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Research, part of a Special Feature on Restoring Riverine Landscapes

River Rehabilitation for Conservation of Fish Biodiversity in Monsoonal Asia

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ABSTRACT. Freshwater biodiversity is under threat worldwide, but the intensity of threat in the Oriental biogeographic region of tropical Asia is exceptional. Asia is the most densely populated region on Earth. Many rivers in that region are grossly polluted, and significant portions of their drainage basins and floodplains have been deforested or otherwise degraded. Flow regulation has been practiced for centuries, and thousands of dams have been constructed, with the result that most of the rivers are now dammed, often at several points along their course. Irrigation, hydropower, and flood security are among the perceived benefits. Recent water engineering projects in Asia have been exceptionally aggressive; they include the world's largest and tallest dams in China and a water transfer scheme intended to link India's major rivers. Some of these projects, i.e., those on the Mekong, have international ramifications that have yet to be fully played out. Overexploitation has exacerbated the effects of habitat alterations on riverine biodiversity, particularly that of fishes. Some fishery stocks have collapsed, and many fish and other vertebrate species are threatened with extinction. The pressure from growing impoverished human populations, increasingly concentrated in cities, has forced governments to focus on economic development rather than environmental protection and conservation. Although legislation has been introduced to control water pollution, which is a danger to human health. it is not explicitly intended to protect biodiversity. Where legislation has been enforced, it can be effective against point-source polluters, but it has not significantly reduced the huge quantities of organic pollution from agricultural and domestic sources that contaminate rivers such as the Ganges and Yangtze. River scientists in Asia appear to have had little influence on policy makers or the implementation of water development projects. Human demands from agriculture and industry dominate water allocation policies, and in-stream flow needs for ecosystems have yet to be widely addressed. Restoration of Asian rivers to their original state is impractical given the constraints prevailing in the region, but some degree of rehabilitation will be possible if relevant legislation and scientific information are promptly applied. Opportunities do exist: enforcement of environmental legislation in China has been strengthened, leading to the suspension of major dam projects. The 2003 introduction of an annual fishing moratorium along the Yangtze River, as well as breeding and restocking programs for endangered fishes in the Yangtze and Mekong, offer the chance to leverage other initiatives that enhance river health and preserve biodiversity, particularly that of fish species. Preliminary data indicate that degraded rivers still retain some biodiversity that can be the focus of rehabilitation efforts. To strengthen these efforts, it is important to identify which ecological features enhance biodiversity and which ones make rivers more vulnerable to human impacts.

Key Words: *restoration; rehabilitation; dams; pollution; fisheries; Yangtze; Mekong; Ganges; Salween; river management*

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INTRODUCTION

When we think of charismatic and endangered megafauna, tigers, rhinos, and pandas immediately come to mind. With a little more consideration we could add some aquatic species to this list, such as whales, sea turtles, and albatrosses. Freshwater animals are less likely to be categorized as endangered, and none of them seem to have sparked the public interest to the same extent as threatened marine and terrestrial species. For instance, river dolphins receive much less attention than their marine counterparts, despite the fact that three of the five taxa of “true” river dolphins, i.e., those that never enter the sea, are endangered or critically endangered (IUCN 2004). The Yangtze dolphin (*Lipotes vexillifer* Miller) is one of the most threatened mammals on Earth, numbering fewer than 100 individuals, and both the Ganges and Indus subspecies of *Platanista gangetica* (Roxburgh) are endangered. These river dolphins share another characteristic: they are endemic to the Orient, i.e., tropical or monsoonal Asia. Crocodiles, river turtles, specialist river birds, and large freshwater fishes in the region are also increasingly rare and globally threatened by overharvesting and habitat degradation (Wei et al. 1997, Dudgeon 2000*a*,*b*, Baird et al. 2001, Hogan et al. 2001, 2004).

Although it could be argued that the status of large, conspicuous freshwater vertebrates is not necessarily a good indicator of the status of all the taxa that share their environment, there are nevertheless grounds for serious concern about freshwater biodiversity in monsoonal Asia. A recent series of reviews (Dudgeon 1999, 2000*a*,*b*,*c*,*d*, 2002*a*,*b*) has underscored the alarming condition of the region’s rivers, which has been apparent for over a decade (Dudgeon 1992). The major rivers of the Oriental Region, including the Indus, Ganges, and Yangtze (Chang Jiang), have experienced centuries of sustained human impact and are among the most degraded, densely settled, and human-modified river basins on Earth. Their waters are grossly polluted, and dams and impoundments influence their natural discharge to such an extent that the lower Ganges and the Indus virtually cease to flow during the dry season (Postel and Richter 2003). Pressure from large impoverished human populations has forced most Asian governments to focus on economic growth rather than environmental protection; the government response has been to implement massive development projects. There is an urgent need to halt ongoing habitat degradation and to restore or rehabilitate damaged Asian rivers or to manage them in a way that will sustain biodiversity.

This article examines the threats to riverine diversity in monsoonal Asia and describes how some of them can be addressed given the constraints arising from human use of water resources. Attention focuses mainly on fishes and the impacts of dam construction, with examples mainly from China, but this is not to imply that other taxa, threat categories, or countries are of less importance. Examples from elsewhere, e.g., Southeast and East Asia, are used when they offer informative parallels or contrasts with China.

THREAT CATEGORIES

The gravity of threats to freshwater biodiversity in Asia results from the combination of three factors:

1. Asia supports a significant part of the world’s biodiversity: for instance, Indonesia alone is home to about 15% of the word’s species, and it has more amphibians and dragonflies than any other country (Braatz et al. 1992).

2. Regardless of whether water is extracted, diverted, contained, or contaminated by humans, that use compromises its value as a habitat for organisms. As a result, most freshwater taxa are affected by a combination of threat factors, and this vulnerability to multiple interacting and often synergistic impacts puts freshwater biodiversity uniquely at risk among the Earth’s biota.

3. Asia is the most densely populated region on Earth, with more than 50% of the human population in ~15% of the land area, and many people live in poverty. Five Asian countries account for about half of the global annual growth in population, and, although populations are becoming increasingly concentrated in cities, many people still live in rural areas, e.g., more than 70% in India. As a result, much of the landscape can be described as “human-dominated” (Hannah et al. 1994). Deforestation and logging rates are the highest on Earth, and forest fires are frequent (Laurance 1999, Taylor et al. 1999, Achard et al. 2002).

Threats to the biodiversity of Asian rivers and their associated wetlands include flow modification, habitat degradation, pollution, increased salinity, and overexpolitation (e.g., Dudgeon 1999, 2000*b*, *c*,*d*). In China, for example, ~46 X 10^9 t of urban and industrial wastewater are discharged annually; slightly less than half consists of industrial effluent, and about half of that is discharged into the Yangtze (SEPA 2004). Until recently, less than 20% of the industrial discharge and municipal wastewater in China was treated; as a result, many rivers failed to meet government standards for drinking water supplies, and some were unsuitable even for agricultural purposes (Wang 1989, SEPA 1998, Wu et al. 1999). The water along ~80% of the 50,000 km of major rivers in China was too polluted to sustain fisheries, and fish were entirely eliminated from at least 5% of the total river length (Wang 1989, FAO 1995, Wu et al. 1999).

