THE MEKONG
BIOPHYSICAL ENVIRONMENT OF AN INTERNATIONAL RIVER BASIN

Edited by

IAN C. CAMPBELL
Principal Scientist, River Health Group,
GHD,
Melbourne, Australia
and
Adjunct Research Associate, School of Biological Sciences,
Monash University

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Academic Press is an imprint of Elsevier

CHAPTER

9

Fisheries of the Mekong River Basin

Kent G. Hortle

Fisheries and Environment Consultant, 23A Waters Grove, Heathmont 3135, Australia

OUTLINE

1. INTRODUCTION

The Mekong is one of the world's largest rivers (Chapter 4) with a basin that supports a population of about 70 million people, for most of whom the staple diet is rice, fish and other aquatic animals. On the basis of altitude, hydrology, and landforms, the basin is usually divided into the Upper Mekong (in China and Myanmar), comprising about 20% of the catchment, and the Lower Mekong (LMB) (in Laos, Thailand, Cambodia, and the Viet Nam delta and central highlands).

For about two-thirds of its length (from lower Yunnan to the sea), the Mekong is a lowland system, less than about 370 m ASL, and about 60% of the LMB comprises tropical lowlands where most people live, and where extensive and diverse aquatic habitats support a wide range of species which can be caught or cultured. Rainfall patterns and the flow of the Mekong and its tributaries are highly predictable from year to year, and the rural economies depend upon the annual alternation of dry and wet seasons, which in particular support "rain-fed" rice agriculture, fishing, and collection of other wild products. Aquatic organisms are well-adapted to the seasonal extremes, breeding and feeding in the vast area of seasonal wetlands where large quantities are caught each year, particularly as the waters recede.

Most people in the LMB are rural farmers with fisheries as a secondary occupation. "Fisheries" as a term covers the catching, collecting, or aquaculture of fish, as well other aquatic animals (OAAs) including shrimps, crabs, molluscs, insects, reptiles, and amphibians. Fisheries also include the processing, transporting, and marketing of products, and support many associated industries such as boatbuilding, the making of fishing gears, and the provision of ice and salt.

Fisheries products are predominantly used as food (the focus of this review) but also as fish- or stock-feed, as fishing bait, and even as fertilizer. Many Mekong system fish are important in the aquarium trade, and recreational or sport fishing is becoming increasingly popular, especially in more affluent areas, but there is very little published information on these two kinds of fisheries.

This review introduces the LMB fishery from a historical perspective, and then discusses some general features of the fisheries of the Mekong system, including estimates of their size and value. Section 4 describes the main habitats of the LMB, their fisheries, and estimates of areal yield. Aquaculture is reviewed in Section 5, and finally Section 6 briefly covers some aspects of management of the LMB fisheries.

2. HISTORICAL PERSPECTIVE

Until about 5000 years ago, the LMB was inhabited by small groups of hunter gatherers who ate many kinds of wild foods, including fish, crustaceans, and molluscs (Gorman, 1971). Neolithic farming based on flooded rice developed as people settled on the most fertile areas, including the Tonle Sap-Great Lake system and other floodplains including along the Mun and Chi Rivers in Thailand and the Vientiane plain in Laos, as well as the highland plateau in Yunnan around Lake Erhai (see Chapter 3). Rice has long been the energy staple, with protein and micronutrients provided by fish and OAAs as is evident from archaeology. For example, excavations of old settlements at Angkor Borei in southeast Cambodia dated at 1600-2400 years ago included the bones of hundreds of species in at least 17 families of fish (Voeun, 2001). A "rice-fish" diet has been the norm for at least 2000 years in most of the Mekong Basin (MB). Dense settlements based on recession rice cultivation in fertile floodplains first developed in the delta region, during the Funan period, first to seventh century AD (Chandler, 2003; Fox and Ledgerwood, 1999) and then spread to other areas supporting the Angkor Empire (ninth to fifteenth century AD) which was centered on the Great Lake-Tonle Sap system. Later evidence for the importance of fisheries includes the many bas-reliefs of Angkor Wat, the Bayon, and other temples depicting fish, other aquatic animals, and fisheries (Roberts, 2002), as well as the observations of Zhou Daguan, a Chinese visitor to Cambodia in 1296-1297 AD, who commented on the richness of aquatic resources of the Great Lake, and the abundance of many kinds of fish as well as frogs, tortoises and turtles, lizards, large prawns, crocodiles, and molluscs (Zhou, 2001). French explorers during the late nineteenth century also noted the abundance of fish and the ease of catching very large fish, or large quantities of fish along the Mekong and its tributaries, and how, for example, the Vietnamese exploited the fruitful fisheries of the Tonle Sap (Gamier, 1996).

Environmental changes and fishing pressure became significant as the LMB population expanded during the twentieth century from about 5 million in 1900 to about 65 million now; Cambodia's population alone grew from about 1.1 million to about 14 million in 2008. The direct impacts of population growth include increasing catches for local consumption, competition for water by other industries, particularly agriculture, modification of hydrology and water quality by dams, and clearing of forests. The development of commercial fisheries for export from the Tonle Sap and northeast Thailand also increased fishing pressure, and led to conflicts with the growing rural subsistence populations (Bush, 2008). The "frontier" for underexploited fisheries is moving rapidly into the last inaccessible parts of Laos and northern Cambodia along new roads. Even in the 1990s in some relatively isolated and uninhabited areas with extensive natural aquatic habitats, fish were still so large and abundant that local people placed little economic value on them (e.g., Baird and Phylavanh, 1998). New gears and methods have also expanded from more populated areas along a "technological frontier"; efficient and cheap mass-produced gears such as nylon gill nets and cast nets as well as illegal gears such as fine-mesh nylon fyke nets and electrofishers, first introduced in the 1970s, have only recently reached some remote places.

Throughout the basin, the perception has become widespread that fisheries are experiencing "fishing down" or "ecosystem fishing." This is a process in which increasing effort leads to larger total catches but smaller catches per unit effort (CPUE); catches of larger fish and larger species—particularly carnivores—decline, while catches of smaller species—particularly herbivores or omnivores—increase (Allan *et ah,* 2005; Baran and Myschowoda, 2008; Pauly *et al.*, 1998).

The "Mekong Project," a United Nations project conceived in the early 1960s, envisaged basinwide economic development based on tributary and mainstream dams to provide hydroelectricity, to support irrigation and other industries, to control flooding and to improve navigation. Plans for coordinated research and development of fisheries throughout the LMB (rather than just by individual countries) were partly motivated by the increasing recognition that large dams would cause significant international transboundary impacts, as well as a realization that an unknown but probably significant number of species were transboundary migrants. As part of the Mekong project, the Mekong Basinwide Fisheries Studies of the 1970s (Lagler, 1976b; Pantulu, 1986a,b; Taki, 1978) included surveys of fish distribution, standing crop, fish migration, and general observations on fishing activities and aquaculture at locations throughout much of the basin and in the sea off the mouth of the Mekong. The fishery studies produced a general description of the main elements of the fishery and the distribution and migration patterns of many species, but suffered from limited coverage in some areas and a lack of any accurate data on the size of small-scale artisanal catches. This probably led to an underestimate of the size of the fishery, and an underappreciation of the importance of the flood pulse to production, a concept which was formalized later (Junk *et al.*, 1989). "Development" at the time was typically framed in rather simple top-down "technical" terms of increasing production of goods and services, with impacts on capture fisheries to be compensated for by stocking of new reservoirs or by aquaculture. Relatively little consideration was given to the role of fisheries as a part of complex livelihoods, the differential impact of gains and losses between social groups, and effective approaches to implementing fisheries management (or any kind of development) in an equitable and sustainable manner.

The second Indo-China War (1964-1973), the Khmer Rouge regime (1975-1979), and subsequent conflicts impeded economic development in Viet Nam, Cambodia, and Laos, so that relatively few of the dams (and none of the mainstream dams) envisaged in the Mekong project were built. Warfare was very environmentally destructive, particularly as a result of the widespread use of defoliants and carpet bombing in Mekong watersheds and in the delta, where virtually all mangroves were destroyed by defoliants (Westing, 1976). Most fisheries development also stalled during this period as a result of disruption of social and government structures and traditional livelihoods, internal postwar migration, and subsequent rapid population growth. However, in northeast Thailand in the 1980s and 1990s, clearing of forests, intensification of agriculture, development of agricultural processing industries, and construction of many dams had a range of impacts; river-floodplain fisheries have no doubt declined (Roberts, 1993), but reservoir and rice field fisheries have increased in importance. In Laos and Cambodia, capture fisheries have been maintained through much of the mainstream Mekong and in many large tributaries where floodplains remain intact, as well as in rice fields which continue to expand in area. Development in the Viet Nam delta accelerated after 1975, with canalization and settlement of the extensive swampy areas of the plain of reeds and Long Xuyen quadrangle (Nguyen and Wyatt, 2006); internal migration added to population growth in newly settled areas, and large areas of regrowth mangroves were cleared along the coast for intensive shrimp culture (de Graaf and Xuan, 1998). Internal migration to the Viet Nam highlands after 1975 was supported by forest clearance for highland crops, such as coffee, and construction of many small irrigation reservoirs which support stocked fisheries.

A revived Mekong Committee in the early 1990s commissioned a review of LMB fisheries (Anonymous, 1992a), and its recommendations on research and development formed a basis for aid-funded programs in the 1990s. This review pointed out the continuing weak information base, the unreliability of official statistics based on estimates of commercial catches, and the lack of data on artisanal fisheries, which might be contributing an unmeasured 80-95% of total catches.

Partly as a response to the 1992 review, fishery issues were targeted in several aid-funded programs; these included support for several household surveys that did much to upgrade estimates of the likely size and value of the fishery (e.g., Ahmed *et al.*, 1998; Funge-Smith, 1999a; Sjorslev, 2000 and others summarized in Hortle, 2007). National fishery agencies received direct support from many donors and a range of "basinwide" projects were funded through the MRC, with various other agencies such as the FAO, the Asian Institute of Technology, and the WorldFish Center also working on projects throughout the basin. Sverdrup-Jensen (2002) prepared a recent "sector review" of the basin's fisheries which updated yield estimates, taking into account preliminary data on subsistence catches and some new estimates of yield per unit area. The review also noted that the MRC's fisheries programs had done much to raise the profile of fisheries and the awareness of threats to capture fisheries, as well as encouraging dialog between LMB countries, including through the establishment of an international Technical Advisory Body (TAB). The 2002 review also reiterated many of the issues that were raised in the 1992 review, and suggested some general responses to ongoing problems in the sector. MRC (2003) and van Zalinge *et al.* (2004) provided similar more recent descriptions of the LMB fisheries.

The LMB fisheries reviews tended to identify technical issues and also to reflect the perspective of national governments, which is a consequence of review teams working mainly with staff of national fisheries agencies. The later reviews (Sverdrup-Jensen, 2002; van Zalinge *et al,* 2004) also reflect recent changes in emphasis of national policies by including recommendations for a more decentralized approach to management of local fisheries issues, for example, via comanagement.

With recent political stability, the growth in regional economies, and continuing pressure to raise living standards, the Mekong system's environment is entering a new phase during which some of the grand ideas envisaged in the Mekong project may be implemented: a massive increase in electricity production through hydropower, regulation of the Mekong mainstream, road building, conversion of forests to plantations, increased agricultural output through irrigation, and development of secondary industries. Much of the LMB lowland landscape has been altered, but in this new phase of intensive damming it is the hydrological regime—based on high and seasonal rainfalls in extensive mountain ranges—that will be brought under increasing control, causing a wide range of direct and secondary impacts to aquatic environments. There is a long-standing need to identify clearly the costs and benefits of developments, to support efforts to mitigate and manage impacts on fisheries and other existing uses, and to provide clear advice on which schemes are so harmful that they should be rejected outright.

A major and perhaps insurmountable challenge will be to develop an acceptable framework within which countries voluntarily modify their management of water and natural resources for the benefit of their neighbors. Dams impact downstream users, but it is less appreciated that impacts on fisheries—based on migratory resources—can be manifested up- and downstream, as well as across the Mekong itself, which is an international boundary between Laos and Thailand and Laos and Myanmar. While many agencies and NGOs play important roles in the development process, the MRC is the only international organization staffed and funded by national governments that is mandated to bring fisheries (and other sidelined issues) into considerations of water resources development from a transboundary perspective. Its Fisheries Program continues to support basinwide fisheries ecology and valuation studies, fisheries management, and aquaculture of indigenous species, as well as publishing and disseminating a range of fisheries information and supporting basinwide workshops and coordination meetings.

3. GENERAL FEATURES OF MB FISHERIES

3.1. Diversity and Fishing Pressure

The MB's fisheries are characterized by a diversity of species and habitats, as well as a diversity of gears and fishing activities, as are inland fisheries generally (Welcomme, 1985, 2001). About 900 species are recorded from or are likely to occur in the basin, and among them about 560 are purely freshwater fishes (Chapter 8). Catches at a locality may include more than 200 species, but typically 10 species would make up about 60-70% of the total catch by weight (e.g., Baran *et al*, 2005; Ngor *et al*, 2005, 2006; van Zalinge and Nao, 1999). The least diverse fisheries are in rice fields, where a few species make up most of the weight, whereas diversity is highest closer to the estuary where marine and estuarine species (marine vagrants) are caught with freshwater fishes.

Most of the Mekong system's fish species are small, growing to maturity in their first or second year and many are extremely fecund (e.g., Suwannapeng, 2002) or are repeat spawners adapted to take advantage of the great seasonal change in extent of available habitats. Other aquatic animals (OAAs), including shrimps, crabs, molluscs, insects, reptiles, frogs and toads, probably form about one-quarter of catches on average (Hortle, 2007), with higher proportions sometimes reported (e.g., de Graaf and Chinh, 2000). The extreme contraction of available habitat in the dry season causes stress and mortality of aquatic animals through desiccation, predation, competition, and disease, so the surplus production which can be harvested sustainably each year in inland waters (the catch or yield) in the monsoonal tropics is generally a very large proportion of the peak standing crop or biomass (Hoggarth *et al*, 1999a).

As fishing pressure intensifies, tropical inland fisheries generally exhibit a long-plateau phase of declining CPUE even as total catches continue to increase (Welcomme, 2001). Declining CPUE is widely reported by fishers throughout the LMB (e.g., Ahmed *et al*, 1998; Hortle and Suntornratana, 2008; Phanh *et al*, 2002; Sjorslev, 2002) and is usually attributed primarily to "fishing down" (variously reported as "too many fishers" or "too few fish per fisher") as well as environmental changes. Fishing down is consistent with an apparent dominance in catches in some areas by a few herbivorous or omnivorous species, as is evident for summary data on Cambodian commercial catches (van Zalinge and Nao, 1999) or by dominance of small planktivores in reservoir catches (e.g., Mattson *et al.*, 2001). Declines in the catches of some giant species have also been reported (Mattson *et al.*, 2002) but in general it appears that the Mekong system is not heavily fished down, because medium-sized or large fish are still commonly caught and traded throughout the basin (e.g., Baran *et al.*, 2005; Bouakhamvongsa *et al*, 2006) and predatory species are quite abundant in catches in some areas (e.g., Ngor *et al*, 2006). It is also worth noting that—despite widespread reports to the contrary—the only monitoring data that have been systematically collected during the last decade do not indicate a declining trend in CPUE, but do show that high-flow years have a large effect on catches in the same or subsequent years (Halls *et al*, 2008; Soukhaseum *et al.*, 2007). Therefore, although fishing pressure is affecting some species, in general the capture fishery appears to be extremely resilient to fishing pressure, but is likely to be sensitive to hydrological and other environmental changes, which should therefore receive much more attention in fisheries management.

3.2. Migrations

Because of the large seasonal variations in water availability many fish exploit different habitats in different seasons, often moving in large schools which are the target of intense fishing pressure, either at particularly favorable localities or by fishers who move with the schools. Freshwater fishes may be broadly categorized as "white fish" (migrating between rivers and floodplains) (see Chapter 8), "black fish" (resident on floodplains and also common in rice fields and standing waters), "gray fish" (moving locally between floodplains and dry-season refuges), and "residents" of river channels. The maintenance of habitats (dry-season refuges, flood-season feeding and rearing habitats and spawning habitats) as well as maintaining connectivity and the basic pattern of hydrology is key element in environmental management to conserve fisheries (Poulsen *et al.*, 2002a). Coastal and estuarine fish are also important in fisheries, and many species move considerable distances into the river system. The migration patterns of other aquatic animals are not well-described, but the catadromous giant river prawn *(Macrobrachium rosenbergii)* is heavily fished and is one of the most valuable fishery species (Ngor *et ah,* 2006).

3.3. Participation

About 80% of the basin's population is rural and the economy is largely based on farming as the primary occupation and fishing or aquaculture as the secondary occupation and consequently overlooked in most censuses. Most people live along or near natural rivers, streams, or annually flooded areas in which they can fish, and many villages are close to permanent standing waters. As is generally the case in tropical inland fisheries, the Mekong system is dominated by small-scale or artisanal fishing on a part-time or occasional basis, with fishery products often sold to supplement a household's main income. There is generally a strong gender aspect to capture fisheries with most fishing done by men, whereas women are disproportionately involved in fish processing, marketing, and gear-making. Small-scale aquaculture—often promoted as a supplement or replacement for capture fisheries—tends to shift the burden of work onto women as it tends to be a "household" activity (Hatha *et ah,* 1995; So *et ah,* 1998). In a range of LMB studies reviewed by Hortle (2007), more than 80% of rural households in Thailand, Laos, and Cambodia and 60-95% of households in the Viet Nam delta were involved in capture fisheries. The slightly lower proportion of households involved in capture fisheries in some parts of the delta is offset by a very high involvement in aquaculture, with 15-90% of households culturing fish or OAAs, compared with up to about 15% in most other parts of the basin (Hortle, 2007).

Although most households sell or barter some fish, commercial, full-time, or professional fishing is typically practiced by fewer than 10% of households. In larger water bodies, commercial fishing may be more common, for example, 40% of households in fishing communes around the Tonle Sap Great Lake (Ahmed *et ah,* 1998), and 60% around Nam Ngum Reservoir (Mattson *et ah,* 2000).

Small-scale fishers typically fish in habitats that are accessible by foot or nonmotorized boats, such as rice fields and associated habitats (canals, small streams, and swamps), (Pham and Guttman, 1999) as well as in rivers and streams (Hortle and Suntornratana, 2008). Commercial fishers tend to use larger gear and motorized craft to access open-waters, or obtain licenses for fixed gears that filter large volumes of water. Although small-scale fishing contributes most to total catches, in the most productive areas, commercial fishers take a disproportionate share (Sjorslev, 2002) which may be most of the total catch (Phanh *et ah,* 2002). Where commercial aquaculture is significant, as in the Viet Nam delta, a small percentage of households that make a living purely from aquaculture may contribute most of the **total** yield (Sjorslev, 2002).

Typically, 1-2 members of the average 5-6-person household go fishing or collecting aquatic animals at some time, so about one-third of the basin's population—about 20 million people—are "fishers." The total annual catch of about 2.1 million tonnes (Mt) (Section 4.1) equates to about 100 kg fisher^{1} year^{1}, so if fishers are active for about 2-4 months per year, their daily catch could average about 1-2 kg person^{-1} day^{-1}, but would typically be less because the distribution of catches is usually highly skewed by commercial catches. The benefits of spreading the catch between many households (equity) should be judged against the relatively low return on effort for most fishers (efficiency) as well as the effects on professional fishers who must compete with the numerous subsistence fishers. Across the entire "wetland" area (Table 9.4), average fisher density is about 100 people per km^2, a high figure in comparison with inland fisheries generally (Halls *et al*, 2006) and consistent with the impression of generally high fishing pressure.

3.4. Fishing Gears and Methods

At least 100 types of gears can be distinguished, classified by principle of capture into 16 main groups (Claridge *et ah*, 1997; Deap *et al*, 2003; Ko-Anandakul, 2004; Nguyen *et al.*, 2006a) as follows:

1. Hand capture
2. Scooping devices such as hand nets
3. Wounding gears, for example, gaffs, forks, rakes, spears, bows, and guns
4. Hooks and lines, including pole and line, and longlines
5. Traps include many types and sizes, often in combination with fences
6. Gill nets and entangling nets, often set in multiple layers of differing meshes
7. Surrounding or seine nets
8. Dragged gears, including scrapers, trawl nets, and dragged fences
9. Push nets, hand or boat-mounted
10. Lift nets, hand or boat-mounted
11. Covering gears, including basket traps and cast nets
12. Bag nets, including fyke nets and stationary trawls or dais
13. Illegal methods
14. Anesthetic methods, including explosives, poisons, and electricity
15. Draining/emptying of ponds or watercourses by pumping
16. Attracting devices, including mobile and stationary brush parks
17. Scaring devices, including chains and marble boxes to create noise, and chemicals such as calcium carbide to scare fish into nets

Gears tend to be similar wherever habitats are similar, with local variants designed for certain conditions or target species. Gear usage also varies by time of year and water level. Traditional traps are the most diverse group, often specialized for certain habitats and taxa. Large-scale commercial gears include river barrages, stationary bagnets (dais), trawls, and seines, with a sequence of gear typically used through the fishing season. Traditional gears, particularly traps, are still common and widespread in and around rice fields and smaller water bodies, but in any open water bodies small-scale or family fishers throughout the basin tend to use gill nets, cast nets, and hook and line, now ubiquitous gears which tend to catch a range of species across habitats. Such modern gears have tended to supplant traditional methods because of their efficiency, widespread availability, low cost, and durability.

In all LMB countries, fisheries regulations prohibit the use of gear/methods 13-16 above, but these are still common anywhere conditions are suitable. The regulations are unenforceable in practice; moreover, the basis for each prohibition is not clear so little support can be expected for implementation. For example, brush parks (essentially large man-made snags) are used throughout the LMB to aggregate fish and OAAs, and they form the basis of a significant industry that supplies materials for their construction. Brush parks allow a planned harvest with a fairly predictable timing and yield; yields from brush parks can be high, between 1.2 and 15.5 t ha^{-1} $year^{-1}$ (Welcomme, 2001). The negative effects of brush parks (destruction of forest and over-harvesting) have never been properly assessed against the likely benefits to the system from increased production from the artificial habitat which forms shelter and a substrate for periphyton and food organisms, as well as being a source of fry from fish that spawn within them. The floating macrophyte *Eichhornia* *crassipes* (water hyacinth) is usually associated with brush parks, and is considered highly valuable to fisheries, providing habitat for a rich community of fish food organisms—invertebrates—that feed on periphyton that covers its roots, as well as habitat for fish and shelter for fry, as has been described in detail by Green *et al.* (1976). Brush parks *(kata)* in Bangladesh have been well-described as a successful way of intensifying fisheries production on floodplains, where the food chain to high-value fishes is based on the brush (Islam *et al.*, 2006). Rather than prohibiting brush parks, fisheries agencies might study their actual effects and seek to licence their use.

Apart from prohibition on certain types of gears, minimum mesh sizes are set for most gears in most countries; for example, in Cambodia nets, fences and traps must have a mesh aperture greater than 15 mm. In practice, many gears have smaller apertures—fences, traps, and fyke nets are now often constructed incorporating nylon mosquito netting—2 mm mesh—to retain virtually all small fish and shrimps. Fine-mesh gears, in particular traps set with long fences across floodplains or fish migration routes, are of particular concern and have been a focus of enforcement efforts in Cambodia in recent years.

3.5. Processing, Marketing, and Consumption

The seasonal excess of fish caught during the flood recession has led to the development of many methods of preservation based on salting, drying, and fermentation. Fish sauce and various kinds of fermented fish or OAAs are very characteristic features of cuisines in Asia; Phithakpol *et al.* (1995) describe procedures for 29 different commercial products made from aquatic animals. Fish sauce and fermented fish are eaten by most rural households throughout the dry season, and salted dried fish from the Mekong system is sold throughout the region. Much of the seasonal excess of fish is fed to higher value species, particularly snakeheads *(Channa* spp.) as well as river catfishes *(Pangasius* spp.), which can be sold later to smooth out oversupply.

Most of the fish and OAAs caught or raised within the LMB are probably eaten directly by households, and the proportions that are sold in markets are not known. Markets are relatively more important for the supply of fishery products in Thailand and Viet Nam because of their well-established infrastructure and more diversified economies. Wholesale markets operate at landing sites wherever there are significant commercial fisheries (e.g., in the Tonle Sap-Great Lake system and at various places along the Mekong and in large reservoirs), and wholesalers may make various private arrangements to collect products from fishers or growers, so the marketing chain may be rather opaque. Fishery products are often traded through family-based systems, for example, the catch of many fishers is sold each day by their wives; typically over 90% of sellers are women (Khay and Hortle, 2005). Traders generally sell one main category of product (e.g., inland fresh fish or inland preserved fish). Variable numbers of part-time and occasional sellers complicate the task of assessing the size of a market and quantities of product sold, and sellers may employ variable numbers of people to process fish.

Markets throughout the basin are generally owned by local governments and run privately by lessees. LMB markets operate at three levels, province (capital), district, and village. The number of markets is not known for the basin, but in the entire Viet Nam delta in 2004 there were officially 1181 markets, of which about 20 were large wholesale/retail provincial markets, about 130-200 were district markets (including suburbs), and about 1000 were village markets (Phan Thanh Lam, personal communication, 2008). As the delta has about one-third of the LMB's population, the total number of markets is likely to be 5000-6000. Governments attempted to centrally regulate markets in the past, but government regulation has reduced since economic liberalization in the 1990s and the system overall appears to run efficiently supplying different groups of consumers of different status and tastes (Anonymous, 1992a). In general, larger more valuable fish are traded into cities and also out of the basin, especially to Bangkok and Ho Chi Minh City, capture fish command higher prices than culture fish, and smaller fish continue to be competed for by poorer rural people and those wishing to supply the trash fish market for aquaculture. Markets are characterized by the high proportion of live fish which are transported by river or canal in floating cages, in barges, in trucks, or on motorcycles.

Marine products are also sold throughout the basin; mackerel and dried squid are staples throughout northeast Thailand and are also traded into Laos, and seafood of all types is common throughout the delta, whereas marine products are relatively unimportant in Cambodia.

Export markets are poorly documented, largely clandestine, and may operate along a chain that includes many unofficial taxes or fees. For example, fish traders transporting their products from the Tonle Sap Lake to the Thai border by pickup truck typically made 27 different fee payments to 15 institutions in 16 different places, with the sum of fees plus costs associated with weight loss and spoilage exceeding the profit margin on the shipment by more than three times (Yim and McKenney, 2003). Export of high-value fish from Laos (including fish caught in northern Cambodia) to Thailand is also a large and underregulated industry (Baird, 2006b). The export industry is, in general, relatively "inefficient" compared to the domestic marketing industry. The largest export industries for Pangasiid catfish and shrimp in Viet Nam are well regulated; however, markets are maintained by consistent export quality.

3.6. Fisheries in the Real Economy

In the MB countries, much of the economy is based on nonmarket (or nonmonetized) goods and services, which in less "developed" parts of the basin may provide most or all of the needs of households. For example, along the floodplains of the Se Bang Hieng in southern Laos, households collected on average about 2.4 tonnes (t) year^{-1} of non-timber forest products (NTFPs), which included fish (704 kg household (hh)$^{-1}$ year^{-1}) and OAAs (97 kg hh^{-1} year^{-1}), as well as medicines, fruits, herbs, resins, bamboo shoots, and mushrooms, none of which is visible in the cash economy Mollot *et al.*, (2005). Even where development and agricultural intensification have greatly reduced the yield from "nature," most people still benefit from open-access to wetland resources. For example, in northeast Thailand, virtually all households around Nong Han wetland utilized its resources, collecting on average 711 kg hh^{-1} year^{-1} of NTFPs, which included 61 kg hh^{-1} year^{-1} of fish and 8 kg hh^{-1} year^{-1} of OAAs, as well as a variety of plants including lotus (*Nelumbo* spp.) and water morning glory (*Ipomoea aquatica*), with the wetland provided the equivalent of 32% of an average household's income (Pagdee *et al.*, 2007). In rice fields (the most extensive aquatic habitats) fish and OAAs are usually significant but unaccounted open-access resources (Hortle *et al*, 2008).

Within the cash economy, the informal sector is significant in each MB country. Although little accurate information is available, in

Cambodia about 85% of the workforce and 62% of the estimated Gross Domestic Product (GDP) is within the informal sector (Nuth, 2005). Fisheries are also well-represented within the informal economy, because of the importance of small-scale unregulated middleman and traders, as well as payments that are made to governmental officials for licenses or to allow continuation of illegal fishing activities (Touch and Todd, 2003; Yim and McKenney, 2003). The lack of accurate data on the real economy and the poor representation of fisheries within the official statistics suggest that most official figures on the economic contribution of fisheries should be regarded skeptically (e.g., see compilations by Baran *et al.*, 2007a).

Because the nonmonetary sector is officially nonexistent, and the informal sector is usually underrepresented in official statistics, an apparent improvement in economic conditions (e.g., rising GDP) may actually reflect a loss of natural resources (including fisheries) and a simplification and monetization of production systems, rather than reflecting any actual improvement in living conditions for rural people. Fisheries are particularly likely to suffer from misguided interventions, because their size and importance are grossly underestimated (Coates, 2002) and are particularly sensitive to the impacts of development in other sectors. "Official" (but erroneous) figures may be extremely misleading, for example, "apparent consumption" figures published by the FAO, have been used to show that "highly urbanized populations consume more meat (including fish) per capita than those with less urbanized populations" (York and Gossard, 2004). A more plausible interpretation is that urbanization is correlated with improved data collection systems since the analysis is based on "official" consumption figures of: Cambodia 9, Laos 9, Thailand 34, and Viet Nam 17 kg person^{-1} year^{-1}, values which are much less than the survey-based figures presented in the following section.

4. LMB FISHERY YIELD AND VALUE

4.1. LMB Fisheries Yield

Yield can be estimated directly (from catches plus aquaculture yield) either from consumption and market sales, or indirectly based on estimates of yield per area. Official data on catches are likely underestimates (Coates, 2002). Accurate data have been collected for catches from some well-defined areas (such as rice fields or reservoirs), but large-scale surveys are often unreliable because of the difficulty of obtaining coverage of the huge diversity of gears (especially illegal gears) and fishers, and the likelihood that fishers routinely lie about catches to avoid taxes. A major catch survey in the 1990s in Cambodia produced national estimates that have been widely quoted (Baran and Myschowoda, 2008; Hortle *et al.*, 2004), despite the original authors explaining that the data were simply "expert guesses" (van Zalinge and Touch, 1996) with subjective correction factors applied (Sensereivorth *et al.*, 1999). Data from markets are not widely available and would not include the large proportion of fish and OAAs which are either directly consumed or traded off market. Therefore, approaches using yield per unit area (discussed below) or household consumption are most promising for accurately estimating the system yield.

Total consumption of fish and OAAs within the LMB was estimated based on 20 studies (Hortle, 2007). Various adjustments were made to standardize units to fresh weight, to fill in missing data in some studies (e.g., for preserved fish or OAAs), and to extrapolate to provinces where data were collected for only part of a province. The estimated total consumption of about 2.6 Mt year^{-1} (Table 9.1) is consistent with the range based on areal yield estimates. The MB's fisheries provide a significant proportion of the world fisheries yield, estimated

TABLE 9.1 Estimated consumption of fish and OAAs in the LMB, Year 2000 after Hortle (2007)

Country	Population (millions)	Inland fish	Inland OAAs	Inland fish plus OAAs	Marine products	Total aquatic
Cambodia	11.4	482	105	**587**	11	598
Laos	**4.9**	168	41	209	**2**	211
Thailand	22.5	721	191	911	130	1042
Viet Nam	17.5	692	161	853	129	982
Delta	15.1	640	149	**789**	119	908
Highland	2.4	52	12	64	10	74
Total	56.3	2062	498	2560	273	2833

Units are x 000 t year^{-1} as FWAEs, that is, converted to the weight of animals "as landed."

at 95 Mt year from all capture fisheries and 59.4 Mt year^{-1} from aquaculture in 2004 (FAO, 2007). About 10% of the MB yield was assumed to be derived from aquaculture based on figures compiled by Phillips (2002), but these do not include much of the small-scale household yield. Household surveys suggest that aquaculture contributed about 20% and is probably increasing in importance, especially in the Viet Nam delta.

Consumption-based estimates may be biased to some extent by differences between responses in interviews and actual consumption figures. On the other hand, the consumption figures are conservative as basis for a yield estimate, because they do not take into account at least 120,000 t year^{-1} of small fish from the capture fishery that are used as "trash fish" to feed aquaculture fish and other animals, including crocodiles; they exclude wastage prior to consumption of at least 10% (Hortle, 2007); and they do not cover local clandestine exports which could be quite significant.

A large proportion of catches is consumed locally, but improvements in roads and marketing systems increasingly allow redistribution of catches and products from aquaculture, particularly from rural areas to cities (Baird and Flaherty, 2005; Phonvisay, 2003). Hence, consumption within a province or country may include significant local (intrabasin) imports. It can be assumed that the highly productive provinces around the Tonle Sap-Great Lake system and in the upper delta are nett exporters, with Laos and northeast Thailand probably nett importers of both fresh and dried and fermented fish. Cambodian fisheries products are sold throughout the Viet Nam delta, but the export of aquaculture fish, including snakeheads and catfish to Cambodia probably balances this trade.

The consumption-based estimates are higher than official estimates, which grossly underestimate the entire LMB yield (Table 9.2). The discrepancy suggests that either the official figures are too low, as is likely (Coates, 2002) or that the consumption figures are too high, which seems less likely. Catches may vary significantly between years, and the proportion contributed by aquaculture is increasing, so the basinwide figure should be considered indicative.

Official aquaculture exports from the basin (mainly from Viet Nam) are now about 1 Mt year^{-1} and increasing (Section 6.1). Hence, an updated summary of the total basinwide yield is about 3.6 Mt year^{-1}, with aquaculture contributing about 40% of the total.

TABLE 9.2 LMB Year 2000 consumption-based estimates (k year^{-1}) compared with some "official" figures after Hortle (2007)

Country	Consumption-based estimate	Official estimate	Ratio (%)	Reference for "official" estimate
Cambodia	587	338	174	Sam *et al.* (2003): consumption and catch estimates
Laos	209	62	334	Souvanaphanh *et al.* (2003): areal yield times areas of habitat
Thailand	911	76	1204	Pawaputanon *et al.* (2003): commercial figures, mainly reservoirs
Viet Nam (delta only)	789	682	116	GSO (2003): yield minus sea catches
Total	2560	1157	221	

Units are x 000 t year^{-1} as FWAEs. Note that Cambodia recently adopted the consumption-based estimate as its official estimate (Nao Thuok, personal communication).

4.2. The Value of LMB Fisheries

Fisheries have both indirect and direct values. Indirect values include biodiversity values (see Chapter 8) and cultural values (Baran *et al.*, 2007a). Direct values are usually based on first-sale or market prices. Sverdrup-Jensen (2002) provided figures on total yield and value which equated to an average first-sale price of about US$0.73 kg^{-1} based on limited data, and which are now out-of-date. A preliminary appraisal of unpublished MRC data from detailed monitoring during 2003-2004 showed that weighted average prices across inland species in representative markets were lowest in the Viet Nam delta (US $1.40 kg^{-1}), slightly higher in Phnom Penh, Cambodia (US$1.60 kg^{-1}), higher again in some small city markets in northeast Thailand (US $1.90 kg^{-1}) and were highest in Vientiane, Laos ($2.60 kg^{-1}). These prices are biased towards larger, high-value species which are selectively traded in markets; on the other hand the market price of all foods has risen significantly since the survey, for example, by about 40% based on late 2008 figures in Vientiane. Figures quoted by Truong *et al.* (2008) suggest a first-sale price across all capture species in the Viet Nam delta in 2004 of about US$0.62, and prices of at least $1.20 kg^{-1} for freshwater fish exports and US $3.10 for brackish water (mostly shrimp) exports. Phonvisay and Bush (2001) reported that retail selling prices of fish traded from the south of Laos to Vientiane were approximately double the first-sale price, a markup ratio reasonably consistent with the difference between the market and first-sale prices noted above for Viet Nam ($0.62/$1.40).

An up-to-date estimate of typical retail market prices (allowing for recent increases) is about US $2-$3.60 kg^{-1}, and for first-sale prices is about US$1-1.80 kg^{-1}. With a total yield of about 3.6 Mt, the LMB fishery is "worth" about US $3.6-6.5 billion dollars as a first-sale value. The economic value of fisheries also includes the downstream processing of products (Truong *et al.*, 2008), or associated industries. Of course the true worth of the fishery could be judged in many other ways, for example, based on its replacement cost, its value to livelihoods, its relative profitability or by including its benefits to and impacts on the environment, or perhaps in terms of opportunity costs. Nevertheless the price-based estimates provide a crude yardstick which is useful in comparisons with the often-quoted benefits from other sectors, such as hydroelectricity and irrigated agriculture. The uncertainties in the estimates illustrate the need for better data collection.

4.3. The Value of Associated Industries

Many industries support fisheries, including gear-making, boatbuilding, and salt and ice production, all of which are carried out at scales varying from individual households to large commercial operations. Most rural households near waterways own a small boat, typically a two-person wooden sampan 9-10 m in length, which costs about US$1000-2000 or about US$3000-5000 with an engine. It is likely that there are several million sampans in the MB with a combined value of several billion dollars. In 2004, there were 105,055 registered fishing boats (generally larger powered vessels) in the Viet Nam delta alone (Truong *et ah,* 2008). Salt is produced both by evaporation of sea salt (e.g., at Kampot in Cambodia) and also from salt mines on the Korat Plateau. About one-third of the 2.6 Mt of fish and OAAs that are consumed each year is preserved (Hortle, 2007), most by fermentation or salt-drying, which typically requires salt in the proportion of one-fifth of the weight. Hence, the industry probably consumes about 170,000 tonnes of salt each year. The lack of ice, until recently, has led to a strong preference for sale of live animals, but ice is now produced in many small factories and transported widely to landing sites and to markets; however, there are no accurate statistics on the industry.

4.4. Fisheries and Nutrition

Fishery products (fish and OAAs) are the main source of animal protein throughout the basin (Hortle, 2007), as well as a key source of micronutrients. National average values for per capita consumption (Table 9.3) are within the ranges generally reported for developed countries (about 13-67 kg person^{-1} year^{-1}), and actual consumption on average is about 75% of consumption expressed as Fresh Weight Animal Equivalent (FWAE) (Hortle, 2007). Per capita consumption varies widely from each country, being highest near productive water bodies and lowest in drier or mountainous regions. A large proportion of fish are small and are eaten whole, so their skeletons are an important source of calcium in a region where dairy foods are rare; the iron provided by fish is particularly important for women, and fish

TABLE 9.3 Per capita fish and OAA consumption estimates

	Inland				
Country	**Fish**	**OAAs**	**Fish plus OAAs**	**Marine products**	**Total aquatic**
Cambodia	42.2	**9.2**	51.4	**1.0**	52.4
Laos	**34.6**	**8.4**	43.0	0.5	43.5
Thailand	32.0	**8.5**	40.5	**5.8**	46.2
Viet Nam	39.5	**9.2**	48.7	**7.4**	56.1
Delta	**42.5**	**9.9**	52.4	**7.9**	60.3
Highland	21.2	**4.9**	26.1	**4.1**	30.2
TOTAL	36.6	**8.8**	45.5	**4.9**	50.3

Units are kg per capita year^{-1} as FWAEs, not actual consumption, after Hortle (2007).

eyes and some of the other organs contain high concentrations of vitamin A (Mogensen, 2001; Roos *et ah*, 2007a,b). The health benefits of fish have been widely promoted, but in the LMB the habit of eating raw or partly preserved fish and OAAs has led to high rates of infection with certain parasites, including liver and intestinal flukes (Hortle, 2008); educating people to cook fish properly should be a key element of public health education. Fisheries development is often promoted as a way to increase the intake of nutrient-dense foods to combat malnutrition, which remains common in the LMB (MRC, 2003). However, the benefits of any dietary improvement may be negated by the effects of common water and food-borne parasites that infect most people in the basin (Nguyen *et ah,* 2006b, Phathammavong *et ah,* 2007; Tep *et ah,* 2006; Wongstitwilairoong *et al.*, 2007). Improvements in basic hygiene and sanitation must be made at the same time as improvements in the food supply, which should include fisheries within a general development framework.

4.5. Habitats and Yield

Aquatic habitats are most extensive in the lowlands; of most importance to fisheries are (1) large river-floodplain systems, (2) rice fields and associated habitats, (3) large man-made reservoirs, and (4) the estuary and brackish-water zone. Marine fisheries (coastal and offshore) also depend upon nutrients in the Mekong's plume and the division of the fishery into inland and marine by a line across the mouth is quite arbitrary in an ecological sense. Numerous smaller streams and rivers run from uplands of northern Laos, northern Thailand and the Annamite mountain chain (which roughly follows the western border of Viet Nam), as well as from the smaller mountains that delimit the catchment in southeast and northern Cambodia; uplands form a fifth habitat that is of relatively minor direct importance in fisheries. Land-use data (Table 9.4 and Figure 9.1) indicate that wetlands—land that is covered permanently or seasonally by water—cover about 30% of the LMB. Most (about 80%) of the wetland area is rice field habitat. Virtually all wetland habitats are in lowland areas, whereas forest and swidden characterize uplands.

At least 90% of the wetland area is seasonal as is evident from the low proportion of permanent water bodies. Seasonality is more extreme than suggested by the GIS data, because digitizing the area of permanent water bodies (with the exception of the Great Lake) gives a value about 80-90% of their maximum area.

Major floods cover up to 58,000 km^2 or about 30% of the flood area (Table 9.5); this figure includes 6300 km^2 (or about 10%) of permanent water bodies. Other wetland areas are not subject to flooding by the major rivers but are inundated by local rainfall or by local diversions from smaller watercourses. About 60% of the wetland areas in Cambodia and Viet Nam lie within the major flood zone, which includes the highest quality habitats for fisheries production. About half of the land covered by floodwaters is rice fields, about one-quarter is more natural land such as forests, shrubland, or swamps, and the remainder includes plantations (such as flood-tolerant paperbarks *{Melaleuca))* in the delta.

The estimates of wetland areas are simplified in Table 9.6 and combined with estimates for areal yields from each habitat (as discussed below) to show that the total yield of the inland capture fishery of the LMB is about 1.3-2.7 Mt $year^{-1}$, a range that is consistent with the estimate from consumption studies. The two main habitats contributing most to the total catch are likely to be river-floodplain habitats (high areal yield over a moderate total area) and rice field habitats (low-moderate yield over a very large area). However, the extent of wetlands and the areal yield figures are subject to considerable uncertainty which should be reduced by further research.

TABLE 9.4 Land use and wetlands in the LMB

Land use type	Laos	Thailand	Cambodia	Viet Nam delta	Viet Nam highlands	Total LMB	% of total
Rice field habitats	10.6	98.3	28.5	20.2	1.6	159.2	25.1
Forest within flood zones and grassland/ shrub / swamps	2.6	1.4	11.7	1.0	0	16.8	2.6
Large-scale aquaculture	0	0.1	0	2.4	0	2.4	0.4
Permanent water bodies	2.4	4.5	5.0	1.8	0.2	13.8	2.2
Other land in flood zone—includes plantations and crops	0.1	0.3	1.5	3.7	0	5.6	0.9
Total wetlands	15.7	104.5	46.7	29.1	1.8	197.8	31.3
Wetland as % of total	7.6	51.5	29.9	84.6	5.6	31.3	
Forest and degraded forest	182.3	56.2	102.0	1.7	**25.7**	367.8	58.1
Field crop	1.2	35.4	3.5	0.4	1.8	42.3	6.7
Plantation	0	5.6	0.7	3.0	2.1	11.5	1.8
Swidden	5.2	1.4	3.1	0	0	9.6	1.5
Urban and other	2.2	0	0.4	0.2	1.1	3.9	0.6
Total nonwetlands	190.9	98.6	**109.7**	5.3	30.6	435.1	68.7
Nonwetlands as % of total	92.4	48.5	70.1	15.4	94.4	68.7	
Total	206.6	203.1	156.4	34.4	32.4	632.9	**100**

Areas are x 000 km . Land use is based on MRC GIS data post-2000, which is more current and comprehensive than MRC wetland data cited by Hortle (2007). GIS data does not resolve small areas of a particular class, so for example, aquaculture areas are underestimated.

5. HABITATS AND THEIR FISHERIES

5.1. Lowland River-Floodplain Systems and Their Ecology

The Mekong River and large tributaries such as the Tonle Sap-Great lake system include a great variety of in-stream habitats as well as a range of seasonal and permanent water bodies (lakes and marshes) on their floodplains, of which the Great Lake is the largest. The flow of rivers is highly seasonal with much of the total annual discharge during the wet season (see Chapter 4). Although storage in reservoirs and abstraction for irrigation are significant in Thailand, overall the river system is relatively unregulated, with a fairly predictable monotonic flood pulse each year. In Cambodia and the upper Viet Nam delta floodplains are less than 20 m ASL and most of the wetland area is flooded by river water in most years (Table 9.5); the Great Lake depth increases by up to 9 m during each flood season (Chapter 11), and much of the floodplain is covered by several metres of floodwater for 3-4 months each year. Because of the extensive, deep, and prolonged flooding, this part of the LMB is generally considered to support the most productive fisheries (Lamberts, 2006; van Zalinge *et al.*, 2004). In Thailand and Laos, a small proportion of the total wetland area comprises

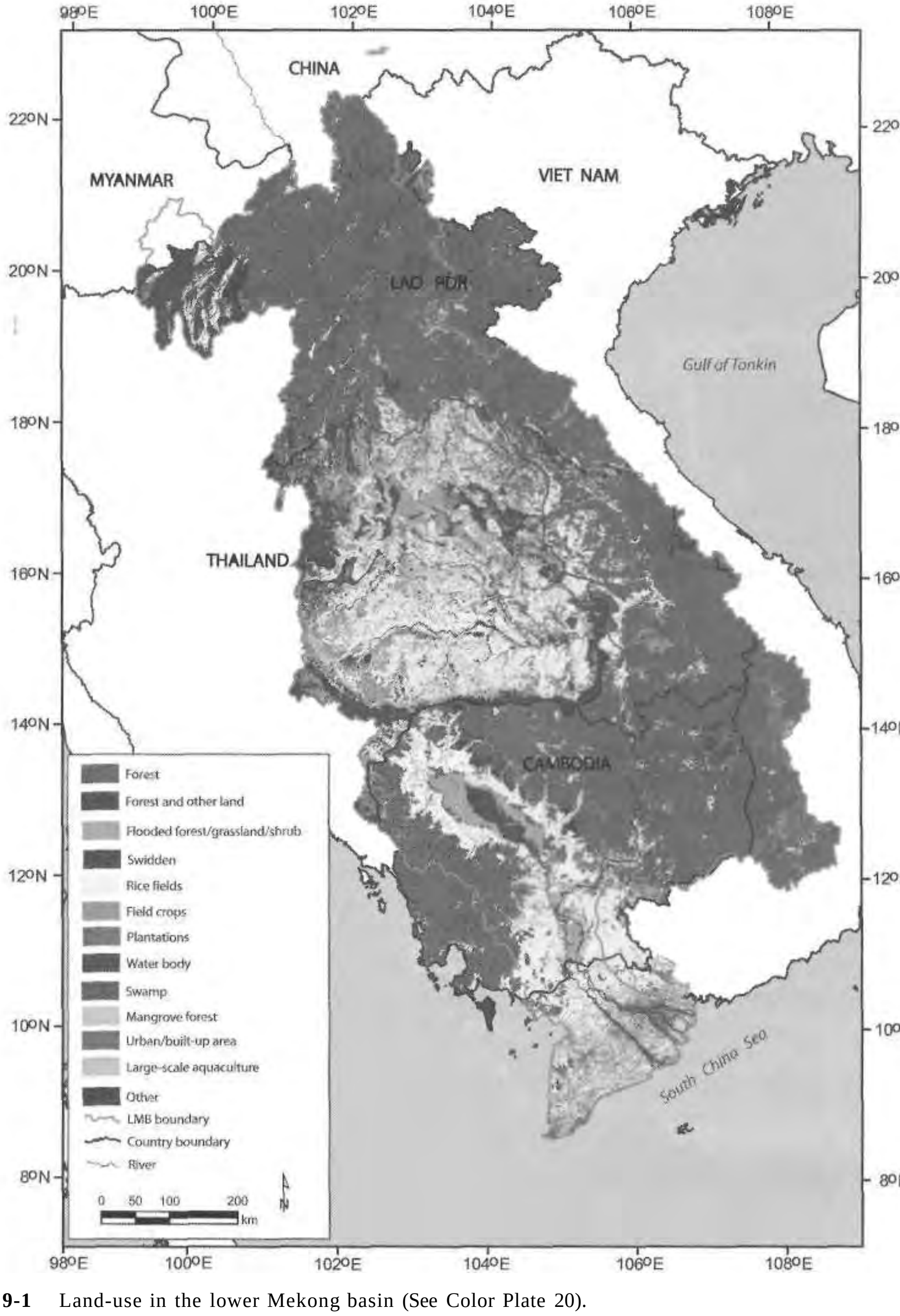

FIGURE 9-1 Land-use in the lower Mekong basin (See Color Plate 20).

TABLE 9.5 The extent of **a** major flood in the LMB

Statistic	Laos	Thailand	Cambodia	Viet Nam delta	Viet Nam highlands	Total LMB
Land area within major flood	**4.6**	**7.8**	28.3	17.3	**0**	58.0
Proportion of land within major flood (%)	2.2	**3.8**	18.1	50.5	**0**	9.2
Proportion of total wetland area within the major flood (%)	**29.4**	**7.5**	**60.5**	59.7	**0**	29.3

Units are x000 km . Flood areas are for the year 2000 estimated from Radarsat imaging, elevation data, and modeling.

TABLE 9.6 Approximate extent of wetlands and likely yield of fish and OAAs **in** the capture fishery of the LMB, Year 2000

Wetland category	Area (x000 km^2)	Areal yield estimate (kg ha^{-1} $year^{-1}$)	LMB yield estimate (x000 t $year^{-1}$) Low estimate	LMB yield estimate (x000 t $year^{-1}$) High estimate
Seasonally flooded land and water within the major flood zone, including some rice fields	58.0	100-200	580	1160
Rain-fed rice fields and associated habitats not within the major flood zone	129.9	**50-100**	650	1299
Large water bodies, including reservoirs	7.5	100-300	**75**	225
Total	**195.4**	**67-137**	**1305**	**2684**

Excludes aquaculture.

floodplains, and flooding is highly variable in extent and duration between years.

Migration patterns of fishes within the Mekong mainstream and lowland tributaries can be grouped into three main "systems": the upper, middle, and lower systems, with the break between the middle and lower systems well-defined by Khone Falls (Poulsen *et al.*, 2002a). In each system, many species appear to exhibit similar life history patterns that are governed by the position of key habitats, including dry-season refuges, flood-season feeding and rearing habitats, spawning habitats, and migration routes. However, the entire lowland river-floodplain system can be regarded ecologically as a single unit under the flood pulse concept (FPC) Gunk and Wantzen, 2004; Junk *et al*, 1989). Flooding supports high productivity by transferring nutrients and organic detritus (an energy source) from the main rivers to their floodplains, as well as rewetting soil which releases mineralized nutrients to support primary production, particularly the growth of algae (periphyton and phytoplankton) that are considered particularly important both in supporting zooplankton (the main food for fish larvae) as well as providing a direct food source for fish (see Chapter 11). During the flood, larger fish move onto floodplains and feed on terrestrial vegetation, fruits, detritus, and terrestrial animals (such as insects and other arthropods), and many fish species also spawn in flooded areas. The fry of black and gray fish originate from spawning on the floodplain, whereas white fish fry—from spawning upstream in rivers—arrive as drift in the rising floodwaters (Chea *et al*, 2003; Nguyen *et al*, 2006c, 2,008; Thach *et al*, 2006). Spawning in upper Cambodia results in enormous quantities of fry drifting downstream with rising floodwaters; one study made a crude estimate of 120 million fish per day, most of which are cyprinids or Pangasiid catfishes. Invertebrates such as shrimps are also a large component of the early wet-season drift (Hortle *et al*, 2005a).

Most of the larger "white fish" leave floodplains soon after water levels peak and then migrate via rivers to dry-season refuges, such as deep pools, which may be distant from the floodplains, for example, in northern Cambodia and near Khone Falls (Baran *et al.*, 2005; Poulsen *et al.*, 2002b). Most of the smaller white fish follow later towards the end of the flood recession, moving with the falling waters in migration "waves," which seem to be timed around lunar cycles (Baird *et al.*, 2003a). Black and gray fishes move short distances to dry-season refuges on or near floodplains. Catches of small-scale fishers may comprise mostly black or gray fish, especially where there are significant floodplain water bodies (Dubeau *et al.*, 2001), whereas large-scale commercial fisheries tend to target migratory white fish, as shown by summary data for Cambodia by van Zalinge and Nao (1999). However, black fish productivity may depend partly on feeding upon white fish which have migrated onto floodplains, so there is a need both for better data on catch composition as well as on the basis for production. Fishing pressure is very heavy during the flood recession when fish are migrating, as they are caught in large quantities by gears that filter the water (such as dais) or that use large fences or barriers to divert them into traps. Many small-scale fishers are active only during the flood recession when fish are highly concentrated and are most catchable; areas where fishing is particularly intense include the Tonle Sap, and Khone Falls, just upstream of the border of Laos and Cambodia (Baran *et al.*, 2005).

World data (Welcomme, 1985) and recent detailed studies in other Asian systems (de Graaf *et al.*, 2001) show that total catches (kg ha^{-1} year^{-1}) are well-correlated with the extent of annual flooding, as is also evident in the only long-term dataset of a significant fishery in the MB, where catches are well-correlated with flood height or the area and duration of flooding (Halls *et al*, 2008). Where fishing effort and other conditions are constant, larger catches result from larger numbers of fish or higher mean size or both (e.g., Halls *et al*, 2008). In general, larger floods of longer duration allow more fish to survive and grow to a larger size, so flood amplitude and duration have a direct effect on fish catches, other factors being equal. Other features of the flood pulse such as its timing, continuity, smoothness, and rapidity of change (Welcomme and Halls, 2004) may affect productivity (Lamberts, 2008), but there is no information which would allow a precise prediction of the importance for fisheries production of changes in the shape or timing of the flood pulse. Retention of water on floodplains during the dry season also enhances fish production, but the "optimal" balance between wet- and dry-season flows is unclear, because production does not depend upon hydrology alone, but other factors such as nutrient release from exposed sediments during the flood pulse (Welcomme and Halls, 2004).

The Mekong and its tributaries transport processed allochthonous (terrestrial) organic material and nutrients to the lowlands and the estuary in a more or less predictable way, with a succession of organisms associated with habitat changes down the system and dependent upon the flow of materials and energy broadly conforming to the river continuum concept (RCC) (Vannote *et al.*, 1980). A downstream transport of fine particulate organic matter and dissolved forms of organic carbon takes place continuously, and the quantity and variety of visible coarse particulate matter moved downstream by the Mekong during major floods is quite extraordinary—many thousands of tonnes of trees, logs, sticks, leaves, bark, and detritus are flushed through each day. Such organic material supports detritus-based food chains on floodplains as well as the many species of "mud-eating" animals in the estuary and coastal waters. The RCC has not been studied in the Mekong system, but as a generally accepted concept it is useful in predicting, for example, that reservoirs are likely to reduce productivity downstream in rivers and the estuary by trapping sediment, organic material and nutrients, and that the ongoing logging of the catchments is likely to have a wide range of effects downstream.

Although the EPC and the RCC have some predictive value, the Mekong system differs greatly from the river systems on which these concepts were developed, mainly in North and South America, where rice fields are not a common land use. The FPC and RCC also primarily relate to the ecology of "natural" systems, hardly appropriate for the Mekong where, for example, nutrient flows in some areas may be dominated by the inputs from artificial fertilizers (MRC, 2003), as well as untreated sewage disposal for 70 million people; 24 million livestock (cattle, buffalo, and pigs) (Nesbitt *et al,* 2004); and many more ducks, chickens, and other domestic animals. It seems obvious that the river system (including its fisheries) cannot be managed sensibly without a much better understanding of its ecology, particularly the relative importance of the various flows of nutrients and energy.

5.1.1. Yield front Floodplain-River Systems

Other factors being equal, a larger river system—as indicated by catchment area or river length—tends to produce a larger total catch of fish, as discussed in detail by Welcomme (1985). Hoggarth *et al.* (1999a) suggest that typical floodplain yields are 70-140 kg ha^{-1} $year^{-1}$, and a recent review of world data by Halls *et al.* (2006) suggest that catches are sustained around 100-150 kg ha^{-1} $year^{-1}$ over a range of fishing effort of 5-30 fishers km^{-2}. Comprehensive data from Bangladesh, where hydrology and the fauna are similar to the Mekong, include a range of yields of up to 574 kg ha^{-1} $year^{-1}$ for wild fish (Ali, 1997), with some higher yields recorded where floodplain water bodies were stocked. The main environmental factors which affect yields have been well-documented in a number of studies that systematically compared catches from a range of river-floodplain systems (Ali, 1997; de Graaf *et al,* 2001; Halls *et al.*, 1999; Hoggarth *et al,* 1999a). The highest yields are consistently associated with systems where floodplains are (1) open to fish access from adjacent rivers, (2) have deep and extended flooding, and (3) have depressions that allow water to persist through the dry season. Conversely, low yields are recorded where floodplains are (1) isolated from rivers by levees, (2) relatively shallow, and (3) dry out quickly. These findings are likely to apply to the Mekong system and are consistent with much anecdotal information, although they have not been documented in systematic studies. The theoretical bases for fish production in floodplain fisheries are discussed in Halls *et al.* (2001), Halls and Welcomme (2004) and Welcomme (1985), and are generally supported by empirical studies, which show that most of the variation in catches between years is directly related to the size of the annual flood, the retention of water in the dry season, and fishing pressure.

5.1.2. Yield from LMB Floodplains

Only four studies provide estimates of yield from floodplains in the Mekong system based on actual catch measurements.

Dubeau *et al.* (2001) estimated yield from a well-defined "floodplain" area adjacent to the Tonle Sap. About 82% of the area would be flooded during the highest flood and perhaps half of the surveyed area is active floodplain in an average year; most is rain-fed or recession rice fields and water persists through the dry season in permanent lakes which cover about 5% of the area. Fishers were surveyed throughout the year using logbooks and commercial catches were monitored accurately. Several approaches were used to estimate the total catch of 243-532 kg ha^{-1} $year^{-1}$ (mid-value 388 kg ha^{-1} $year^{-1}$) from the entire area. Small-scale artisanal fishers caught 94% of the catch. The total estimate includes only fish and OAAs caught within the study area, that is, not including fish which swam into the Tonle Sap and were caught there (or elsewhere), therefore an estimate of 300-400 kg ha^{-1} $year^{-1}$ may be conservative, and would be consistent with the study site having the attributes that favor high yield, as mentioned earlier for Bangladesh.

In the Mekong delta over a 90-day flood fishing season, a site in a deepwater but acid-affected floodplain produced 63 kg ha^{-1} and a deepwater, nonacid site produced 119 kg ha^{-1} (de Graaf and Chinh, 2000). In this region, rice is grown throughout the dry season by irrigating from canals, so dry-season catches in rice fields and associated habitats would increase the total yield.

Troeung *et al.* (1999) compared the yields from three large commercial fishing lots on forested, partly cleared (31% forest), and completely cleared floodplains. This study appeared to show little effect of partial clearing (yield falling from 95 to 92 kg ha^{-1} $year^{-1}$) and a relatively large reduction (to 55 kg ha^{-1} $year^{-1}$) in completely cleared areas, with the total value of the catch declining disproportionately as large high-value species such as snakeheads became less abundant. However, because artisanal catches were not included it is likely that total catches were much higher in all three study areas, as in the study by Dubeau *et al.* (2001) discussed previously, and would perhaps have been highest in the completely cleared area, where the largest numbers of artisanal fishers would be operating, and where catches would be made from recession rice fields during the dry season.

In Cambodia, but outside the Mekong system, a yield of 630 kg ha^{-1} $year^{-1}$ was reported from a largely artificial coastal floodplain created by polders (Lim *et al.*, 2005). Although this yield seems high, the study area is deeply flooded (to 2 m) each year and a large proportion is permanent water bodies which support year-round fishing. The flooded area may also have been underestimated by a factor of about 2, so a yield of 300-400 kg ha^{-1} $year^{-1}$ may be reasonable.

Crude estimates for the Tonle Sap-Great Lake system include 139-190 kg ha^{-1} $year^{-1}$ (Lieng and van Zalinge, 2001) and 230 kg ha^{-1} $year^{-1}$ (Baran *et al.*, 2001), but these were apparently based on estimates of catch which are subject to great uncertainty.

Overall, the limited data from the LMB, and studies elsewhere, indicate that a likely yield from river-floodplain systems is 100-200 kg ha^{-1} $year^{-1}$, with possibly higher yields in more productive parts of the system in Cambodia and the upper parts of the Viet Nam delta, and lower yields where flooding is of relatively short duration and depth, such as in Laos and Thailand.

5.2. Rice Fields and Associated Habitats

Rice originated in Asia, and the dominant lowland cultures in the LMB are often regarded as "rice-fish" societies. Modification of landscapes for rice farming has been proceeding for over 2000 years in the LMB, and traditionally managed rice fields teem with life. The abundant black fish are carnivores (or mainly carnivorous), feeding on tadpoles, frogs, crabs, shrimps, and insects, which themselves are also significant elements of fisheries (Halwart, 2006; Hortle *et al.*, 2008). Rice field fertility and the food chain depend upon the rapid turnover of a nonrice aquatic biomass of a few hundred kg (dry weight) ha^{-1}, with blue green algae particularly important in biological nitrogen fixation (Roger and Kurihara, 1988); artificial fertilization and conversion of rice stubble to manure in the dry season by cattle grazing increases available nutrients. The managed inundation of rice fields stimulates nutrient release from sediments, initiating primary production, with a consequent succession of plants and animals adapted to the temporary environment (Bambaradeniya and Amarasinghe, 2004; Heckman, 1974, 1979). In many respects rice fields are miniature floodplains, with a short-managed "flood pulse," similar to that described for larger natural systems (Junk *et ah*, 1989), despite the different origin of the floodwater. Rice fields are, however, generally more stressful environments, with a lower diversity than natural floodplains, but with relatively high productivity and yield when the shorter duration of inundation is taken into account.

Fish and OAAs typically breed several times during the wet season, with fish fry or immature stages colonizing newly flooded fields. Most large rice field animals, including the common black fishes, can move over land, bypassing the many barriers that are built through the agroecosystem. Growth is rapid and many species reproduce continuously, so that fishers harvest aquatic animals throughout the wet season along the edges of rice fields and in nearby water bodies (Hortle *et al.*, 2008; Meusch *et ah*, 2003). In the dry season, some animals survive in refuges (canals, ponds, and nearby streams) while some aestivate deep below the dried surface of the fields, where they may be dug up by "mud-fishing." Insects are a major component of the fishery, with large quantities of dragonfly larvae (Manning and Lertprasert, 1973) caught with small seines, and large water beetles and bugs (Hortle *et al.*, 2005b) caught by light trapping.

As well as black fishes, river/stream fishes may migrate into rice fields for short periods to spawn and feed, with the proportion of white fish in catches dependent on the connectivity to nearby floodplain water bodies, rivers, or streams (Meusch *et al.*, 2003). However, rice fields are at times hostile environments for river fishes, because the water underlying actively growing rice is typically anoxic and contains limited palatable biomass (Vromant *et al.*, 2004). Fish and OAAs which spend significant periods of time in rice fields must be tolerant of anoxia, elevated temperatures and fluctuating water levels. Snakeheads, walking catfish, and climbing perch dominate rice field catches throughout the LMB (Hortle *et ah*, 2008) and are probably the most important fishery species in the LMB, given the vast extent of rice fields and associated habitats, and the fact that these species may also be the most abundant on floodplains. As the environment of floodplains is modified for rice cultivation the proportion of blackfishes increases. In five provinces of northeast Thailand, over half of the weight of fish that were eaten by people comprised black-fish, consistent with the recent expansion of rice-field habitats (Prapertchob *et al.*, 1989). In Long An province, Viet Nam, an intensively farmed rice field landscape, snakeheads, climbing perch, and walking catfish also made up more than half of the catch (Pham and Guttman, 1999). These amphibious carrnivores, together with frogs, may also be important in controlling some of the pests of rice, so reducing the need for use of pesticides. The dominance of carnivores is of some interest and contrasts with river-floodplain fisheries, where omnivorous and herbivorous fish are most important in catches.

At higher, colder locations in the north of the basin, rice fields are often stocked with temperate or subtropical fishes, such as carp and goldfish, which have formed wild populations. The need for stocking arises because diversity, biomass, and richness in terraced rice fields decline with altitude (Margraf *et al.*, 1996).

Apart from rain-fed rice which accounts for about 80% of all rice fields by area (Nesbitt *et al*, 2004), rice is also grown on floodplains as floodwaters are rising (long-stemmed flood rice) and in paddies as floodwaters are receding (recession rice). Within the floodplains, recession rice is the dominant land use; rice fields retard the flood recession and with associated water bodies support a dry-season fishery. Hence, floodplains support a double-pulse of fisheries productivity—predominantly white and gray fish are caught as they retreat from the floodplain during the recession, whereas a fishery during the dry season in rice fields and floodplain water bodies catches predominantly black and gray fish. In the Viet Nam delta, most rice fields are double cropped for rice (each crop requiring about 100 days), with small quantities of fish and OAAs also caught, and then the fields are inundated by floodwaters which support fisheries production. Rice-fish systems are widely promoted and rice is also grown in rotation with shrimps in coastal areas.

5.2.1. *Yield from Rice Fields*

The yield of wild fish and OAAs from unstocked rain-fed rice field habitats can be conservatively estimated as 50-100 kg ha^{-1} year"^{1}, based on several studies in the LMB and elsewhere, as discussed by Hortle *et al.* (2008). Yields are likely to be favored by inundation of rice fields to greater depths and for longer duration (Khoa *et al.*, 2005), and where fanners maintain ponds as dry-season refuges (Angporn *et al.*, 1998). Small water bodies including ponds and reservoirs up to about 100 ha in area are usually intimately connected with surrounding rice fields, and fish and fishers tend to move through the landscape; their yield cannot generally be separately accounted, but is part of the "rice field landscape" yield. As discussed below, small water bodies may be very productive, which may compensate for losses of fishery production in intensively farmed landscapes.

Expansion of the area of rice fields may impact river-floodplain fisheries by depriving them of water through many small-scale diversions into fields, but losses to river fisheries may be compensated for by the additional catches of the more restricted suite of fish and OAAs from rice fields, as well as by capture in small reservoirs (Khoa *et al.*, 2005). The extent of compensation for any losses depends upon management; highly intensive cultivation—high yielding varieties with shallow, short-duration flooding, and high pesticide use may support very limited fisheries, whereas rice-fish culture is likely to produce the highest yields.

5.3. Reservoir Fisheries

In recent decades, dams have been built on all MB river systems in northeast Thailand, several large dams have been built on major tributaries in Laos and Viet Nam, and many more dams are being built or planned. In the MB in Thailand, Virapat and Mattson (2001) estimated there were 1872 reservoirs (mostly built for irrigation) with individual surface areas greater than 100 ha, their total area was 2120 km^2, which may be an underestimate, because the combined area of the 13 largest Thai dams alone is 1665 km^2 (Table 9.7). The 22 largest existing LMB dams have a combined surface area of 2737 km^2, so the total area of LMB reservoirs (larger than 100 ha) is probably 4000-5000 km^2. Most dams were built for irrigation, with relatively few until recently built for hydroelectricity production; some dams—classed as multipurpose—may have small hydroelectric plants while also providing irrigation water. Most dams are designed to store wet-season flows for release during

TABLE 9.7 Some key features of the largest dams in the LMB

Country	Dam name	Code	Status	River system	Completion	Purpose	Elevation (m ASL)	Wall height (m)	Wall length (m)	Inundated area (km^2)	FSL volume (million m^3)	Mean depth (m)	Catchment (km^2)	Inflow (m^3 s^{-1})
China	Xiaowan		Construction	Mekong	**2012**	Hydro	1236	292	nd	190	14,550	76.6	113,300	1220
	Manwan			Mekong	1996	Hydro	994	132	418	nd	920	nd	114,500	1230
	Dachaoshan			Mekong	2003	Hydro	895	111	460	nd	880	nd	121,000	1340
	Mengsong			Mekong	2008?	Hydro	519	28	nd	nd	nd	nd	160,000	2020
Laos	Honay Ho	**HH**		Se Kong	1999	Hydro	883	79.5	400	42	620	14.8	192	9.5
	Nam Leuk	**NL**		Leuk	2000	Hydro	405	45.5	800	13	185	14.5	274	16.4
	Nam Theun 2	**NT2**	Filling	Theun	**2010**	Multi	538	45	48	450	3680	8.2	4013	245.3
	Nam Ngum (1)	**NN**		Ngum	1971/84	Multi	212	75	468	370	7000	18.9	8460	427
Thailand	Nam Pung	**NP**		Pung	1966	Multi	284	41	1720	22	165	7.7	296	4
	Lam Nam Rong	**NR**		Rong	1991	Irrig	143	23.5	1500	25	218	8.7	453	5
	Chulaphorn	**CP**		Phrom	1972	Multi	759	70	700	12	188	15.7	545	5
	Huai Luang	**HL**		Huai Luang	1973	Irrig	198	12.5	1400	31	113	3.6	666	Small
	Nam Pra Phloeng	**PP**		Pra Phloeng	1968	Irrig	272	50	575	19	220	11.6	807	6
	Nam Oon	**NO**		Oon	1973	Irrig	178	29.5	3300	85	520	6.1	1100	12
	Kwan Phayao	**KP**		Ing	1941	Fisheries	405	5	10	24	11	0.5	1161	Small
	Lam Ta Khong	**TK**		Ta Khong	1969/2001	Irrig	227	40.3	527	44	445	10.1	1430	8

	Nong Han	**NH**		Kam	1953	Fisheries	157	5	200	135	64	0.5	1653	Small
	Sirindhorn	**SI**		Dom Noi	1971	Multi	142	42	940	288	1966	6.8	2097	53
	Lam Pao	**LP**		Pao	1968	Irrig	160	33	7800	400	2640	6.6	5964	45
	Ubolratana	**UR**		Pong	1966	Multi	182	35.1	800	410	2264	5.5	12,104	71
	Pak Mun	**PM**		Mun	1994	Multi	108	17	324	60	350	5.8	117,040	759
	Rasi Salai	**RS**		Mun	1994	Irrig		9	nd	110	~440	~4	~48,000	~310
Viet Nam	Buon Tua Srah	**BT**	Construction	Sre Pok	2008?	Multi	488	83	1035	37	787	21.2	2930	100
	Plei Krong	**PK**		Se San	2006	Hydro	570	71	495	53	1049	19.7	3216	128
	Yali Falls	**YF**		Se San	2000	Multi	515	69	1190	53	1037	19.5	7455	270
	Se San 4	**S4**	Construction	Se San	2010	Hydro	215	74	850	54	893	16.5	9326	329

Showing only those with surface area >20 km^2 or volume >150 million m^3.

the dry season, and as such reduce the flood pulse downstream, inevitably impacting river-floodplain fisheries. The combined storage of the existing large dams (excluding those under construction) (Table 9.7) is about 25 km^3, so as yet they have only a minor effect on the seasonality in flow of the entire Mekong, which discharges about 475 km^3 $year^{-1}$ (MRC, 2005).

Many of the reservoirs behind dams support productive fisheries for both indigenous and exotic fishes as well as some other animals, including shrimps (Bernacsek, 1997; Phan and Sollows, 2001; Pholprasith and Sirimongkonthaworn, 1999; Sricharoendham *et al.*, 1999). Reservoirs are not suitable for many river species, which may decline or disappear, but up to about 100 species persist in the largest reservoirs such as Ubolratana (Pawaputanon, 1986) and about 55 species are common in catches in Nam Ngum (Mattson *et al*, 2001). Fewer species persist in smaller reservoirs, a "species-area effect" caused *inter alia* by fewer niches and less spawning habitat. Not surprisingly, the reservoir fauna includes black fishes (such as snakeheads, gouramies, and spiny eels) which live in standing waters, as well gray fishes (such as some cyprinids, some catfishes, glass-fishes, leaf-fishes, and some gudgeons) which are floodplain spawners. However, larger reservoirs with large tributary rivers continue to support many species that require running water for spawning, including many migratory cyprinids (especially carps) and catfishes (e.g. Mattson *et al.*, (2001) for Nam Ngum reservoir). The larger reservoirs have an extensive pelagic zone that seems to be well-suited to at least one indigenous species of planktivorous freshwater herring, *Clupeichthys aesarnensis* (Jutagate *et al.*, 2003), which may form a large component of catches; for example, about one-third of total catches in Nam Ngum (Mattson *et al*, 2001) and 50-60% of catches in Sirindhorn Reservoir (Sricharoendham *et al.*, 1999).

There are no fish in the Mekong system that have evolved within large lakes, so fish from other continents are often stocked to fill particular niches. These include African tilapias *(Oreochromis* spp.), hardy fish which are adapted to the littoral zone, herbivorous grass carp *(Ctenopharyngodon idella),* and planktivores, including silver carp *{Hypophthalmichthys molitrix)* and bighead carp *{Hypophthalmichthys nobilis),* which are large fast-growing species that can support commercial fisheries. Tilapias and silver carp are particularly useful in eutrophic systems as they can feed on and digest and assimilate blue-green algae (Piyasiri and Perera, 2001; Xie and Liu, 2001), which are thought either not to be eaten or to be inefficiently processed by indigenous fishes.

5.3.1. Productivity and Yield of Reservoirs

Secondary production in reservoirs is often high initially, when nutrients are released from inundated terrestrial vegetation, and then may decline over a period of some years, later stabilizing at a lower level. However, in the MB, the natural decline in productivity may be offset where other sources of nutrients or organic material compensate, for example, where large tributary rivers supply organic material from a forested catchment, as postulated for Nam Ngum (Mattson *et al.*, 2001). An expansion of population into the catchment area of reservoirs may lead to increased nutrient inputs which can increase productivity, but at the risk of sedimentation. In the few cases where catches have been accurately monitored after a reservoir filled, small-scale artisanal catches appear to increase, whereas catches of larger predatory species decline as they are fished down (Mattson *et al.*, 2001; Pholprasith and Sirimongkonthaworn, 1999). Official data, such as those compiled by Bernacsek (1997), appear to be the estimates of commercial catches and understate yields in comparison with studies where catches have been accurately monitored (Table 9.8). Artisanal catches in Ubolratana

TABLE 9.8 Estimated fisheries yields from reservoirs and small water bodies in the LMB

Waterbody	Location	Year constructed	Year(s) of survey	Area (km^2)	Mean depth (m)	Catch ($t\ year^{-1}$)	Yield ($kg\ ha^{-1}\ year^{-1}$)	Species makeup	Dominant fishes	Source
Ho 31 Reservoir	Viet Nam Highlands	nd	1997-1999	0.0537	~1	6	1139	99% stocked exotic	Silver carp, bighead carp, common carp, and Indian carps	Tran *et al.* (2001)
Yang Re Reservoir	Viet Nam Highlands	1984	1997-1999	0.56	6.1	32	575	87% stocked exotic	Silver carp, bighead carp, common carp, and Indian carps	Tran *et al.* (2001)
Ea Kar Reservoir	Viet Nam Highlands	1978	1997-1999	1.41	5.2	55	388	98% stocked exotic	Silver carp, bighead carp, common carp, and Indian carps	Tran *et al.* (2001)
Ea Kao Reservoir	Viet Nam Highlands	1979	1997-1999	2.1	5.1	123	588	77% stocked exotic	Silver carp, bighead carp, common carp, and Indian carps	Tran *et al.* (2001)
Ea Soup Reservoir	Viet Nam Highlands	1980/2002	1997-1999	2.4	6.1	51	214	98% self-recruiting indigenous	Indigenous fish	Tran *et al.* (2001)
Lak Lake	Viet Nam Highlands	Natural	1997-1999	6.58	1.0	83	126	97% self-recruiting indigenous	Indigenous fish	Tran *et al.* (2001)
Huai Muk Reservoir	NE Thailand	nd	2002?	2.0	~1	13	66[a]	79% exotic	Common carp	Nachaipherm *et al.* (2003)
Kaeng La Wa Reservoir	NE Thailand	1983	2002?	19	1.4	512	269	~62% exotic	Common carp and Nile tilapia	Nachaipherm *et al.* (2003)
Huai Luang Reservoir	NE Thailand	1973	2000	31	3.6	781	252	63% exotic	Nile tilapia and common carp	Nakkaew *et al.* (2002)

Continued

TABLE 9.8 Estimated fisheries yields from reservoirs and small water bodies in the LMB—Cont'd

Waterbody	Location	Year constructed	Year(s) of survey	Area (km^2)	Mean depth (m)	Catch (t $year^{-1}$)	Yield (kg ha^{-1} $year^{-1}$)	Species makeup	Dominant fishes	Source
Nam Oon Reservoir	NE Thailand	1973	2002?	85	6.1	1032	121	50% exotic	Common carp	Nachaipherm *et al.* (2003)
Nam Ngum Reservoir	Laos	1971/84	1998	370	18.9	6833	185	All self-recruiting indigenous	*Clupeichthys aesarnensis* (28%), cyprinids	Mattson *et al.* (2001)
Ubolratana Reservoir	NE Thailand	1965	1992	410	16.0	3714	61	97% self-recruiting indigenous	Cyprinids	Polprasith and Sirimong-konthaworn (1999)
16 Village Ponds	Thailand		1994-1996	1.8-20 ha	~2		26-2881, med. 652	Most stocked	Silver carp, bighead carp, common carp, Indian carps, silver barb, and Nile tilapia	Lorenzen *et al.* (1998a)
17 natural and reservoirs	Laos		1995-1997	1-60 ha	39,569.0		60-690	Various	Stocked and indigenous	Lorenzen *et al.* (1998b)

[a]Reservoir was silted and weed-choked.

Reservoir make up about one-half of total catches according to Pholprasith and Sirimongkonthaworn (1999) (Table 9.4).

The features that favor high productivity per unit area in reservoirs include shallow depth, small size, and optimal nutrient status. Stocking and higher fishing pressure lead to higher catches, as is evident from systematic catch assessment in highland reservoirs in Viet Nam (Phan and Silva, 2000; Tran *et ah,* 2001) and from smaller water bodies in Thailand (Lorenzen *et ah,* 1998b). Accurate data on a few reservoirs (Phan and Sollows, 2001) and official data from all Vietnamese reservoirs (Ngo and Le, 2001) show that yield declines exponentially with reservoir size.

The highest yields are recorded from small, shallow, stocked reservoirs or other small water bodies (Table 9.8). Smaller reservoirs are more productive for fisheries for several reasons: (1) smaller reservoirs have more shoreline relative to area and shorelines are more productive and accessible than deeper water, (2) they have a lower proportion of deep water, so are less likely to stratify and lockup nutrients, and (3) the fish in small reservoirs are more easily caught, avoiding wastage of productivity in a large standing stock of fish that are not growing. Fisheries production also appears to be correlated with the proportion of a reservoir that is "drawn-down" each year during the dry season (Nissanka, 2001); probably through a similar process of nutrient release from reflooding of exposed shoreline sediments as described for the flood pulse. Most large reservoirs in the highly seasonal Mekong system are highly drawn-down each year, a factor that contributes to the apparently high measured yields.

An estimate of total annual catches of 25,428 tonnes from LMB Thai reservoirs larger than 100 ha by Virapat and Mattson (2001) equates to a yield of 120 kg ha^{-1} $year^{-1}$, which is probably an underestimate based on the figures in Table 9.8. As the mean size of reservoirs in Thailand is much smaller than Nam Ngum or Nam Oon, and as areal yields are higher in smaller reservoirs, the yield of reservoirs is likely to average at least 200 kg ha^{-1} $year^{-1}$. Reservoir yields in the LMB, therefore, appear to be quite significant and sustainable, and should be considered in any balanced assessment of dam impacts, which should also take into account that most of the yield is taken by the many unmonitored small-scale fishers. However, the figure of 240,000 t $year^{-1}$ from reservoirs quoted by Sverdrup-Jensen (2002) and others from Virapat and Mattson (2001) appears to be a misquote. The origin of the estimate of reservoir catches quoted by van Zalinge *et ah* (2004) is not clear.

5.3.2. Assessing the Impacts of Dams

The type and scale of impacts of dams vary greatly depending on baseline conditions at a location, the nature and size of the scheme, and mitigation and management measures adopted. Negative effects on downstream fisheries include the direct effects on productivity caused by trapping of nutrients and detritus, release of hypolimnetic water which may be anoxic and toxic due to the presence of hydrogen sulphide, rapid downstream water-level fluctuations caused by hydroelectric releases, and blockage of spawning migrations (Jackson and Marmulla, 2001; Kruskopf, 2006; Schouten, 1998). Fishing activities may also be impacted by water-level fluctuations. Because dams and weirs are so numerous and variable in the LMB, it would be unwise to generalize about the extent of the impacts of all existing dams, particularly as useful pre- and postproject data are almost nonexistent. However, the severity of the negative impacts is likely to depend on the size of the dam the size of the dammed watercourse, and the location of the dam relative to fish migration routes, valuable habitats, and settlement patterns. The Pak Mun dam was particularly controversial as it cut off Thailand's largest river system from the Mekong as well as submerging important spawning and feeding habitat for fish migrating from the Mekong (Amornsakchai *et ah,* 2000; Jutagate *et ah,* 2001). The Rasi Salai Dam, further upstream on the Mun, was also particularly poorly conceived, flooding extensive floodplain wetlands and the villages that depended upon them, as well as being sited on a salt dome (Sretthachau *et ah,* 2000). After long periods of protests by affected villagers the gates of both of these dams were opened, which allowed riverine fish to migrate past the dams 0utagate *et ah,* 2005), and in the case of Rasi Sali reduced the negative impacts on the diverse floodplain wetlands that had been submerged by the reservoir. The severe negative impacts of both dams could have been reasonably foreseen from their location on the mainstream of the Mun River in heavily settled locations.

The proposed mainstream Mekong dams are also likely to have very significant negative impacts. The dams proposed in upper Cambodia would be particularly damaging, causing direct interference to migration and spawning and recruitment to floodplains. Mainstream dams in the LMB would be >30 m high and would form reservoirs 75-200 km long (Roberts, 1995) transforming large reaches of the Mekong into standing water. Apart from the issues of location and size, the operational regime of dams varies greatly; fluctuating flows from hydroelectric releases are particularly damaging, as are accidental or emergency releases (Wyatt and Baird, 2007). Damming for interbasin diversions is also likely to be particularly damaging for river fisheries, because the flow of the dammed river is cut off while the channel and banks of the receiving river must erode to adjust to the increased flow. Recent interbasin schemes include Nam Theun to Hinboun, and Nam Theun 2 to Se Bang Fai, and Nam Song and Nam Leuk to Nam Ngum (Koizumi, 2006; Roberts, 2004; Warren, 2000; Watson and Schouten, 2001). Dams on the tributary rivers of major reservoirs (such as several that are being built upstream of Nam Ngum) are likely to impact spawning habitat and the inflow of nutrients and detritus that support reservoir fisheries.

The impacts of large dams on fish migrations are often discussed in environmental impact assessments (EIAs), and fish passes have been built in many countries (and on the Pak Mun Dam in the Mekong system) in an attempt to mitigate impacts. Apart from the technical difficulty of passing large numbers of fish, fishways are likely to be ineffective on large dams that modify the environment, so that conditions are no longer suitable for migrating fishes (Roberts, 2001a), as for example, when fish migrate upstream to spawn in rapids but find themselves in a large reservoir. Should fish manage to swim into tributaries and spawn, fish fry or larvae are unlikely to negotiate the downstream passage through the reservoir and turbines (Agostinho *et ah,* 2007).

Large dams are designed to cause permanent changes in the environment, so efforts to maintain the existing fish migrations are likely to be futile. If a large dam is to be constructed, mitigation should focus on those aspects where demonstrable benefits are likely to provide a reasonable return on investment, for example, maintaining water quality in the reservoir and in the discharge, and reregulation of the fluctuating flows which characterize hydropower dams. Impacts of dams and technical mitigation measures are discussed in detail by Jackson and Marmulla (2001) and Kruskopf (2006). Dams cause an unavoidable loss of production on downstream floodplains, which is likely to be roughly proportional to the reduction in the extent of annual flooding. The compensating effect of fisheries development in reservoirs varies depending upon the characteristics of the reservoir previously noted and management measures, such as fish stocking. The productivity of the large deep dams such as those built in China (Table 9.6) and those proposed on the mainstream and on some tributaries is

PLATE 1 Simplified tectonic map of Indochina with information drawn from various sources cited in the text but chiefly from Mouret (1994). The Indochina block sits between the South China Block to the north-east and the Central-Sunda Plate to the south-west. The boundaries between these three blocks are, respectively, the Red River Shear and the Danang Line in the north-east and the Rovieng, Pursat, and Sakeo Lines in the south-west. The possible former courses of the Mekong River are discussed in the text. (See Fig. 1 in Chapter 2, p. 14.)

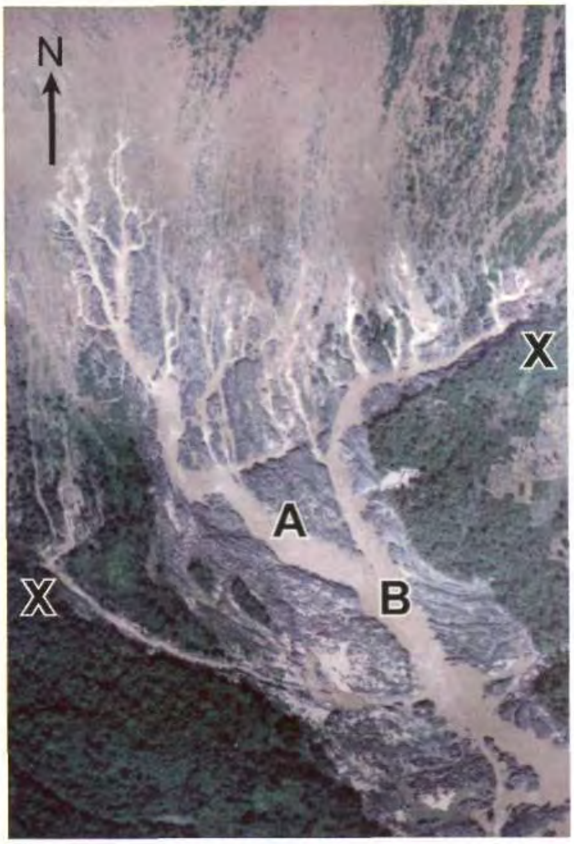

PLATE 2 Vertical view of anabranch of the Mekong River close to Kon Phapheng in Siphandone area, Laos. Structural lineations, aligned from top to center of the image and curving to the right in the lower portion of the image, control the alignment of small-scale rivulets and the avulsive channel within the forest on the far left. Major channels may conform to the lineation (A) or cut through the lineation (B) but are disrupted by a distinct fault line running obliquely across the image (X to X). From air photograph, 1993, 1:15,000. Horizontal field of view ~1.5 km. (See Fig. 2 in Chapter 2, p. 15.)

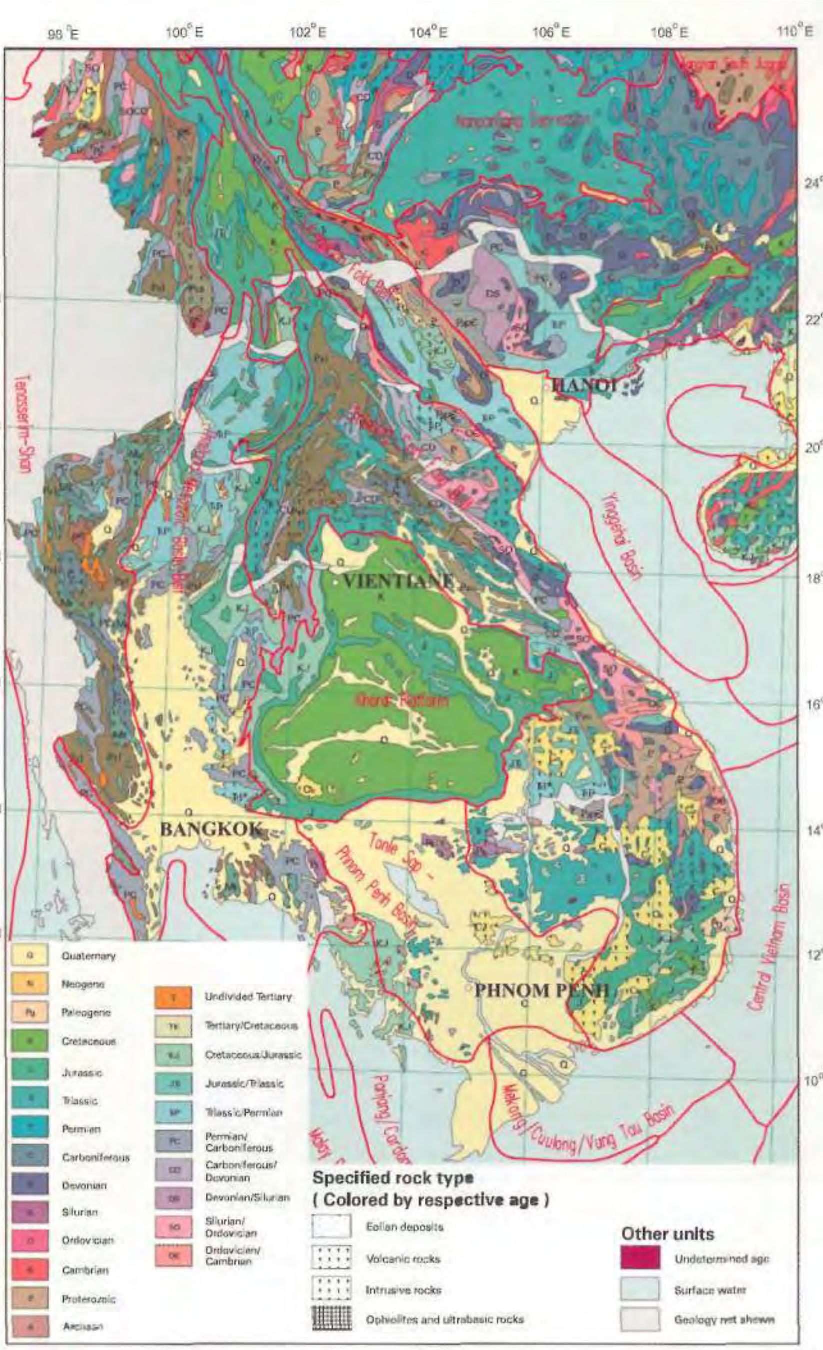

PLATE 3 Geological map of Indochina. Boundaries of the main geological provinces are shown as red lines. Scale: 1:5,000,000. Redrawn from Steinshouer *et al.* (1997). (See Fig. 3 in Chapter 2, p. 19.)

PLATE 4 The Mekong downstream of Chiang Saen, Thailand. The river is in rock with very little accommodation space for sediment. Photograph: Avijit Gupta. (See Fig. 2 in Chapter 3, p. 31.)

PLATE 5 Upper Mekong Valley near Er Lake. Photograph: Avijit Gupta. (See Fig. 6 in Chapter 3, p. 37.)

PLATE 6 Sediment stored in the channel and narrow valley of the Mekong. Photograph: Avijit Gupta. (See Fig. 10 in Chapter 3, p. 43.)

PLATE 7 Rock-cored islands showing sediment accumulation around a rocky barrier. Photograph: Avijit Gupta. (See Fig. 11 in Chapter 3, p. 48.)

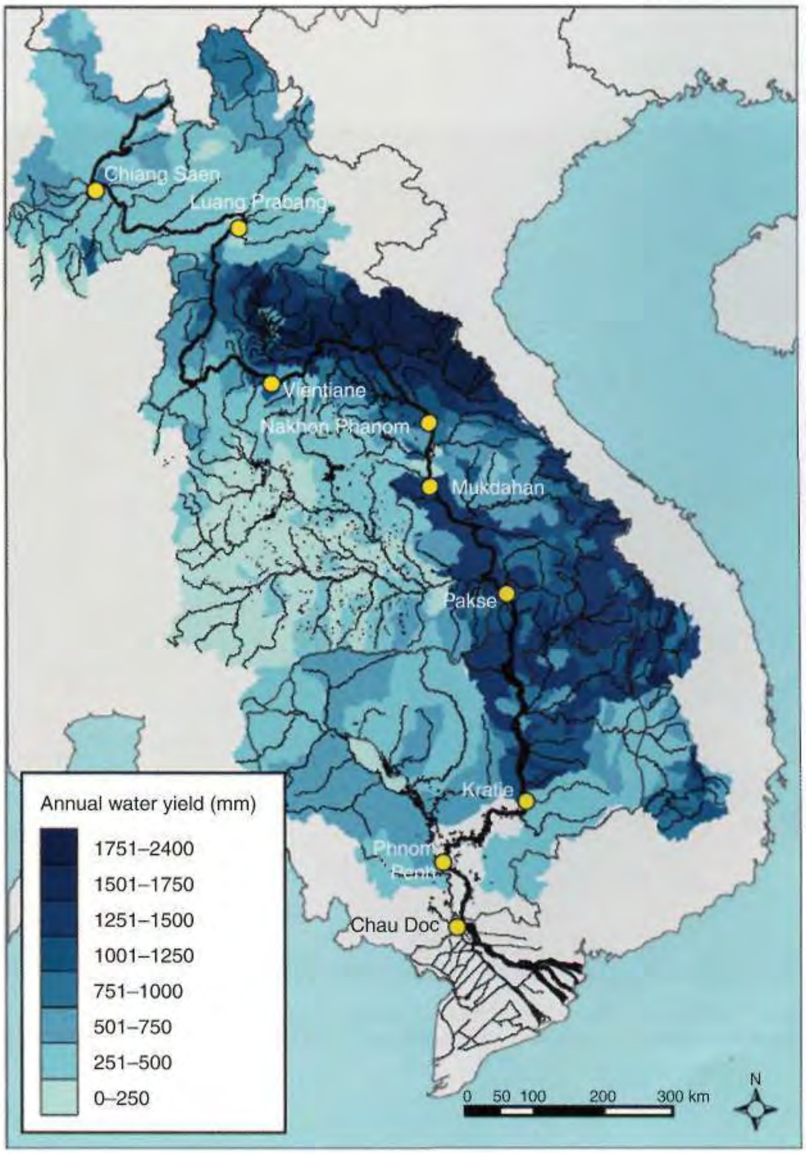

PLATE 8 Annual water yield of the Lower Mekong Basin (from MRC, 2008). (See Fig. 3 in Chapter 4, p. 58.)

PLATE 9 The blue area shows the extent of flooding in the Lower Mekong in 2006. The backflow into Tonle Sap is clear, as is the flooding at the upper end of the delta (Source: Dartmouth Hood Observatory image used in MRC, 2007). (See Fig. 5 in Chapter 4, p. 60.)

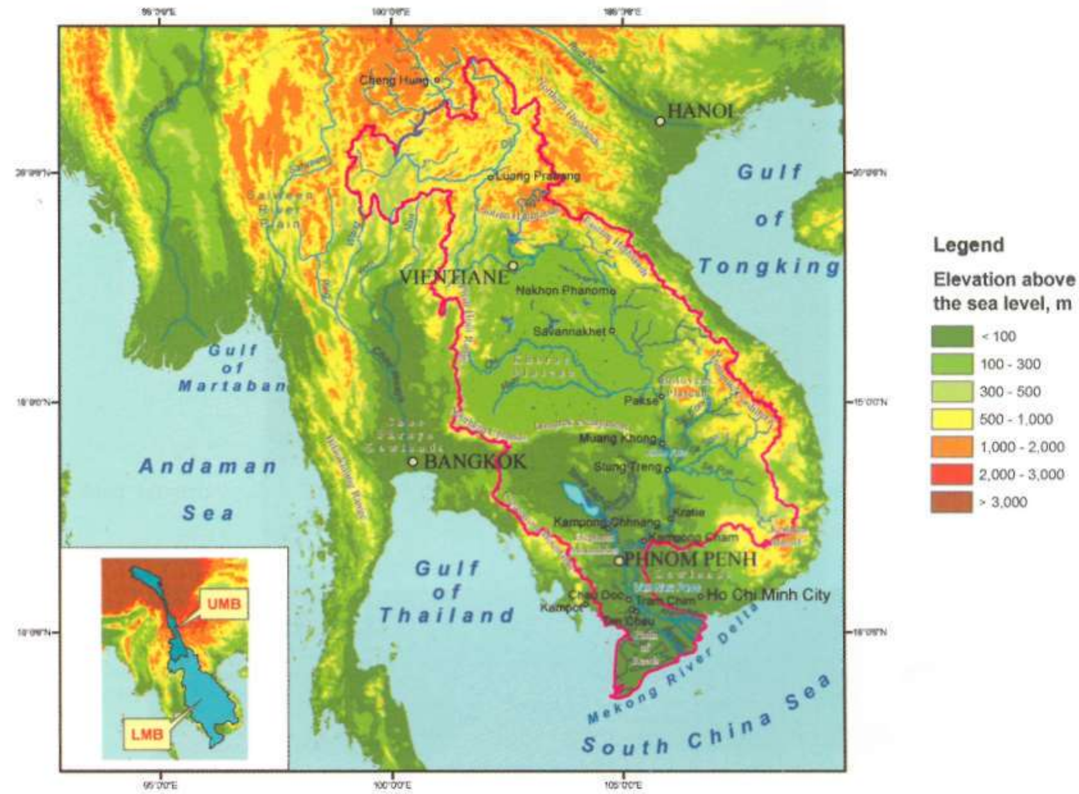

PLATE 10 Mekong River Basin: topography and major towns and cities along the Mekong River. (See Fig. 1 in Chapter 5, p. 79.)

PLATE 11 Anastomosed bedrock-controlled fluvial network—Siphandone. Landsat-7, horizontal field of view is approximately 40 km. (See Fig. 8 in Chapter 5, p. 89.)

PLATE 12 Oblique aerial view of 4000 islands reach of Mekong River (large island is approximately 900 m wide at widest point). Photograph: Stuart Chape. (See Fig. 9 in Chapter 5, p. 89.)

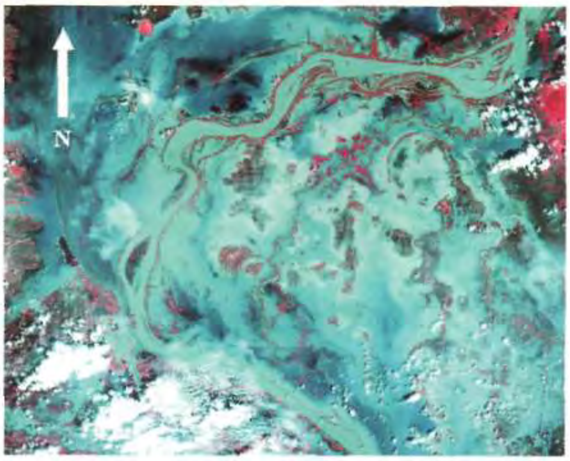

PLATE 13 Satellite image of the Mekong River during flood season in vicinity of Kampong Cham. Landsat-7: field of view approximately 45 x 45 km. (See Fig. 11 in Chapter 5, p. 91.)

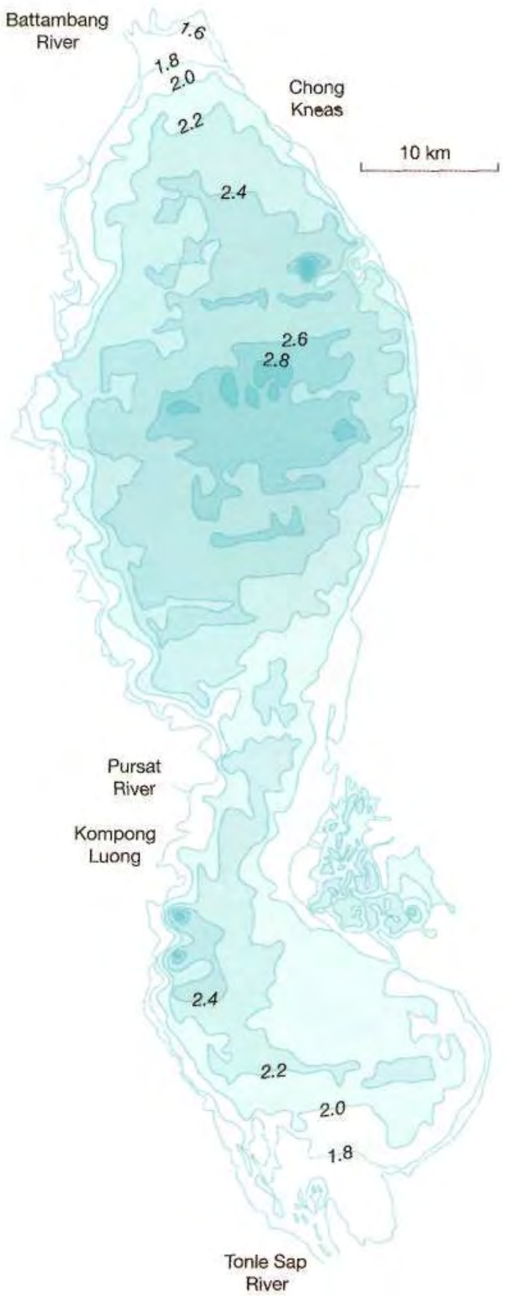

PLATE 14 Bathymetry of the Tonle Sap lake. Contours are in meters for dry-season water level. (See Fig. 13 in Chapter 5, p. 93.)

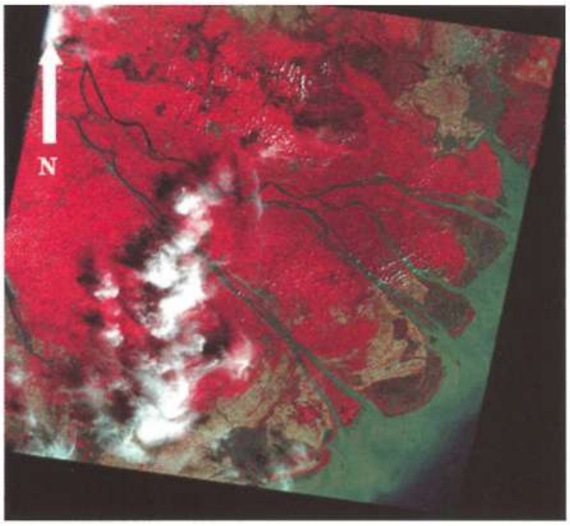

PLATE 15 Satellite image of the Mekong River delta—Landsat-7: 185 x 185 km. (See Fig. 14 in Chapter 5, p. 94.)

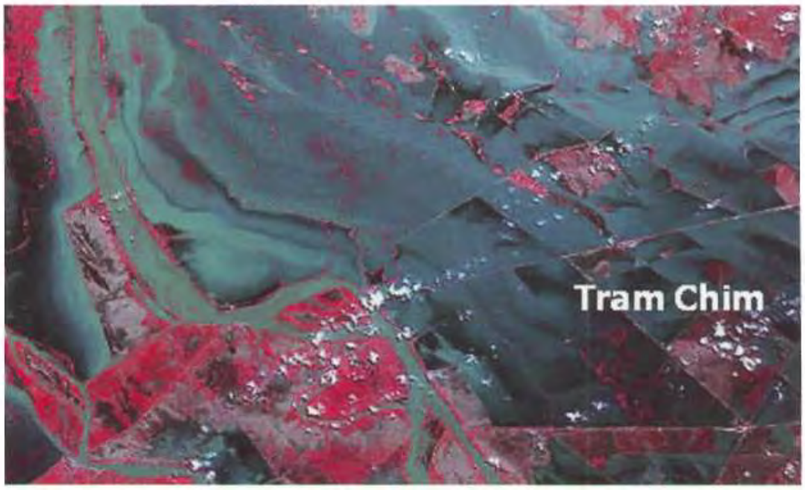

PLATE 16 Example of distributary channel and floodwater flow over the Plain of Reeds; 20 July 2000—Horizontal field of view approximately 25 km. (See Fig. 15 in Chapter 5, p. 95.)

PLATE 17 Distribution of wetlands (courtesy of MRC). (See Fig. 17 in Chapter 5, p. 97.)

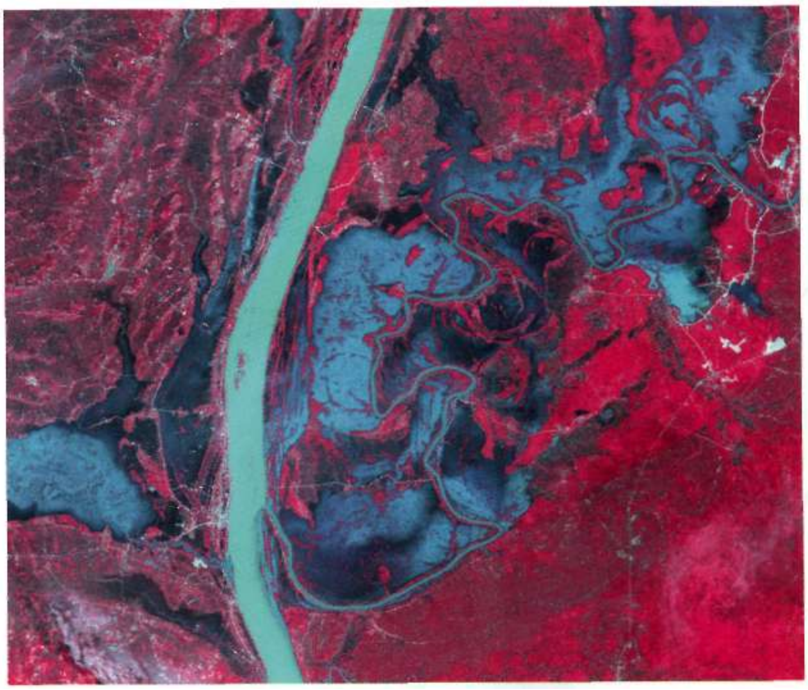

PLATE 18 Wetland inundation at tributary confluence with the Mekong River. Flow top to bottom of image. Landsat-7: field of view approximately 30 x 30 km. (See Fig. 18 in Chapter 5, p. 98.)

PLATE 19 Inundation of floodplain to left of riparian levee. Photograph: Joe Garrison, Garrison Photographic, Phnom Penh. (See Fig. 21 in Chapter 5, p. 102.)

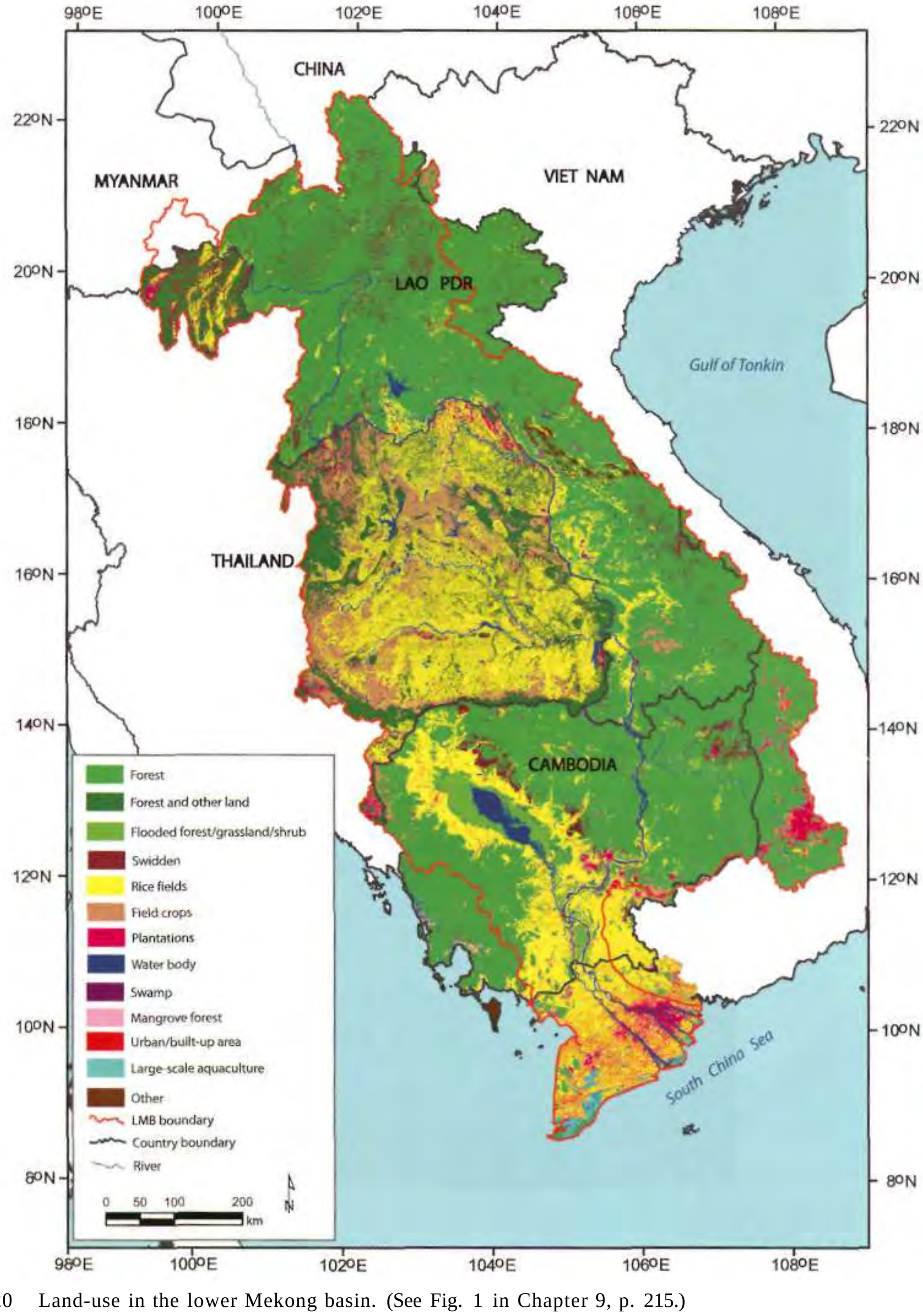

PLATE 20 Land-use in the lower Mekong basin. (See Fig. 1 in Chapter 9, p. 215.)

PLATE 21 Aerial photograph of flooded forest vegetation in the Battambang river area. Photograph: Joe Garrison, Garrison Photographic, Phnom Penh. (See Fig. 8 in Chapter 10, p. 263.)

PLATE 22 Fish traps at the mouth of the Battambang River in 2004. Photograph: Ian Campbell. (See Fig. 9 in Chapter 10, p. 265.)

PLATE 23 Irrawaddy dolphin calf from Koh Pidau Pool, Kratie Province, Mekong River. (See Fig. 2 in Chapter 15, p. 367.)

PLATE 24 An Irrawaddy dolphin from Kampi Pool, Kratie Province, Mekong River. The Irrawaddy dolphin *it* a charismatic mega-vertebrate species that is ideal as a flagship species in the Mekong River. Photograph: Yim Sak Sang (See Fig. 7 in Chapter 15, p. 384.)

unlikely to compensate for lost productivity on floodplains, because the water held in such deep reservoirs is spread over a relatively small area, and such dams stratify, with nutrients depleted as seston settles below a thermocline which develops at about 10-20 m depth (Sitthichaikasem, 1990).

Although the socioeconomic impacts of large dams are well documented (Lawrence, 2008), small dams and weirs that attract little publicity may have a large overall effect on system yield, and deserve more attention because they may also provide better opportunities for mitigation of negative impacts and for enhancing positive impacts, as well as being less socially disruptive than large dams. The impacts of small dams on capture fisheries may be a nett benefit in relatively arid lowland parts of the basin. For example, Schouten (1999) found, based on fisher interviews, that more species of fish (70 cf. 46) were present upstream of a dammed Tonle Sap tributary than upstream of an adjacent undammed tributary (the Stung Chinit), and he concluded that the shallow reservoir provided an important dry-season refuge. Subsequent rehabilitation of a reservoir on the Stung Chinit has led to perceptions of various negative impacts on fisheries by villagers as discussed by Arthur *et al.* (2006), but no actual catch data were collected, and increased access, population, and fishing pressure could also be causing changes; moreover, the entire system around the reservoir would take time to adjust.

In Thailand, two of the large LMB reservoirs were built to raise the water level (0.5-1 m) of natural swamps to support fisheries production (Table 9.6). Although no accurate data are available for total catches of these "fisheries" reservoirs, Nong Han is accessed by almost all nearby households for subsistence, and provides very large catches of fish and OAAs as well as a range of other wetland products (Pagdee *et al.,* 2007). Villagers in the lower Songkhram basin included improved water flows to swamps or deepening or raising small weirs as their first choice for improved fisheries management (Hortle and Suntornratana, 2008). In Laos, Khoa *et al.* (2005) found that catches in small irrigation reservoirs compensated for lost catches on rice fields. Local fisheries management of a small (28 ha) floodplain waterbody in southern Laos included installation of a sluice gate to maintain water levels (Tubtim and Hirsch, 2005). Overall, it is reasonable to conclude that dams that are small and shallow and weirs offer significant opportunities for conservation and enhancement of fisheries, because they provide dry-season refuges, potentially high productivity, an extended fishing season, and allow efficient fishing activities by small-scale fishers. As mentioned earlier, smaller schemes can be considered part of the rice field landscape, indicating the possible benefits of an integrated approach to development of fisheries and agriculture.

5.4. Mekong Delta and Estuary

The Vietnamese refer to the delta as *Cuu Long,* "Nine Dragons," because the river system is divided into nine main distributaries. The rivers have been interconnected to form a hydraulic network by large canals, mostly 50-60 m wide, the first of which were built in the early nineteenth century (Bourdeaux, 2005). The levees formed by canal spoil provide space for roads and settlements, and the canal construction allowed drainage of marshes, human penetration and settlement, and rice farming and fishing. Secondary canals (typically 10 m wide) and small tertiary canals further subdivide the landscape. Many of the canals have watergates that when opened allow drainage and ingress of water for irrigation but are closed to prevent floodwater intrusion. Pumps are used to drain canals when watergates are closed; hence, canals may be isolated from the river systems for months, reducing access for fish and fish fry. The canal system functions as a vast reservoir and distribution system for irrigation, and is also the basis for much transportation, including of fishery products and ice. The total length of canals is many thousand kilometres, for example, in Can Tho Province alone there are 4032 km of canals (Akira, 2005); and they occupy perhaps 3% of the delta's area, making them extremely important as an artificial habitat. A large fishery operates year-round in the canals and in the main river systems. Common commercial gears include trawlers (typically operated by two people), dai nets, lift nets, and brush parks. On many permanent watercourses, fish are held in cages underneath floating houses, and most commercial fishers transfer some part of their catch to cages for holding or grow-out. Fence net culture is also becoming common, and the edges of rivers are in many cases effectively enclosed and their use privatized for aquaculture. Most fish are transported alive to markets in locally made wooden sampans, either in containers or in the hull of vessels, through which water is exchanged.

Fisheries in the delta are increasingly integrated with agriculture and forestry. The VAC (Vuong-Ao-Chuong/Garden-Pond-Barn) system is one of the most common systems that integrates fruit trees, aquaculture, and pig farming. Rice-fish farming is also widespread in the delta, and rice alternated with shrimp farming is common near the coast, and *Melaleuca* trees are grown together with rice crops to improve soils in acid sulfate soil area. About 60% of the Vietnamese part of the delta is irrigated (MRC, 2003) from the canal system. During the flood season and for most of the dry season, water is fresh throughout the estuary, but late in the dry season river inflows into the canal network are less than irrigation withdrawals, so saline water is drawn inland up to 60 km, the limits of the "estuary."

The Mekong's freshwater plume extends up to 500 km into the south China Sea, so marine productivity is thought to be heavily influenced by river-derived nutrients, detritus, and sediment (Lagler, 1976a). Plankton and fish larvae biomass are highest at the edge of the plume during the flood season (Lagler, 1976a), consistent with more detailed studies that show the general importance of river plumes to nearshore productivity (e.g., Grimes and Finucane, 1991). Coastal fisheries depend upon this productivity, but nutrients are also recycled back to the river system, through food to the basin's population, as well as in the form of trash fish for aquaculture feed. Marine and estuarine fishes and other animals are likely to follow favored salinity levels, as well as the food chain that depends upon plankton that typically blooms where turbid nutrient-rich river waters meet clear, nutrient-poor salt waters. There is little quantitative information available on the estuarine fisheries of the Mekong delta; monitoring data are lacking and in socioeconomic surveys, it is not possible to separate the estuarine component of the inland catch (Sjorslev, 2002) or, in coastal areas, the marine component from catches (Phanh *et ah,* 2002).

About 60% of the area of the Viet Nam delta is underlain by pyrite-rich soils (Hanhart, 1997). Clearing and burning of *Melaleuca* forests by early farmers caused exposure and oxidation of pyrite generating sulphuric acid; soils became so acidic over a vast area in the northeast corner of the delta that only a single species of reed could survive, leading to its description as the Plain of Reeds (Hanhart, 1997). Birds and fish were scarce throughout the acid-affected areas, and the construction of new canal systems since the 1970s initially worsened acidity by exposing pyritic soil to oxidation, but eventually allowed flushing by alkaline river water (Anonymous, 1992b). Gradual improvement in pH and improved access via roads and canals have allowed development of agriculture, capture fisheries, and aquaculture. Acid drainage is still a major issue in many parts of the delta, and no doubt influences fish production, but specific details are lacking.

Most of the smaller coastal estuarine channels have been blocked by watergates, and large dykes have been built inland and near the coast (parallel to the sea) to control saline water intrusion which facilitates farming of rice as well as other crops, such as fruit trees and freshwater aquaculture. The most easterly of the nine main Mekong distributaries has been completely dammed by the Ba Lai dam at Ben Tre, closed in May 2002 to limit saltwater intrusion (Anonymous, 2002); the dam would also prevent migration of fish and OAAs, but no data are available on the impact on fisheries of this structure, which would include impacts on fish and shrimp migrating upstream as far as Laos. Since the 1990s, there has been an ongoing evolution of farming systems in the delta. In some areas, there were conflicts between farmers who wished to maintain freshwater conditions and those who preferred to allow the seasonal ingress of saline water so they could grow shrimp (Penaeid species) in brackish-water ponds or flooded rice fields.

5.4.1. Yield from the Delta

The upper delta is part of the lowland river-floodplain system, whereas the remainder of the delta comprises irrigated rice fields, plantations of fruit trees, brackish-water aquaculture ponds, and the estuarine and canal systems. Capture fisheries in the major flood zone are likely to yield 100-200 kg ha^{-1} $year^{-1}$ as discussed in Section 5.1.2. Yields from rice fields have probably been reduced greatly in some areas by intensification, but small-scale aquaculture and intensive fishing in canals would tend to compensate for losses. Marine coastal capture fisheries in the delta provinces were estimated to yield about 726,000 t $year^{-1}$ in 2004 (Truong *et al.*, 2008) of which a large proportion is trash fish that supports aquaculture production. As discussed in the following section, the highest yielding aquaculture systems are in the delta.

5.5. Upland Fisheries

Uplands that are undulating, hilly, or mountainous land at altitudes greater than about 300-400 m, make up about 40% of the LMB corresponding approximately to land classed as forest in Table 9.1. Much of the forest is secondary regrowth, gardens and, particularly in Thailand, includes some land converted to plantations. People are mainly concentrated along streams or highland valleys, where rice and plantation crops are grown, with swidden or shifting cultivation common on hillsides. Major tributaries flow from the northern highlands in Laos and the Annamite chain in Laos, Cambodia, and Viet Nam while smaller highland tributaries run from the southern uplands in Cambodia toward the Tonle Sap. Rainfalls in mountainous areas are generally higher than the average of the Mekong catchment, so for example, the Se San-Se Kong-Sre Pok, the largest tributary system, contributes about 21% of the total annual flow of the Mekong from only 10% of its catchment area (Pantulu, 1986a). In general, tributaries with large upland catchments have less seasonally variable flows than many purely lowland systems as a result of more even rainfall, and forested and often karstic catchments; they are also relatively clear and cold with a range of in-stream habitats that favor specialized species.

The distribution of fish and other aquatic animals within tributaries is not well-described, but the results of several surveys suggest that lowland Mekong species are found in their lower reaches (which can be considered part of the entire lowland river-floodplain system), some generalist species are found throughout tributaries, and some species (including endemics) are restricted to particular reaches (especially headwaters) or particular habitats, for example, rocky fast-flowing reaches, or caves as for the Nam Theun and Xe Bang Fai Rivers (NT2PC, 2006; Roberts, 2004). In some Lao tributaries, lowland species migrating upstream may be blocked by natural barriers such as waterfalls or cascades (Noraseng and Warren, 2001; Warren, 1999) and some karst rivers flow through cave systems that may also block migrations (Shoemaker *et al.*, 2001). Fish species diversity usually declines with altitude because of the smaller size of streams, lower temperatures, and a more restricted range of habitats (Welcomme, 1985), but the relationship between altitude or stream size and fish diversity in Mekong tributaries has not been well documented. In the Nam-Theun-Xe Bang Fai system, Kottelat (1996) recorded 38-41 species per lowland site near the Mekong and 3-16 species per site in highland upstream of the Nam Theun 2 dam site.

Swidden agriculture is expanding and fallow periods are decreasing, increasing erosion and probably affecting the water quality of rivers (Sjorslev, 2000; Sprenger, 2006). People who live along streams typically erect barriers to divert fish and other aquatic animals into traps, clear streamside vegetation, and build small weirs to divert water into ponds and rice fields (Choulamany, 2005). As temperature declines with altitude, stocking of exotic temperate or subtropical fishes (such as carp or goldfish) in ponds in highland areas is also common (Choulamany, 2005; Funge-Smith, 1999b). There are no systematic studies on the overall effects of such small-scale but very extensive environmental modifications, but it can be assumed that indigenous species and stream and river fisheries would generally be negatively impacted by the environmental changes. On the other hand, fisheries production is enhanced by weirs and ponds functioning as dry-season refuges (Choulamany, 2005), and ponds and rice fields provide new habitats for fisheries production. Stocked highland rice fields, for example, may produce about 199 kg of fish per hectare per year (Funge-Smith, 1999b).

Some isolated and relatively unpopulated upland tributaries are lightly fished because access is poor or restricted by unexploded ordinance, and fishing is difficult in some large, rapid, and inaccessible rivers, particularly in the wet season, which may lead fishers to use explosives or longlines (NT2PC, 2006). Upland rivers are also inherently less productive for fisheries than the large lowland rivers that are connected to active floodplains, which provide a greatly increased area for aquatic production during the annual flood pulse.

There are few specific details on the fisheries of upland sections of most tributaries; even fish distribution records are found mainly within EIA-related studies for hydroelectric dams, and most information is not readily available (Warren, 2000). One ground-breaking survey covered upland fisheries of Luang Phabang, a rugged mountainous province (247-1600 m) in northern Laos (Sjorslev, 2000). Although rice and livestock farming were the most important activities, 83% of households (42% of people) engaged in capture fisheries, with the focus of most fishing effort from rivers and small streams and producing 90% of reported catches, the remainder being caught in rice fields (7%) and ponds (3%). Although villages in this province are concentrated in valleys, even highlanders go fishing (including collecting aquatic animals). Recent catches included at least 73 taxa covering a wide range of mainly white fishes, and only two exotic species—Nile tilapia and common carp—were reported, both escapees from pond aquaculture. As is commonly found in more well-studied lowland fisheries, villagers used a wide range of gears—cast nets, gill nets, scoop nets, hooks, traps as well as collecting by hand, with the methods varying with habitat. Fishing effort varies about twofold through the year, peaking at the driest time when fish and other aquatic animals are most concentrated. This highland fishery also showed the usual gender division in which about two-thirds of fishing trips are made by men. Fish and other aquatic animals provided around 20% of total animal protein intake, ranking equally with beef and pork. Other aquatic animals represented about 15% of the weight reported for recent catches. Choulamany (2005) and Meusch (2005) described various aspects of the fisheries of highland rice fields in Laos and northern Viet Nam, respectively, and list fishes, amphibians, reptiles, crustaceans, molluscs, and insects caught or cultured in rice field farming systems. Fisheries are important in these more settled areas, based predominantly on rice fields and associated habitats. The perceptions of villagers are similar to those often noted in lowland surveys; for example, declining catches per fisher are attributed to habitat changes and increasing numbers of fishers (Choulamany, 2005). In response to the perceived decline in fisheries, communities have implemented local regulations controlling fishing, and they stock exotic species in ponds.

In the highlands of Viet Nam, there is little information on the fisheries within the river systems, except for that of Lak Lake, the largest waterbody in the province (658 ha). Lak Lake lies at a relatively low altitude (~300 m) within a natural floodplain of a Sekong River tributary and supports an intensive fishery, with catches comprising approximately 50% indigenous floodplain and river fishes, one-quarter shrimps and the remainder mainly self-recruiting introduced species (Thai *et ah*, 2001). In this region, there are many small irrigation reservoirs—about 500 with a total surface area of 105 km^2 in the main province, Dak Lak (Ly *et al.*, 2006), and more than half the reservoirs are less than 10 ha in area (Phan and Sollows, 2001); smaller reservoirs have larger catch per unit area.

Hydroelectric dams have been built on several tributaries in Laos and Viet Nam, and because of their elevation and large size all major tributaries are currently the subject of development or feasibility studies for further hydroelectric dams (Chantawong, 2006; Lawrence, 2008). Reports of negative impacts of tributary dams on downstream fisheries have been widely documented, with transboundary impacts of particular concern (e.g., Wyatt and Baird, 2007). Upland people are disproportionately swidden farmers from ethnic minorities and are generally poorer, less literate and less educated than people from the dominant lowland groups, who immigrate to work on dam projects and who may stay and capture ongoing benefits from the project, including the new reservoir fisheries that require capital and technical know-how.

5.6. Fisheries in the Upper Mekong Basin in China

The upper Mekong, or Lancang, runs from tributaries on the Tibetan Plateau in Qinghai and the Tibetan Autonomous Region (TAR) (formerly Xizang) through Yunnan (Chapter 14). The catchment is relatively narrow and steep, highly dissected and erosional; contributing about 16% of river flow but a high sediment load. Southern Qinghai, where the Mekong rises, is a high grassy plateau, mostly at about 3500 m ASL, with peaks to 6500 m, with glacier fields which are an important source of melt-water during the dry season (MRC, 2005). Six large high-altitude natural fold-fault lakes in Yunnan along the main eastern Mekong tributary, the Ehr (or Yangpi) River, have a combined surface area of 273 km^2; the largest, Lake Erhai covers about 259 km^2.

Although mean population density of the Upper Mekong Basin (UMB) is relatively low, settlements are concentrated on the limited areas of flat land near lakes and along rivers, and in forested areas in southern Yunnan, where swidden cultivation extends onto steep hillsides (Heinonen and Vainio-Mattila, 1997). Terraced rice paddies are a dominant land use on flat or gently sloping land throughout the province; rice fields and associated habitats generally support productive fisheries, as is documented in southern Yunnan by Luo (2005).

High altitude and latitude lead to low temperatures in the Mekong and tributaries, which, together with swift currents and elevated sediment concentrations restrict colonization by the diverse lowland tropical fauna of the Lower Mekong. Conversely, most animals adapted to these elevated conditions are not found in the lowlands downstream. About 140 fish species are now recorded from the Mekong system in Yunnan (Chapter 8); an earlier review by Yang (1996) recorded 130 species. The fish fauna is allied to both the Chinese and Mekong (lowland Indochinese) faunas, but the fauna is less diverse and more specialized than that of the Lower Mekong. Fishes of the rivers and streams of Yunnan's mountainous environment are adapted to high and variable flows and include specialized fast-swimming cyprinids *(Cyprinus, Garra,* and *Onychostoma* spp.) and montane species of loaches (Balitoridae) and catfishes (Siluridae and Sisoridae), which are adapted to live on or within stony substrata (Yap, 2002). Yunnan's lakes have been colonized by river fishes, some of which have evolved into specialized endemics, including pelagic "snow trouts" (Cyprinidae, Schizothoracinae) and spring fish, *Cyprinus* species. These endemic fishes were the target of important fisheries, but they have been affected by eutrophication and competition from exotic fishes that were introduced to boost fisheries productivity since the 1950s. Temperate herbivorous species introduced to most Yunnan lakes include silver carp *(H. molitrix),* bighead *(Aristichthys nobilis),* and grass carp (C. *idella)* (Xie *et al.,* 2001). Lake Erhai was formerly oligotrophic (Hsiao, 1946), but is now eutrophic as a result of pollution from a large paper plant and other industries; its indigenous fishes are extinct or close to extinction, and have been replaced by pollution-tolerant introduced aquaculture species, including cyprinids such as crucian carp, *Carassius auratus;* common carp, *Cyprinus carpio;* the Chinese false gudgeon, *Abbottina rivularis;* as well as the small short-lived ice fish, *Neosalanx pseudotaihuensis* (Salangidae) (Yan and Chen, 2007). Pollution, eutrophication, and replacement of indigenous fish by exotics appear to be common phenomena in lakes inYunnan (Kong *et al.,* 2006; Whitmore *et al., 1997;* Xie *et ah,* 2001).

Four small hydroelectric dams have been built on the Yangpi River, and four major dams have been built on the Mekong (Table 9.7), with several more dams under construction or planned. Large dams on the Mekong mainstream have limited value for fisheries because they are in narrow, steep-sided gorges, which form deep but unproductive water bodies. Moreover, the sides are prone to landslides and slumping into the reservoirs which together with natural sediment loads and erosion caused by settlement lead to high turbidity as has occurred at Manwan (Fu and He, 2007). As Roberts (2001b) predicted, Manwan is filling much faster with sediment than the dam builders expected (Fu and He, 2007), which is reducing its functionality and depriving the downstream Mekong of sediment. Naturally unfavorable conditions for reservoirs on this part of the Mekong are exacerbated by an influx of settlers that leads to increased erosion and pollution from industries (He, 2004).

Upstream of Yunnan in the Lancang River system in the TAR and Qinghai, Walker and Yang (1999) list only eight species of fish, of which six are also found in Yunnan (Table 9.9). Few fishes can tolerate the extreme conditions at high altitudes, and some of the recorded species may be found upstream of Yunnan only at certain times. All those recorded are small species (<31 cm maximum length) and only the snow trout, *Scizothorax lantsangensis* is noted as important in fisheries of the Lancang in Qinghai; steep gorges make access difficult, and

TABLE 9.9 Fishes recorded from the Upper Lancang River in Qinghai, China (from Walker and Yang, 1999)

Family	Subfamily	Species		Note	Maximum length (cm)
Balitoridae	Nemacheilinae	*Triplophysa microps*	(Steindachner, 1866)	Also in Yunnan	**6.8**
(River loaches)	(Stone loaches)	*Triplophysa orientalis*	(Herzenstein, 1888)		14.2
Cyprinidae	Schizothoracinae	*Gymnocypris potanini*	(Herzenstein, 1891)	Also in Yunnan	**16**
(Barbs, carps)	(Snow trouts)	*Diptychus kaznakovi*	(Nikolskii, 1903)	Also in Yunnan	30?
		Schizothorax lantsangensis	(Tsao, 1964)		31.1
		Schizothorax lissolabiatus	(Tsao, 1964)	Also in Yunnan	**30**
Sisoridae	Glyptosterninae	*Pareuchiloglanis gracilicaudata*	(Wu and Chen, 1979)	Also in Yunnan	15?
(Sucker catfish)	(Hillstream catfishes)	*Pareuchiloglanis kamengensis*	(Jayaram, 1966)	Also in Yunnan	15?

ethnic Tibetans do not have a fishing tradition. In all of the water bodies of the Qinghai-Xizang plateau, there are 112 native and 17 introduced species, so more species may be found to be present in the Lancang, which is poorly surveyed (Walker and Yang, 1999). Lake fisheries are important in the north of Qinghai, outside the Mekong catchment.

There is little published information on fisheries activities in the UMB in China. Heinonen and Vainio-Mattila (1997) visited villages near nature reserves in Yunnan and observed that hunting was more important than fishing, but that most people went to fish in nearby rivers when they had time, and that nets, electricity, and poisoning were all used. Baran *et al.* (2007a) concluded from personal observations that fishing is "not a dominant activity in this region." This contrasts with the findings of Luo (2005), based on a 3-month survey in Xishuangbanna, the most densely populated part of Yunnan, that wild fish and OAAs caught in rice fields and rivers are important throughout the region in people's diet and as a source of income. In rice fields alone, 60 fish species were recorded, as well as frogs, snails, crabs, and shrimps. Overfishing and illegal fishing using electrofishing, poisoning, and explosives, as well as impacts of agricultural intensification appear to be impacting fish production. The most important species caught or cultured now in the villages surveyed by Luo were exotics, including the African tilapias *Oreochromis mossambicus* and *Oreochromis niloticus* as well as the golden apple snail *Pomacea canaliculata.* Aquaculture is expanding, even at altitudes up to 1200 m ASL, reportedly producing over 12,000 t year^{-1}, mostly from ponds, but also with significant production from rice-fish systems.

According to official statistics, the Chinese provinces of the MB contribute a low proportion of the total Chinese inland fisheries production of about 17 Mt year^{-1} (2.5 Mt year^{-1} from capture and 15 Mt year"^{1} from culture). According to Xie and Li (2003), in all of Yunnan, capture fisheries produce about 20,000 t year"^{1}, but this figure is likely to be an underestimate, as is usual for capture fishery statistics which may understate commercial catches and which do not include catches by small-scale family and artisanal fishers (Coates, 2002). About 80,000 ha in Yunnan is devoted to aquaculture; assuming a mid-range productivity of 2.5 t ha^{-1} (based on fig. 9 of Xie and Li), aquaculture might add 200,000 t $year^{-1}$ to the province's production. Most of Yunnan lies outside the MB, so the total fisheries production in the Chinese part of the MB is likely to be less than 100,000 t $year^{-1}$ or less than 4% of the 2.6 Mt $year^{-1}$ estimated as the total yield from the LMB by Hortle (2007). In Qinghai and in the TAR of MB, fishery production figures were not reported by Xie and Li, but presumably would add little to the total estimate.

Although river/floodplain fisheries may be of limited direct importance, the Chinese portion of the UMB is of great significance to fisheries in the downstream countries. The effects on hydrology and water quality of the existing and planned cascade of dams are discussed in Chapter 16. Such changes will have direct effects on all components of aquatic ecosystems, and a wide range of negative effects on fisheries has been predicted (Roberts, 2001a), but no field data are available which would allow an objective evaluation of the effects of these dams. Of particular concern are direct and indirect effects on fish migrations and spawning. In northern Laos, many fish species migrate upstream along the Mekong and presumably some would have moved into China each year to spawn (Poulsen and Viravong, 2002); annual upstream migrations would be consistent with the patterns observed elsewhere in the basin and in other well-studied river fisheries. The longest postulated migration is that of the giant catfish *(Pangasianodon gigas)* which Smith (1945) believed, based on observations by Pavie in 1904, migrated annually from the Cambodian floodplains upstream via the Mekong into China to spawn in Lake Erhai. The existing dams have already cut off the route for all such migrations before they could be documented in any systematic way, so it will never be known which species migrated into China or to what extent their recruitment downstream has been affected. Operation of the four completed dams causes dramatic diurnal variability in flows, which based on many studies elsewhere would be expected to affect migration triggers for fishes downstream (Baran, 2006). Apart from the likely impacts of dams, much concern has been expressed about the effects of clearing of shoals to improve navigation; based on other studies, a wide range of negative effects has been predicted on fisheries in the vicinity and downstream (Roberts, 2001a). The EIA work associated with the project is of little value in predicting impacts (Finlayson, 2002; McDowall, 2002; Roberts, 2001a), and no field data to quantify the effects have been collected.

Apart from fish, Yunnan supports many species of other aquatic animals, such as crabs, shrimps, molluscs, frogs, and turtles; diversity is likely to be high, as has been noted for many groups of land vertebrates by Yang *et al.* (2004). For example, in the MB in southern Yunnan, 13 species of shrimp are recorded (Cai and Dai, 1999), but there is little information on most groups of aquatic animals (Campbell, 2001) or on their importance in fisheries in the region. Significant resources should be devoted to monitoring the effects of ongoing hydrological and land-use changes on fishery species and fisheries to document their value and to evaluate the effectiveness of any management measures.

6. AQUACULTURE

Aquaculture in the LMB includes production and sale of fry or fingerlings, raising of fry produced by hatcheries, raising of wild-caught fry, and grow-out of wild-caught fish. Freshwater aquaculture is practiced in ponds, rice fields, and in cages or fenced-off areas in rivers. Brackish-water aquaculture is practiced along the coast in the Viet Nam delta in ponds and tidal flats.

Aquaculture was not common when populations were small and wild fish were abundant. Aquaculture typically develops along a path of "intensification and enclosure" which parallels population growth and the modification of landscapes, including the expansion of agriculture, especially rice farming and water management. Aquaculture is rarely a totally separate activity from capture fisheries. In its simplest form, wild fish or fry are caught and "grown-out" or reared in cages or ponds, a common practice of commercial fishers, particularly in the delta in Cambodia and Viet Nam. Typically catches are divided; large high-value fish are sold, small low-value fish are eaten in the fishers' households, and "trash fish" are fed to other fish that are being grown-out. Feed may also include leftover food or offal from animal or fish processing as well as farm wastes. Where aquaculture is promoted as a separate or even "new" activity for farmers, the linkages with wild capture fisheries remain: "self-recruiting" fish are usually present in ponds, broodstock or fry may be caught from the wild, "trash" fish are used to feed captive fish, and wild fisheries are impacted by competition for space and water, the enrichment or pollution of water by feed and waste, and by escapes of aquaculture fish. Aquaculture is unlikely to ever substitute for the capture fishery, because much of the aquaculture production is based on conversion of wild-caught fish, with a proportion lost in the process. Moreover, aquaculture requires much greater investments in capital and labor than capture fisheries, so increased production by a household may not translate to a proportional increase in profitability.

Exotic species were widely adopted during the 1960s as techniques for their culture were well-known. They include primarily herbivorous species such as the Indian and Chinese major carps, large fast-growing fishes which include species that efficiently convert phytoplankton to edible biomass. Some of these carps are likely to be substituted by native species as culture techniques are refined. Other stocked species include Nile tilapia *O. niloticus* and its hybrids, African walking catfish *(Clarias gariepinus)* and its hybrids, and South American pirapitinga *Piaractus brachypomus* and pacu *Colossoma macropomum,* which originate from dilute acidic blackwater areas making them suitable for aquaculture in some parts of the delta.

Domestication of some important Mekong species has been achieved quite rapidly and research now centers on improving strains for maximum yield (Froese and Pauly, 2008; MRC, 2003). Pangasiids are particularly promising as several species are air-breathers that tolerate extremely high densities under intensive culture (Trong *et al.,* 2002; van Zalinge *et al.,* 2002). Three giant species (giant carp *Catlocarpio siamensis,* giant catfish *P. gigas,* and Jullien's barb *Probarbus jullieni)* are regularly stocked in ponds and small reservoirs (Mattson *et ah,* 2002). Progress is also being made in techniques for culturing a range of other indigenous species (Cacot and Phengarouni, 2006; Dang *et ah,* 2005; Nuanthavong and Vilayphone, 2006; Prasertwattana *et al.,* 2006; Singsee *et ah,* 2003; Trinh *et al.,* 2006).

Aquaculture development has been most intense in the Mekong delta, where flat terrain, year-round availability of water from the canal system, and settlement patterns favor intensification of production. Recently, integrated agriculture-aquaculture (IAA) systems have been promoted to support smaller scale aquaculture within agricultural systems. IAA aims to minimize nutrient losses from a farm, through concentrating wastes and manures in fish ponds or trenches, where they support a crop of fish, and from which sludge is periodically removed and recycled onto fruit trees or other crops (Nhan *et al.,* 2007). By contrast, larger commercial systems are usually flow-through, which leads both to inefficient use of nutrients and pollution of downstream water bodies.

6.1. Aquaculture Yield

Aquaculture systems range from extensive stocking with no or little feeding at low intensity to intensive systems involving very high densities of aquatic animals that are fed frequently to maximize growth rates. Small-scale aquaculture typically produces less than 1 tonne ha^{-1} from ponds, while intensive systems for shrimp produce up to 9 t ha^{-1} of ponds, and intensive *Pangasius* catfish culture produces up to 1000 t ha^{-1} (Anonymous, 2007). Reliable and up-to-date figures for the actual extent of aquaculture and production figures are only available for official aquaculture for the Viet Nam delta (Truong *et ah,* 2008) and indicate an average yield across all systems (including cage culture) of 1.2 t ha^{-1} $year^{-1}$.

Phillips (2002) estimated that aquaculture production in freshwaters of the LMB had grown from about 60,000 t $year^{-1}$ in 1990 to 260,000 t $year^{-1}$ in 1999/2000, with a further 135,000 tonnes estimated to be produced in brackish-water aquaculture, of which about 72,000 tonnes was high-value shrimp. A significant proportion of brackish-water production was exported, so aquaculture appeared to account for about 10% of the total estimated LMB consumption of 2.6 Mt $year^{-1}$ in 2000 (Hortle, 2007). However, the official figures used by Phillips include commercial production and understate or ignore household production. Small-scale or artisanal aquaculture is common throughout the basin, most often in ponds, and commercial aquaculture is most developed in Thailand and Viet Nam. About 6-8% of rural households are engaged in aquaculture in Thailand and Laos (Phillips, 2002); in Cambodia up to 5% of households and in the delta in Viet Nam 14-61% of households are engaged in aquaculture (Hortle, 2007).

Household surveys suggest that aquaculture contributes less than 10% of the total yield in Cambodia and Laos (e.g., Ahmed *et ah,* 1998; Sjorslev, 2000). In the lower Songkhram basin (northeast Thailand), where a large river-floodplain fishery persists, about 10% of total production was from aquaculture (Hortle and Suntornratana, 2008); elsewhere in Thailand, the proportion may be higher, but is not known because reservoirs and rice field habitats may be the main sources of production. However, in the Viet Nam delta, aquaculture's contribution to total yield varies between about 30% in Long An (Pham and Guttman, 1999) up to 80% in Tien Giang (Setboonsarng *et ah,* 1999), with a mean contribution of about 50%, including data from Tra Vinh and An Giang (Phanh *et al.,* 2002; Sjorslev, 2002). People in the delta consume about 30% of the basin's total inland fish and OAAs (Table 9.3), implying a minimum basinwide contribution to consumption of about 15% from aquaculture, so the overall contribution could be up to 20%, allowing for about 10-20% of Thai consumption (basinwide proportion 35%) being aquaculture-derived.

The area under aquaculture systems in the delta expanded from about 5% in the early 1990s to about 15% by 2004 and about 75% of this area is devoted to shrimp farming (Truong *et al.,* 2008). The total official aquaculture production in the delta increased to about 800,000 tonnes by 2004, of which about 60% was freshwater (mostly catfish) and of the remainder about 70% was shrimp. Most of the production was exported and shrimp provided the most revenue (Truong *et al.,* 2008). Aquaculture continues to expand, and production of Pangasiid catfishes has grown to about 1 Mt $year^{-1}$ (Anonymous, 2007), implying that total aquaculture production in the delta could now be about 1.5 Mt $year^{-1}$. Most of the recent increase in catfish production is based on intensive systems which provide high yields per unit area. Pond culture yields 50-300 t ha^{-1}, net pens along river banks yield 1000 t ha^{-1}, and fish may be grown in cages at densities of 100-300 kg m^{-3} (Anonymous, 2007).

7. MANAGEMENT OF FISHERIES

Fisheries laws within each LMB country (in draft in Laos) provide national governments with ownership of "living aquatic resources" on public land and waters, and the ability to regulate and license their exploitation. National objectives of fisheries management include conservation, promotion of aquaculture, improved efficiency, disease control, and "sustainable fisheries development."

Preventing conflicts within the sector requires, however, more focused objectives that clarify the balance between potentially competing (or interfering) activities, for example, capture versus culture fisheries, small- versus large-scale fishers, and internal consumption versus export. The importance of transboundary migrating species and the large-scale ecological linkages in the system imply a need for much more specific objectives than simply promoting "sustainable development." Technical measures include managing fish (e.g., by stocking), managing the environment—water and habitat, or managing fishers and their activities. The specific measures depend upon local conditions and particular objectives; for example, to maximize catches and spread the benefits among poor people, few restrictions may be applied in river-floodplain fisheries, as such systems can withstand heavy fishing pressure. If maximum value is desired, various restrictions (i.e., managing the fishers) may reduce "fishing down," thereby reducing the total catch but increasing the catch of large and valuable fish. Stocking of some species may augment catches in both situations, particularly if certain niches can be filled. In most situations, however, managing the environment is of primary importance as is well-known to MB peoples, who apply various aphorisms to describe the dependence of fish on water and habitat, for example, *where there is water there is fish* in Khmer. Many recent surveys record that people throughout the basin perceive an ongoing decline in fish catches, and generally wish to correct the situation by applying measures that restrict certain fishing activities or modify aquatic systems to increase fish abundance and growth. Until recently, however, government policies have largely not taken into account the opinions of the primary resource users. Governments assumed that capture fisheries will inevitably decline, and have promoted aquaculture as a solution.

Large or middle-scale gears and small trawlers are licensed in well-defined and productive fisheries—the Cambodian floodplains, some reservoirs, and rivers and canals in the Viet Nam delta, but the licensing system collects very little revenue in comparison to the value of the resource (Touch and Todd, 2003). In practice, most fisheries have become "open-access" to small-scale fishers, with very limited enforcement of regulations or active management of habitat for fish. Open-access tends to lead to the well-known "tragedy of the commons," in which individuals maximize their catches because any benefits from conservation are unlikely to accrue to them personally, leading to ever-increasing fishing pressure (Hardin, 1968). Ownership of fisheries resources on seasonally flooded land (the largest area of aquatic habitat) is ambiguous under national laws. Landholders have little incentive to improve habitats (such as refuge ponds or small watercourses) on their land if others derive the benefits, so they generally prefer to invest in measures that increase agricultural output (such as higher yielding plant varieties supported by pesticides), even if fisheries yield is reduced.

Given the huge variation in ecological and socioeconomic conditions, national governments cannot define objectives or management measures which will be appropriate at each locality and which can be adjusted in a timely manner to suit changing conditions. Comanagement—governments and communities working together—has been increasingly promoted throughout the basin (Hartmann, 2000). Comanagement delegates authority to users (often by formalizing traditional ownership) to set local objectives and to devise and test the best mixture of technical measures through a process of adaptive management. Government's role is to legislate some commonly agreed rules and create mechanisms for local management, as well as to provide technical and financial support to communities and to assist with enforcement and conflict resolution. For comanagement to succeed, many conditions must be met; these include clearly defined boundaries, clearly defined membership, the benefits to individuals must exceed costs, management rules must be simple and enforceable by the community, and cooperation at leadership and community levels is necessary (Pomeroy *et al.*, 1998).

Comanagement has been quite successful in some reservoirs, partly because boundaries are clear and fishing activities are observable (Hoang *et al.*, 2006; Nguyen *et al.*, 2003; Niphonkit *et al*, 2008). Similarly, in the Viet Nam delta, comanagement has recently had success in a rice-shrimp-farming area (Nguyen *et al.*, 2006d). Successful comanagement in the complex and less well-defined river-floodplain fisheries is more problematic (Khumsri *et al.*, 2006), but has been achieved where traditional family and social structures are largely intact, traditional ownership has been recognized by government, and locally formulated regulations "make ecological sense" to fishers (Baird *et al.*, 2003b). Commonly adopted measures include fish conservation zones (FCZs) to protect broodstock in deep pools (and in some areas of Laos in caves), banning of destructive methods and methods that catch spawning fish or frogs and juveniles of some species, closed seasons, and protection of inundated forest habitat along the Mekong (Baird, 2006a; Baran *et al.*, 2005; Hogan, 1998). Community-based management may cause conflicts as exclusion is not only of "outsiders" but also of nearby communities who may have traditionally shared the resource (Tubtim and Hirsch, 2005). Community-based management may lead to a better return on effort or more economically efficient harvesting when outsiders are excluded (Lorenzen *et al.*, 1998a), but the total yield may be reduced, an outcome that could be inconsistent with government objectives for food security. In Cambodia, community fisheries management is being heavily promoted, but with varying success (Kaing *et al.*, 2005). Conflicts between subsistence and commercial fishers in fishing lots continue, the legitimacy of community-appointed inspectors is questioned (Ly, 2003; Ratner, 2006; Resurreccion, 2006), more people are fishing, there is increased use of illegal gears, especially fine-mesh nets and electrofishers, and catches appear to have declined despite increasing individual effort. The apparent problems in Cambodia are largely a result of general social breakdown caused by recent wars and civil unrest, and should not discourage a continuing focus on community-level management.

Some issues within the fisheries sector require involvement of government at regional, national, or international levels. These include the conservation of long-distance migratory species, including endangered giant fishes, regulation of exports and imports of live fish, fish products and fish feed, and exchange of research and technical information. Some approaches to establishing management structures at different levels are discussed by Hoggarth *et al.* (1999b) and in the MB, the MRC has a key role to play in coordinating international efforts.

Although there have been some examples of successful fisheries management in the LMB, the major threats to fisheries arise from activities in other sectors, particularly as national policies tend to favor large irrigation and hydroelectric projects that may cause major impacts. For such projects, all LMB countries now implement EIAs, which should fairly evaluate all impacts, but the EIA process has been heavily criticized and has been generally ineffective in evaluating alternatives or leading to mitigation of impacts (Blake, 2005; Schouten, 1998; Warren, 2000).

Even if the EIA process can be improved, assessments are not required for smaller developments (e.g., land conversion, small weirs, roads, housing), resulting in an accumulation of many small changes that eventually completely alter landscapes and their aquatic environments. For example, there are at least 11,000 MRC-registered irrigation schemes in the LMB, most in northeast Thailand, with most including several barriers across watercourses many of which would obstruct fish passage, and if built now the vast majority would not be required to undergo any EIA. Many other barriers are formed by levees and roads. Baran *et al.* (2007b) identified 14,459 "built structures" in the Tonle Sap basin, most having some degree of barrier effect and many designed to store or divert water. Each barrier potentially reduces fishery production by preventing migration, especially of fish moving upstream to spawn, and of fry drifting downstream. Measures other than conventional EIA are needed to improve outcomes for fisheries and to encourage the use of "fish-friendly" designs. Fisheries agencies could be given more control over the environment, as for example, under Thai fisheries law where the Department of Fisheries may require construction of fishways over barriers, or under Cambodian fisheries law which includes clauses that aim to protect flooded forest around the Tonle Sap-Great Lake system. In general, however, conservation of fisheries should be supported through engineering codes of practice for fish-friendly structures, such as "overshot" weirs (Baumgartner *et ah,* 2006) and by environmental guidelines and regulations which apply to all sectors and which if implemented could produce a range of benefits. A number of other approaches including catchment management could be effective if appropriate management structures and systems are established.

Although it is likely that the Mekong system can continue to sustain current yields, as populations grow pressure on fisheries will increase. Providing alternative livelihood opportunities in other labor-intensive industries would reduce the number of people in the fishery, which would increase per capita returns and provide greater flexibility for different management approaches.

8. CONCLUSIONS

The fisheries of the Mekong River basin are vital for the nutrition and livelihoods of millions of people and appear to be particularly diverse and productive as a result of the persistence of the natural flood pulse through a wide range of habitats.

Most households in the basin are engaged in fisheries to some degree and rely upon fish and other aquatic animals to provide food security and support their livelihoods. Based on available data, the yield from the LMB is now estimated to be about 3.6 Mt year^{-1}, of which aquaculture accounts for about 1.5 Mt year^{-1}, most of which is exported. The main habitats which support the LMB's yield are rivers and their floodplains (which cover a moderate area but have a high yield per unit area) and rice-fields and associated habitats (which cover most of the total wetland area and provide a low-to-moderate yield per unit area). In the upper Mekong basin fisheries are poorly described but appear to be significant, and the inputs of nutrients and organic detritus in the Mekong's plume support a large coastal fishery.

Although the importance of fisheries is increasingly recognized, management information should be improved by systematic basin-wide research on aspects such as: biodiversity, productivity, attributes of the flood pulse, the size and value of fisheries, the contribution from aquaculture, the possibilities for conserving or increasing production, and ways to mitigate the impacts of water resources developments. The actual management systems and processes to be applied also require a great deal more trial and refinement for local conditions, and should be the subject of basinwide appraisal to document the key factors in success and failure.

However, a shortage of detailed technical information should not be a barrier to increased efforts to apply adaptive management at a variety of scales within fisheries, as research can be included within a management framework. Similarly, the general impacts of developments in other sectors on fisheries are well known, so the lack of specific information should not prevent efforts to take fisheries into account in planning and EIA processes.

While "overfishing" may continue to be a problem for individual fishers and could even eliminate some of the largest species, fishing pressure alone is unlikely to cause irreversible effects on system productivity and fisheries yield. The greatest threats to the Mekong's fisheries arise from large-scale environmental modifications made to support other sectors, particularly hydroelectricity and irrigated agriculture. Experiences in many developed countries (and also from the Mekong) show that single-sector approaches are often shortsighted and may lead to great deal of environmental damage which can only be undone at great cost, if at all.

Despite the threats to river-floodplain fisheries, there are also opportunities, which include improving habitat management, controls on fishing in deep pools to protect broodstock, reinstating fish passage across the many existing barriers, improvement of design in water-management structures and creation of refuges on floodplains. Fisheries opportunities also exist within rice field habitats (e.g., development of refuge ponds and IPM to reduce pesticide use), within reservoirs (e.g., management of stocking and fishing pressure), and in aquaculture through integration with agricultural systems and domestication of Mekong species. Improving management would, however, require general improvements in governance and ownership of living aquatic resources, to ensure that some of the value derived from fisheries is reinvested in their conservation and development.

ACKNOWLEDGMENTS

Preparation of this review was supported by funding from the Fisheries Programme of the Mekong River Commission. I thank the Water Studies Centre of Monash University for providing office space and access to library resources. Ms Penroong Bamrungrach kindly provided GIS data and assisted in map production. Ms Pham Mai Phuong, Dr Suchart Ingthamjitr, Mr Ngor Pengby, and Mr Phan Than Lam are also thanked for providing helpful information. Drs Chris Barlow and Ian Campbell kindly provided comments on a draft text.

References

Agostinho, A. A., Marques, E. E., Agostinho, C. S., de Almeida, D. A., de Oliveira, R. J., and de Melo, J. R. B. (2007). Fish ladder of Lajeado Dam: Migrations on one-way routes? *Neotropical Ichthyology* 5(2), 121-130.

Ahmed, M, Hap, N., Ly, V., and Tiongco, M. (1998). "Socio-Economic Assessment of Freshwater Capture Fisheries in Cambodia. Report on a Household Survey," Danish International Development Assistance and Mekong River Commission, Phnom Penh, Cambodia, 138pp.

Akira, Y. (2005). Zoning for risk assessment of water-related natural disasters in the Mekong delta, Unpublished Masters Thesis. Can Tho University, CanTho, Vietnam, 130pp.

Ali, Y. (1997). "Fish, Water and People. Reflections on Inland Openwater Fisheries Resources of Bangladesh," The University Press Ltd., Dhaka, Bangladesh, 126pp.

Allan, J. D., Abell, R., Hogan, Z., Revenga, C, Taylor, B. W., Welcomme, R. L., and Winemiller, K. (2005). Overfishing of inland waters. *BioScience* 55(12), 1041-1051.

Amornsakchai, S., Annez, P., Vongvisessomjai, S., Choowaew, S., Thailand Development Research Institute, Bangkok, Kunurat, P., Nippanon, J., Schouten, R., Sripatprasite, P., Vaddhanaphuti, C, Vidthayanon, C, Wirojanagud, W., and Watana, E. (2000). "Pak Mun Dam Mekong River Basin Thailand," Submission to the World Commission on Dams, www.dams.org, 170pp.

Angporn, P., Guttman, H., Turongruang, D., Mingkano, P., and Demaine, H. (1998). "Survey of Trap Pond Owners in Sisaket and Roi Et Provinces, Thailand," AIT Aqua Outreach Working Paper T-6. AIT Aqua Outreach, Bangkok, Thailand, 45pp.

Anonymous. (1992a). "Fisheries in the Lower Mekong Basin. Review of the Fishery Sector in the Lower Mekong Basin. Main Report," Interim Committee for Coordination of Investigations of the Lower Mekong Basin, Bangkok, Thailand, 92pp.

Anonymous. (1992b). "Fisheries in the Lower Mekong Basin. Review of the Fishery Sector in the Lower Mekong Basin. Annexes," Interim Committee for Coordination of Investigations of the Lower Mekong Basin, Bangkok, Thailand, llpp Annexes + Plates.

Anonymous. (2002). Cuu Long Delta's largest irrigation project erects dam on Ba Lai River. *Viet Nam News 27* March 2002, 4.

Anonymous. (2007). Catfish processing takes off in delta as global demand soars. *Catch and Culture* 13(2), 16-17.

Arthur, R., Baran, E., So, N., Leng, S. V., Prum, S., and Kura, Y. (2006). "Influence of Built Structures on Tonle Sap Fish Resources," Cambodia National Mekong Committee and WorldFish Center, Phnom Penh, Cambodia, 55pp.

Baird, I. G. (2006a). Strength in diversity: Fish sanctuaries and deep-water pools in Lao PDR. *Fisheries Management and Ecology* 13, 1-8.

Baird, I. G. (2006b). *Probarbus jullieni* and *Probarbus labeamajor.* The management and conservation of two of the largest fish species in the Mekong River in southern Laos. *Aquatic Conservation: Marine and Freshwater Ecosystems* 16, 517-532.

Baird, I. G. and Flaherty, M. S. (2005). Beyond national borders: Important Mekong River medium sized migratory carps (Cyprinidae) and fisheries in Laos and Cambodia. *Asian Fisheries Science* 17, 279-298.

Baird, I. G. and Phylavanh, B. (1998). "Preliminary Survey of Aquatic Resources, with a Special Emphasis on Freshwater Fish and Fisheries, in the Xe Lamphao River Sub-basin (Dong Kanthoung proposed NBCA) in Mounlapmok District, Champasak Province, Southern Lao PDR," Environmental Protection and Community Development in Siphandone Wetland Project, Pakse, Laos, 31pp.

Baird, I. G., Flaherty, M. S., and Phylavanh, B. (2003a). Rhythms of the river: Lunar phases and migrations of small carps (Cyprinidae) in the Mekong River. *Natural History Bulletin of the Siarn Society* 51(1), 5-36.

Baird, I. G., Haggan, N., Brignall, C, and Wood, L. (2003b). Local ecological knowledge and small-scale freshwater fisheries management in the Mekong River in southern Laos. *In* "Putting Fishers Knowledge to Work," Haggan, N., Brignall, C, and Wood, L. (eds.), pp 87-89. Fisheries Center, University of British Columbia, Vancouver, BC, Canada.

Bambaradeniya, C. N. B. and Amarasinghe, F. P. (2004). "Biodiversity Associated with the Rice Field Agroecosystem in Asian Countries: A Brief Review," International Water Management Institute, Colombo, Sri Lanka, 24pp.

Baran, E. (2006). Fish migration triggers in the Lower Mekong Basin and other tropical freshwater systems. *MRC Technical Paper* 14,1-56.

Baran, E. and Myschowoda, C. (2008). Have fish catches been declining in the Mekong River Basin? *In* "Modern Myths of the Mekong," Kummu, M., Keskinen, M., and Varis, O. (eds.), pp 55-64. Helsinki University of Technology, Helsinki, Finland, 187pp.

Baran, E., van Zalinge, N. P., and Ngor, P. B. (2001). Floods, floodplains and fish production in the Mekong Basin: Present and past trends. *In* "The Asian Wetlands Symposium 2001," Universiti Sains Malaysia, George Town, Pinang. Malaysia, 27-30 August 2001, llpp.

Baran, E., Baird, I. G., and Cans, G. (2005). "Fisheries Bioecology at the Khone Falls (Mekong River, Southern Laos)," WorldFish Center, Penang, Malaysia, 84pp.

Baran, E., Jantunen, T., and Kieok, C. C. (2007a). "Values of Inland Fisheries in the Mekong River Basin," WorldFish Center, Phnom Penh, Cambodia, 76pp.

Baran, E., Starr, P., and Kura, Y. (2007b). "Influence of Built Structures on Tonle Sap Fisheries," Cambodia National Mekong Committee and the WorldFish Center Phnom Penh, Cambodia, 44pp.

Baumgartner, L. J., Reynoldson, N., and Gilligan, D. M. (2006). Mortality of larval Murray cod *(Maccullochella peelii peelii)* and golden perch *(Macquaria ambigua)* associated with passage through two types of low-head weirs. *Marine and Freshwater Research* 57, 187-191.

Bernacsek, G. M. (1997). "Large Dam Fisheries of the Lower Mekong Countries. Review and Assessment. Vol. 1 Main Report,". Mekong River Commission, Bangkok, Thailand, 118pp + Annexes.

Blake, D. J. H. (2005). "A Review of the Nam Theun 2 Environmental Assessment and Management Plan (EAMP) As It Pertains to Impacts on Xe Bang Fai Fisheries," International Rivers Network, Berkeley, California, 23pp.

Bouakhamvongsa, K., Viravong, S., and Hortle, K. G. (2006). Monitoring river fishers along the Mekong River in Lao PDR. MRC *Conference Series* 6, 295-300.

Bourdeaux, P. (2005). Reflections on the notion of the "riverine civilization" and on the History of the Mekong delta seen through some aspects of the settlement of the village of Soc S6n (1920-1945). *In* "Proceedings of a Conference: Water in Mainland Southeast Asia," Centre for Khmer Studies, Siem Reap, Cambodia, and the International Institute for Asian Studies, Amsterdam, the Netherlands. 30 November-2 December 2005.

Bush, S. R. (2008). Contextualising fisheries policy in the Lower Mekong Basin. *Journal of Southeast Asian Studies* 39(3), 329-353.

Cacot, P. and Phengarouni, L. (2006). Artificial reproduction of the carp *Cirrhinus microlepis* performed in the south of Laos by using LHRHa implant. *MRC Conference Series* 6, 171-196.

Cai, Y. and Dai, A. Y. (1999). Freshwater shrimps (Crustacea: Decapoda: Caridea) from the Xishuangbanna region of Yunnan Province, southern China. *Hydrobiologia* 400, 211-241.

Campbell, I. (2001). Invertebrates, biodiversity and the Upper Lancang-Mekong Navigation Project. *In* "Biodiversity Management and Sustainable Development. Lancang-Mekong River in the New Millenium." (Min Cao, Kevin Woods, Huabin Hu and Liming Li, eds) pp 97-105. China Forestry Publishing House, Kunming, China, 245pp.

Chandler, D. (2003). "A History of Cambodia," Silkworm Books, Thailand, 296pp.

Chantawong, M. (2006). The Mekong's changing currency. *Watershed* 11, 12-25.

Chea, T., Lek, S., and Thach, P. (2003). Fish larvae and juvenile drift at the confluence of four rivers near Phnom Penh: The Mekong upstream and downstream, the Tonle Sap and the Bassac River, June-September 2002. MRC *Conference Series* 4, 21-28.

Choulamany, X. (2005). Traditional use and availability of aquatic biodiversity in rice-based ecosystems. III. Xieng Khouang and Houa Phanh Provinces, Lao PDR. *In* "Aquatic Biodiversity in Rice-based Ecosystems," Halwart, M., Bartley, D., and Margraf, J. (eds.). FAO Inland Water Resources and Aquaculture Service, Rome, Italy, 18pp.

Claridge, G., Sorangkhoun, T., and Baird, I. (1997). "Community Fisheries in Lao PDR: A Survey of Techniques and Issues," Technical Report 1. IUCN, The World Conservation Union, Vientiane, Laos, 69pp.

Coates, D. (2002). "Inland Capture Fishery Statistics of Southeast Asia: Current Status and Information Needs." RAP Publication 2002/11: 1-114. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Dang, V. T., Nguyen, M. T., Hoang, Q. B., Thi, T. V., Pham, D. K., Nguyen, T. H. V., and Trinh, Q. T. (2005). Artificial propagation of Hoeven's slender carp *(Leptobarbm hoevenii). MRC Conference Series* 5, 89-96.

Deap, L., Degen, P., and van Zalinge, N. P. (2003). "Fishing Gears of the Cambodian Mekong," *Inland Fisheries Research and Development Institute of Cambodia Technical Paper Series* 4, 1-269.

de Graaf, G. J. and Chinh, N. D. (2000). "Floodplain Fisheries in the Southern Provinces of Vietnam," www .nefisco.org, 9pp.

de Graaf, G. J. and Xuan, T. T. (1998). Extensive shrimp farming, mangrove clearance and marine fisheries in the southern provinces of Vietnam. *Mangroves and Salt Marshes* 2, 159-166.

de Graaf, G., Born, B., Uddin, A. M. K., and Marttin, F. (2001). "Hoods Fish and Fishermen," The University Press, Dhaka, Bangladesh, 110pp.

Dubeau, P., Ouch, P., and Sjorslev, J. G. (2001). "Estimating Fish and Aquatic Animal Productivity/Yield per Area in Kampong Tralach: An Integrated Approach." *Inland Fisheries Research and Development Institute of Cambodia Technical Paper Series* 3, 143-164.

FAO. (2007). "The State of World Fisheries and Aquaculture 2006," Food and Agriculture Organization of the United Nations, Rome, Italy, 162pp.

Finlayson, B. (2002). "Report on Environmental Impact Assessment: The Navigation Improvement Project of the Lancang-Mekong River from China-Myanmar Boundary Marker 243 to Ban Houei Sai of Laos," Mekong River Commission, Phnom Penh, Cambodia, 12pp.

Fox, J. and Ledgerwood, J. (1999). Dry-season flood-recession rice in the Mekong Delta: Two thousand years of sustainable agriculture? *Asian Perspectives* 38(1), 37.

Froese, R. and Pauly, D. (eds.). (2008). "FishBase." World Wide Web Electronic Publication Version (04/2008), www.fishbase.org.

Fu, K. D. and He, D. M. (2007). Analysis and prediction of sediment trapping efficiencies of the reservoirs in the mainstream of the Lancang River. *Chinese Science Bulletin* 52(Supp. II), 134-140.

Funge-Smith, S. J. (1999a). Small-scale rural aquaculture in Lao PDR (Part 1). *FAO Aquaculture Newsletter* 22, 1-7.

Funge-Smith, S. J. (1999b). Small-scale rural aquaculture in Lao PDR (Part 2). *FAO Aquaculture Newsletter* 23, 1-4.

Gamier, F. (1996). "Travels in Cambodia and Part of Laos," Volume 1, The Mekong Exploration Commission Report. 1866-1868. Translated by W. E. J. Tips. White Lotus Co., Bangkok, Thailand, 346pp.

Gorman, C. (1971). The Hoabinhian and after: Subsistence patterns in Southeast Asia during the late Pleistocene and early Recent Periods. *World Archaeology* 2(3), 300-320.

Green, J. R., Corbet, S. A., Watts, E., and Lan, O. B. (1976). Ecological studies on Indonesian lakes. Overturn and restratification of Ranu Lamongan. *Journal of Zoology* **180,** 315-354.

Grimes, C. B. and Finucane, J. H. (1991). Spatial distribution and abundance of larval and juvenile fish, chlorophyll and macrozooplankton around the Mississippi River discharge plume, and the role of the plume in fish recruitment. *Marine Ecology Progress Series* 75, 109-119.

Halls, A. S. and Welcomme, R. L. (2004). Dynamics of river fish populations in response to hydrological conditions: A simulation study. *River Research and Applications* 20, 985-1000.

Halls, A. S., Hoggarth, D. D., and Debnath, K. (1999). Impacts of hydraulic engineering on the dynamics and production potential of floodplain fish populations in Bangladesh. *Fisheries Management and Ecology* 6, 261-285.

Halls, A. S., Kirkwood, G. P., and Payne, A. I. (2001). A dynamic pool model for floodplain-river fisheries. *Ecohydrology and Hydrobiology* 1(2), 323-339.

Halls, A. S., Welcomme, R. L., and Burn, R. W. (2006). The relationship between multi-species catch and effort: Among fishery comparisons. *Fisheries Research* 77, 78-83.

Halls, A., Lieng, S., Ngor, P., and Tun, P. (2008). New research reveals ecological insights into dai fishery. *Catch and Culture* 14(1), 8-12.

Halwart, M. (2006). Biodiversity and nutrition in rice-based aquatic ecosystems, *journal of Food Composition and Analysis* 19, 747-751.

Hanhart, K. (1997). "Management of Acid Sulphate Soils Project," Review and Assessment Report For Phase 1 (1989-1995). Environment Unit, MRC Secretariat, Bangkok, Thailand, 45pp.

Hardin, G. (1968). The tragedy of the commons. *Science* 162, 1243-1248.

Hartmann, W. (2000). It's co-management or no management. *Catch and Culture* 5(4), 1-4, 11-12.

Hatha, P., Narath, S., and Gregory, R. (1995). "Stocks and Shares" A Study of the Roles and Responsibilities of Cambodian Women and Children in Small-Scale Aquaculture," Working Paper C-2. http://www.aquainformation.ait.ac.rn/aanripage/doaxments/outreach/workingpapers/WP-C-2.htm. Asian Institute of Technology, Bangkok, Thailand, 5pp.

He D., Zhao W., Chen L. (2004). The ecological changes in Manwan Reservoir area and its causes. *In* 'International Conference on "Advances in Integrated Mekong River Management" 25-27 October 2004. Lao Plaza Hotel, Vientiane, Lao PDR. pp. 123-131. 360 pp.

Heckman, W. C. (1974). The seasonal succession of species in a rice paddy in Vientiane, Laos. *Internationale Revue der Gesamten Hydrobiologie* 59, 489-507.

Heckman, W. C. (1979). Rice field ecology in Northeastern Thailand. *Monographiae Biologicae* 34, 1-227.

Heinonen, J. and Vainio-Mattila, K. (1997). "Biodiversity/Ecotourism Assessments in Yunnan, China." Special Report. ADB RETA 5771 Poverty Reduction & Environmental Management in Remote Greater Mekong Subregion Watersheds Project (Phase I). Asian Development Bank, Manila, Philippines.

Hoang, T. T., Phan, P. D., Truong, P. H., Ly, T. N., Nguyen, T. T., Duong, P. T., and Sollows, J. D. (2006). Established process and activities of fisheries co-management model in Lak Lake, Daklak Province, Viet Nam. *MRC Conference Series* 6, 311-320.

Hogan, Z. (1998). Aquatic conservation zones: Community management of rivers and fisheries. *Watershed* 3(2), 29-33.

Hoggarth, D. D., Cowan, V. J., Aeron-Thomas, M., McGregor, J. A., Garaway, C. A., Payne, A. I., and Welcomme, R. L. (1999a). "Management Guidelines for Asian Floodplain River Fisheries. Part 2: Summary of DFID Research,". Food and Agricultural Organisation of the United Nations, Rome, Italy, 117pp.

Hoggarth, D. D., Cowan, V. J., Halls, A. S., Aeron-Thomas, M., McGregor, J. A., Garaway, C. A., Payne, A. I., and Welcomme, R. L. (1999b). "Management Guidelines for Asian Floodplain River Fisheries. Part 1: A Spatial, Hierarchical and Integrated Strategy for Adaptive Co-management," Food and Agricultural Organisation of the United Nations, Rome, Italy, 63pp.

Hortle, K. G. (2007). Consumption and the yield of fish and other aquatic animals from the lower Mekong basin. MRC *Technical Paper* 16, 1-88.

Hortle, K. G. (2008). Liver and intestinal flukes: An underrated health risk in the Mekong basin. *Catch and Culture* 18(2), 14-18.

Hortle, K. G. and Suntornratana, U. (2008). Socio-economics of the fisheries of the lower Songkhram River Basin, northeast Thailand. *MRC Technical Paper* 17, 1-85.

Hortle, K. G., Lieng, S., and Valbo-Jorgensen, J. (2004). An introduction to Cambodia's inland fisheries. *Mekong Development Series* 4, 1-41.

Hortle, K. G., Chea, T., Bun, R., Em, S., and Thach, P. (2005a). Drift of fish juveniles and larvae and invertebrates over 24-hour periods in the Mekong River at Phnom Penh, Cambodia. MRC *Conference Series* 5, 19-34.

Hortle, K. G., Roth, T., Garrison, J., and Cans, G. (2005b). Harvesting insects—A growing industry in Cambodia. *Catch and Culture* 11(1), 9-10.

Hortle, K. G., Troeung, R., and Lieng, S. (2008). Yield of the wild fishery of rice fields in Battambang Province, near the Tonle Sap Lake, Cambodia. *MRC Technical Paper* 18, 1-62.

Hsiao, S. C. (1946). A limnological study of Erh Hai, Yunnan, China: Physico-chemical characteristics. *Journal of Animal Ecology* 15, 1-8.

Islam, M. S., Rahman, M. M., Haider, G. C, and Tanaka, M. (2006). Fish assemblage of a traditional fishery and the seasonal variations in diet of its most abundant species

Wallago attu (Siluriformes: Siluridae) from a tropical floodplain. *Aquatic Ecology* 40, 263-272.

Jackson, D. and Marmulla, G. (2001). "The Influence of Dams on River Fisheries," Report to the World Commission on Dams, www.dams.org, 17pp.

Junk, W. J. and Wantzen, K. M. (2004). The flood pulse concept: New aspects, approaches and applications—An update. RAP Publication 2004/16, pp 117-140.

Junk, W., Bayley, P., and Sparks, R. (1989). The flood pulse concept in river-floodplain systems. *Canadian Special Publications in Fisheries and Aquatic Sciences* 106, 110-127.

Jutagate, T., Lamkom, T., Satapornwanit, K., Naiwinit, W., and Petchuay, C. (2001). Fish species diversity and ichthyomass in Pak Mun Reservoir, five years after impoundment. *Asian Fisheries Science* 14, 417-424.

Jutagate, T„ Silva, S. S. D., and Mattson, N. S. (2003). Yield, growth and mortality rate of the Thai river sprat, *Clupeichthys aesarnensis,* in Sirinthorn Reservoir, Thailand. *Fisheries Management and Ecology* 10, 221-231.

Jutagate, T., Krudpan, C, Ngamsnae, P., Lamkom, T., and Payooha, K. (2005). Changes in the fish catches during a trial opening of sluice gates on a run-of-the river reservoir in Thailand. *Fisheries Management and Ecology* 12, 57-62.

Kaing, K., Sung, S., and Un, K. (2005). Participation in fisheries co-management in Kandal Province, Cambodia. *MRC Conference Series* 5, 143-153.

Khay, D. and Hortle, K. G. (2005). Monitoring sales of fish and other aquatic animals at retail markets in Phom Penh, Cambodia. *MRC Conference Series* 5, 3-18.

Khoa, S. N., Lorenzen, K., Garaway, C, Chamsinhg, B., Siebert, D., and Randone, M. (2005). Impacts of irrigation on fisheries in rain-fed rice-farming landscapes. *Journal of Applied Ecology* 42, 892-900.

Khumsri, M., Sriputinibondh, N., and Thongpun, W. (2006). Fisheries co-management in Lower Songkhram River Basin: Problems and challenges. *MRC Conference Series* 6, 121-126.

Ko-Anandakul, K. (2004). "Fishing Gears of the Songkhram River Basin (in Thai)," Department of Fisheries (Thailand) and Mekong River Commission, Bangkok, 87pp.

Koizumi, H. (2006). "Nam Ngum Dam after 30 Years of Operation," Koei Research Institute International Corporation, Japan, 68pp + Annexes.

Kong, D.-P., Chen, X.-Y., and Yang, J.-X. (2006). Fish fauna status in the Lugu Lake with preliminary analysis on cause and effect of human impacts. *Zoological Research* 1, 94-97.

Kottelat, M. (1996). "Potential Impacts of Nam Theun 2 Hydropower Project on the Fish and Aquatic Fauna of the Nam Theun and Xe Bangfai Basins, Lao PDR," Report to NTEC Development Group, Vientiane, Lao PDR, 57pp.

Kruskopf, M. (2006). "Influence of Built Structures on Tropical Floodplains Worldwide," Cambodia National Mekong Committee and WorldFish Center, Phnom Penh, Cambodia, 88pp.

Lagler, K. F. (1976a). "Fisheries and Integrated Mekong River Basin Development," Field Investigations Appendix Volume 1. Annex E: Coastal Fishery Field Investigations, Terminal Report of the Mekong Basinwide Fishery Studies. University of Michigan School of Natural Resources, Michigan, USA, 39pp.

Lagler, K. F. (1976b). "Fisheries and Integrated Mekong River Basin Development," Executive Volume, Terminal Report of the Mekong Basinwide Fishery Studies. University of Michigan School of Natural Resources, Michigan, USA, 367pp.

Lamberts, D. (2006). The Tonle Sap Lake as a productive ecosystem. *International Journal of Water Resources Development* 22(3), 481-495.

Lamberts, D. (2008). Little impact, much damage: The consequences of Mekong River flow alterations for the Tonle Sap ecosystem. *In* "Modern Myths of the Mekong," Kummu, M., Keskinen, M., and Varis, O. (eds.), pp 3-18. Helsinki University of Technology, Helsinki, Finland, 187pp.

Lawrence, S. (2008). "Power Surge. The Impacts of Rapid Dam Development in Laos," International Rivers Network, Berkely, CA, USA, 88pp.

Lieng, S. and van Zalinge, N. P. (2001). Fish yield estimation in the floodplains of the Tonle Sap Great Lake and River, Cambodia. *Cambodia Fisheries Technical Paper Series* 3,23-26.

Lim, P., Villavueva, M. C, Chhouk, B., Chay, K. K., Brun, J. M., and Moreau, J. (2005). Fish assessment in the rehabilitated polders of Prey Nup (Cambodia). *Asian Fisheries Science* 18, 241-253.

Lorenzen, K., Garaway, C. J., Chamsingh, B., and Warren, T. J. (1998a). Effects of access restrictions and stocking on small water body fisheries in Laos. *Journal of Fish Biology* 53, 345-357.

Lorenzen, K, Juntana, J., Bundit, J., and Tourongruang, D. (1998b). Assessing culture practices in small waterbodies: A study of village fisheries in north-east Thailand. *Aquaculture Research* 29, 211-224.

Luo, A. (2005). Traditional use and availability of aquatic biodiversity in rice-based ecosystems II. Xishuangbanna, Yunnan, People's Republic of China. *In* "Aquatic Biodiversity in Rice-based Ecosystems," Halwart, M., Bartley, D., and Margraf, J. (eds.), pp 1-11. FAO Inland Water Resources and Aquaculture Service, Rome, Italy. A CD-ROM.

Ly, S. (2003). Cambodia fisheries conflicts in the post war era and the creation of fishing communities: A case of fishing lot conflicts around Tonle Sap River and the Great Lake. *Journal of Regional Fisheries,* 43(2), 89-106.

Ly, N. T., Sollows, J., Hartmann, W., Phan, D. P., Hoang, T. T., Nguyen, T. T., Truong, H. P., and Duong, T. P. (2006). Is there fisheries co-management in Daldak province, Central Highlands of Viet Nam? MRC *Conference Series* 6, 147-158.

Manning, G. S. and Lertprasert, P. (1973). Studies on the life cycle of *Phaneropsolus bonnei* and *Prosthodendrium molenkampi* in Thailand. *Annals of Tropical Medicine and Parasitology* 67(3), 361-365.

Margraf, J., Voggesberger, M, and Milan, P. P. (1996). Limnology of Ifugao rice terraces, Philippines. *In* "Perspectives in Tropical Limnology," Schiemer, F. and Boland, T. (eds.), pp 305-319. SPB Academic Publishing BV, Amsterdam, Netherlands, 347pp.

Mattson, N., Nilsson, H., and Phounsavath, S. (2000). "The Fishery of Nam Ngum reservoir Lao PDR," Mekong River Commission, Vientiane, Lao PDR, 72pp.

Mattson, N. S., Balavong, V., Nilsson, H., Phounsavath, S., and Hartmann, W. (2001). Changes in fisheries yield and catch composition at the Nam Ngum Reservoir, Lao PDR. *ACIAR Proceedings* 98, 48-55.

Mattson, N. S., Buakhamvongsa, K., Sukumasavin, N., Nguyen, T., and Ouk, V. (2002). Mekong giant fish species: On their management and biology. MRC *Technical Paper* 3, 29.

McDowall, R. M. (2002). "Evaluation of: Report on Environmental Impact Assessment: The Navigation Channel Improvement Project of the Lancang-Mekong River from China-Myanmar Boundary Marker 243 to Ban Houei Sai of Laos," Mekong River Commission, Phnom Penh, Cambodia, 9pp.

Meusch, E. (2005). Traditional use and availability of aquatic biodiversity in rice-based ecosystems. IV. Lai Chau and Hoa Binh provinces, Viet Nam. *In* "Aquatic Biodiversity in Rice-based Ecosystems," Halwart, M., Bartley, D., and Margraf, J. (eds.). FAO Inland Water Resources and Aquaculture Service, Rome, Italy, 14pp.

Meusch, E., Yhoung-Aree, J., Friend, R., and Funge-Smith, S. (2003). The role and nutritional value of aquatic resources in the livelihoods of rural people: A participatory assessment in Attapeu Province, Lao PDR. *In* "Dialogue on Water, Food and the Environment." Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific and IUCN—The World Conservation Union, Bangkok, Thailand, 34pp.

Mogensen, M. T. (2001). The importance of fish and other aquatic animals for food and nutrition security in the lower mekong basin, MSc Thesis. Department of Human Nutrition, The Royal Agricultural and Veterinary University, Denmark, 129pp -I- Appendices.

Mollot, R., Phothitay, C, and Rosy, S. (2005). Hydrology, habitat and livelihoods on the floodplains of southern Lao PDR. *MRC Conference Series* 5, 155-174.

MRC. (2003). "State of the Basin Report 2003," Mekong River Commission, Phnom Penh, Cambodia, 300pp.

MRC. (2005). "Overview of the Hydrology of the Mekong Basin," Mekong River Commission, Vientiane, Lao PDR, 73pp.

Nesbitt, H. J., Johnston, R., and Solieng, M. (2004). Mekong River water: Will river flows meet future agriculture needs in the Lower Mekong Basin. *ACIAR Proceedings* **116e,** 86-104.

Ngo, S. V. and Le, T. L. (2001). Status of reservoir fisheries in Vietnam. *ACIAR Proceedings* 98, 235-245.

Ngor, P. B., Aun, S., Deap, L., and Hortle, K. G. (2005). The *dai trey linh* fishery on the Tonle Touch (Touch River), southeast Cambodia. *MRC Conference Series* 5, 35-56.

Ngor, P., Aun, S., and Hortle, K. G. (2006). The *dai bongkong* fishery for giant river prawns, *Macrobrachium rosenbergii,* in southeastern Cambodia. *MRC Conference Series* 6, 3-32.

Nguyen, X. V. and Wyatt, A. B. (2006). "Situation Analysis: Plain of Reeds, Viet Nam," United Nations Development Programme, Vientiane, Lao PDR, 60pp.

Nguyen, T. N., Vo, T. D., Truong, H. P., Phan, T. H, Phan, D. P., Nguyen, N. V., Tran, M. H, Nguyen, T. B., Hoang, D. T. V., and Sollows, J. D. (2003). The future of fisheries co-management in six reservoirs in the Central Highlands of Viet Nam. MRC *Conference Series* 4, 195-213.

Nguyen, N. D., Smallwood, C, Nguyen, V. H, Nguyen, X. T., and Nguyen, T. T. (2006a). "Fishing Gears of the Mekong Delta," Research Institute for Aquaculture 2 and Mekong River Commission, Ho Chi Minh City, Viet Nam (in Vietnamese), 351pp.

Nguyen, P. H, Nguyen, K. C, Nguyen, T. D., Le, M. B., Bern, C, Flores, R., and Martorell, R. (2006b). Intestinal helminth infections among reproductive age women in Viet Nam. *Southeast Asian Journal of Tropical Medicine and Public Health* 37(5), 865-874.

Nguyen, T. T., Nguyen, N. D., Vu, V. A., and Truong, T. T. (2006c). Monitoring of fish larvae during the annual flood of the Mekong and Bassac rivers, Mekong Delta, Viet Nam. *MRC Conference Series* 6, 71-88.

Nguyen, V. H, Mai, T. T. C, Pham, B. V. T., Pham, T. B. H, Sollows, J., and Davidson, J. (2006d). Strengthening co-management of water resources for rice-shrimp farming in Soc Trang Province—Viet Nam. MRC *Conference Series* 6, 127-146.

Nguyen, N. D., Vu, V. A., Doan, V. T., Lam, N. C, and Nguyen, V. P. (2008). Monitoring of fish larvae in the Mekong and Bassac Rivers, Viet Nam, 2006. MRC *Conference Series* 7, 31-40.

Nhan, D. K., Phong, L. T., Verdegem, M. J. C, Duong, L. T., Bosma, R. H, and Little, D. C. (2007). Integrated freshwater aquaculture, crop and livestock production in the Mekong delta, Vietnam: Determinants and the role of the pond. *Agricultural Systems* 94, 445-458.

Niphonkit, N, Sriputinibondh, N, and Buttaprom, W. (2008). Co-management of reservoir fisheries in Huay Luang Reservoir, Udonthani, Thailand. MRC *Conference Series* 7, 93-98.

Nissanka, C. (2001). Effect of hydrological regimes on fish yields in reservoirs of Sri Lanka. *ACIAR Proceedings* 98, 93-100.

Noraseng, P. and Warren, T. J. (2001). "Fish Migration and Species Composition in a Major Mekong Tributary: A Rapid Assessment of Lower Sedone River Fisheries using CPUE," The Small-scale Wetlands Indigenous Fisheries Management Project, Pakse, Lao PDR, 17pp.

NT2PC. (2006). "Fish and Aquatic Habitats Survey in NTPC Area, 2006," Nam Theun 2 Hydroelectric Project. Final Report. Nam Theun 2 Power Company, http://www.namtheun2.com/Fish%20and%20Aquatic%20Habitats%20Survey%20-%20Aug06.pdf, 96pp.

Nuanthavong, T. and Vilayphone, L. (2006). Reproduction and nursing of *Cirrhinus molitorella* in a small fish farm in Luang Prabang Province, Lao PDR. MRC *Conference Series* 6, 197-204.

Nuth, M. (2005). "The Informal Economy in Cambodia. An Overview," Economic Institute of Cambodia, Phnom Penh, Cambodia, 5pp.

Pagdee, A., Homchuen, S., Sangpradab, N., Hanjavanit, C, and Uttharak, P. (2007). Biodiversity and economic value of wetland resources at Nong Han, Udonthani Province, Northeast Thailand. *Natural History Bulletin of the Siam Society* **55(2),** 323-339.

Pantulu, V. R. (1986a). The Mekong River system. *In* "The Ecology of River Systems," Davies, B. R. and Walker, K. F. (eds.), pp 695-719. Dr W. Junk Publishers, Dordrecht, The Netherlands, 793pp.

Pantulu, V. R. (1986b). Fish of the Lower Mekong Basin. *In* "The Ecology of River Systems," Davies, B. R. and Walker, K. F. (eds.), pp 721-741. Dr W. Junk Publishers, Dordrecht, The Netherlands.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., and Torres, F. (1998). Fishing down marine food webs. *Science* **279,** 860-863.

Pawaputanon, O. (1986). Fisheries and fishery management of large reservoirs in Thailand. *In* "The First Asian Fisheries Forum," McLean, J. L., Dixon, L. B., and Hosillos, L. V. (eds.), pp 389-392. Asian Fisheries Society, Manila, The Philippines.

Pham, V. N. and Guttman, H. (1999). "Aquatic Resources Use Assessment in Long An Province, Vietnam (Results from 1997 Survey)," College of Agriculture and Forestry/Asian Institute of Technology, Ho Chi Minh City, Viet Nam/Bangkok, Thailand, 32pp + Appendices.

Phan, P. D. and Silva, S. S. D. (2000). The fishery of the Ea Kao reservoir, southern Vietnam: A fishery based on a combination of stock and recapture, and self-recruiting populations. *Fisheries Management and Ecology* 7, 251-264.

Phan, D. P. and Sollows, J. D. (2001). Status and potential of reservoir fisheries in Dak Lak Province, Vietnam. *ACIAR Proceedings* 98, 36-42.

Phanh, T. L., Pham, M. P., Nguyen, T. T., Visser, T., and Hortle, K. G. (2002). "Tra Vinh Fisheries Survey. Tra Vinh Province-Viet Nam," RIA2, Department of Fisheries, Tra Vinh; Department of Statistics, Tra Vinh; AMFC of the MRC Fisheries Programme, Ho Chi Minh City, Viet Nam, 69pp + Annexes.

Phathammavong, O., Moazzam, A., Xaysomphoo, D., Phengsavanh, A., and Kuroiwa, C. (2007). Parasitic infestation and nutritional status among schoolchildren in Vientiane, Lao PDR. *journal of Paediatrics and Child Health* 43, 689-694.

Phillips, M. J. (2002). Freshwater aquaculture in Lower Mekong Basin. MRC *Technical Paper* 7, 62.

Phithakpol, B., Varanyanond, W., Reungmaneepaitoon, S., and Wood, H. (1995). "The Traditional Fermented Foods of Thailand," ASEAN Food Handling Bureau, Kuala Lumpur, Malaysia, 35pp.

Pholprasith, S. and Sirimongkonthaworn, R. (1999). The fish community of Ubolratana Reservoir, Thailand. *In* "Fish and Fisheries of Lakes and Reservoirs in Southeast Asia and Africa," Densen, W. L. T. (ed.), pp 103-115. Westbury Publishing, Otley, UK, 432pp.

Phonvisay, A. (2003). "Monitoring of Fish Trade Study of the Siphandone Fishery, Champassak Province, 2003," Living Aquatic Resource Research Centre, Ministry of Agriculture and Forestry, Lao PDR, 60pp.

Phonvisay, A. and Bush, S. (2001). Baseline study of fish trade in Champasack. LARReC *Research Report* 4, 1-70.

Piyasiri, S. and Perera, N. (2001). Role of *Oreochromis* hybrids in controlling *Microcystis aeruginosa* blooms in the Kotmale Reservoir. *ACIAR Proceedings* 98, 137-148.

Pomeroy, R. S., