province is given in Li (1982); Chu and Chen (1989, 1990); Yang (1991); and Kottelat and Chu (1988).

All of these works are in Chinese, although a few include limited English abstracts; they are not easily available and, as such, the dissemination of the knowledge abroad is very limited. Also, the language barrier makes it difficult to obtain broader evaluations of the quality of the work. In general, most of the work is of reasonable quality. It suffers, however, from a lack of critical approach, and from neglect of the work of foreign authors.

About 90 species of fish are believed to be endangered and one, the carp *Cyprinus yilongensis* from Yunnan, has been confirmed as extinct as Lake Yilong was drained dry for 20 days in 1981 (Chen and Cui, 1993).

A recovery program has been initiated for the sturgeons *Acipenser dabryanus*, *A. sinensis*, and *Psephurus gladius* (Changjiang Aquatic Resources Survey Group, 1988). The Institute of Chinese Sturgeons within the Gezhouba dam Corporation (whose major dam blocked the passage of migrant species) has released 11 million fry into the Yangtze river over the last 11 years, and the Yangtze River Fisheries Research Institute with the US Fish and Wildlife Service are studying the management and creation/restoration of spawning grounds (Kynard et al., 1995).

An important flagship freshwater species is the Yangtze river dolphin or baiji *Lipotes vexillifer* which, like other freshwater cetaceans, faces threats from dam construction, accidental kills from fishing gear, collisions with vessels, and dynamite used for construction and illegal fishing. In China, the baiji has been declared a National Treasure (as has the giant panda), and it is now

admitted that it cannot survive without intervention. However, its rank as a National Treasure has not halted the decline in its population. It is now proposed that the few remaining be captured and preserved in a semi-natural reserve. This operation is not without risk. For example, 7 of 12 Yangtze finless porpoises *Neophocaena phocaenoides* in a reserve were killed during capture operations by untrained staff (Leatherwood and Reeves, 1994).

A description of the freshwater plants of China is presented by Yan (1983).

India

Freshwater sites of exceptional biodiversity interest: Streams in Kerala and northeast India (Assam, Manipur, Nagaland, Meghalaya, Himachal Pradesh, Mizoram, Tripura); major floodplains

Freshwater biodiversity (species recorded):

Amphibians: 206

Crocodylians: 3

Turtles: 18

Fish: 748 (90% of estimated total)

Crabs: 60 (60% of estimated total)

Shrimps: 100 (70% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: -

Material in local language: -

Material in English: +

Local skill to identify freshwater fish: +

The latest handbook on Indian fishes is by Talwar and Jhingran (1991). They record 930 species from India and 'adjacent countries' (Pakistan, Nepal, Bhutan, Bangladesh, Burma and Sri Lanka). In a handbook with a similar coverage, Jayaram (1981) recognized 742 species. The inclusion of 'adjacent countries' is an established Indian ichthyological tradition although almost no new material from these countries has been available to Indian authors since 1940. An estimate of the fish fauna of India itself has never been published. The count, based on Talwar and Jhingran, after the deletion of introduced species and corrections of salient errors and omissions, is of 748 species. Some state or regional accounts are also available. These essentially consist of distillations of the text and illustrations of earlier works. Indeed, there seem to be a number of problems with

existing publications on freshwater biodiversity. Many Indian publications on fish taxonomy suffer from a lack of criticism approach and lack of exposure to the outside world. In many cases the fieldwork is conducted by associates, not by the researcher who writes the actual paper. As a result, despite the many publications, the knowledge of Indian fish fauna remains unsatisfactory. Contrary to many other Asian countries, the problem here is not the lack of data, but rather an abundance of uncritical compilations and users, resulting in inconsistency (see examples in Pethiyagoda and Kottelat, 1994 and Kottelat, 1990d).

Meanwhile, some excellent fieldwork remains largely unpublished, the results of which, together with careful examination of well-preserved material show that the diversity of the Indian fish fauna is underestimated and that many widespread species actually are a composite assemblage of strikingly distinct species. Reexamination of material collected in the last century also indicates that several species have been overlooked which may now be extinct.

De Silva (1989: 150) lists instances of decline and disappearance of indigenous species as possible consequences of introduced fish species, although he asserts that the carp (p.142) has not endangered any of the Indian native fish. In fact, species of the native genus *Schizothorax* have disappeared from waters to which the carp had been introduced (Jhingran and Sehgal, 1978, cited by Welcomme, 1988: 20). A symposium volume on Indian threatened fishes (Dehadrai et al., 1994) includes accounts on many states and fish groups, although some papers are not as strong as others. There is a strong bias towards large fish (especially mahseer *Tor* species popular with anglers) and very little attention is given to smaller species.

A relevant and useful publication on the wetland flora of the subcontinent is available (Cook, 1996).

Indonesia

Freshwater sites of exceptional biodiversity interest: Malili lakes in Sulawesi (#98); Lake Lindu (#89); Lake Poso (#87); Lake Sentani in Irian Jaya (#129). The following peat swamps each have their own set of endemic fish, crab or

shrimp species: Berbak Reserve (#8), Tanjung Puting National Park (#74) and probably other yet unsurveyed areas of Borneo (##71, 75, 77, 78).

