CHAPTER

8

Fish Diversity in the Mekong River Basin

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OUTLINE

1. INTRODUCTION

1.1. Ecological Classification of Fishes

Fish that are found in inland waters are usually categorized at family level based on their evolutionary history as "primary" freshwater fishes (a long evolutionary history in freshwaters), "secondary" (some salt tolerance), and "peripheral" (species from marine families that live in freshwaters for part or all or their lives) (Berra, 2001). The distribution of primary division fish reflects past and present river connections, whereas the distribution of the secondary and peripheral division fishes is also influenced by marine dispersal. From an ecological perspective, the "evolutionary" classification of fishes has limitations, because some peripheral division fishes have fully adapted to freshwaters; the ancestors of two primary division catfish families (Ariidae and Plotosidae) reinvaded the sea, with some species subsequently reinvading freshwaters; and some primary division fishes are found in brackishwaters, or even in full seawater as, for example, the catfish, *Pangasius krempfi* from the Mekong.

Known occurrences of fishes in fresh, brackish, and marine environments are documented on the website FishBase (Froese and Pauly, 2008). In the Mekong system (and in the Oriental region generally) the breeding requirements of peripheral division fishes are not well documented. Juveniles or adults may be commonly found in fresh, brackish, or salt water, but most peripheral division fishes that occur in freshwater probably require brackish or saline water for development of their eggs or larvae. Many of these could be regarded as "facultatively catadromous," that is, adults or juveniles usually move into freshwaters, but require a connection with the sea to complete their life cycles. Well-known examples include the barramundi (*Lates calcarifer*), mangrove jack (*Lutjanus argentimaculatus*), and some mullets (Mugilidae), typical "freshwater" fishes that breed in coastal areas. Hence, the number of principal freshwater fishes within the peripheral division is not known with certainty for the Mekong. Lagler (1976) attempted to subdivide peripheral species in the Mekong into additional categories based on the degree or duration of their usual penetration into inland waters.

1.2. Fish Diversity in Inland Waters in the Oriental Region

Relative to area, inland waters support a disproportionate number of species of fish and many new species are being described each year. FishBase, in 2005, listed 28,900 species of which 13,000 (45%) were primary of secondary freshwater species (Froese and Pauly, 2008; Lévêque *et al.*, 2008).

In 2005, there were about 4400 fish species, or about 15% of the world's total fish fauna (Lévêque *et al.*, 2008), recorded from freshwaters in the Oriental region. This region, which contains the Mekong, extends from Pakistan through India, IndoChina, the Indonesian archipelago, and southern China. The regional freshwater fish fauna is dominated by the otophysan fishes, which include the cypriniformes (carps, barbs, minnows, and loaches) (about 1380 spp.) and siluriformes (freshwater catfish) (about 535 spp.) and this dominance is also apparent in the Mekong; of about 730 species that occur in freshwaters, about 500 or about 68% are otophysan fishes (cyprinids or catfishes) (Table 8.1).

Otophysan fishes possess characteristics that have allowed them to adapt to rivers and streams, environments which are frequently turbid, turbulent, with fluctuating chemistry and temperature (Moyle and Cech, 1988). These characteristics include a Weberian apparatus, a chain of bones that connects the swim bladder to the inner ear, which gives them an acute sense of hearing that is particularly useful while in turbid water or at night. These fishes are the dominant group on all continents except Australia and Antarctica (Briggs, 2005). By contrast, coastal and marine waters are dominated by nonotophysan groups of fishes, such as perch-like fishes (perciformes), which typically rely on sight and visual cues for feeding, intraspecific interactions, and predator avoidance.

Within the Oriental region, the fauna of rivers tends to be more similar in adjacent drainages which have been recently connected. On the basis of cyprinid species distribution, Yap (2002) found the Mekong fauna most similar to that of the Chao Phraya, and also found the fauna of the Mekong, mid-Mekong, Lower Mekong, and Chao Phraya are equally similar to each other, reflecting recent or continuing connections. This contrasts with earlier findings of Taki (1978), based on more limited surveys and species records, who considered that within these four subareas, the Lower Mekong primary fish fauna was most similar to the Lower Chao Phraya and the Middle/Upper Mekong fauna were more similar to the Upper Chao Phraya, a pattern that resulted from former connection of these rivers and an ongoing barrier effect for some species of the Khone Falls on the Great Fault Line. The Mekong and Chao Phraya group at a higher level with the Mae Klong and the rivers that drain into the Sunda Shelf, reflecting past connections (Yap, 2002). Work on the genetics of individual species also shows that present distributions largely reflect faunal exchanges across the Sunda Shelf early in the Pleistocene and that regional populations have subsequently diverged in isolation (Dodson *et al.*, 1995; McConnell, 2004).

While geological history has influenced aquatic biodiversity throughout Southeast Asia where extraordinary numbers of species have accumulated in several river systems, river dynamics and hydrology play an important role in maintaining ecosystem diversity. The naturally fluctuating environmental conditions over space and time, both within and between years, drive this ecological diversity. Likewise, reducing this hydrological and ecological diversity is a driver of biodiversity loss. Variations in the hydrological cycle also counteract dominance by certain species because no species will have optimal conditions for long time. The result is that different species will be at an advantage at different times. The chances that certain species will be outcompeted to extinction are therefore reduced (Ward and Stanford, 1983). This is reflected, for example, in discrete changes in relative species compositions of catches between years for the same fishing gears used in the same habitats.

2. FISH SPECIES DIVERSITY AND ENDEMISM

The Mekong Fish Database (MFD) developed by the Mekong River Commission (MRC, 2003) provides the most comprehensive data source on Mekong fishes, although it does not include any information on species from areas upstream of Yunnan and in Myanmar. Froese and Pauly (2008) and other references have been used to supplement the MFD where necessary.

The MFD lists 924 named species (898 indigenous) most of which have been recorded

TABLE 8.1 Fish taxa recorded from MRC (2003) except that MRC (2003) classifies the noodlefish (Sundasalangidae) as part of Osmeriformes, however, there is now general agreement that the family should be classified under Clupeiformes. Habitat occurrence data from Fishbase. Numbers in parenthesis refer to number of taxa excluding introduced species.

					Number of species which occur in habitats classed by salinity					
Order	**Common names for the main families**	**Families**	**Genera**	**Number of species**	**Freshwater only**	**Fresh and brackish**	**Fresh, brackish and marine**	**Brackish only**	**Brackish and marine**	**Marine only**
Orectolobiformes	Bamboo sharks	1	1	3			1		1	1
Carcharhiniformes	Requiem sharks, catsharks, hammerheads	3	5	8			2		4	2
Rajiformes	Rays, sawfish	4	6	13	2	3	3		3	2
Osteoglossiformes	Bony tongues, featherbacks	2	3	5	4	1				
Elopiformes	Tarpons, tenpounders	2	2	2			2			
Anguilliformes	Eels	4	8	13			7		4	2
Clupeiformes	Herrings, shads, anchovies	3	17	33	4	5	9		13	2
Gonorhychiformes	Milkfish	1	1	1			1			
Cypriniformes	Carps, barbs, minnows, loaches	4	105	387 (371)	377 (364)	10 (7)				
Characiformes	Characins	1 (0)	1 (0)	1 (0)	1 (0)					
Siluriformes	Catfish, sheatfish	13 (12)	39 (37)	127 (124)	92 (89)	13	12		10	
Aulopiformes	Lizard fishes, Bombay ducks	2	3	7					3	4

Gadiformes	Codlets	1	1	1					1	
Batrachoidiformes	Toadfishes	1	2	2					2	
Lophiiformes	Anglerfishes	1	2	2			1		1	
Atheriniformes	Silversides, priaprium fishes	2	5	7	1	3			3	
Beloniformes	Needlefishes, halfbeaks, ricefishes, rivulines	5	12	29	6	5	5	1	4	8
Cyprinodontiformes	Live bearers	1	2	2 (0)		2 (0)				
Gasterosteiformes	Pipefishes, armoured sticklebacks	3	8	13	5		3		2	3
Synbranchiformes	Swamp eels, spiny eels	3	6	13	9	4				
Scorpaeniformes	Scorpionfishes	2	7	7					3	4
Perciformes	Perches, threadfins, croakers, archerfishes, gobies, sleepers, gouramies, snakeheads	29 (28)	105 (103)	207 (203)	38	37 (33)	62	2	50	18
Pleuronectiformes	Soles, tonguefishes	2	7	19	2	3	6	1	6	1
Tetraodontiformes	Puffers	1	9	22	13	3	1		5	
Total		91 (87)	357 (341)	924 (898)	554 (537)	89 (80)	115	4	115	47

upstream from the mouth of the river (MRC, 2003). Some coastal species that have not actually been recorded from the river have been included in the database because they are highly likely to be found within the river system at some time. About 60% of the listed endemic species are primary freshwater fishes while secondary freshwater fishes derived largely from marine families, and estuarine comprise about 40%.

With 24 orders and 87 families of indigenous fish listed in the MFD, higher level taxonomic diversity in the Mekong may exceed that in any other river in the world, even when it is considered that four orders are only represented by marine visitors (Table 8.1).

The Mekong shares most of its indigenous species (about 60%) with the other large Southeast Asian rivers. The nonostariophysan fishes of the Mekong (species that are not cypriniforms or catfishes) are widespread throughout Southeast Asia (Taki, 1975, 1978). Kottelat (1989) found that the Mekong and Chao Phraya had more than 50% of their fish fauna in common (Table 8.2). On the basis of fish distributions, Taki (1978), Kottelat (1989), and Rainboth (1991, 1996) reached the conclusion that the Upper Mekong formed part of the Chao Phraya Basin in the past.

In contrast, the fish fauna of the Vietnamese rivers on the eastern slope of the Annamite chain is more similar to the fauna of the East Asian rivers and shares only a few species with the Mekong. It is rather species poor in comparison (Banarescu, 1972; Rainboth, 1991).

The high incidence of species of marine origin may be explained by the extensive estuarine zone and the high diversity of fishes associated with the large shallow water area known as the Sunda Shelf in the South China Sea. A number of large rivers feed into this area which has allowed many species to adapt into the estuarine environment. Some of these species have subsequently colonized habitats further upstream in the freshwater zone. In the Mekong, colonization has been made easier because there are no natural barriers along the 700 km from the Khone Falls to the mouth.

According to the MFD, the Mekong has 219 endemic species; all are "freshwater" fishes (freshwater or fresh-brackishwater occurrence), so about 35% of this group and 24% of all species occur only in the Mekong (Table 8.2).