Contamination of water and risks to human health have prompted governments throughout Asia to introduce legislation to control pollution (Dudgeon et al. 2000). These regulations are intended to ensure an uncontaminated supply of water for humans rather than preserve species or ecosystem goods and services. Furthermore, existing legislation generally has a negligible impact on reducing the huge quantities of organic pollution arising from agriculture and domestic sources. Legislative enforcement is weak in many areas (Dudgeon 1999, Dudgeon et al. 2000), but it can be effective against point-source industrial polluters, although control of small-scale village enterprises is limited. According to Low (1993:534) a major constraint is " ... adequate manpower and funding, as well as the will to act ... which many countries lack. The financial and economic gains from unfettered development are too attractive to be hampered by enforcement of anti-pollution legislation."

Deforestation of drainage basins causes sedimentation, degrades rivers, and can have unexpected consequences for freshwater biodiversity (Brewer et al. 2001). In addition, the conversion of floodplains and riparian zones to agriculture has detrimental effects on plants and animals in riverine wetlands (e.g., Dudgeon 2000*c*). Translocation of native species and exotic introductions are an additional threat to indigenous biota, and their influence as drivers of freshwater biodiversity loss is projected to increase substantially (Sala et al. 2000), in part because exotic species are more successful in habitats that have already been modified or degraded by humans (e.g., Bunn and Arthington 2002, Koehn 2004).

Flow regulation, which includes dam-building for hydroelectricity and impoundment of rivers to control floods and provide irrigation water, has a history of more than 4000 yr in Asia, and its many effects range from the alteration of natural flow regimes to the obstruction of fish breeding migrations (e.g., Dudgeon 1995, 2000*a*). The ecological consequences of human-induced changes in flow variability are well established elsewhere (e.g., Poff et al. 1997, Nilsson and Berggren 2000, Bunn and Arthington 2002); aggressive attempts to regulate flow are continuing over much of Asia. The monsoon climate causes highly variable natural flow regimes, and the dense human settlement of river floodplains has spurred the development of water engineering schemes for flood protection during high-flow periods and for water storage during low-flow periods and dry seasons. In China alone, for instance, floods kill thousands of people annually, and the 1931 floods in the Yangtze caused ~3 X 10^6 deaths.

Globally, dams retain ~10,000 km^3 of water: the equivalent of five times the volume in all the world's rivers combined (Nilsson and Berggren 2000). The extent of water engineering in Asia is evident from the fact that 55% of the world's largest dams (> 15 m tall) have been built in China and India alone (WCD 2000). Giant structures such as the Three Gorges Dam are under construction, and interbasin water transfers are planned, including a long-standing proposal to transfer water from the Yangtze to the more arid north of China (Dudgeon 1995). In 2002, the Indian government initiated a feasibility study for a scheme that would link India's major rivers by 2016 and transfer water from the north to the south of the county through 12,500 km of canals (Prakash 2003, Bandyopadhyay and Perveen 2004). Even if linking does not go ahead, global climate change is likely to be a driver of even more aggressive flow modifications in monsoonal Asia. Most change scenarios for the region predict an increase in climatic extremes and a greater frequency of floods and droughts (see Dudgeon 2000*a*), all of which will demand water engineering responses.

In the face of ongoing threats and environmental degradation, the preservation of biodiversity will require the restoration or rehabilitation of Asian rivers. Both terms refer to the reparation or mitigation of the damage caused by human disturbance. More specifically, restoration means returning an ecosystem to its original structural condition, with its functional processes intact, by removing the causes of degradation. In contrast, the goal of rehabilitation is a partial rather than a complete recovery of ecosystem structure or function within the context of its present-day human use (FISRWG 1998). Rehabilitation is a more realistic option in Asia, because it allows for management intervention with some degree of human disturbance. Accordingly, efforts aimed at improving the condition of Asian rivers are referred to in this paper as “rehabilitation.” Given the degraded state of many of these rivers, almost any management intervention would contribute to their rehabilitation. Only in the relatively few places in which humans have had less impact, does river management in Asia constitute restoration to the river's original condition. This situation is rare, because management interventions seldom take place before degradation is severe and fisheries are at or near collapse.

HAS POLLUTION CONTROL BEEN EFFECTIVE?

To reduce water pollution in one of Asia’s major rivers, the Indian Government initiated the Ganga Action Plan in 1985. The objective of this centrally funded scheme was to treat the effluent from all the major towns along the Ganges and reduce pollution in the river by at least 75% (Natarajan 1989, Krishnamurti et al. 1991, Payne et al. 2004). The Ganga Action Plan built upon the existing, but weakly enforced, 1974 Water Prevention and Control Act. A government audit of the Ganga Action Plan in 2000 reported limited success in meeting effluent targets (Narayana Murty 2000). Development plans for sewage treatment facilities were submitted by only 73% of the cities along the Ganges, and only 54% of these were judged acceptable by the authorities. Not all of the cities reported how much effluent was being treated, and many continued to discharge raw sewage into the river. Test audits of installed capacity indicated poor performance, and there were long delays in constructing planned treatment facilities. After 15 yr of implementation, the audit estimated that the Ganga Action Plan had achieved only 14% of the anticipated sewage treatment capacity (Narayana Murty 2000). The environmental impact of this failure has been exacerbated by the removal of large quantities of irrigation water from the Ganges, which offset any gains from effluent reductions.

In China, river pollution remains a serious problem, but significant steps have been taken to address the issue. In 2002, the Environmental Quality Standard for Surface Water (Standard Code GB 3838-88) was revised (GB 3838-2002), and enforcement measures against polluters were strengthened so as to make more effective use of the 1984 Law for Prevention and Control of Water Pollution. A national network of sites for monitoring water quality in Chinese rivers was also established, although the number of monitoring stations varied from year to year, e.g., 741 in 2002, 407 in 2003. The State Environmental Protection Administration (SEPA), with financial support from the central government, initiated a series of key water pollution prevention and control projects across the country under the auspices of a series of national five-year plans for the prevention and control of water pollution. Enforcement of effluent control standards for industry and additional legislation introduced in 2002 intended to reduce pollution from large livestock-rearing operations have had some results. The proportion of discharged industrial effluent treated according to accepted standards is now close to 80% in some major cities (SEPA 2004). Trends in the data acquired annually from the national network of monitoring sites provide evidence that river health is improving. Each site is classified according to national water quality standards ranging from Grade I (excellent) to Grade V (poor) and Worse than Grade V. The grading system is based on faecal coliform counts and, among other things, loadings of biological oxygen demand and chemical oxygen demand as well as the contents of nitrogen and phosphates (Table 1). The proportion of Grade I sites has increased slightly, and the percentage of those in the lower categories, particularly the category Worse than Grade V, has fallen. However, because of continued high levels of organic pollution and less stringent enforcement of effluent standards in small towns, more than half of the sites are still ranked as Grade IV or lower. There are particular problems in river tributaries, in which water quality is generally poorer than it is in mainstreams, and concerns remain over the effect of the accumulation of pollutants behind the Three Gorges Dam (SEPA 2004).