Freshwater biodiversity (species recorded):

Amphibians: 270

Crocodylians: 3

Turtles: 15 (9 excluding Irian Jaya)

Fish: 1300 (70% of estimated total)

Crabs: 90 (45% of estimated total)

Shrimps: 70 (60% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: +

Material in local language: +

Material in English: +

Local skill to identify freshwater fish: +

The marine and freshwater fish fauna of Indonesia (as well as eastern Malaysia, Brunei and Papua New Guinea) is dealt with in the classic 11-volume monograph by Weber and de Beaufort (1911-1962). The two volumes dealing with the main groups of freshwater fishes appeared in 1913 and 1916 and are outdated. Kottelat et al. (1993) provide diagnoses and illustrations (in English and Indonesian) for the 962 species from inland waters of western Indonesia and Sulawesi (also including eastern Malaysia and Brunei); 293 species were not included in Weber and de Beaufort and 251 were included under a different identification. Irian Jaya is covered by Allen (1991) (see Papua New Guinea), and there is virtually no available data on the freshwater fishes of the Moluccas and Lesser Sundas area, except for recently obtained (and still unpublished) data from Halmahera island.

The knowledge of the Indonesian fish fauna must still be regarded as rudimentary. For the area covered by Kottelat et al. (1993), the list of additions and new discoveries since the book was written includes 75 species for which information has already been published and some 100 for which information is available but not yet published. This represents an increase of 18% in only four years. These 'additional' species were obtained with little effort, and it is estimated that at least 400-600 additional species remain to be discovered.

One of the most important freshwater biodiversity sites in Asia is the Malili lakes of Sulawesi yet they are afforded protection only as Tourist

Parks which allows, inter alia, the introduction of exotic species. The unique biogeographic position of Sulawesi results in a large portion of its fauna and flora being endemic to the island (Whitten et al., 1987b, c). This also applies to its freshwater fauna. More than half of the 60 Sulawesi freshwater fishes (including 15 of the 17 known species of Telmatherinidae), 1 snake, 3 crabs, about 10 shrimps, some 60 molluscs, 1 macrophyte and possibly sponges and water mites are endemic to this group of five lakes (Kottelat, 1990b-c, 1991, and unpubl.; P. Bouchet, pers. comm.).

The Asian bonytongue *Scleropages formosus* is now bred under artificial conditions in West Kalimantan and, in theory, a proportion of the young have to be returned to the Kapuas river to restore a much exploited population. It is not known if the a comprehensive monitoring plan is in operation to determine the efficacy of this approach.

Useful publications on macrophytes include an annotated checklist to Indonesian freshwater herbs (Giesen, 1991) and descriptions of the freshwater plants of Papua New Guinea (Leach and Osborne, 1985). Family revisions of submerged macrophytes in *Flora Malesiana* are listed earlier. Information on the macrophytes is available for Sumatra (Whitten et al., 1987a), Sulawesi (Whitten et al. 1987b), and Java and Bali (Whitten et al., 1996).

Two monographs on the freshwater molluscs of Java are available (van Benthem Jutting, 1953, 1956).

Japan

Freshwater sites of exceptional biodiversity interest: Lake Biwa (#16) (Kira, 1995)

Freshwater biodiversity (species recorded):

Amphibians: 52

Crocodylians: 0

Turtles: 4

Fish: 150 (95% of estimated total)

Crabs: 6 (60% of estimated total)

Shrimps: 25 (80% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: +

Material in local language: +

Material in English: +

Local skill to identify freshwater fish: +

Masuda et al. (1984) compiled diagnoses in English and Japanese and illustrations of the 3200 fish species then known from the Japanese archipelago. Nakabo et al. (1993) compiled diagnoses and identification keys in Japanese. Okiyama et al. (1988) compiled information on larval stages in Japanese. Some 150 species of freshwater fishes are listed in Masuda et al. (1984); judging from the data in Nakabo et al., and allowing for differences in the concept of what a species is, it seems clear that the actual figure is higher.

The aquatic plants are discussed by Kadono (1994).

Democratic People's Republic of Korea, Republic of Korea

Freshwater sites of exceptional biodiversity interest: None known

Freshwater biodiversity (species recorded):

Amphibians: 13

Crocodylians: 0

Turtles: 2

Fish: 90 (?% of estimated total)

Crabs: 0

Shrimps: 5 (90-100% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: -

Material in local language: +

Material in English: -

Local skill to identify freshwater fish: +

Apparently no data on DPRK's freshwater fishes have been published in the last 50 years. Jeon (1980) recorded 90 species of freshwater fishes from RK, provided identification keys and discussed their zoogeography. There is apparently neither monographic treatment nor field guide to the fishes of the country.

Lao P. D. R.

Freshwater sites of exceptional biodiversity interest: Khône Falls

Freshwater biodiversity (species recorded):

Amphibians: 37

Turtles: ?

Fish: 262 (50% of estimated total)

Crabs: 7 (15% of estimated total)

Shrimps: 10 (15% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: -

Local skill to identify freshwater fish: -

The publications on Laotian fishes comprises Taki's (1974) synopsis, a few scattered papers in scientific journals, and some grey literature. These very limited data have been obtained mainly from the Mekong mainstream and a very few of the major tributaries. The rest of the country is still virtually unknown from the ichthyological point of view. Taki records 203 species from Laos; most of them are illustrated and diagnosed. Data on the Mekong fauna in Thailand indicates that this figure is too low, and a recent survey in two river basins increased it to about 280 (Kottelat, in prep.). In additional areas with similar topography in Thailand and Yunnan suggest that probably 100 to 200 species with restricted distribution should be expected in the unexplored rapids and hill streams.

Malaysia

Freshwater sites of exceptional biodiversity interest: The following peat swamps each have their own set of endemic fish, crab or shrimp species: North Selangor swamp forest (#9), Southeast Pahang swamp forest (#1), Sedili Kecil swamp forest (#5), Third Division and Sibul swamp forest (#30, 31).

Freshwater biodiversity (species recorded):

Amphibians: 158

Crocodylians:

Turtles: ?

Fish: 600 (85% of estimated total)

Crabs: 88 (65% of estimated total)

Shrimps: 55 (55% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: -

Local skill to identify freshwater fish: +

There is currently a single book on the freshwater fishes of western Malaysia, by Mohsin and Ambak (1983). Unfortunately it is quite superficial, many species are not included, nomenclature is out of date, and information on habitats and conservation are often misleading. The authors recorded 382 species of which they describe the 121 they collected. Their list of 118 rare or extinct species has been cited frequently in conservation

literature, but is inaccurate. Many of these species are common but are rarely collected because of their small size or unpleasant habitats (e.g. swamps).

According to a list of all fish species known from inland waters of mainland Southeast Asia (Kottelat, 1989) there are 264 freshwater fishes known from the whole Malay Peninsula (Peninsular Malaysia + southern Thailand). This list has been updated by Lim et al. (1993) who recorded about 260 freshwater fishes for Peninsular Malaysia only. Unpublished data show that the figure is now around 300 species.

Kottelat and Lim (in press) list 249 fish species from inland waters of Sarawak. Inger and Chin (1962) report and describe 129 species from Sabah; in an up-dated edition, Chin (1990) added 11 species. These two states are covered by Kottelat et al. (1993).

Ng (1988) revised and illustrated the 40 species of freshwater crabs known from peninsular Malaysia; 8 new species have been described since. Ng (pers. comm.) estimates that some 30-40 species are known from Sarawak and Sabah, including several cave species. An estimated 25 species of freshwater shrimps are known from Peninsular Malaysia and 30 from Sarawak and Sabah.

Maldives

The Maldives are a group of low-lying coral atolls. Freshwater occurs in aquifers and no native freshwater fish has ever been recorded.

Mongolia

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded):

Amphibians: 0

Crocodylians:

Turtles: ?

Fish: 56 (90% of estimated total)

Crabs: 0

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: +

Material in local language: -

Material in English: -

Local skill to identify freshwater fish: not known

The only monographic treatment of the fishes of Mongolia is by Shatunovskii (1983). It provides keys, descriptions (in Russian) and illustrations of 56 species. This figure is possibly underestimated as it seems that several species of *Oreoleuciscus* might be confused under a single name. Additional information can be found in Travers (1989). The figure of 75 known fish species in Finch (1996) may include subspecies and exotic species.

Nepal

Freshwater sites of exceptional biodiversity interest: Lake Rara (#3) with rich invertebrate fauna and species of *Schizothorax* (Terashima, 1984)

Freshwater biodiversity (species recorded):

Amphibians: 36

Crocodylians: 2

Turtles: 11

Fish: 129 (80% of estimated total)

Crabs: 20-30 (20-30% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: -

Material in local language: -

Material in English: +

Local skill to identify freshwater fish: +

J. Shrestha (1981) provided keys, descriptions and illustrations of the 120 fish species reported from Nepal; later she recorded 129 species (Shrestha, 1994). T.K. Shrestha (1990) discussed fish and fisheries in Nepal. Beside general comments, there is no concrete information on conservation of aquatic organisms. There is also a general discussion on fishing regulations in other countries, but no data on local regulations.

Pakistan

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded):

Amphibians: 17

Crocodylians: 2

Turtles: 5

Fish: 159 (90% of estimated total)

Crabs: 10 (15% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: -

Material in local language: +

Material in English: -

Local skill to identify freshwater fish: +

Mirza (1990) illustrates and describes (in Urdu) 159 fish species known from Pakistan freshwaters. In 1975 he discussed their zoogeography. Some of the estuarine fishes are diagnosed and illustrated by Bianchi (1985).

Papua New Guinea

Freshwater sites of exceptional biodiversity interest: Lake Kutubu (#22) with 11 endemic fishes

Freshwater biodiversity (species recorded):

Amphibians: 183

Crocodylians: 2 (?3)

Turtles: 7

Fish (including Irian Jaya): 329 (70% of estimated total)

Crabs: 25 (20-30% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: +

Material in local language: -

Material in English: +

Local skill to identify freshwater fish: not known

Allen (1991) describes and illustrates 329 species then known to occur in inland waters of Papua New Guinea and the Indonesian province of Irian Jaya.

Holthuis (1979, 1982) discussed the crustaceans of the whole island. New Guinea is of special interest for its presence of real freshwater crayfish (Holthuis, 1986). Cave shrimps have also been recorded.

Philippines

Freshwater sites of exceptional biodiversity interest: Lake Lanao (#59)

Freshwater biodiversity (species recorded):

Amphibians: 63

Crocodylians: 1

Turtles: 3

Fish: 330 (80% of estimated total)

Crabs: 41 (60% of estimated total) - all endemic

Shrimps: 40 (60% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: -

Local skill to identify freshwater fish: -

There are very few sources of recent data on the freshwater fishes of the Philippines. Herre (1953) published a then extensive bibliography to the fishes of the Philippine archipelago, including freshwater species. The latest general and authoritative account on the freshwater fishes is by Herre (1924a-b). Herre recorded 36 'true' freshwater fishes. A few species have been added since to a total of about 45, almost all of them endemic to the Philippines (especially on Palawan and Mindanao). To these should be added 38 freshwater species (mostly endemic) of otherwise marine families and 234 species occurring in freshwaters but returning to the sea to spawn which Herre listed in 1959. The recorded freshwater fish fauna thus totals about 330.

The limitations resulting from the lack of ground surveys is obvious. A survey of inland waters of the island of Leyte yielded some 120 species (Kottelat, unpubl.) including five endemic species, three of them presently known from the single ca. 5 km long Lagu creek (Watson and Kottelat, 1994, 1995). This stream appears to be a veritable 'hot spot' of fish biodiversity, but it is questionable whether this pattern is real or a result of Leyte being better collected than the adjacent islands (Samar, Cebu, Bohol, etc.), and of that precise stream being very well collected as it is adjacent to a campus where ecology is taught.

Lake Lanao on Mindanao Island is noteworthy for its species flocks of some *Puntius* species which have been the subject of numerous studies (see Kornfield and Carpenter, 1984, for a recent summary). Eighteen Lake Lanao *Puntius* species are believed to be derived from a single *P. binotatus*-like ancestor; *P. binotatus* is widespread all over Southeast Asia where it displays only relatively limited variability in appearance and habitat. An assessment by an ichthyologist with field experience of the status of the flock and the causes of its possible extinction should be a high priority as soon as security permits.

Singapore

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded):

Amphibians: 24

Crocodylians: 1

Turtles: 6

Fish: 45 (100% of estimated total)

Crabs: 6 (100% of estimated total)

Shrimps: 11 (90% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: +

Material in local language: +

Material in English: +

Local skill to identify freshwater fish: +

The knowledge of the freshwater biodiversity of Singapore is outstanding: there is detailed or very detailed information on the taxonomy, ecology, distribution, and conservation status of most groups. Of course the small size and the wealth of the country have facilitated surveys, but a key factor has also been the presence in local institutions of a succession of scientists with an interest in freshwater diversity.

Synopses of the Singaporean freshwater fishes include Alfred (1966), Munro (1990) and Lim and Ng (1990). The last of these is a field guide with color illustrations of all species, which is inexpensive and available locally; similar guides also exist for amphibians and reptiles (Lim and Lim, 1992) and freshwater life (Ng, 1991a). Freshwater crustaceans are discussed in Ng (1988, 1990, 1994b), planktonic copepod crustaceans by Fernando and Ponyi (1981), and rotifers by Fernando and Zankai (1981).

Some 45 native freshwater fish species are now recognized from Singapore. Lim and Ng (1990) list 22 feral species and this list is probably not exhaustive, considering the importance of the aquarium fish trade in Singapore and related risks of escapes. Ng (1994b) lists six freshwater crabs (three of them endemic to the island) and 11 freshwater prawns.

General discussions on aquatic conservation in Singapore can be found in Ng (1991b) and Ng and Lim (1992) which include freshwater biodiversity. The effect of introduced aquatic organ-

isms on the native biodiversity is discussed by Ng et al. (1993). Endangered species are listed in the Singapore Red Data Book (Ng and Wee, 1994) and Ng (1995a). The Singapore Red Data Book is apparently unique in Asia, if not in the world, in that a diversity of marine and freshwater aquatic organisms are considered, and that invertebrates are dealt with thoroughly.

The detailed field data available for Singapore illustrate that some species have very specialized and restricted distributions. Ng and Wee (1994: 179) report a still unnamed shrimp known on Singapore from a very short stretch (a few meters) of a fast-flowing forest stream. In the Malay Peninsula, this species is also known from a few isolated populations. Singapore also illustrates the fact that even streams in easily accessible areas are still insufficiently surveyed as several species have been described only in recent years. Others have long been confused with similar looking species from other areas. Finally, old museum material includes specimens not identifiable with any known extant species which likely represent undescribed, extinct species (Ng and Kottelat, 1994: 605).

Sri Lanka

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded):

Amphibians: 39

Crocodylians: 1

Turtles: 2

Fish: 90 (95% of estimated total)

Crabs: 21 (50% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: +

Material in local language: -

Material in English: +

Local skill to identify freshwater fish: + (outside official institutions)

The freshwater fishes of Sri Lanka are described and illustrated in color by Pethiyagoda (1991); he recorded 88 native species and 21 exotic ones. Although the fish fauna of the island has commonly been considered well known, on-going work shows that new species are still being

discovered (about 10 since 1985) and that many species identified as being the same as Indian fishes by earlier authors actually are distinct, often unnamed species.

For years, only seven freshwater crabs had been recognized from Sri Lanka. Recent field-work has demonstrated this figure to be a very crude underestimate. The revision of a single genus, then assumed to be represented by a single species, shows that it in fact includes at least 10 species (Ng, 1995b) and on-going research will show this trend to be valid for other genera too.

Taiwan

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded):

Amphibians: 26

Crocodylians:

Turtles: ???

Fish: 95 (100% of estimated total)

Crabs: 35 (80% of estimated total)

Shrimps: 15 (80-90% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: +

Material in local language: +

Material in English: -

Local skill to identify freshwater fish: +

Shen (1994) published color illustrations and diagnoses of all fishes of Taiwan. Tzeng (1986, 1990) published two books describing and illustrating in color all 95 fish species from Taiwan's freshwaters and indicating their conservation status. All this material is in Chinese.

Some 35 species of freshwater crabs are known from Taiwan, 25 of which were described in 1994 (Shy et al., 1994).

Thailand

Freshwater sites of exceptional biodiversity interest: Pa Phru (#35) peat swamps has its own endemic fish, and crustaceans; Mae Klong (#23)

Freshwater biodiversity (species recorded):

Amphibians: 107

Crocodylians: 1

Turtles: 12

Fish: 690 (90 % of estimated total)

Crabs: 63 (50% of estimated total)

Shrimps: 50 (70% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: -

Local skill to identify freshwater fish: +

The last exhaustive treatment of the freshwater fishes of Thailand is by Smith (1945) who recorded some 450 species. Since then, the country has witnessed more ichthyological activity than any neighboring country by local and foreign ichthyologists, but no recent monographic treatment of the fish fauna has been published. Kottelat (1989) compiled a list of the then known species from the Indochinese peninsula and updated the nomenclature; allowing for changes which have occurred since, some 690 species are now recorded from Thailand and adjacent areas.

The freshwater crabs of Thailand are listed by Naiyanetr (1980) and updated in Ng and Naiyanetr (1993) who recognize 63 species. Brandt (1974) listed and illustrated 314 species and subspecies of freshwater molluscs.

Vietnam

Freshwater sites of exceptional biodiversity interest: none known

Freshwater biodiversity (species recorded):

Amphibians: 80

Crocodylians: 2

Turtles: 16

Fish: 450 (80% of estimated total)

Crabs: 12 (<10% of estimated total)

Shrimps: 30 (20% of estimated total)

Technical and human capacity:

Availability of recent monograph of freshwater fish species: +

All species with good illustrations: -

Material in local language: +

Material in English: -

Local skill to identify freshwater fish: +

Identification guides to the freshwater fishes of northern and southern Vietnam have been published by Yen (1978), Yen et al. (1992) and Truong (1993). They include descriptions in Vietnamese, keys and illustrations to some 450 species. These books suffer from the isolation in which Vietnamese scientists have worked for many years. Their nomenclature is outdated and often irreconcilable with that of adjacent countries, the quality of illustration is quite poor, the authors were not aware of recent work by foreign authors and it is doubtful whether some species could be reliably identified. The earlier work by Chevey and Lemasson (1937) for the Red River basin is missing the more recently discovered species, but is still useful.

Selected programs and activities

Darwin Initiative in the Himalayas

This project is being undertaken by the UK Institute for Hydrology and the University of Wales. It is investigating the consequences of river catchment management on freshwater biodiversity in the Indian and Nepalese Himalayas. The study covers the spatial distribution patterns of aquatic biodiversity, stream water chemistry and fluvial sediments in river catchments of the Himalayas, with the aim of assessing and using these parameters as indicators of environmental change caused by anthropogenic impacts such as intensive agriculture and deforestation.

Gangetic River Dolphin Watch Program

WWF India has entered into a partnership with the Global Rivers Environmental Education Network (GREEN) and they have a proposal under preparation for a Gangetic River Dolphin Watch Program along the Ganges in Nepal, India and Bangladesh with India project being implemented by WWF-India. At three or four locations along the Ganges, a program will be implemented involving water quality testing, water use surveys in the river basin, and population status survey of the Gangetic river dolphin *Platanista gangetica* and threats to these. An awareness campaign will be undertaken involving NGOs, schools and community groups. Emphasis is on the catchment approach.

Wetlands International Asia-Pacific

The mission of Wetlands International is to sustain and restore wetlands, their resources and biodiversity for future generations through research, information exchange and conservation activities. Since 1987 Wetlands International - Asia Pacific (WI-AP) (formerly Asian Wetlands Bureau) has been implementing a large program

with a broad range of activities with relevance to freshwater biodiversity conservation. These include assessments (including ichthyological surveys) for conservation and sustainable management of many wetland areas, and the promotion of development of integrated (multi-sectoral) national and regional wetland action plans which include specific actions related to freshwater biodiversity. WI-AP is also implementing a range of training and information/awareness activities which incorporate freshwater biodiversity conservation aspects. One of the aims of WI-AP is to support a greater recognition of the importance of freshwater biodiversity as part of the promotion of wise use and conservation of wetlands.

South East Asian Aquatic Biodiversity Program

The Laboratory of Ecology and Systematics of the National University of Singapore has an ongoing research program on Aquatic Biodiversity in South East Asia. The program includes basic and applied research on aquatic biodiversity and ecology, documentation of aquatic biodiversity, development of databases, elaboration of identification tools, environmental impact assessment studies using freshwater systems, setting up and utilizing gene banks, a study of the genetic diversity of food catfishes, advice on aquaculture species, publication of field guides and handbooks (in both printed and electronic formats), and international collaboration with individuals and institutions. Immediate targets of the program include handbooks on the freshwater crabs of Borneo and the Philippines, a field guide to S.E. Asian fishes, and a field guide to Malayan aquatic insects.

Biodiversity in Mainland South East Asia

The Swedish Natural History Museum is developing the above project (known as MASEA)

which aims to develop systematic disciplines at local MASEA biodiversity centers, to promote biosystematic databases, and to stimulate and participate in the organization of a network of biodiversity research institutions in S.E. Asia. The ichthyological component proposes to assist in inventories of the fauna and to support international cooperation on fish biodiversity.

Fishbase

Fishbase is a computerized database developed by the International Center for Living

Aquatic Resources Management and is available on CD-ROM. It includes data on fish taxonomy, distribution, biology, reproduction, larval stages, etc. and includes photographs and distribution maps. The database is still being developed and present coverage is variable depending on geographical areas etc. The present coverage of Asian freshwaters is still rudimentary.

Recommendations

Project Design

- 1) Wherever inland waters are to be altered in the course of a project, freshwater biodiversity needs to be addressed as early as possible, using appropriate expertise and methods, in order to be sure of complying with Operational Policy 4.04 on Natural Habitats.
- 2) Rapids, peat swamps, and caves should be considered for inclusion in the list of 'critical natural habitats' (sensu OP 4.04).
- 3) Fundamental field work conducted by teams led by competent scientists needs to be supported, perhaps as part of project preparation seen in the context of training and capacity building. Urgently-needed information can be as basic as reliable lists of species, but also includes species' distributions, empirical data on food, reproduction and migrations. The results should be made available internationally and without delay in the form of refereed publications. Results should include the preparation of field guides and other identification tools.
- 4) Efforts should be made to seek positive mitigation options and to forge partnerships between engineers, economists and biodiversity specialists.
- 5) When considering introductions of freshwater species, the alternative of improvement without introduction, should first be considered. Tests should be conducted with the native fauna to ascertain their suitability for use in aquaculture. If, after due consideration, it is decided that an exotic introduction is warranted, then extensive pre-project surveys should be conducted and the existing codes of practice implemented (see Coates, 1995).

Environmental Assessment, Mitigation and Monitoring

- 6) Freshwater biodiversity components in environmental assessments should be:
 - conducted by experts with demonstrated experience (that is, experience in their field, not experience in writing EAs);
 - addressed independently of fisheries and wetlands;
 - placed in a proper geographic context (river basins) and related projects or impacts of different projects should be investigated together;
 - propose innovative and realistic mitigation measures, and where no proven solutions exist, projects should be taken as an opportunity to test new and promising possibilities.
- 7) An international meeting should be convened to bring together engineers and biodiversity specialists to explore meaningful mitigation measures to counter biodiversity loss resulting from infrastructure and other development projects, and out of that to produce a handbook of relevant case studies and best practice.
- 8) EAs should be designed to obtain sound data on which to base practicable monitoring of the impacts of the project on biodiversity. These should include the search for undisturbed sites or rivers which will not be affected by the project (or other on-going or planned projects) and which can be used as controls.
- 9) Any proposed species recovery program must first address the reasons for the initial decline or loss of the species concerned. If habitat restoration is not possible, captive breeding programs should be considered, but they are no substitute for naturally maintained biodiversity.

Policies and Strategies

10) Freshwater biodiversity should be explicitly covered in National Environmental Action Plans, Biodiversity Action Plans, National Conservation Strategies, National Wetland Action Plans, and Country Assistance Strategies.

11) Protected area and fisheries legislation needs to be reviewed to determine how the best interests of freshwater biodiversity can be accommodated.

12) The management and conservation of freshwater biodiversity should be wholly adopted as part of water resources policy.

Knowledge Development

13) Concern for freshwater biodiversity implies that prior knowledge be available. The freshwaters of very few Asian countries has been surveyed in detail, and only for the most conspicuous animal groups. Clearly a major priority is large-scale collection of baseline data (species lists, distribution maps, understanding of ecological requirements, reproduction and migration information). The information so gained needs to be disseminated and this can be developed well through the production of local language field guides. Priorities are listed below.

14) Additional support should be considered to increase the breadth and depth of *Fishbase*, coordinated by ICLARM in Manila, and to the development and application of the *Wetland Database* of Wetlands International.

Capacity Building

15) A major training program should be instigated to build up indigenous capacity in freshwater biodiversity and wetland subjects. Efforts should focus on young, motivated students, giving them a solid background in locally-relevant biology from the start. This is the only way that competent and innovative researchers will be trained.

Economic Assessment

16) The benefits of proper management of all levels of freshwater biodiversity and the cost of unfavorable management should be quantified, and valuation systems developed. It is recommended that a World Bank Research Grant be sought for this purpose.

17) Devise protocols which would allow a rapid assessment of water quality and biological health, and could be used to compare one river with another and as a basis for monitoring.

Indicators

18) The use of freshwater organisms as indicators of environment and water quality has often been advocated, but very few steps have been taken in that direction. A prior knowledge of the habitats and biology of individual species is required in order to select those suitable as indicators.

Priorities for Surveys and Identification Material

As already stated, there is an urgent need for basic survey work and knowledge development in many Asian countries.

Countries for which there is little or no reliable data and thus where broad surveys are required: Burma, Laos, Cambodia, Bhutan (and Afghanistan and North Korea when politically feasible).

Countries for which some data are available, but their quality and the existing geographical gaps justify extensive field work: Philippines, Nepal, Vietnam.

Countries for which some good and recent data as well as identification tools are already available, but where there are still huge geographical gaps to be covered and extensive surveys are needed: Indonesia, Papua New Guinea

Countries in which critical or sensitive habitats should be surveyed: caves in China, peat swamps in Indonesia and Malaysia.

Countries in which there is an abundance of literature, but in which the quality of knowledge is poor and the threats to the freshwater communities so severe, that competent and critical field work is urgently needed: India

In most countries, there is a very urgent need for basic literature and especially field guides. The proper identification of organisms is the keystone of all biodiversity work. If surveyors and researchers are not able to identify the local

aquatic community correctly, their reports will be of little use and the adequacy and appropriateness of the decisions taken will always be in doubt.

Countries with no comprehensive or accessible field guides, the compilation of which would require prior surveys: Burma, Laos, Cambodia, Bhutan, Afghanistan.

Countries with no comprehensive or accessible field guides, the compilation of which could be achieved quite rapidly through collaboration between local and foreign scientists: Thailand (this could form an important basis for guides for Laos and Cambodia).

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Appendix A. Fish species exclusively known from caves in South and East Asia

CHINA

Gibbibarbus cyphotergous (Guizhou)
Sinocyclocheilus anatrostris (Guangxi)
Sinocyclocheilus angularis (Guizhou)
Sinocyclocheilus anophthalmus (Yunnan)
Sinocyclocheilus hyalinus (Yunnan)
Sinocyclocheilus microphthalmus (Guangxi)
Typhlobarbus nudiventris (Yunnan)
Protocobitis typhlops (Guangxi)
Oreonectes anophthalmus (Guangxi)
Triplophysa gejiuensis (Yunnan)
Triplophysa xiangxiensis (Hunan)

INDIA

Horaglanis krishnai (Kerala)
Schistura sijuensis (Meghalaya)

INDONESIA

Bostrychus sp. (Sulawesi)
Puntius sp. "microps" (Java)

MALAYSIA

Sundoreonectes tiomanensis (Tioman Island)

PHILIPPINES

Caecogobius cryptophthalmus (Samar)

THAILAND

'*Puntius*' *speleops* (Chaiyaphum)
Nemacheilus troglotaractus (Kanchanaburi)
Schistura jarutanin (Kanchanaburi)
Schistura oedipus (Mae Hong Son)
'*Homaloptera*' *thamicola* (Mae Hong Son)
Pterocryptes sp. (Kanchanaburi)

Appendix B. Considerations for Aquatic Biodiversity Studies in Environmental Assessment

(Based on: Kottelat et al. 1993. *Freshwater Fishes of Western Indonesia and Sulawesi*. Periplus, Jakarta)

Some pointers are given below for people conducting environmental impact assessments or writing environmental management plans for aquatic biodiversity in the context of development projects. Many such reports do not do justice to the importance of the freshwater environment, and it is hoped that these ideas may lead to some improvements.

Pre-planning stage. Consider the nature of the project and its likely impacts on an aquatic system. The project may have one or more of the following effects:

- direct destruction of habitat such as filling in of wetlands, removal of sand/gravel substrate, river channeling;
- direct alteration of flow regimes such as provision of instream storage, diversion of water for consumption purposes;
- direct changes to the physical and chemical characteristics of the water such as discharge of effluents, or change of water temperature due to the discharge of cooling water from power plants;
- direct changes to the aquatic community by the addition/introduction of exotic species, selective removal of some species, or enhancement of others;
- alteration of watershed characteristics such as loss of vegetation and resulting soil erosion, loss of storage due to land use changes resulting in accentuated flood or low flows;
- alteration of riparian/littoral vegetation such as stream bank cleaning and timber harvesting.

Impacts are normally thought of as negative, but some changes may actually benefit some species. Water control structures, for example, may lessen both the destructiveness of scouring during floods and the severity of low-flow conditions, thereby possibly improving the productivity of some fish species. It must be kept in mind, however, that the enhancement of one species very

often occurs to the detriment of a larger number of others, resulting in an overall loss of diversity. Species enhancement can very often be a temporary phenomenon, as seen in the initial fish 'bloom' and subsequent decline that is common in new reservoirs.

An initial prediction of potential impacts (usually referred to as 'scoping') can greatly improve the efficiency of subsequent data collection and management interpretation. However, the scoping exercise is dependent on:

- the existence of a reasonable species inventory for the aquatic system;
- an understanding of the habitat requirements of important species and of whether those habitats exist in the area of impact; and
- at least some knowledge of the impact similar development/industrial projects have had on comparable aquatic systems elsewhere.

Where such information does not exist, some initial baseline inventory must precede scoping, and the scoping exercise itself becomes increasingly uncertain. Scoping should be prudent and inclusive: it is better to eliminate issues from consideration later on than discount important impacts at the beginning.

Planning stage. Consider the nature of the project and its likely impacts on a river or lake; i.e. which problems are paramount - toxicity, or temperature rise, or organic load, or increased sediment. This will help in the design of the fieldwork. Tributaries, swamps and ditches near to the project site should also be noted and surveyed because they may act as refuges or as breeding sites. The filling in of a swampy area may have as much effect as an effluent discharge.

Fieldwork stage. A single sampling of a lake or of a stretch of river is unlikely to give a very good picture of the species present or their relative abundance or life histories because of diurnal and seasonal movements, and of year to year

natural variations in abundance. The project proponent should not be expected to compensate for the shortcomings of government fisheries inventories programs, but at least one full year of intensive sampling in the zone of potential impacts should be regarded as the minimum requirement for an impact assessment.

The first step in the program is to undertake a survey and mapping (at an appropriate scale) of the major aquatic ecosystems or habitat types. This mapping should then be used to organize subsequent sampling of fish distribution and abundance. Such sampling should be taken at regular intervals (e.g. once per month) and include both night-time and day-time sampling. Sampling on each occasion should continue until repeated efforts result in no extra species. Sampling of fishermen's catches and market stalls can provide some useful information if the location of the catch can be verified, and that not too much confidence is placed in local names as a means of counting species, particularly the small, uneconomic species. Perhaps the most valuable information that can be gained from fishermen and fishing stalls is an indication of the current level of fishing effort and catch, and thus a measure of the social and economic significance of the resource that may be placed at risk by the development project. It must be kept in mind though, that current catch is not necessarily a reflection of the potential or capability of the fishery. It must be remembered that there is no substitute for the survey workers catching the fish themselves, or at least accompanying fishermen, and that smaller meshes than those used by fishermen must be used in addition to standard nets, in order to catch the important small species and the young of larger species.

Assessment stage. As previously explained, the function of initial scoping is impact prediction (i.e. what are the potential consequences of the project?). Environmental assessment should be fully integrated into project feasibility planning so that the project is designed to avoid impact and comply with environmental standards. The major role of impact assessment is impact quantification (what will be the magnitude of unmanageable impacts?) and impact significance (how important

are measured impacts and do they warrant further management attention or cast doubt on project acceptability?). Of these two functions, the first should be the most 'scientific'; however, in many cases our knowledge of cause-effect relationships is so poor that impact quantification becomes dependent on the best technical judgment of the assessment specialist. Impact significance is a much more a 'value judgment' and will be determined within the context of government policy and political decision-making. Significant fisheries impact might be one which affects the ability of the fisheries sector to meet its objectives, whether such objectives are expressed in production targets by a government fisheries management, or the desire of local fishermen to maintain their livelihood. The responsibility of the environmental assessment planning specialists should be to provide political decision makers with the best possible technical information and scientific judgments to serve as a basis for their decisions.

The prediction and quantification of impacts must take into consideration the complexity of inter-relationships in aquatic systems. Some important considerations are:

- Riparian trees and other vegetation provide shade, moderate the temperature, and reduce the amount of silt washed into the water. They also provide organic material such as leaves, fruits and flowers and invertebrates which are fed upon by fishes and other animals and which 'drive' the energy flow in the water in an environment with very low primary productivity. Thus the removal of vegetation along a water course can have profound effects on productivity.
- Consider the requirements of the important species within an aquatic system throughout their whole life cycle - breeding, spawning, larval stages, migration, feeding, and shelter from predators. An adverse impact on just one requirement may negate the best-intentioned efforts to protect the others.
- Organic effluents with a high biological demand reduce the oxygen concentrations in the water below the thresholds of many species. Some fish will remain, even in polluted water, but they will be the most tolerant, widespread, and often the least desirable of the species that

inhabit an aquatic system. In other words, biodiversity will have been lost.

- When considering major water diversions or concentrations of pollutants, impact assessments must be based not just on the river characteristics observed at the time, but on predicted potential low flows (e.g. the 1 in 10 years, 1 in 20 years, or even the 1 in 30 year low flows).
- Consider the impacts of the whole project, not just in the area immediately adjacent to the project but on important downstream resources also. Will the project interact with existing activities downstream to produce cumulative impacts which are significant?
- What are the driving forces or critical limiting components of the system - detritus, marginal or submerged vegetation, low flows - and what will be the impact of the project on these?

After the surveys are complete it should be possible to draw out food webs and thus cause-and-effect networks which will serve as a context for discussions of impact.

Management Stage. The final, and most important, stage of impact assessments is the devel-

opment of a plan to manage impacts. Such a plan should include a program of impact mitigation and a monitoring program. Mitigation activities should include avoidance, modification or abandonment of particularly damaging project components, treatment or re-use of waste materials and, finally, site rehabilitation or restoration. For mitigation to be fully effective, the impact assessment process must be integrated into project design and feasibility studies from the very beginning. All unnecessary clearance of vegetation should be avoided. Replacement of trees along the river banks and lake sides should be encouraged - even if the project itself has not been directly responsible for their loss. Species planted should be native, not introduced. Consider recommending regulating ponds that could prevent effluent discharge during times of low flow. Consider the possibilities of utilizing or treating the effluent.

Monitoring should serve two purposes; first, to provide a measure of the effectiveness of the management program, and second, to provide early warning of unpredicted impacts. Project monitoring should be linked to the baseline aquatic inventories carried out early in the environmental assessment process and have a sound statistical base.

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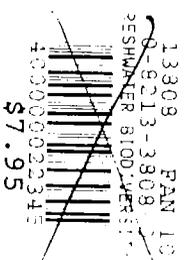
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