TABLE 8.2 Percentage similarity (determined using the Jaccard Index) of the fish faunas of Southeast Asian rivers (based on Kottelat, 1989; adapted from Visser *et al.*, 2003)

	Mekong	Chao Phraya	Salween	Malay Peninsula	Mae Khlong	SE Thailand + SW Cambodia	Annam
Mekong	*	56	11	30	31	21	7
Chao Phraya		*	11	34	35	22	7
Salween			*	11	14	11	6
Malay Peninsula				*	28	22	6
Mae Khlong					*	36	12
SE Thailand + SW Cambodia						*	18
Annam							*

By contrast, the coastal and marine fishes listed in the MFD all have broad distributions, with the range of many species extending throughout the tropical areas of the Indo-Pacific. About 76% (166) of the Mekong's endemic species are cypriniformes (cyprinids, loaches, and algae eaters) and 12% are catfishes. About 54% of the endemic species (118 species) occur either only in Laos or Yunnan or both Laos and Yunnan. Further, the proportion of the Mekong endemics in terms of the fauna is also much higher in Laos (41%) and in Yunnan (40%) than in Thailand (24%), Cambodia (15%), or Viet Nam (7%), where the Mekong catchment is mostly lowlands that are inhabited by widespread lowland or coastal fish species. Hence endemism in the Mekong is largely a result of speciation by representatives of several families of primary division fishes which are specialized for, and tend to become isolated within, upland tributaries. In the Mekong basin, the specialized species with restricted distributions in these upland habitats are at particular risk of extinction when habitats are drastically altered; for example, as a result of dam construction. Other land-use changes are also of concern; for example, of the 28 endemic species from Yunnan, 6 species are found only in Lake Erhai and these have been affected by eutrophication and the introduction of exotics (see Hortle, Chapter 9).

3. HABITAT DIVERSITY AND SPECIES ASSEMBLAGES

3.1. Mekong Mainstream and Major Tributaries

A very large number of fish species are found in the mainstream (Fig. 8.1). However, few if any species are confined to it, even the largest species such as the giant Mekong catfish (*Pangasianodon gigas*), and *Pangasius sanitwongsei* have been recorded from some of the larger Mekong tributaries.

Current speed and channel morphology change as the river flows downstream affect the species that favor specific parts of the river, and the upper and lower reaches of the Mekong harbor different fish faunas. Because of the heavy sediment load, the Mekong River mainstream and the lowland sections of tributaries are highly turbid during the flood season. Catfishes are well adapted to this environment with their sensitive barbels that allow them to locate food without the help of their eyes. The threadfins (Polynemidae) use their filamentous pectoral fins in a similar way and both groups are well adapted to an environment with almost no light penetration (Moyle and Cech, 1988). The golden spotted grenadier anchovy (*Coilia dussumieri*) possesses a series of light organs (photophores) along the flanks and belly and on the lower jaw (Whitehead *et al.*,

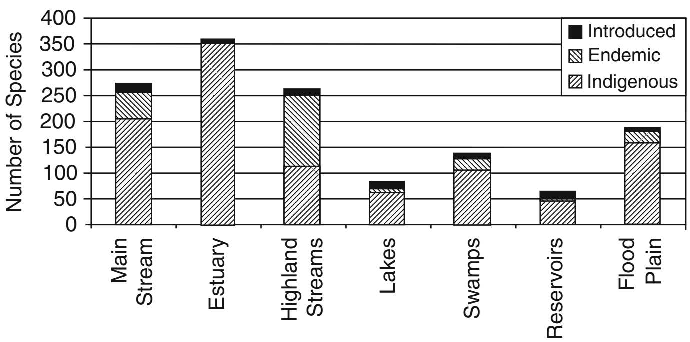

FIGURE 8.1 The number of species (species richness) in various aquatic habitats in the Mekong Basin (modified from Valbo-Jørgensen and Visser, 2003; data from MRC, 2003).

1988); however, their purpose is unknown in the murky waters of the Mekong.

Examples of species that show preference for certain parts of the mainstream are the endemic *Mekongina erythrospila* and *Labeo dyocheilus* that have a preference for fast-flowing water and are rare or absent downstream of Kratie where there are no rapids (Roberts and Warren, 1994). Although a number of species are capable of ascending the rapids at Khone Falls this still constitutes a barrier to marine visitors, and several secondary freshwater species, such as the anchovies (Engraulidae), threadfins (Polynemidae), and sea catfishes (Ariidae), do not occur upstream of the falls (Roberts and Baird, 1995).

A large proportion of the mainstream species including all the pangasiid catfishes are migratory some moving over long distances. *P. krempfi,* for example, migrates more than 700 km from the estuary to beyond Khone Falls to spawn (Hogan *et al*., 2007) and the Mekong Giant Catfish moves from lower to upper reaches to reach its spawning grounds in the golden triangle or beyond. Other species migrate laterally into tributaries and floodplains to feed and spawn (Chan *et al*., 2001). For many species, the lowland mainstream channels serve as migration corridors connecting habitats which serve different purposes in the fish's life cycle. Poulsen and Valbo-Jørgensen (2000) identified three major migration systems governed by the position of key habitats in the basin.

3.2. Estuary

The extent of the Mekong estuary depends on the criteria used. By some definitions, it may extend as far upstream as Kratie because tides are sometimes registered there, others define the upper border as the apex of the delta at Phnom Penh further dividing it into an upper and lower estuary where the borderline corresponds to the point to which saltwater penetrates. During the flood season, the water is fresh throughout the estuary; but during the dry season salt water intrudes to Can Tho and My Thuan in the Bassac and Mekong Rivers, respectively (MRC, 1997). However, the Mekong River provides a significant input of silt and nutrients to the South China Sea and this influence extends hundreds of kilometers beyond the river mouth (Tang *et al*., 2004). This nutrient input is a major determinant of aquatic productivity in this area. In addition, the soil in the delta region contains high levels of sulfate, and during the dry season when the water exchange is low, the water in rice fields and canals becomes acidic creating an inhospitable environment for fish, allowing only hardy species to survive.

The estuary is the most species-rich part of the basin because of the mixture of marine, brackish-water, and freshwater species (Fig. 8.1). The mangroves serve as important nursery areas for many fish and invertebrate species living in both the river and along the coast. Marine and freshwater fishes move up or down the river according to the prevailing salinity and thus may occur at the same location in different seasons. Marine species mainly ascend the river during the dry season, the distance depending on their level of tolerance to freshwater. The opposite is true for freshwater species that descend further into the estuary during the flood season.

The estuarine species, the last group, are permanent residents and are able to tolerate variations in salinity that happens over the year. Gobies that are among the most prominent fish families in the estuary are, for example, renowned for their tolerance to variable salt concentrations. The mudskippers (*Periophthalmus* spp. and *Periophthalmodon* spp.) are so well adapted to the life in the tidal littoral where they have become semiterrestrial leaving the water to feed on the mudflats that are exposed at low tide. These fish are able to survive out of the water for very long time because they breathe air using their modified gill cavities.

Most estuarine species stay in the downstream reaches in Viet Nam. However, some may stray further upstream into Cambodia. The sawfish *Pristis microdon* has, for example, been recorded from the Tonle Sap and in the past it is known to have gone up the Mekong mainstream to Khone Falls on the border between Laos and Cambodia. However, none of these are permanent residents in the freshwater reaches of the river and most of them would not be able to complete their lifecycle without returning to the marine environment. These species are nevertheless an important part of the Mekong's ichthyofauna and depend upon the river's inputs of nutrients and organic material. They illustrate the complexity of the area whereby different components of the fish assemblage occur at different times of the year—thereby adding a temporal component to the heterogeneity of the environment.

3.3. Individual Tributary Basins

The faunasw of the large tributaries are similar to that of the Mekong River at least in the lower reaches. However, it is important to note that while the Mun and the Songkhram Rivers are lowland rivers with enormous floodplains, most of the rivers joining the Mekong from the east have their origin in the Annamite mountain range and part of their course is mountainous and their floodplains are small. The fish fauna of the Mun and the Songkhram, therefore, resembles the mainstream fauna more than the other river basins. The Se San, the largest of the eastern tributaries, is the result of the merge of three major rivers Sekong, Srepok, and Se San and it drains northeastern Cambodia, southern Laos, and the Central Highlands in Viet Nam meeting the Mekong River mainstream at Stung Treng. Many of the smaller streams in the Se San catchment flow through natural forest ecosystems and have high transparency due to low-silt load (Rainboth, 1996). Data on species diversity in individual Mekong tributaries is extremely scarce (Table 8.3), and the number of species cataloged from each subbasin is to a large extent a result of the intensity with which they have been surveyed. The Tonle Sap is, for

TABLE 8.3 The number of species recorded from Major Mekong tributaries and the Bassac River which is a distributary (and thus better described as part of the main stream)

Basin	Number of species	Dominating fish families
Nam Ou (Lao)	72	Cyprinidae (50%) Balitoridae (19%) Sisoridae (7%) Others (24%)
Nam Ngum (Lao)	122	Cyprinidae (47%) Balitoridae (12%) Bagridae (7%) Siluridae (6%) Cobitidae (5%) Others (24%)
Nam Mang (Lao)	57	Cyprinidae (47%) Balitoridae (9%) Bagridae (7%) Cobitidae (7%) Others (30%)

Continued

TABLE 8.3 The number of species recorded from Major Mekong tributaries and the Bassac River which is a distributary (and thus better described as part of the main stream)—Cont'd

Basin	Number of species	Dominating fish families
Nam Kading (Lao)	98	Cyprinidae (49%) Balitoridae (14%) Sisoridae (8%) Others (29%)
Nam Songkhram (Thailand)	181	Cyprinidae (45%) Siluridae (7%) Cobitidae (6%) Bagridae (5%) Pangasiidae (5%) Others (32%)
Xe Bang Fai (Lao)	157	Cyprinidae (48%) Cobitidae (8%) Balitoridae (8%) Others (36%)
Xe Bang Hiang (Lao)	160	Cyprinidae (42%) Cobitidae (9%) Balitoridae (8%) Siluridae (6%) Others (36%)
Nam Mun (Thailand)	176	Cyprinidae (46%) Bagridae (6%) Siluridae (6%) Pangasiidae (6%) Others (37%)
Se San (Sesan, Sekong, Srepok) (Cambodia and Viet Nam)	149	Cyprinidae (42%) Balitoridae (17%) Cobitidae (11%) Others (30%)
Great Lake (Cambodia)	167	Cyprinidae (37%) Bagridae (8%) Siluridae (7%) Pangasiidae (5%) Others (44%)
Tonle Sap (Cambodia)	228	Cyprinidae (38%) Bagridae (7%) Siluridae (5%) Pangasiidae (5%) Others (44%)
Bassac (Cambodia and Viet Nam)	155	Cyprinidae (23%) Gobiidae (8%) Bagridae (6%) Cobitidae (5%) Clupeidae (5%) Engraulidae (5%) Siluridae (5%) Cynoglossidae (5%) Others (39%)

example, relatively easy to access because of its vicinity to Phnom Penh, the river is fished intensively and has been subject to scientific studies since colonial times. It is, therefore, not surprising that the highest number of species (296 according to Baran *et al.*, 2007) have been recorded here. Also the Delta and the Thai Basins are relatively easy to access, while the upper reaches of rivers in Laos, and Myanmar are difficult to get to and therefore much less studied and the number of species here are likely much higher than has been recorded, so far.

Eleven fish families occur that each account for more than 5% of the species in a subbasin of the Mekong. The dominating family in all parts of the basin is Cyprinidae with between 23% and 50% of all species. All species of Cyprinidae have low tolerance to salt water and the family, therefore, has the lowest diversity in the Bassac. Hillstream loaches (Balitoridae) are important but only in the Laotian rivers and in the Se San system, accounting for 8-19% of the species. Other widespread families include loaches (Cobitidae) and the catfish families Bagridae and Pangasiidae. It should be noted that the group "others" (i.e., families with less than 5% of the species) is important everywhere and accounts for 24-44% of the species (Table 8.3).

3.4. Deep Pools

Chan *et al.* (2005) defined a deep pool as . . . "*significantly deeper than surrounding areas and holds water in the dry season, during which it may become disconnected from the main river. A deep pool is also defined ecologically as being of significance for the conservation of a number of fish species.*" Viravong *et al.* (2004) reported that, based on a hydroacoustic survey, most of the deep pools in southern Laos and northeastern Cambodia are best described as canyons, fissures, or cracks in the bottom. They also stated that deep pool morphology and depth are very variable and seem to be important factors in determining the number of fish seeking shelter in the pools. The fish showed preference for deep pools with serrated rocks with steep, almost vertical, sides. The contour of deep pools may, thus also, be important in determining which and how many species are present.

During a recent survey in Cambodia, 97 deep pools were identified by interviewing local fisherfolk (Chan *et al.*, 2005). Viravong *et al.* (2004) surveyed several of these pools using hydroacoustic equipment and found one of them to be 79 m deep. In southern Laos, fisheries officers report around 70 pools (Poulsen *et al.*, 2002). Deep pools are also present further upstream along the Thai-Lao border but have not been systematically surveyed.

Poulsen *et al.* (2002) listed 53 species that fishers have stated reside in deep pools during at least part of the year. Viravong *et al.* (2004) and Baran *et al.* (2005), from catch data, identified a wide range of catfishes (Pangasiidae, Siluridae, Bagridae, Bagriichthidae, and Ariidae), an algae-eater (Gyrhinocheilidae), and a number of cyprinids being caught in deep pools. Deep pools thus seem to serve as a dry-season refuge to a large number of species, and the absence or presence of these is one of the most important factors in determining species composition in a particular reach of the Mekong River mainstream (Poulsen and Valbo-Jørgensen, 2000). However, only the small-scale croaker (*Boesemania microlepis*) seems to be a definite deep pool species (Baird *et al.*, 2001). It is interesting to observe that the sheatfishes (Siluridae) that are among the most abundant deep pool species are morphologically similar to the electric knifefishes (Gymnotidae) that are abundant in deep pools in some South American rivers (Lundberg *et al.*, 1987). However, no Mekong species are known to possess electric organs similar to the ones found in the South American family.

3.5. Floodplains and Other Wetlands

The total area of wetlands (including all seasonally inundated land) in the Lower Mekong Basin is estimated at 185,000 km^2 (Hortle, Chapter 9), with additional areas inundated in some years when the Mekong flood extends into the Saigon River catchment. Aquatic habitats are extremely diverse throughout the basin and include rice fields (the most extensive habitats), rivers and their floodplains, natural swamps, lakes and reservoirs, and in the delta, canals, intertidal mudflats, and mangroves.

As a result of growing populations, more natural floodplains are being converted into rice paddies. In addition, rain-fed rice cultivation is extending the effective upper boundaries of floodplains as land has been cleared and leveled on terraces to create rice fields.

Floodplains are not evenly distributed in the basin. Along the Upper Mekong, floodplains are few and small. Plains are found only on the Plain of Jars in Laos and in association with the large tributaries Mae Kok and Mae Ing in Thailand. Along the Middle Mekong, flooding is much more intense, but floodplains along most of the mainstream are still small. The plains along the large western tributaries (Nam Songkhram and Nam Mun on the Khorat Plateau) are extensive, while floodplains on rivers with origin in the Annamites are much smaller. Most of the floodplains are found from Kratie to the South China Sea, particularly around the plain of reeds on the border between Cambodia and Viet Nam, and along the Tonle Sap and Great Lake enormous areas are deeply flooded every year. In June or July, the Tonle Sap reverses its flow and the Great Lake starts filling up, and its surface expands up to six fold each year from about 2500 km^2 in the dry season to 15,000 km^2 during the flood (Campbell, Chapter 10; van Zalinge *et al*., 2004). The duration of the flood varies considerably among different parts of the basin. In the tributaries of the Middle Mekong, the floodplains are only inundated for 1-2 months, while in the Lower Mekong and in the Delta the floodplains may be under water for 6 months or more.

Along the Mekong and Tonle Sap Rivers, multiple channels and man-made canals cut through the levees and allow the water to enter the floodplains before the banks are overflowed. As water levels peak, the flow in the canals slows and eventually reverses as river level drops. These places provide important entry points for fish migrating onto the floodplain for spawning or feeding and for drifting eggs and larvae to become dispersed there.

Most medium to large Mekong fish species exhibit some degree of migratory behavior and utilize the floodplain during at least part of their life cycle typically for feeding and as nursery grounds for their juveniles. The large number of species found in floodplains is thus basically a subset of the species found in the main river channel. A range of the larger species takes advantage of access to direct inputs from terrestrial food sources such as insects, seeds, and fruits. At the same time, there is a boom in primary and secondary productivity in the warm shallow water which has abundant nutrients from the flood waters as well as from decomposing terrestrial plants in the newly flooded areas generating plenty of food for juveniles and small fish species, which in turn serve as food for piscivores (Poulsen and Valbo-Jørgensen, 2000). Production on floodplains is the major contributor to overall river productivity including being the main biological production source for species migrating through river channels. The flood cycle generates a dynamic environment where availability of, and access to, food and shelter continuously changes, favoring different sets of species at different times; preventing any one species becoming permanently dominant.

Small permanent floodplain water bodies such as marshlands and swamps are dry-season refuges and important for the recolonization of large areas during the flood. These water bodies are home to numerous small species, including *Boraras micros, Indostoma* spp., dwarf pipefish, *Nandus* spp., small anabantids, *Betta* spp., *Trichopsis* spp., and small gobies (Welcomme and Vidthayanon, 2003). Although fishes remain isolated during the dry season, many water bodies become connected during the flood which limits speciation between them.

Rice fields are habitats created by humans but rice is naturally a plant growing on river floodplains and in swamps, and the plant has been cultured in Asia for thousands of years. However, as a result of growing populations, more and more natural floodplains are converted into rice paddies and they now constitute one of the most widespread aquatic habitats in the Mekong with an estimated 10 million ha of wet-season rice (Dao Trong Tu *et al.*, 2004). Low-intensity cultivation with minor inputs of fertilizer and pesticides still allows fish to utilize rice fields the same way as they use the natural floodplains. However, fewer niches are probably available in the rice and there is less shelter to seek protection from predators. Nevertheless, rice fields flooded by the river usually still have a large number of species present. More than 80 species were recorded in surveys of Cambodia and Laos (Halwart and Bartley, 2005). Some of the most common species are walking catfish *Clarias batrachus*, snakeheads (*Channa* spp.), swamp eels (*Monopterus albus*), labyrinth fishes (Anabantidae, Osphronemidae, and Belontiidae), and a variety of small cyprinids such as *Rasbora* spp. However, juveniles of larger growing species also use the rice fields as nursery areas. Some large species have even been reported to spawn in the rice fields, including *Wallago attu* and *W. leeri* (Poulsen and Valbo-Jørgensen, 2000; Valbo-Jørgensen and Poulsen, 2000).

3.6. Highland Streams

In the numerous Mekong tributaries in Yunnan and in the upper reaches of tributary basins in Laos with origins in the Annamites, many species evolved in isolation. These species are adapted to high altitudes and are sometimes confined to single streams or caves. As a result, the mountain regions contain many endemic species. Water here is clear, cold, and oxygen rich, and the streams tend to be rocky with many rapids, and the current strong and turbulent as a result of the high gradient. The fish present mostly feed on algal films on stones and rocks and invertebrates.

The most species-rich families in highland streams are rheophilic primary freshwater species of the families Cyprinidae, Balitoridae, Cobitidae, and Sisoridae. A number of species possess special adaptations to survive in the torrential streams. Such species include the Balitorid genera *Homaloptera* with enlarged pectoral and pelvic fins, and *Sewellia* where the enlarged ventral fins together with the flattened belly form a ventral sucking disc. Such fish cling to rocks and stones, thereby allowing them to live in faster flowing water. The algae eaters (Gyrhinocheilidae) attach themselves to solid objects by using the mouth as a sucker, thereby preventing normal respiration through the mouth. Instead, they possess a small hole above the gill opening, leading into the gill chamber, through which they can inhale water for respiration.

Many species of sisorid and torrent catfishes (Amblycipitidae) can only be found in rapids here. Fish in the sisorid genus *Glyptothorax* possess small grooves under the head that constitute an adhesive apparatus (Thomson and Page, 2006) that enables the fish to stick to stones, etc., preventing them from drifting with the current. Freshwater species of gobies (Gobiidae) are often found in sections with very strong current, where they cling to stones and rocks with a sucker formed by the fused pelvic fins.

Given that many of these areas are difficult to access and some have never been surveyed, many additional and new species are likely to be found here.

3.7. Caves

There are a number of limestone caves in Laos and they probably harbor several species of fish that are unknown to science. Cave fishes tend to have a very limited distribution as they normally do not venture out of their habitat and they are sometimes restricted to a single cave system (Kottelat and Whitten, 1996). Unfortunately, this fauna is almost unstudied in the Mekong Basin, but at least three species of cave fishes *Poropuntius speleops*, *Troglocyclocheilus khammouanensis* (Cyprinidae), and *Schistura kaysonei* (Balitoridae) have been found. They are all either blind or have much reduced eyes showing that they evolved in the caves.

3.8. Lakes

True lakes are found in the upper parts of the basin including Yunnan where six lakes with a total surface area of 273 km^2 are located (Chen Kelin and Li Chun, 1999; Zhou Bo, 1999). These lakes are relatively species poor, Cibuhu Lake and Jianhu Lake both have seven species and the largest, Erhai Lake (250 km^2), has 18 species (Yang, 1996).

Many small water bodies are found in the mountains between Laos and Viet Nam but nothing is known about their fish faunas. In the Central Highlands region of Viet Nam, the largest natural lake is Lak Lake, which is a shallow water body with an area of 600 ha. Some 49 species of fish live in it (Viet Nam Environment Protection Agency, 2005), but several of them are probably exotic because culture-based fisheries enhancements is the most popular way to manage fisheries in that region.

The Great Lake of the Tonle Sap is the largest water body in the system with a dry-season area of 2500 km^2 and it is the largest lake in SE Asia. The fish stocks in the lake are replenished in each flood season from three different sources: (1) the resident fauna that survives in the lake and in water bodies on the floodplain and spawn during the flood season; (2) migratory fishes (including some marine visitors) that enter the lake at the onset of the flood to feed and spawn along the shores and in the floodplains; and (3) eggs and fry from fish that spawn in the Tonle Sap River and upstream in the Mekong River that are carried into the lake by the incoming flow. Because of the connection with the Tonle Sap River, and thus the Mekong River, most of the species occurring there will likely eventually be recorded from the lake as well (Campbell *et al.*, 2006). More species can be anticipated to occur near the Tonle Sap River than in the northern part of the lake where no large rivers are present.

Of the confirmed records of 167 species of fish from the Great Lake (Table 8.3), only a little dragonet species, *Tonlesapia tsukawakii*, which was described recently, is endemic to the lake (Motomura and Mukai, 2006). Few fish species, all of marine origin, seem to be permanently restricted to the open lake including clupeids, croakers (Scianidae), and tongue fishes (Soleidae) (Lamberts, 2001). All the other species are mainly found in the flooded forest.

3.9. Reservoirs

About 25,000 small reservoirs have been created as water storages for irrigation purposes in the Mekong region (Sverdrup-Jensen, 2002). A number of large hydropower reservoirs have been formed on several large tributaries, including the Nam Ngum, the Mun, and the Se San Rivers and several are at various stages of planning and construction. For Laos alone, more than 60 dams (including five on the

Mekong mainstream) are at various stages of construction or planning (Powering Progress, 2007). Until now, only two mainstream dams have been built in China but several more are planned for in that part of the basin. Reservoirs have thus become important fish habitats in all the basin countries. However, as only few Mekong species are adapted to lacustrine conditions this environment is not optimal for them unless they are able to access flowing water periodically. It is especially the lack of suitable spawning grounds that prevent many species to establish themselves in the reservoirs, although this is partly mitigated where tributaries to the reservoir allow them to move to suitable spawning grounds upstream.

There are important differences between shallow small reservoirs and deep hydropower reservoirs. In deep reservoirs, most of the water mass may be completely devoid of fishes. The water is normally stratified and the bottom layers are hypoxic or anoxic and no fishes are able to live there, and few species in the river system are adapted to a pelagic life. Exceptions to the latter are the little clupeids, the Thai river sprat (*Clupeichthys aesarnensis*), Sumatran river sprat (*Clupeichthys goniognathus*), and the glass perch *Parambassis siamensis* (Chandidae) that thrive in the open water of many reservoirs, although none of these seem to be as abundant in the river. In some cases, the predatory cyprinids of the genus *Hampala* also become pelagic in reservoirs feeding on the clupeids (Welcomme and Vidthayanon, 2003). Most of the diversity in reservoirs is found along the shores and among old tree trunks where these have not been removed before reservoir filling. However, oscillations in water level resulting from the drawdown make the shoreline a dangerous place where the fish may be trapped and their eggs or juveniles destroyed.

Reservoirs are thus relatively species poor, and because stocking with alien species better adapted to this environment is the preferred way of compensating for the species lost and enhancing fisheries throughout the basin, introduced species such as tilapia (*Oreochromis niloticus*), common carp (*Cyprinus carpio*), and Chinese and Indian major carps constitute a disproportionately large part of the fish species in reservoirs (Welcomme and Vidthayanon, 2003).

4. LIFE HISTORIES

4.1. Reproduction and Reproductive Migration

In tropical lowland areas, fishes are usually divided into guilds based on their migratory patterns: black fish, white fish, and sometimes an intermediate group of gray fish. A few species remain within the river channel and rarely move on to the floodplain (Taki, 1978). These include some large predators such as the drumfish, *B. microlepis* and the large predatory cyprinid *Aaptosyax grypus*. Other fish found in the lowlands include estuarine fishes as well as hill-stream fishes that are forced downstream during dry periods when flows are low.

According to Baran *et al.* (2007), of 296 fish species known from the Tonle Sap system the migration guilds of only about one-third are known. However, about 200 species are caught in the dai fisheries of the Tonle Sap and a similar river channel fishery in Tonle Touch in southern Cambodia (MRC data; Ngor *et al.*, 2005). It seems likely that most of these fishes are migrating downstream so would be categorized as white fish. Of the river fish recorded by Taki (1978) in the Middle Mekong based on repeated sampling, about half were considered migratory and half sedentary.

4.1.1. White Fish

Because of the large fluctuations in water level in the Mekong Basin, many Mekong fish species exploit different habitats in different seasons, and are thus migratory. Those that do so over longer distances, for example, from floodplains into and along main river channels, are termed "white fishes." These can be grouped into three main categories based on their migratory patterns: anadromous, catadromous, and potamodromous. Although the migrations appear to be obligatory in some species, in some they may be facultative with the fish simply responding to changes in living space and food caused by the annual flood patterns.

Anadromous fishes live most of their adult life in the sea, but must enter freshwater to spawn. Examples from the Mekong included the pangasiid catfishes *P. krempfi* (Hogan *et al.*, 2007) and *Pangasius mekongensis* (Gustiano *et al.*, 2002).

Catadromous fishes spawn in the brackish or saline water in the estuary or the sea; fry or juveniles enter freshwater where they grow until they are ready to return to the sea. Examples from the Mekong include the giant mottled eel (*Anguilla marmorata*, Anguillidae) and sea-bass or barramundi (*L. calcarifer*, Centropomidae).

Potamodromous fishes are the most important group in the Mekong, these fishes live their entire life in fresh water but migrate, often for long distances, within the river system in order to spawn, feed, or seek refuge. Potamodromous migrations can be further divided into longitudinal and lateral movements. The longitudinal migrations are along the main river channels, while the lateral migrations are from the main rivers into floodplain areas. Some species migrate both longitudinally and laterally (e.g., a longitudinal migration to spawning grounds followed by a lateral migration into feeding areas).

In a comparative study of the larval drift in the Mekong and Bassac branches, 127 species of fish belonging to 28 families were identified, of which most species were Cyprinidae, Siluridae, Gobiidae, Pangasiidae, and Bagridae (Nguyen *et al.*, 2001). The most common and abundant species were the cyprinids *Henicorhynchus* spp. and *Paralaubuca riveroi*, and the pangasiid catfishes *Pangasianodon hypophthalmus* and *Pangasius macronema*.

Most of the Mekong species spawn in a restricted period in the beginning of the flood, known exceptions to this rule are the *Probarbus* species, *Hypsibarbus malcolmi*, and *B. microlepis* that all spawn during the dry season; the former species in shallow water in the mainstream (Roberts and Warren, 1994), the latter two in deep pools (Baird and Phylavanh, 1999).

At the onset of the flood, most migratory species move upstream to spawn (Bouakhamvongsa and Poulsen, 2001) which takes place while the water level is still increasing ensuring that eggs and larvae are carried by the water into nursery areas on the floodplain. Observations on phenomena that correlate with fish migration were reviewed by Baran (2006) who referred to them as "triggers", a term not universally accepted. He found that one or several such phenomena had been identified for 30 species (Table 8.4). It is probable that the actual triggers are chemical cues, because water quality changes in a predictable way at the onset and during the annual cycle of flooding, and river fish have well-developed senses of smell and taste (Lucas *et al.*, 2001).

The actual spawning grounds for most Mekong fish species have still not been identified. Some species, such as the pangasiids, are believed to spawn in rapids in the main stream. The large quantities of ripe fish, of a variety of species, that are moving into many of the tributaries in

TABLE 8.4 Factors correlating with the timing of fish migrations, that have been identified for those Mekong fish species reviewed by Baran (2006)

Stimulus	Number of fish species responding
Water level and current	26
First rains	9
Changes in turbidity	9
Appearance of insects	3

Lao PDR, Thailand, and Northern Cambodia probably are spawning there. From the spawning grounds, eggs, larvae, and fry drift downstream with the current until they reach the floodplain areas that constitute the main feeding grounds.

After spawning, the spent adult fish also move into the flooded areas. During the flood season, the fish are feeding intensively in the flood zone, growing and building up fat layers for the following dry season, which is a time of starvation for most fish. When the water level falls and the floodplain dries up most fish leave the floodplain, and seek refuge in permanent water bodies. Of particular importance as dry-season refuges are deep pools (Poulsen and Valbo-Jørgensen, 2000; Poulsen *et al.*, 2002). The fish following this generalized pattern thus utilize three distinct habitats: spawning and feeding grounds, and dry-season refuges. The existence of these three key habitats plays a decisive role in identifying the type of species and its span in a particular reach of the river (Poulsen and Valbo-Jørgensen, 2000).

In the Mekong, there may be hundreds of species of white fishes. They include many species of cyprinids, pangasiids and large river loaches which are the targets of river fishers, but although they are important to the fishery only a few species dominate the catch at any given locality.

4.1.2. Black Fish

Fish that reside permanently in swamps, marshes, canals, ponds, and similar environments, or use them for dry-season refuge, are known as black fish. In such places, high temperatures and low-oxygen levels prevail. This prevents more sensitive species from surviving. Many black fish possess accessory breathing organs, such as the labyrinth organ in labyrinth fishes (Anabantoidei), which allows these fish to breathe atmospheric air. The swamp eels are similarly capable of supplementing their oxygen intake by breathing air through an accessory respiratory organ, formed by two lung-like sacs that originate from the gill chamber. The featherbacks are capable of breathing air by inflating the swimbladder, and they come to the surface to breathe from time to time. Snakeheads and swampeels are among the hardiest species, and may survive deeply buried in the mud if their water body dries up. They may also crawl over land in search of a more suitable habitat as does the climbing perch (*Anabas testudineus*) and the walking catfish (*C. batrachus*) (Smith, 1945).

Black fishes are opportunistic breeders, and may have an extended spawning season. Some are able to reproduce all the year, but peak-spawning activity is normally during the flood season. The brood size is normally small but survival chances increased through various types of parental care that have developed in several unrelated fish groups: the swamp eel *M. albus* and several labyrinth fishes build a froth-nest; snakeheads construct a nest of vegetation; the male clown featherback (*Chitala ornata*) aerates the eggs, and keeps them free of sediments by fanning water over them with his tail (Smith, 1945). Clown featherback and snakeheads also defend eggs and juveniles against potential predators (Smith, 1945).

There is a relatively small number of species in the Mekong that are classified as black fishes, but they are disproportionately important to the fishery on the floodplain and in rice fields. They are valued by people there because they can live for days in little water, so they are easy to transport and require no preservation, as a result they are common in fish markets.

4.1.3. Gray Fish

Gray fish constitute an intermediate group that migrate into the floodplain for breeding and feeding at high water, but mainly seek shelter in the adjacent main river channel during the dry season. However, in some of the species, part of the population may stay on the floodplain while part moves to the river

(Chan *et al*., 2001). They are less capable of surviving under extremely low-oxygen levels than the black fish, but do not have elaborate repeat spawning reproductive behaviors. They include some cyprinids and catfishes as well as some featherbacks, glassfish (Ambassidae), and needle fish (Belonidae).

4.2. Feeding Guilds

Out of the 391 species for which details on feeding habits are available, about half are carnivorous (Fig. 8.2). Insects, both aquatic and terrestrial, are clearly of great importance as they are reported to be eaten by the greatest number of fish species. To some extent, this apparent importance may be a result of dietary studies often being based on larger fishes. Larval and juvenile fishes typically feed on plankton, particularly in flooded areas, switching to larger items (including insects) as they grow. Fish is also an important food item, and several species feed on fins and scales and may be considered as parasites (Table 8.5). Among the more curious examples is the cyprinid *Luciocyprinus striolatus* that has been reported to feed on monkeys (Roberts, 2004). About 37% of the species are feeding on both animal and plant matter, while only 8% are strictly herbivorous.

TABLE 8.5 Food items recorded in the diets of Mekong fishes (from Valbo-Jørgensen, 2003)

Food item	Number of species
Insects	201
Fish	149
Algae	90
Insect larvae	80
Zooplankton	75
Detritus	69
Worms	67
Shrimps/prawns	57
Phytoplankton	48
Periphyton	44
Fruits	31
Crabs	25
Snails/gastropods	20
Terrestrial plants	12
Scales	11
Aquatic macrophytes	11
Fins	10
Scavenge	9
Flowers	6
Frogs	5
Bivalves	5

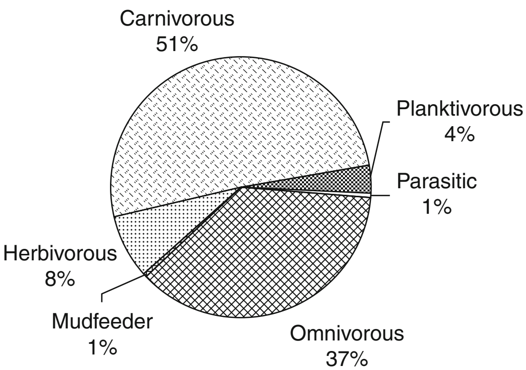

FIGURE 8.2 Proportion of Mekong Basin fish species with various diets.

The large numbers of species that feed on algae, phytoplankton, and periphyton probably reflect that these are the only food items available during the dry season. During the dry season when water levels drop, the water becomes less turbid and dense growths of filamentous algae develop in some parts of the river (Viravong *et al*., 2004). The Mekong Giant catfish lacks teeth in adults (Roberts and Vidthayanon, 1991) and is thought to be herbivorous feeding on such algae. During the flood, a number of large species enter the forest to feed on fruits including several *Pangasius* species, the elephant ear gourami (*Osphronemus* *exodon*), and cyprinids like *Tor* spp., and mad barb (*Leptobarbus hoeveni*).

5. SIZE DIVERSITY

The fish species of the Mekong range from minute species such as *Sundasalanx mekongensis* (Sundasalangidae), *Oryzias* spp. (Adrianichthyidae), and various gobies and cyprinids, all growing to only a couple of centimeters and some become sexually mature at a length of less than 15 mm. The smallest species tend to be of marine origin as was also observed by Roberts (1972) in the Amazon.

On the other hand, some of the largest freshwater fishes in the world are also present including the 3-m-long Mekong giant catfish (*P. gigas*), the enormous stingray (*Himantura chaophrya*), which reportedly can attain a weight of 600 kg, and the giant barb (*Catlocarpio siamensis*) which is the largest cyprinid species in the world growing to a size of close to 3 m. Some of the marine visitors grow even larger (Fig. 8.3). The fish fauna thus spans over three orders of magnitude in length—as is normally seen in large rivers (Welcomme, 1985).

6. GENETIC DIVERSITY

The few Mekong fish species that have been studied show a high level of genetic diversity, which suggests the presence of distinct populations or stocks (Hara *et al.*, 1998; Na-Nakorn *et al.*, 2006; Sekino and Hara, 2000; So, 2006; So *et al.*, 2006; Takagi *et al.*, 2006). High intra-specific diversity is due to limited gene flow between populations, which is common amongst riverine faunas where populations in individual sub-catchments, or areas, become relatively isolated from each other due to a mix of behavioural and ecological factors. This phenomenon is enhanced in the Mekong where several sub-catchments were independent basins until relatively recent geological history (see Carling, Chapter 2). High intra-specific diversity means that management of the fish must consider genetic diversity. For capture fisheries each stock should be managed separately, as the likelihood of population crashes is higher as a result of smaller effective population sizes. High intra-specific genetic diversity is an advantage in aquaculture, because wild heterogeneous populations are the main sources of genetic material for improving farmed breeds. But the culture of

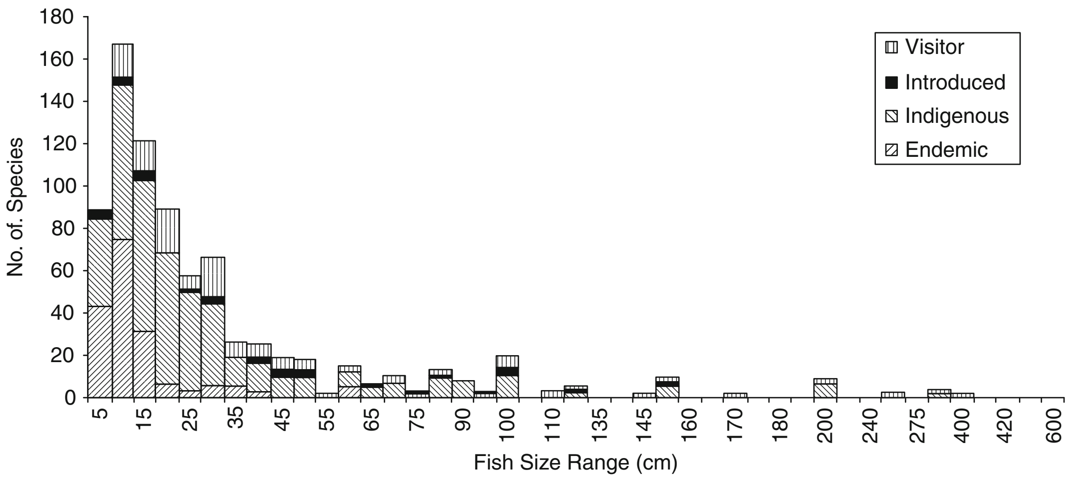

FIGURE 8.3 The number of Mekong fish species plotted against the maximum adult size in cm.

native species must consider the impact of releases or escapes on wild genetic diversity. The introduction of alien genes through aquaculture is a major cause of genetic erosion. Unless adequate information and management is in place, it should not be assumed that the culture of natives is less risk prone than that of alien species.

7. DETERMINANTS OF DIVERSITY

The number of fish species in the Mekong system appears to be high after size (as indicated by catchment area) is taken into account (Welcomme, 1985, p. 94). Kottelat and Whitten (1996) suggested that the Mekong system is a biodiversity "hotspot" and Groombridge and Jenkins (2002) identified it as globally important. However, comparisons between river systems are somewhat tenuous because recorded counts of species from different systems are not of equivalent accuracy nor do they cover the same ecological groupings, and different authors treat marine vagrants differently. Moreover, new species are being described and additional species recorded regularly from the Mekong and other rivers.

The Mekong is likely to be a relatively rich system, based on general attributes that favor high species richness and numerous endemics (Lévêque *et al.*, 2008). It has a large habitat area, as indicated by surface area and annual discharge (de Silva *et al.*, 2007), with an unusually high-peak discharge (Adamson *et al.*, Chapter 4; Burnhill and Adamson, 2007); and in relatively recent geological time an even larger effective size as part of the Sunda Shelf river system. It is a highly productive tropical system. Also, it has a geological history of river systems that were fragmented and rejoined over recent geological time as sea levels rose and fell and glaciers progressed and regressed. This has affected immigration, speciation, and extinction rates and allowed the Mekong species to evolve in a wide range of habitats while variation in hydrology and the variety of habitats allowed the persistence of many species which required different conditions (Rainboth, 1996). Finally, the orientation of the river system, running north-south, allows the resident fauna to move latitudinally in response to glacial progression and regression (see Oberdorff *et al.*, 1997).

Probably, only the Amazon River system with more than 3000 fish species estimated (Dr Sven Kullander, personal communication) is richer in species than the Mekong. On a per unit area basis, the Mekong is in fact richer because the Amazon is more than eight times larger.

8. RESEARCH

During colonial times, French researchers studied the Tonle Sap and the Great Lake intensively. Prior to the American war in Viet Nam, substantial American sponsored research also took place especially in Laos. In the 1990s, the MRC and FAO began supporting fish research resulting in a guide to the fishes of Cambodia (Rainboth, 1996) and MFD (MRC, 2003). An atlas covering the basin is in preparation.

It is not surprising that small cryptically colored species such as the hill stream loaches and the akysid and sisorid catfishes are still being described. However, several large species have recently been discovered. It was only in 1986 that *L. striolatus* which grows to 2 or 3 m was described, *Probarbus labeamajor* which grows to 1.5 m was described in 1992. Even extremely important commercial species, such as *Helicophagus leptorhynchus*, *Belodontichthys truncatus*, and *P. mekongensis* have only been recognized within the last decade.

Ironically more is known about the fish fauna, thanks to the hydropower development which has taken place in the region. Taxonomic surveys in remote areas that were previously unstudied have been undertaken as part of hydropower environmental impact assessments (EIA). As a result Kottelat, for example, discovered 64 new species in Laos (Kottelat, 2000). However, as many of the species discovered in this way are endemic to the impacted basins, they are threatened. Worse, many rare species may not be collected at all during a short sampling effort in connection with an EIA. Hydropower projects are likely to continue to be the main supporters of taxonomic surveys in the years to come as most of the countries do not have the necessary human resources and their financial situation does not allow them to support this type of research which is mostly considered "redundant."

9. SOCIOECONOMIC VALUE OF FISH BIODIVERSITY

The riparian countries in the Mekong Region are often pictured as rice-farming economies, but the population of the Mekong Basin is culturally as diverse as its geography. There are more than 100 different ethnic groups present, all of them with ancient traditions that influence the way they use natural resources. Rural communities are highly diversified, incorporating a wide range of resource uses, and demonstrating high levels of seasonal and annual adaptation to their environments. The ubiquity and high diversity of aquatic organisms combined with the low cost of fishing gears made from local materials opens fishing as a part- or full-time occupation for large numbers of people. The capture and collection of a variety of aquatic animals and plants for a range of domestic and small-scale commercial purposes is among the most important ways by which poor people make use of common pool resources. Communities living on the riverbanks and floodplains, and in floating homes, as well as the rice farmers are all heavily dependant on these resources. Here, fishing becomes an integrated part of the livelihood for entire communities. For most fishers, fishing is not the only occupation, and for many it is not the main business. But practically, the entire rural population of the Mekong is dependent in one way or another on living aquatic resources caught from the wild. For the poorest, such as landless people, fishing may be the only option during a large part of the year. The Mekong freshwater fishery underpins food security in the region.

The diversity of fish species, habitats, and seasonal influences leads to a highly diverse fishery where the diversity of methods of exploitation rivals that of the species themselves. This level of diversity promotes wide participation in the fishery across all age, gender, and ethnic groups. Thus, the high diversity of fishes in the Mekong contributes considerable socioeconomic benefits which are spread reasonably equitably among the population and, in particular, allow livelihood opportunities for underprivileged groups.

Fisheries take place in all water bodies: rivers and streams of all sizes and their associated wetlands many of which are seasonal. In densely populated areas, the waters of even the smallest ponds may be fished several times every day. As we have seen above, each type of habitat has its own community of aquatic organisms, which results in unique patterns of resource use by local people (Meusch *et al.*, 2003). Fishing takes place when the opportunity arises (time or availability of fish). Women and children, for example, fish and collect other aquatic animals near their homes or set small traps while harvesting rice or other aquatic plants. Rice paddies constitute a multipurpose resource that are utilized for both rice production and capture fisheries. Seasonal integration of fishing with other activities constitutes the main livelihoods for millions of people throughout the Mekong Basin.

The agricultural calendar and the seasonality in abundance of fish are among the most important features governing local lifestyles. The variety of species ensures a spread of the risk involved with the exploitation of natural resources; in countries with weak social-security systems, the open access fishery provides a safety net that allows many people to survive during times of unemployment.

In the Mekong Basin, people use an extremely diverse collection of modern and traditional artisanal fishing gears such as traps, spears, and bows and arrows. In Cambodia, 150 gear types have been documented (Deap *et al.*, 2003), and a similar diversity can be found in the other riparian countries. Traditional gears are often highly selective in terms of species and some of them have been developed over many generations to match the behavior of the fish. They may require considerable local knowledge to operate, as they are often closely adapted to the local environment. Sometimes, they can only be used under particular hydrologic conditions. Boats, large expensive gears, and more intensive methods may be necessary for fishing in larger rivers, but habitats like flooded forests, swamps, rice fields, and streams can be fished using low-intensity smaller scale gears.

Meusch *et al*. (2003) recorded almost 200 species of aquatic plants and animals that are frequently used by villagers. Apart from fin-fish, other aquatic animals being used include crabs, shrimps, frogs, shellfish, turtles, and insects—in some cases, these animals are as important for household consumption as fish (Meusch *et al*., 2003). The catch is often separated as the valuable species for sale and the remaining for own consumption. This often manifests itself in the large individuals selected for commercialization and small growing species for food. Under high fishing pressure, the fishing down process often means that only small opportunistic and prolific species are available for local consumption.

Fish abundance fluctuates as a result of reproduction and migration cycles and although fish are available all year round, their catchability varies. Fish are most numerous during the high water season, but they are dispersed in a large volume of water and are therefore more difficult to catch. The fish become much more vulnerable during migration periods especially when they have to pass narrow or shallow points, and at this time many people fish, including occasional fishers who may only fish at this time of the year. The fishers target the channels connecting the floodplain with the main stream, tributaries to reservoirs and lakes and calmer zones below waterfalls or rapids where fish tend to rest. Individual success depends on the experience and knowledge of the fisher. Some fishers follow the fish for hundreds of kilometers. Along mountain streams and river reaches without floodplains, fishing may be confined to the period when fish are moving through the area. Communities living here thus rely on habitats and ecosystems located elsewhere in the system (Mollot *et al*., 2003).

During the dry season the fish seek shelter in a few refuges which are vulnerable to fishing. In depressions on the floodplain, fish and other aquatic animals become increasingly concentrated in a decreasing volume of water as the dry season advances. The fish hiding here are thus relatively easy to catch and capture may be assisted by draining or pumping. Fish and other aquatic animals burying in the mud may be dug out. In deep pools in the main stream, it may require specialist knowledge and specially designed fishing gears to catch the fish (Viravong *et al*., 2004)—although the illegal use of explosives may kill large amounts of fish indiscriminately.

In the species-rich Mekong, the majority of the biomass of the total fish catch in any particular locality usually comprises 10 or fewer species (Hortle, Chapter 9). The role of diversity in sustaining total production is not well understood. Since the loss of energy at each step in a natural food chain is usually about 80-90% (Odum, 1971), "fishing down the food chain" by increasing fishing pressure can lead to increased total yields in a fishery, but reduced catches of larger more valuable species and decreased catch per fisher result in significant changes to the economic benefits of the fishery (Welcomme, 2001). Yields can also be increased in some systems by increasing nutrient loading and stocking with species that feed on algae. The highest yielding systems in inland waters are small eutrophic lakes stocked with a few species of plankton-feeding fishes. However, such fish are often of relatively low value per unit weight and the distribution of benefits to part-time fishers is frequently reduced as the fishery becomes commercialized. In enriched systems with fewer species, there are also greater risks of diseases, and water quality problems that may affect other uses.

All of the Mekong countries have policies to increase food production. This necessarily involves competition with other uses of water including maintenance of aquatic ecosystems and their fisheries. The conservation and sustainable use of biodiversity has also been identified as a priority by all lower Mekong governments. However, maintaining biodiversity while simultaneously increasing food production to support expanding populations presents a major technical challenge. Better integrated natural resources management is required in order to achieve these multiple goals. The Mekong River ecosystem provides a multitude of services that benefit its people. Many of these are undervalued and not included in formal economic analyses and subsequent decision making. In addition to fisheries, these include the role of the ecosystem in the regulation of climate, recycling of nutrients and providing sanitation, and the maintenance of the hydrological cycle, including drought and flood mitigation and the provision of drinking water. The best scenario for sustainable fisheries is not through simplistic trade-offs between fisheries and other food production practices, but through more holistic approaches which consider balancing the full suite of benefits that the maintenance of ecosystem integrity and function will bring to the region.

10. MAJOR DRIVERS OF BIODIVERSITY LOSS

Globally, the rate of biodiversity loss from freshwater ecosystems is the fastest of all of the world's major biomes (Secretariat of the Convention on Biological Diversity, 2006). For example, based on published data from around the world, the Living Planet Index (Hails, 2006) aggregates trends of some 3000 wild populations of species and shows a consistent decline in species abundance between 1970 and 2000 of about 50% for inland water species compared to 30% for marine and terrestrial species. This is hardly surprising considering the demands and pressures placed upon freshwater and the extent of conversion of freshwater and coastal aquatic habitat to alternative uses.

Human impacts on aquatic ecosystems in the Mekong Region have been at a low level until recently. However, expanding industrial and agricultural development is gaining momentum and the pressure on aquatic habitats is intensifying with negative consequences for aquatic species and therefore also for fisheries, food security, and human well-being. This development simply mirrors what has happened in countries throughout the world (FAO, 2007). Ricciardi and Rasmussen (1999), for example, found that the loss of freshwater species in North America is comparable to or higher than that of tropical forests species, and that contemporary extinction rates are 1000 times higher than natural levels. But due to the unparalleled diversity of organisms in the Mekong Basin, human population density and growth, the scale of the potential problem is far greater than in most other parts of the world and the consequences of biodiversity loss for human livelihoods severe.

10.1. Hydropower Development

Especially in the Upper and Middle part of the basin, countries have a high-hydropower potential on the mainstream and on major tributaries. However, extensive reservoir and dam constructions will have serious impacts on the aquatic fauna well beyond the actual location of the dam. Dams and weirs fragment the ecosystem by preventing the fish from reaching habitats that are crucial for them to complete their life cycles, and the transformation of the riverine habitat into a lake eliminates part of the fauna. Dams also hinder fish from moving downstream. Allowing fish to travel upstream through fish passes, etc., therefore is unlikely to solve the problem of enabling fish to complete their life cycle unhindered.

Dams on lower order mountain streams may well threaten a number of endemic species with very limited distribution including cave species that may become extinct and species adapted to life in strong current, which in most cases will not adapt to life in a reservoir. Dams on lowland high-order tributaries are more likely to affect species that are widespread in the system. However, the cumulative effect of a series of dams on tributaries may have similar or greater impact.

In the Nam Ngum Basin, the seven-line barb (*Probarbus jullieni*) (a species which is red listed by IUCN and for which trade is regulated by CITES) previously spawned in the Nam Ngum River. Since the Nam Ngum dam was built almost 40 years ago, the species can no longer reach its former spawning grounds, but it continues to migrate up the tributary Nam Lik that joins the Nam Ngum below the dam and is thus maintained within the Nam Ngum watershed. In contrast, the Mun River was dammed near the mouth, since then the migratory species coming from the Mekong were no longer able to ascend the river or any of its subbasins resulting in a considerable loss of biodiversity and fish production. However, after the gates were opened during the spawning season to mitigate the impact many of the species returned (Jutagate *et al*., 2005).

Apart from physically blocking up and downstream movements of aquatic organisms, dams also cause perhaps more serious ecological disturbances by suppressing or displacing the flood. Lack of flooding prevents the fish and their eggs and larvae in reaching growth areas on the floodplains while excessive flows at the wrong time of the year can wash away young fish or wash drifting fry past the target floodplains resulting in the loss of most individuals. The physiological stimuli that trigger fish to migrate and spawn are also disturbed resulting in the wrong timing of movements and reproduction.

10.2. Navigation

Because of the poor development of rail and road infrastructure in the Mekong Basin, the Mekong mainstream and major tributaries are important arteries that connect distant cities, provinces, and countries. Both people and tradable goods are shipped for great distances up and down the river. Ocean going ships are only able to ascend the Mekong to Phnom Penh, but since French colonial times considerable efforts have been invested in developing navigation further.

Navigation in itself may have little impact on the fish fauna except in cases such as accidental spills of toxic substances such as oil. Some spills would have the potential to terminate all aquatic life over maybe hundreds of kilometers downstream. Depending on the season, the most sensitive areas would be vegetated areas with slow current such as floodplains where sensitive juveniles could be killed in large numbers. In the dry season, there would be a much smaller volume of water to dilute the spill, and the fish stocks are at their lowest, impacts may therefore be greatest at this time.

However, the engineering works involved with improving the water ways may have considerable both short-term and long-term impacts. The removal of rocks and rapids with the use of explosives may kill large quantities of fish and it will destroy spawning grounds and important habitats for specialized fish fauna. If explosives are used at the wrong time—entire populations of fish can be killed because some congregate seasonally in very confined areas.

The removal of rocks and shallows, which slow the current and provide shelters for fish, has negative implications for both the resident fauna and for migratory fish that normally rest behind such rocks. Deepening of the river by dredging the bottom may increase the silt load and lead to the silting up of spawning grounds downstream. If carried out at a sensitive place, dredging may severely affect biodiversity; one example is the Quatre Bras where even small changes in the flow patterns may result in eggs and fry no longer being carried up the Tonle Sap leading to a reduction in the number of species and potentially a substantial decrease in fish production in both the river and the Great Lake (Ngor 1999).

10.3. Land-Use Changes and Deforestation

Shrubs, forests, and mangroves are cleared for many reasons. People cut down the trees for fuel wood, for building houses and boats, and fishers build brushparks. Ground is also cleared for vegetation to allow for planting crops. In the Delta, the mangrove that was already severely reduced during the war is cleared for prawn aquaculture production on a large scale (Binh *et al*., 1997). Large companies cut not only valuable trees but also destroy large areas of forest in the process. At the same time, they open up the forest for people to settle there. Many companies also violate the provisions stated on their concessions, and there is little or no control with how these companies act.

The direct consequences of this development are that important allochtonous inputs (insects, fruits, seeds, leaves, etc.) to the aquatic ecosystem disappear or are reduced. Special habitats such as the flooded forest where the fish seasonally gorge on food of terrestrial origin disappear. Not only are such habitats naturally very diverse, but they also harbor some of the highest levels of biodiversity. The loss of mangroves will reduce biodiversity and production in the Delta and beyond as this is an important nursery for the species that enter the estuary and venture further upstream for feeding.

The clearance of vegetation also lead to increased erosion and thus in silt load. As a response, fish communities switch from visually sensing toward species with other means of orientation (such as tactile). The large amounts of sediment can also destroy spawning grounds and deep pools may fill up. Production of phytoplankton and algae that form the basis of the food chain and serve directly as food for many species will also be negatively affected due to reduced light penetration in the water. This impact will manifest itself the most on floodplains, including the Great Lake.

10.4. Agricultural Development

Agricultural development is the mantra of all the riparian countries. However, the loss and degradation of habitat for fish, such as seasonally flooded forests and wetlands, for conversion into rice paddy, may undermine food security if the important contribution of fish and other aquatic animals to local diets and livelihoods continues to be eroded. In particular, the considerable resources of food provided by healthy floodplain ecosystems should not be undermined (Mollot *et al*., 2003).

The trend in agriculture has been to move away from diversity towards more efficient and intensive monocultures. Intensification of farming requires a controlled environment and high-yield crop varieties that are more vulnerable to pests and thus require more pesticides that are hostile to fishes and other animals living in the fields. Pesticides and fertilizers are currently mainly used in the most affluent areas of the basin and where crop production is most intense. The capacity among farmers to administer the use of these chemicals is generally low. This leads to fish kills and also makes fish toxic to eat.

With intensification of production, wetlands continue to be converted to other uses, even where it is not economically viable. Not only does this result in reduced overall production from fisheries but the fauna that characterizes these habitats are being lost and dry-season refuges for other species disappear as well.

Dikes are constructed along the rivers to prevent flooding of crops and settlements but these also prevent larvae and adult fish from accessing their nursery and feeding habitats on the floodplains, including rice fields. This considerably reduces habitat availability and complexity. In the past, people always considered the seasonal flooding as something positive generating production and prosperity (Petillot, 1911) and rural people still recognize that the seasonal fluctuations are crucial in maintaining their fisheries and livelihoods (Mollot *et al.*, 2003). The traditional varieties of rice that are well adapted to growing on the floodplains can therefore be promoted rather than replaced by modern varieties that do not tolerate deep flooding.

Enormous amounts of water are needed for irrigation. This water is abstracted from the river directly or from irrigation reservoirs. This leads to reduced water availability during the dry season with severe consequences for the fish already struggling to survive at this time of the year. It is of particular concern that less water reaches the Mekong Delta because it increases saltwater intrusion and acidification of the water there. Water needs to be used more efficiently including through crop diversification toward less water consuming crops. The recently completed Comprehensive Assessment of Water Management in Agriculture (Molden, 2007) draws attention to the serious problems the world is facing resulting from the use of water by agriculture. It notes that a shift in thinking is required to a perspective of managing the ecosystem services that aquatic systems provide. Although agriculture is an important service, it is one of the many that needs to be considered.

10.5. Mining

Some of the mountainous regions in the basin are rich in minerals, and there is little control over the companies that receive mining concessions. Mining may lead to increased siltation and leachates from the mines may contain toxic minerals and residues of chemicals used during the processing of ore. Accidental spills of chemicals may also be lethal to aquatic organisms. Remote areas are home to many of the endemic species that may be eradicated by mining activities.

10.6. Industry

The absence of major cities in the Mekong Basin has until now spared the region from large-scale development of polluting industries—although this may change in the future. Pollution from industries includes the continuous discharge of effluents, the impact of which will depend on the degree to which the water is treated, diluted, or recycled, and accidental spills. Effluents will gradually diminish biodiversity because the fish that cannot survive in the polluted water will move away; especially sensitive stages such as eggs and larvae may be particularly vulnerable to pollutants. Polluted water may also deter migrating fish from entering certain areas and thus act as a barrier in the same way as a dam. Poisonous spills from factories can kill fish over large stretches of river, as it was seen with the 1992 dry-season spill from a sugar factory, when a 9 km expanse of molasses drifted down the Phong, Chi, and Mun Rivers to eventually reach the Mekong, leaving behind 500 tonnes of dead fish (Roberts, 1993; Sneddon, 2002).

10.7. Aquaculture and Culture-Based Fisheries Enhancements

Aquaculture is rapidly expanding throughout the Mekong Region following the world trend. In the upper countries, most production is based on the pond culture of alien species, especially tilapia. In Cambodia, and especially Viet Nam, production is dominated by cage culture of giant snakehead (*Channa micropeltes*) and *P. hypophthalmus*. About a dozen alien species are regularly bred in the Basin for food purposes (Welcomme and Vidthayanon, 2003) and more are likely to be introduced in the future. Two percent of the Mekong fish species are alien species that have become established, many of them through escapees from aquaculture installations like the African catfish (*Clarias gariepinus*), Tilapia, common carp, and silver carp (*Hypophthalmichthys molitrix*) (Welcomme and Vidthayanon, 2003). However, the riparian countries through the MRC are now exploring aquaculture of indigenous species (Phillips, 2002). There are also a significant number of alien aquarium fishes in the basin and some alien ornamentals are reared commercially in captivity. These activities are completely unregulated and several ornamental species (including *Gambusia affinis, Poecilia reticulate*, and *Hypostomus* spp.) are now widely established throughout the basin. Unless strict management is undertaken by the riparian countries, establishment of many more species in the future seems inevitable (Welcomme and Vidthayanon, 2003).

Various problems have materialized in connection with the use of alien fish in aquaculture and for stocking. (Welcomme and Vidthayanon, 2003): Introduced species can disturb habitats and in so doing, alter ecosystem characteristics to such a degree that native species are threatened; common carp, for example, searches for food in muddy bottoms of lakes and rivers and thereby remobilizes sediment and increases biochemical oxygen demand (BOD), this can lead to turbid conditions that reduce light penetration and plankton production (Welcomme and Vidthayanon, 2000); grass carp (*Ctenopharyngodon idella*) feeds on aquatic macrophytes and may change the composition of the aquatic vegetation and therefore also the species composition in water bodies it colonizes (Kottelat, 2001), it may also inflict damage on the rice if it is allowed to enter the paddies. Competition between introduced and native species is another cause of potential difficulty. Competition may be for breeding sites especially in nest-building species, or it may be for food. Another major cause of negative impacts has been the explosive expansion of populations of alien species with rapid growth and short life cycles such as Tilapia (*Oreochromis* spp.) and several cyprinid species. This is often accompanied by stunting, leading to dense populations of small individuals, which compete with, and reduce the numbers of, more valuable species (Welcomme and Vidthayanon, 2000).

The most extreme genetic impact is hybridization. The exotic African catfish (*C. gariepinus*) is capable of hybridizing with the indigenous *Clarias macrocephalus*. Also the two indigenous species *P. hypophthalmus* and the giant Mekong catfish (*P. gigas*) can hybridize in captivity, but they are not known to do that in the wild. Interbreeding between species or hybrids in the natural environment can pose risks, especially if the offspring are not sterile, because valuable adaptive characteristics, such as timing of migration and the ability to locate natal streams may be lost. Alternatively, the hybrid can prove more successful and vigorous than the parents, in which case the latter may become out-competed. Hybridization thus reduces natural genetic diversity. Concerns over genetic disruption are not limited to alien species since moving native strains and varieties of native species around the basin can cause similar effects. Most large rivers have a high degree of genetic diversity within many species groups and this is also apparent in limited data available from the Mekong. Where stocking material, including escapes from aquaculture, is drawn from a wide area and interbasin transfers of varieties occur, the risks of such effects are particularly high. For this reason, broodstock for the production of stocking material must be carefully selected. Material to be stocked should be derived only from parents drawn from the receiving subbasin (Welcomme and Vidthayanon, 2003). Too little diversity resulting from stocking with material derived from too few breeders is another risk which can result in a narrow genetic base leading to rapid degradation of the material used for stocking, which in turn will lead to poor growth and reproductive potential of the species concerned (Welcomme and Vidthayanon, 2003). This risk exists also in the case of stocking undertaken to support wild populations (such as the giant Mekong catfish).

For many species, culture is still based on wild seed. For example, snakeheads have a relatively low fecundity and due to their habit of guarding the young, the fry normally swarm around the adult in the surface rendering them very vulnerable to fishing by fry collectors. In smaller water bodies, snakehead may disappear due to this overfishing. *P. hypophthalmus* is a much more fecund species which is an adaptation to the high mortality of its eggs and young caused by spawning in the main river. The dai fishery for *P. hypophthalmus* fry in the late 1990s caught about a billion fish a year, with many more fish killed as bycatch (Hortle and Lieng, 2005). Although it was never proved that the fry fishery was responsible for the declining catches of this species, the fishery was banned in both Cambodia and Viet Nam by 2000 and now virtually all aquaculture fish are a result of hatchery production (Poulsen *et al.* 2008). A *Pangasius* hook fishery continues on a small scale in Cambodia to supply fish from local pond culture, with about 3 million fry caught annually (mostly *Pangasius bocourti*) (Hortle and Lieng, 2005).

A large proportion of the aquaculture production in the Lower Mekong, particularly for snakehead and catfish, depends on low-value "trash fish" for feeding. Depending upon the season and locality, a significant proportion of that trash fish can come from the freshwater fishery. The "trash fish" which is used as feed for carnivorous species are caught using small meshed nets and is made up by a mixture of small species from where the more valuable elements have been picked out. Locally, this indiscriminate fishery may put an enormous pressure on fish resources and biodiversity. The tendency to overfeed the farmed fish may contribute to the creation of anoxic conditions at the local level where current is slow, and eutrophication of the river system. Alternative sources of feed are being developed and further improvements on the effectiveness of the utilization of feed need to be made in order to reduce pressure on wild resources.

10.8. Fishing

It is widely but incorrectly assumed that overfishing is the major cause of decline of the Mekong fishery. There is, in fact, no evidence of a decline in total production, but it is clear that populations of certain species especially the larger slower growing high-value species are in decline. For the Mekong species listed in the IUCN Red List, none are listed as in decline due to fishing alone. For most, the major factor determining their status is environmental change including loss and degradation of habitat. Neither is there evidence in the Mekong, nor in fact anywhere else, of fisheries being the primary driver of the extinction of fish species (Allan *et al*., 2005; Bayley, 1995). Certainly, the fishery needs improved management, but the priority requirement is improved environmental management in order to sustain the fishery and the biodiversity that underpins it.

Fishing intensity is certainly very high even in some of the relatively remote parts of the basin and increased numbers of people fishing leads to catch per unit effort declining leading to further intensification. The fishery also uses unsustainable fishing methods such as explosives, poison, and electrofishing that kill large amounts of fish indiscriminately. Poison can empty small streams and water bodies completely from fish. Explosives are used to access fish in places where they would otherwise be impossible or difficult to reach with other methods such as deep pools where many species of fish, including the broodstock that will spawn the following flood season, are concentrated during the dry season and many of the individuals killed by this method are not even recovered. Another destructive method is the dry pumping of small natural water bodies which allows the capture of all the fish trapped in such ponds toward the end of the dry season thereby killing the fish that would have spawned and thus restocked the flooded areas next season.

The top-down approach to fisheries management currently in use in most parts of the basin is not efficient because of the vast size of the basin compared to the number of staff employed by the fisheries departments. The preferred solution is delegating responsibility for resource management to the communities through comanagement arrangements. However, to be effective this needs to be accompanied by greater influence over the management of the environment upon which the fishery is based. The current institutional/government approach focuses on overfishing, in particular the failure to control access, which can undermine local management regimes. These regimes invariably, if allowed to flourish, have been quite supportive of biodiversity (Winnett, 1999). Biodiversity conserves the adaptive capacity of the ecosystem giving it an ability to buffer or absorb perturbations including exploitation by fishery dependent communities. Local communities understand such issues well and are likely to use their local knowledge to manage for diversity and sustainability, if they are given the opportunity.

10.9. Climate Change

Globally, climate change is emerging as the greatest driver of biodiversity loss. Certainly, climate change will influence the Mekong in significant ways, both directly, for example, in changes in rainfall patterns and rising sea levels, and indirectly, through shifts in demand and trade of commodities. The exact nature of these changes cannot be easily established for the Mekong and in any event there will likely be a wide margin of variability in predictions.

The life cycles of the Mekong fish species are closely adapted to the rhythmic rise and fall of the water level and changes to this pattern may disrupt many species. Changes in flooding patterns may lead fish to spawn at the wrong time of the year resulting in the loss of eggs and fry. Increasing flash floods may wash juvenile fish and eggs out of their normal habitats thereby increasing chances that they will die from starvation or predation. Prolonged periods of drought will reduce available habitat to the fish especially during the dry season.

What is very clear is that by maintaining the highest possible levels of biodiversity the Mekong River ecosystem stands the best chance of being able to adapt on its own to the changes that are already happening. Climate change is increasing the focus on the crucial role of the services that wetlands provide, for example, in the sustained delivery of freshwater, nutrient recycling, and the mitigation of extreme rainfall events (both droughts and floods), and the role of healthy coastal wetlands in mitigating the damage caused by extreme storms. Using nature's ability to cope with change is a sensible and cost effective response option to climate change and in this process, considerable benefits will also accrue to biodiversity and the fisheries reliant upon it.

While many environmental changes are unavoidable, the Mekong countries have options for how to respond. Maintaining diversity is the key. Appropriate direct responses to climate change are also critical. For example, in areas becoming drier, countries will likely secure their access to water by storing more of it which will escalate impacts on aquatic ecosystems. Climate change considerably increases the urgency and importance of implementing better basinwide environmental management plans which fully promote the optimal use of the full suite of services that the ecosystem provides to people and development.

11. BASIN PLANNING TO SUSTAIN ECOSYSTEM SERVICES

The Mekong River ecosystem provides an enormous range of services which support human well-being. Many of these services, which are underpinned by biodiversity, are greatly undervalued. In many respects, sustaining biodiversity is equivalent to sustaining ecosystem services and therefore sustaining human well-being. The "sector"-based approach to planning and development in the Mekong has resulted in increased service delivery in some areas, for example, food provided through agriculture, or timber through forestry. But this has resulted in other services being negatively impacted, for example, as outlined above, agricultural development can reduce the provisioning of fish through fisheries. To manage the Mekong River environment better and to achieve more balanced and sustainable development, "ecosystem services" based approaches to policy and decision making need to be adopted instead of sector-based approaches which tend to lead to disparities in service delivery and inequities in benefits across the population. Further details of such reasoning and approaches are provided in the Millennium Ecosystem Assessment (2005a,b). This chapter has highlighted the important role of fish biodiversity to human welfare in the region but the service provided by this component of biodiversity is only one of many that should be managed collectively if the basin is to be sustainably developed.

Historically, national policies in most cases have favored the more visible economic sectors such as agriculture, and other sectors with political leverage. Donors also often preferred to invest in monumental projects with tangible and easily measurable outputs such as dams for flood protection, irrigation, or hydropower. The trouble is that it is difficult to balance the economic interests involved with power generation, navigation, agriculture, and industry because it is not easy to provide solid figures that demonstrate the true economic value of the intact aquatic habitat and its associated fish populations. However, as FAO stresses: "*While the precautionary approach should be applied to fisheries... there is an equal need to apply the approach to non-fisheries sectors whose capacity to damage the ecosystem is usually much greater than that of the fisheries themselves*" (FAO, 1997).

As a part of this process, better valuations of the fishery and greater awareness of the role of biodiversity, coupled with more transparent, informed, and impartial decision-making processes, are required in order to improve planning and management. Informal activities, such as subsistence fishing, that are undertaken outside Government control are poorly documented, and knowledge on their sizes, values, and nature are very fragmentary. For these activities to be taken into consideration when planning, crucial data and information are required. However, it is very difficult to find information about these types of activities through official channels. Most often data are not available or are produced by, for example, NGOs or academic institutions, and there is resistance at Government level to use such sources. Governments may also disregard such data because political priorities prevail.

Rural people, who depend directly on biodiversity resources, have significant knowledge about them and their value, and a greater interest in sustaining them. Thus, they need to be better involved in the decision-making process. However, to achieve this they need to be empowered. Biodiversity loss caused by hydropower, irrigation, and navigation development, for example, have seriously inequitable outcomes for development (Mollot *et al.*, 2003). Only by developing and implementing holistic land-use policies that emphasize user participation and an ecosystem/biodiversity-based approach to management will be possible to succeed in turning around the histories of non-sustainability of aquatic resource use (Parveen and Faisa, 2003; Pullin, 1999).

There are a number of international frameworks that can guide governments toward improving governance of natural resources and in all of these the focus is on sustaining benefits to people. These include the Ramsar Convention on Wetlands, the Convention of Biological Diversity, the Convention on Migratory Species, the Convention on Trade in Endangered Species, and the World Heritage Convention.

12. PROTECTING ENDANGERED SPECIES

A large proportion of the many endemic fish species in the Mekong Basin are endangered, and many of them increasingly so. To protect them from extinction, species-specific conservation measures are needed. While it may be necessary to protect some habitats that harbor many specialized endemics with limited distribution, the historical "protected area" approach to species conservation is not appropriate for many species of fish. Unless they are very carefully planned, single local initiatives will, for example, do little to benefit migratory species that depend on habitats that may be widely dispersed (Valbo-Jørgensen *et al.*, in press). Particularly for river systems, establishing protected areas to limit the impacts of specific local drivers of loss (e.g., overexploitation) will fail if they do not limit other threats (e.g., pollution or over extraction of water). Management interventions for isolated parts of such a complex system are likely to have negative impacts on other parts (Meusch *et al.*, 2003). Maintaining individual fish populations should be subordinate to the goal of sustaining the ecosystem that supports multiple species. As long as all rehabilitation actions are consistent with the overriding goal of restoring ecosystem processes and functions, habitats will be restored for multiple species (FAO, 2007). Key habitats such as spawning grounds, nursery areas, etc., for species with strict requirements for such, for example, the Giant Mekong catfish, must of course be protected. But closing part of a watershed for fishing may instead serve as a pretext for doing nothing else and result in habitat fragmentation (Valbo-Jørgensen *et al.*, in press). Degraded or destroyed habitats should be rehabilitated. A key system-wide requirement is to maintain ecosystem connectivity throughout the basin.

It is impossible to formulate management plans for each and every species. Better progress may be made through the identification of critical habitat types where management efforts can be focused, and by using species with stringent habitat requirements as indicators. At the same time, these can be promoted as "flagship species" and it may be easier to raise awareness about the need for implementing appropriate measures and to attract national as well as international funding for management programs. Large migratory species, for example, have strong requirements for habitat quality and ecosystem integrity, and it will not be possible to address the factors that make them vulnerable in isolation from the rest of the ecosystem (Poulsen, 2003).

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