Table 1. The percentage of sites in China's national network for river monitoring that met specified water-quality standards or grades during 2001, 2002, and 2003. The intended use of each is also shown. Raw data were acquired from China's State Environmental Protection Administration.

Classification	2001	2002	2003	Intended water use
Grade I	1.5	2.7	3.4	Drinking, nature reserve
Grade II	18.0	13.8	21.4	Drinking, fisheries
Grade III	10.0	12.6	13.3	Fisheries, recreation
Grade IV	17.7	18.9	23.8	Industry, noncontact recreation
Grade V	8.8	11.1	8.4	Agriculture
Worse than Grade V	44.0	40.9	29.7	None

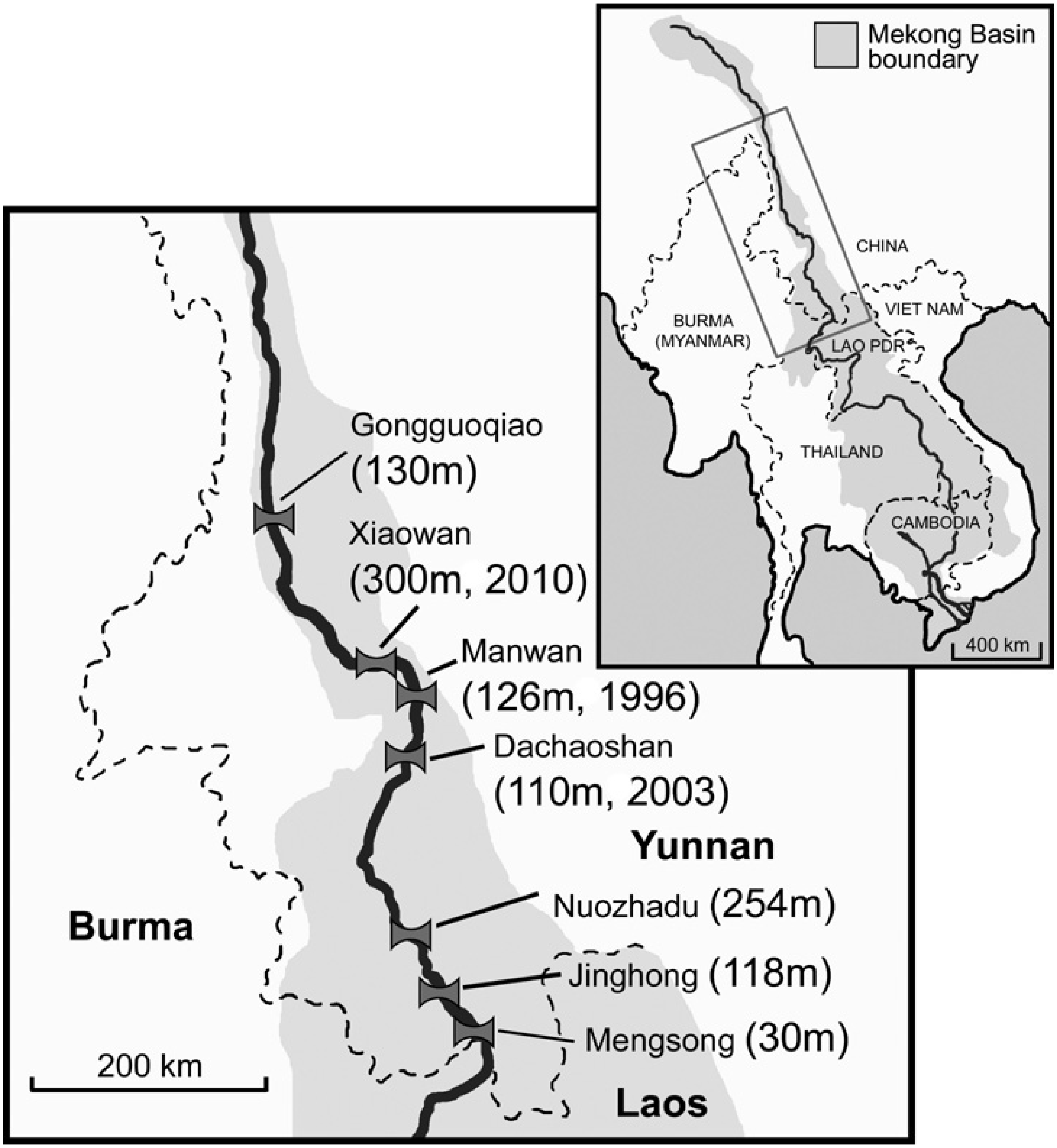
DAMS AS OBSTACLES TO EFFECTIVE RIVER MANAGEMENT

In densely populated Asia, multiple users compete for water resources. Conflicts can arise during the dry season and at other times of the year in areas in which water supplies are limited. Particular problems occur where rivers, such as the Ganges, Indus, and Mekong, traverse international boundaries. Activities upstream, e.g., pollution, water extraction, dam building, have important downstream implications for the natural transfer of energy and materials and the dispersal of pollutants, but the reverse is not true for most system characteristics. However, there are exceptions (see Pringle 2001). Activities upstream can degrade the habitat and amenity value of downstream sections, and the potential for conflict is high because ~40% of the global human population lives in the 263 river basins that are shared by more than one country (Poff et al. 2003, Postel and Richter 2003). Indeed, negotiations over water sharing had a major influence on relations between India and Bangladesh following the construction of the Farakka Dam on the Ganges (Payne et al. 2004). Presently, there is international acrimony in South Asia over the construction of the Baglihar Dam on the Chenab River, a major tributary of the Indus in India (Hassan 2005). Pakistan claims that the construction of this dam violates the Indus Water Treaty and will reduce the volume of water flowing into its territory.

One transboundary scheme that is likely to have very serious consequences for biodiversity involves the Mekong River. It is of special importance because of the relatively undisturbed and unpolluted condition of the river relative to the Indus or the Ganges. There has been no comprehensive biodiversity inventory of the Mekong Basin, but a recent estimated that 1700 species of freshwater fishes inhabit the basin (Sverdrup-Jensen 2002); this provides an indication of its richness. Even by a more conservative estimate of ~1000 species (Rainboth 1996), it ranks third in the world for freshwater fishes next to the Amazon and Zaire Rivers (Dudgeon 2002*b*). A substantial portion of the Mekong River flows through China, where it is known as the Lancang Jiang; it then flows south into Laos, Thailand, Cambodia, and Vietnam. China has ambitious plans for a cascade of huge mainstream dams on the Lancang Jiang. The Manwan Dam and Dachaoshan Dam, both more than 100 m high, have already been built; the 300-m Xiaowan Dam will be completed in 2010 (Fig. 1). The Chinese portion of the Mekong contributes about 50% of the sediment load and 20% of the discharge at its mouth of the river, but most of the flow in Lao PDR and Thailand (Roberts 2001*a*, TERRA 2002).

Because of the enormous size of some of the Chinese dams, downstream effects on flows and sediment loads could be substantial. One prediction is that by 2010 the dams will reduce wet-season discharge and increase dry-season flows by 50% (Chapman and He 1996), although other estimates project larger changes (TERRA 2002). The consequence will be

Fig. 1. Dams planned or constructed on the Lancang Jiang, the section of the Mekong River that flows through China. Dates of completion and dam heights are shown.



to "even out" the peaks and troughs of the natural discharge regime to which the Mekong River biota are adapted (for details, see Dudgeon 2000*a*). Unusually low dry-season flows in the lower Mekong during 2004, together with abnormal fluctuations in river level, have been attributed to the filling of the dams in China (Pearce 2004). Changes in silt load because of sedimentation behind dams will have implications for riverbed erosion and agriculture downstream. Because these effects will be felt by the lower riparian states that have little to gain from the construction of dams in China, the scene is set for international conflicts of interest. Potential impacts on fish ecology will be especially important in land-locked Laos (Roberts 2001*a*) where the freshwater fishing industry provides the main source of dietary protein for the human population. In a related development, China also has plans to dredge portions of the Mekong and to dynamite shoals and rock bars as to facilitate passage of large vessels (TERRA 2002, Dudgeon 2003*a*).

Conflicts of interest over river water also occur within national boundaries. A major consequence of hydropower dams is that their impacts on livelihoods and biodiversity are felt mainly by people in rural riparian communities. The collapse of artisanal fisheries after the 1994 completion of the Pak Mun Dam on the Mekong's largest tributary in Thailand is a conspicuous example (Roberts 1993, 2001*b*). Dramatic declines in fish stocks occurred in 1998 as a result of dam construction on another Mekong tributary, the Theun River in Lao PDR, despite prior assessments that it would degrade the aquatic habitat downstream and obstruct fish breeding migrations (Usher 1996). In contrast to these local impacts, most of the benefits from dams such as low electricity costs, industrial development, and flood protection for people living in low-lying areas, are felt some distance away, especially in towns and cities. The disparity between local and regional impacts and benefits creates conflicts between rural and urban dwellers that are usually settled in favor of the latter because they live closer to centers of political power.

NEEDS (1): APPROPRIATE INSTITUTIONAL STRUCTURES

Conflicts over water use and river management have the best chance of being resolved with minimal environmental damage when management is coordinated at an appropriate ecological scale, but institutional structures for drainage basin management are generally lacking or ineffective in Asia, especially where adjacent countries share drainage basins. Disputes over water resources have been an ongoing feature of Indian relations with Pakistan and Bangladesh (Postel and Richter 2003). Remarkably, the Mekong River Commission (MRC) offers an instructive example of a management structure for an international river basin in what has historically been one of the world's most fractious regions. The MRC is an intergovernmental body with ministerial-level representation that was established in 1995 by an agreement among the governments of Cambodia, Lao PDR, Thailand, and Viet Nam. It was created from the Mekong River Committee, itself a modified version of an international organization established by the four riparian states in 1957, which was intended to coordinate water resource development in the lower basin (for more information, see Dudgeon 1992, 2003*a*). The 1995 agreement mandated international cooperation "... in all fields of sustainable development, utilization, management and conservation of the water and related resources of the Mekong River Basin" (MRC 2002:4). This statement is significant because it eschews a utilitarian approach to developing one or two major economic opportunities, such as hydropower or irrigation, in favor of adopting the broader perspective of holistic management. As a result, the MRC cancelled its plans to build a 12-dam cascade on the Mekong mainstream, which would have had major impacts on the ecology of the Mehong River (Dudgeon 2000*a*). Future developments in the Mekong Basin are to involve joint planning in the context of an overall Basin Development Plan initiated in 2002. The Basin Development Plan is intended "... to identify, categorise and prioritise the projects and programmes to be implemented at the basin level ..." (MRC 2002:8) with regard to matters such as irrigation, watershed management, fisheries, hydropower, navigation, recreation, water supply, and flood management. The National Basin Development Plan units in each riparian country should ensure that stakeholder interests are represented in the overall Basin Development Plan, and that ministerial representation by the MRC for each riparian state on the Mekong River facilitate the transition of plans into action.

Although the MRC provides a model of an institutional structure for the management of an international river basin, it has the shortcoming that China is not included and has not signed the 1995 agreement. China is an informal “dialogue partner” or observer of the MRC, but the chances of China becoming a full member are remote, because membership would interfere with the Chinese plans to build dams along the upper Mekong and enhance navigability further downstream. Furthermore, although there has been excellent cooperation between the five riparian states in the lower Mekong Basin, political commitment to holistic management will be put to the test within the next 5 yr as decisions made in the context of MRC programs within the Basin Development Plan are implemented.

NEEDS (2): ENVIRONMENTAL FLOW ALLOCATIONS

A major focus of the Mekong Basin Development Plan is to formulate a set of rules for the sharing of water sharing among the countries and various end-users to ensure the sustainability of fisheries and aquatic ecosystems (MRC 2000). This is significant because, in most disagreements over multiple uses of water, whether they are international or local, the allocation of water resources to maintain biodiversity and ecosystem function receives scant attention (Poff et al. 2003). Until recently, little attempt has been made to address the issue of environmental flows in China or India (Tharme 2003). However, growing awareness of this matter in China, which has arisen in part from concerns that the Yellow River (Huang He) no longer flows to the sea for a significant part of the year, has stimulated research on ecological and environmental water requirements that address water allocation between humans and the environment (Cui 2001, Ni et al. 2002, Shi and Wang 2002, Zheng et al. 2002). This activity can be seen, in part, as a reflection of a growing global consensus about the need to adopt holistic environmental water allocations that sustain entire riverine ecosystems by providing water levels or discharges that mimic natural hydrologic variability (e.g., Poff et al. 1997, Richter et al. 1997, Arthington and Pusey 2003; see also Liu et al. 2005). Consideration of the need to allocate environmental flows downstream of hydropower projects will contribute to the preservation of fish stocks, other aquatic biodiversity, and ecosystem services, thereby avoiding situations that pit local impacts against distant regional benefits.

There are more than 200 methods available for assessing environmental flows (Tharme 2003), but their relative success has not been fully evaluated, and regionally relevant models for Asia have yet to be developed. Holistic environmental flow methodologies based on explicit links between changes in flow regime and the consequences for ecosystem parameters have been developed recently in Australia and southern Africa (e.g., Arthington and Pusey 2003, Arthington et al. 2003, King et al. 2003, Tharme 2003) and used to evaluate alternative water-allocation strategies in drainage basins for which data are scarce or detailed field investigations are not practical. Such methodologies will be appropriate in Asia where, initially at least, environmental flow allocations will have to be based on limited data and supplemented by best professional judgment and risk assessment. Assuming that this approach is adopted, an environmental flow allocation can be treated as a hypothesis-driven experiment in ecological restoration (Arthington and Pusey 2003, Poff et al. 2003). Rigorous monitoring and evaluation must follow the implementation of each environmental flow allocation, and the results used to refine the initial allocation strategy and inform subsequent environmental flow practices (Poff et al. 2003). This process of refinement is essential given the range of scales over which environmental flows need to be allocated in Asia: from huge mainstream dams in China to smaller dams on Mekong tributaries, and from river reaches downstream of interbasin water-transfer schemes to large- or small-scale irrigation withdrawals.

The science of environmental flows is not likely to develop rapidly unless countries put in place legislative requirements and policy commitments to provide for environmental flows when considering water resource development. This would need to involve a mandatory wide-ranging environmental impact assessment followed by a more focused study on environmental allocations to maintain ecosystem functions that support biodiversity; studies of this type normally use hydrodynamic models (e.g., Arthington et al. 2003, King et al. 2003) to predict the consequences of the many different possible alterations to the natural flow regime. No such detailed analysis has been undertaken for major dams in Asia, and even the downstream ecological effect of the giant Three Gorges Scheme was treated superficially in the environmental impact assessment for the scheme (see Dudgeon, 1995). One hopeful sign is that, at the beginning of 2005, the MRC commenced a flow assessment program based on the evaluation of the beneficial environmental, social, and economic uses of the river, including specific consideration of the need to allocate environmental flows (MRC 2005).

A significant opportunity to incorporate environmental flows into legislation in China is the law on environmental impact assessment promulgated in September 2003, which decrees that construction work cannot begin before the State Environmental Protection Administration (SEPA) has approved environmental impact assessment reports on the proposed project. For some time, this requirement has been flouted, most egregiously by the Three Gorges Company (TGC), a state-owned corporation that has been building the world's largest hydropower project, the Three Gorges Dam. The TGC is also responsible for the U.S. \$5 X 10^9 Xiluodu Dam on the Jinsha River, the main upper tributary of the Yangtze (Fig. 2), as well as three more dams planned for the same section of the river. Upon completion, the Xiluodu Dam will be the second largest hydropower plant in China. In December 2004, the State Council of China reaffirmed the law on environmental impact assessments and, in January 2005, the SEPA ordered work on the Xiluodu Dam to stop until relevant environmental impact assessments had been undertaken and approved. Ancillary projects associated with the Three Gorges Dam were also halted. Following some procrastination by the TGC, the SEPA reported in early February (*Shenzhen Daily* 2005) that work on the Xiluodu Dam had ceased pending approval of the relevant reports, including studies of the impact of the dam on fishes in the upper Yangtze. The TGC was also fined for breaches of regulations. Although the matter has yet to play out, this is an important instance of the SEPA exerting control on the activity of a state-owned corporation, and it indicates a toughening stance toward environmental degradation in China.

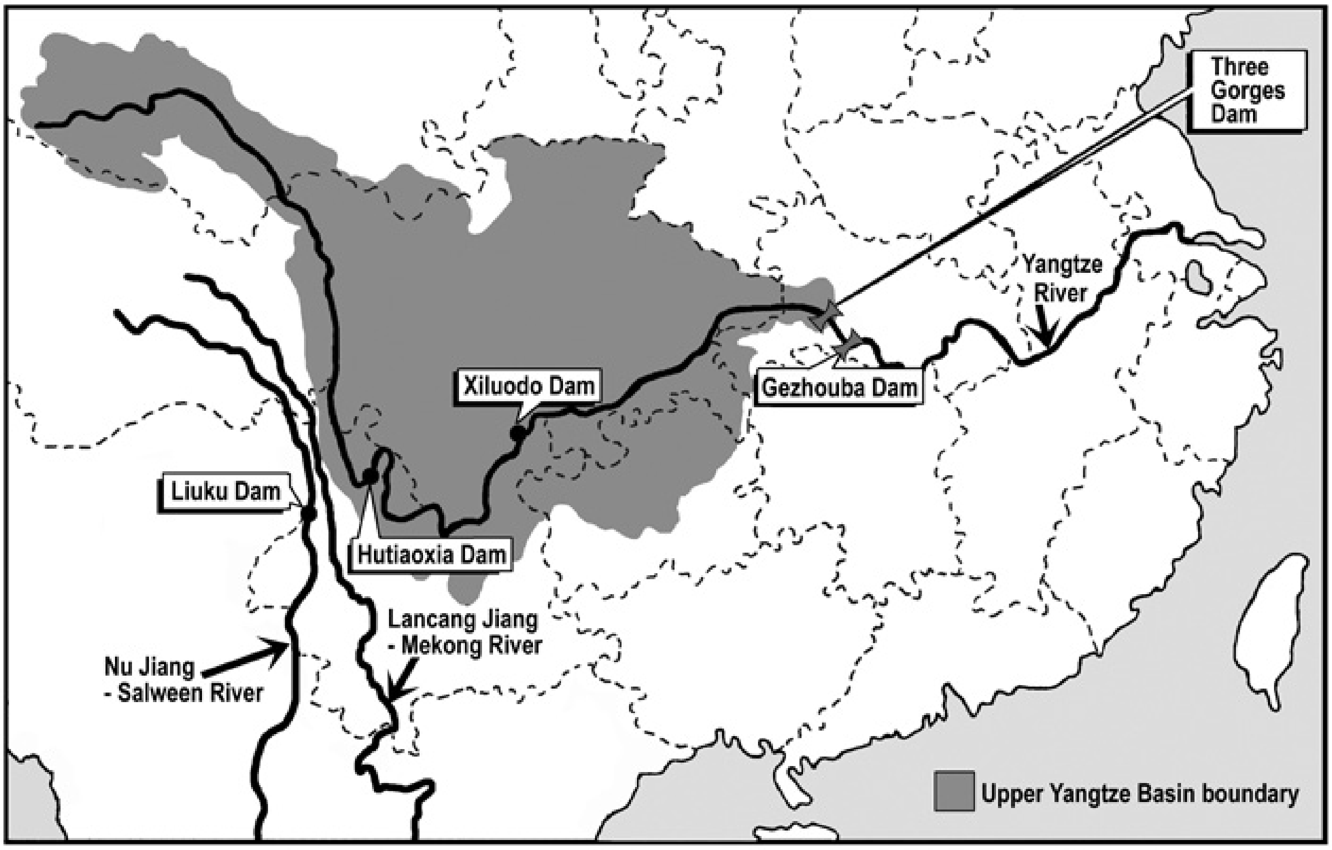
The brake on dam building in China comes at a time when the SEPA has increased enforcement activities on factories that pollute, and this suggests a change in attitude toward the national imperative to develop now and clean up later. This change may reflect an increasing awareness of the consequences that two decades of untrammeled economic growth, e.g., almost 10% in 2004, have had on air and water pollution in China (Marquand 2005). Further evidence of a new attitude was seen in April 2004, when Prime Minister Wen Jiabo ordered the suspension of planning for a cascade of 13 dams on the Nu Jiang, i.e., the portion of the Salween River that flows through China, pending a review of their impact on this UNESCO World Heritage Area. Preparatory work for the first of these dams at Liuku in Yunnan Province (Fig. 2) is already well under way. The fate of the dam array now seems likely to depend on reports to be submitted to the SEPA (Yardley 2005).

PROTECTION OF FISH BIODIVERSITY IN CHINA

A greater emphasis on environmental protection and pollution control may, over the long term, contribute to the rehabilitation of rivers in China and elsewhere, but more focused action will be needed to protect endangered freshwater vertebrates such as fishes, river dolphins, etc. Even though China lacks a truly comprehensive law on nature conservation (Xu et al. 1999), it did enact the China Wildlife Protection Law in 1989 to protect rare and endangered species. Although the law has yet to be completely enforced, China has established a legislative framework for biodiversity conservation and a number of action plans have been initiated (for details, see Xu et al. 1999). A fishery law dating from 1986 and revised in 2000 proscribes fishing of rare and precious aquatic animals (Xu et al. 1999, Fu et al. 2003), and a *National Red Data Book* for threatened Chinese freshwater fishes has been produced (Yue and Chen 1998). It lists 25 species of Yangtze fishes for the first time, in addition to both species of sturgeon that occur in the Yangtze, i.e., the Chinese Sturgeon (*Acipenser sinensis* Gray) and the Yangtze or Dabry’s Sturgeon (*Acipenser dabryanus* Dumeril), and the Chinese Paddlefish (*Psephurus gladius* Martens). These three fishes are globally endangered (IUCN 2004), and classified as a grade-1 protected species in China, where it is now illegal to catch them (Yue and Chen 1998). Restrictions on fishing on the Yangtze are important because this river formerly contributed to approximately 70% of China's freshwater catch of ~5 X 10^6 t/yr. Yields fell to half this value between 1954 and 1970, and continued overfishing, flow regulation, and pollution caused catches to decline further to ~100,000 t/yr (FAO 1995, Dudgeon 2002*a*, Fu et al. 2003, Chen et al. 2004).

Within the last decade, an interprovincial authority, the Administrative Commission of the Yangtze River Fisheries Resources, was established under

Fig. 2. The location of existing and planned major dams on the Yangtze mainstream, including the Three Gorges, Xiluodu, and Gezhouba Dams. The site of the first dam planned for the Nu Jiang (Salweeen River) is also shown.



the Fisheries Bureau of the Ministry of Agriculture to control illegal fishing activities involving the use of electricity, explosives, and poisons, and to protect fishery stocks in the Yangtze. In February, 2003 an annual fishing moratorium of three to six months was introduced to protect 8100 km of the river, including 4090 km of the 6300-km mainstream and more than 4000 km of its tributaries (XNA 2004). This measure builds on the well established and widespread practice of stocking Chinese rivers and lateral lakes with cultured fry of major carp species to maintain or enhance fishery yields (Fu et al. 2003): for example, ~100 X 10^6 fingerlings were released in the Yangtze in 2004 (XNA 2004). Such stocking cannot be regarded as a measure that contributes greatly to biodiversity conservation, because it has implications for the genetic variability of indigenous carp species. However, it may reduce harvesting pressure on rare species that could benefit from the fishing moratorium.

Stocking is not confined to major carp species. Since 1983, ~250,000 artificially propagated larvae of Chinese Sturgeon have been released into the Yangtze each year (Wei et al. 1997, 2004). This stock enhancement began following the construction of the Gezhouba Dam on the Yangtze in 1981 (Fig. 2), which blocked migrations, fragmented populations, and degraded spawning sites of sturgeons and Chinese Paddlefish (Dudgeon 1995, 2000*a*, Wei et al. 1997, Fu et al. 2003, Chen et al. 2004). Concerns about the consequences of stocking on the variability of wild populations appeared to be justified when a genetic bottleneck was detected in samples of Chinese Sturgeon from the river (Zhang et al. 2003). However, this might have been a result of a decline in their numbers, and loss of variability that occurred prior to 1983 could have been a result of dam building, rather than an effect of inbreeding. Artificial propagation of Chinese Paddlefish has also been achieved with limited success. Reports indicate that 100,000 fry were released into the river in 2004 (XNA 2004, but see Wei et al. 2004). Stocks of the endemic and critically endangered Yangtze Sturgeon have not yet been introduced (Wei et al. 2004). Genetic studies of wild Yangtze Sturgeon have shown a precipitous decline in diversity from 1958 to 1999, in parallel with a dramatic decrease in population size (Wan et al. 2003); urgent management of the population is needed to preserve what variability remains. Notwithstanding concerns about the effects that artificially propagated individuals might have on viability or variability of wild populations of these rare fishes, the effectiveness of stocking as a conservation measure will be limited as long as the multiple threats of pollution, flow regulation, and habitat degradation persist in the Yangtze. Establishment of captive breeding populations of *Acipenser* spp. and Chinese Paddlefish as a sort of insurance policy against the loss of these fishes in the wild has been advocated (Yue and Chen 1998, Wei et al. 2004).

In the Pearl River (Zhujiang), China’s second largest river, fishery stocks have suffered impacts and declines similar to those in the Yangtze (Liao et al. 1989). The more than 3000 dams built since 1950 have blocked fish breeding migrations, leading to the virtual extinction of anadromous Reeve’s Shad (*Tenualosa reevesii* Regan) in the river (Blaber et al. 2003). This species formerly supported a highly lucrative fishery in both the Yangtze and the Pearl Rivers (Wang 2003, Chen et al. 2004). Although protective measures do not appear to be widely enforced, Reeve’s Shad has been classified as a protected species by the Ministry of Agriculture since 1987. Successful pond culture of *T. reevesii* has been initiated and may lead to stocking (Wang 2003). All migratory *Tenualsosa* spp. in Asia are highly susceptible to human impacts resulting from overfishing, dam construction, and pollution. It is suspected that the endemic Mekong Shad (*T. thibaudaeui* Durand) is near extinction (Blaber et al. 2003), and the collapse of the once important Hilsa Shad (*T. ilisha* Hamilton) fishery of the Ganges, following the 1975 completion of the Farakka Barrage, has been well documented (e.g., Natarajan 1989, Chandra et al. 1990); that collapse was predicted well before dam construction took place (Hora 1942). According to Blaber et al. (2003), declines have also been reported for both of the other species of Asian shad, the Longtail Shad (*T. macrura* Bleeker) and the Toli shad (*T. toli* Valenciennes).

Problems with protection of rare fishes and implementation of wildlife protection legislation in China exist because the natural resources laws and regulations, especially for fisheries, have been formulated from the standpoint of economic value, which emphasizes utilization rather than protection. Thus the conservation of endangered aquatic species is mainly the responsibility of the Ministry of Agriculture, which has had the historical remit of increasing or expanding the capture quotas of economically important species. Moreover, a separate authority, the Ministry of Water Resources, has an overlapping responsibility with the Ministry of Agriculture, but it is directed toward maintaining water supplies for human consumption and agriculture, whereas protection of water quality is under the jurisdiction of the State Environmental Protection Administration. The conflict between economic development and conservation plus the overlapping and sometimes contradictory responsibilities of government authorities have impeded actions that are needed to preserve biodiversity. Insufficient funding, a lack of trained manpower, and limited data sharing within China do nothing to improve matters (Xu et al. 1999, 2000). Some progress has been made recently: in 2000, a 400-km section of the upper reaches of the Yangtze was designated as a reserve for rare fishes, but portions of it will be affected by rising water levels behind the Three Gorges Dam and by the dams planned for the Jinsha River tributary. Potential reserve sites for rare fishes elsewhere along the Yangtze have been identified (Fu et al. 2003, Park et al. 2003), but they await official designation.

PROTECTION OF FISH BIODIVERSITY IN THE MEKONG

There are few laws protecting freshwater fishes in Asia, and reliable statistics for capture fisheries are lacking (FAO 2000, Dudgeon 2002*a*). However, there are a few exceptions to this generalization, as shown by some examples from the Mekong Basin.

Cambodian law forbids the capture, sale, and transport of two endangered fishes that are endemic to the Mekong River: the Mekong Giant Catfish (*Pangasianodon gigas* Chevey), which is the world's largest freshwater fish (Fig. 3), and the Giant Carp (*Catlocarpio siamensis* Boulenger). Nevertheless, enforcement remains problematic, and both species are still sold illegally at markets or to fish processing factories (Hogan et al. 2001). Another Mekong endemic, the Smallscale Croaker (*Boesemania microlepis* Bleeker), is protected under a 1991 Lao PDR Ministry of Agriculture and Forestry decree that made it illegal to catch them during the spawning season or to sell them at any time of the year; despite that, the sale and export of this species continue (Baird et al. 2001). Severe fishing down of *B. microlepis* stocks to 10 to 20% of previous levels has stimulated the establishment of fish control zones by fishers in southern Lao PDR to protect deep-water spawning habitat; there is evidence of some stock recovery as a result (Baird et al. 2001). It is worth noting that Sverdrup-Jensen (2002) considers fish control zones established by local communities to be more effective in protecting depleted stocks of large fishes than are legal restrictions on fishing methods and gear type, which are largely unenforceable. However, not all community-based fishery management schemes are conservation successes, in part because they may be directed toward maximizing fish yield (van Zalinge et al. 2004). Local fish control zones have been established around deep pools in the Mekong in Lao PDR that are important because they serve as dry-season refuges for endangered species such as the Mekong Giant Catfish (Poulsen et al. 2002). Protection of pools and spawning grounds could also favor large cyprinids threatened by overfishing. They include the genus *Probarbus*, which is represented by three species in the Mekong; two are endemic (Rainboth 1996). *Probarbus jullieni* Sauvage (Seven-line Barb) has been eliminated from much of its former range in southeast Asia, e.g., by dam construction in the Perak River, Malaysia, and it is now globally endangered (IUCN 2004); *Probarbus labeamajor* Roberts (Thick-lipped Bard) and *P. labeaminor* Roberts (Thin-lipped Barb) are classified by the IUCN as data deficient, with the latter being the scarcer of these two Mekong species.

The Mekong Giant Catfish migrates from China to Cambodia and Thailand, where it is not protected. It once formed the basis of a small fishery in northern Thailand, but that fishery has now completely collapsed, and no Mekong Giant Catfish have been caught there since 2000 (Hogan et al. 2004). Attempts to conserve the Mekong Giant Catfish in Thailand have included the release of artificially propagated fingerlings. Approximately 100,000 individuals have been stocked in the Mekong since 1985, but these fingerlings were obtained by sacrificing wild-caught fish to obtain eggs and sperm. Because very few adults are caught, there is a high degree of genetic similarity among their offspring, and the release of this stock might not only deplete the wild population in Thailand through the capture of brood stock, but also erode the genetic diversity of the Mekong Giant Catfish downstream in Cambodia (Hogan et al. 2004). Furthermore, the perceived success of maintaining populations using artificial propagation of this threatened fish has delayed its listing as a protected species in Thailand (Nandeesha 1994). Effective conservation of all migratory fishes in the Mekong is beyond the scope of the national legislative frameworks and will require coordinated action among the countries within the basin. At present, the Mekong River Commission offers the best framework for such cooperation (van Zalinge et al. 2004).

WHAT ROLE CAN SCIENTISTS PLAY?

Given the various human constraints, i.e., organization, legislative, and economic, what role can scientists play in the conservation of freshwater biodiversity in Asia? The provision of reliable information is an obvious contribution, especially if data can be collected over a sufficient period to indicate population trends. Unfortunately, fisheries data for Asian rivers are scant or of rather poor quality. For instance, although a considerable amount of research has been undertaken on Yangtze fisheries since the 1950s, most of it was directed by administrators, not scientists, with no comprehensive planning or consistent effort, and the resulting data are superficial, incomplete, and uneven (Chen et al. 2004). In the Mekong, where the Mekong River Commission has taken responsibility for monitoring fisheries, there is no system for the effective collection of statistical data on landings. Existing official statistics grossly under-report catches, data on large-scale capture fisheries are inaccurate, and the authorities do not collect data on small-scale family fishing, because these fisheries have always been considered of minor importance to the national economy (Sverdrup-Jensen 2002). Furthermore,

Fig. 3. The Mekong Giant Catfish (*Pangasianodon gigas*) has iconic status in the countries of the lower Mekong Basin, yet is now critically endangered, primarily because of overfishing.

there are very few quantitative data available for species and for habitats. The dispersed and varied nature of the fisheries in the Mekong makes the collection of accurate statistics problematic. Similar problems exist for other major inland fisheries in China, India, and Bangladesh (Severdrup-Jensen 2002). Along the Ganges, for instance, the fisheries are so spread out that " ... keeping representative statistics is always a difficult task" (Payne et al. 2004:240).

Despite the lack of reliable data, the freshwater riverine and wetland fishery yields of the Mekong River are conservatively estimated at ~1533 X 10^6 t/yr worth U.S. $1478 X 10^6, excluding yield reservoirs and aquaculture (Sverdrup-Jensen 2002, van Zalinge et al. 2004). This might make the Mekong the largest river fishery in the world, contributing to almost 2% of the global total for all capture fisheries, i.e., ~ 90 X 10^6 t/yr (FAO 2000). Given the magnitude of the Mekong fishery, the lack of reliable statistics is of great concern, because it limits both the management potential and our understanding of the factors that sustain fish productivity. Quantitative data on fisheries yields by species and by habitat are also required. Reliable information on the contribution of the fisheries sector to food security and income creation is necessary for a variety of stakeholders, including politicians and policy makers. For example, water resource planners need data that will allow them to evaluate the possible effects of development schemes on fisheries and assess the overall cost-benefits of their activities. Fisheries data must also be collected and made available, and intelligible, to the general public because, unless the public understands the value of fisheries resources, management systems will not be viable (Sverdrup-Jensen 2004).

Putting this paucity of reliable data on river fisheries into the a wider context of information on freshwater ecosystems, one recent analysis shows that, between 1992 and 2001, scientists in Asia made a relatively minor contribution to the international literature on conservation and freshwater biology (Dudgeon 2003*a*). Most of these papers concerned taxonomy, and many dealt with man-made lakes; there were scarcely any process-orientated investigations that could inform management. This doesn't mean that local and national contributions are unimportant or that the work was not worth doing. However, unless research results receive some exposure in international publications, they can have little impact on raising awareness of the need for conservation at governmental and global levels. Furthermore, if information generated by scientists in one country is not available internationally, it cannot be applied in other countries (Dudgeon 2000*d*, 2003*a*). In particular, case studies that will help develop strategies for the restoration and rehabilitation of rivers and the establishment and assessment water allocations to maintain ecosystems are needed.

One point must be emphasized: we know that running waters in Asia have experienced sustained and severe human impacts and, in certain situations, can recover to the extent that they can support diverse aquatic communities (e.g., Dudgeon 2003*b*). However, simply removing a threat, e.g., by controlling effluents, is no guarantee of restoration to the original pre-impact condition. A community quite different from those that developed in comparable reference systems that were not subjected to the same disturbance may already have become established. Early colonization by exotics or predators may make it impossible for the original species to recover, or recovery may be impeded by some factor that affects the entire system, such as climate change or large-scale modifications of the characteristics of the drainage basin (Ormerod 2004). In addition to studies of water allocation strategies, research is needed in at least three critical areas. First, the environmental factors that enhance species persistence in degraded Asian rivers must be identified. Second, the attributes of species that facilitate persistence or, conversely, increase the probability of extinction, must be determined. Third, management approaches that enhance the restoration or rehabilitation of indigenous biodiversity and ecosystem processes must be formulated and tested. The key issue here is the need for scientists to be “prepositional,” i.e., not just to present facts about the loss of freshwater biodiversity, but to indicate the research that should be undertaken in support of management strategies designed to reconcile the human use of water with the maintenance of ecosystems and the biodiversity they sustain.

CONCLUSION

Freshwater biodiversity and freshwater ecosystems are seriously jeopardized by human activities in monsoonal Asia. This is undoubtedly a consequence of the same large and growing human populations that are forcing the governments in the region to emphasize economic development above everything else. This does not necessarily reflect an absence of legislative frameworks to deal with at least some of the threats to biodiversity. China, for example, has as many environmental laws and policies as some western countries, but they are difficult to enforce and administer because of the many government commissions, departments, and ministries responsible for environmental matters. The State Environmental Protection Administration (SEPA), for instance, must rely on local environmental protection bureaus within municipal and county governments to enforce regulations (Wu et al. 1999). In this situation, the intentions of state or national bodies and provincial authorities may be at odds, especially when adherence to state regulations on pollution would be costly and could impair local economic development. Management is especially problematic for large rivers such as the Yangtze, which crosses several provincial boundaries and falls within the responsibility of a number of local bureaus and provincial authorities. For this reason, the Fisheries

Bureau of the Ministry of Agriculture established the interprovincial Administrative Commission of the Yangtze River Fisheries Resources, which was able to act on a scale that made it possible to introduce an annual fishing moratorium for much of the river. This approach has the support of fisheries scientists in China, although the effectiveness of this authoritarian management system could be enhanced by participatory management, including input from fisher communities (Chen et al. 2004).

Other conflicts that can arise within national borders and between countries are well illustrated by the Mekong River, but the adoption of holistic management as a basis for planning by the Mekong River Commission offers grounds for optimism. There is an urgent need for integrated action and legislation to ensure that critically endangered species, such as the migratory Mekong Giant Catfish, are legally protected in all the countries within their range. Significant obstacles to integrated management of the Mekong Basin will remain as long as China is unwilling to address the downstream consequences of its mainstream dams. The recent suspension of work on the dams along the upper Salween in China could be the first indication of such a change in attitude.

It is clear that additional information could contribute to more effective restoration and management of Asian rivers. However, stakeholder participation and political will are also needed. There are signs of such a commitment in China. A new SEPA Vice-Minister, Pan Yue, has made very forceful use of the media to apply public pressure on recalcitrant ministries and local officials to ensure that legislation and practices that protect the environment are applied. However, the failure of the Ganga Action Plan in India, decades of environmental degradation in China, and the collapse of river fisheries throughout Asia demonstrate that it will be unwise for scientists to assume that governments and policy makers will institute requirements and practices to protect freshwater biodiversity without societal pressure. Such pressure may be mounting. The activities of nongovernmental environmental groups, critical of large-scale dam developments in China, have been widely reported in the state media in recent months. These activities indicate growing societal concern over the management of freshwater resources and parallel longer-established citizen's movements in India, where there is opposition to the construction of the Sardar Sarovar Dam, and in Thailand, where there have been public protests over appropriate operating strategies for the Pak Mun Dam. As part of this wider debate, scientists must communicate the fact that freshwater biodiversity is in crisis and indicate what can be done to ameliorate or improve matters. To be effective, the message must be relevant: books must not simply be added to the library of knowledge; they must be read by those who will apply the information (see Meffe 2001). An overriding priority is to convey the fact that holistic river management and the restoration of the integrity of riverine ecosystems in Asia will benefit humans through the provision of fisheries resources and clean water, notwithstanding any intrinsic value that may be inherent in genes, species, and natural communities. Successful communication of this message will be an essential first step in halting further impoverishment of biodiversity.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol10/iss2/art15/responses/

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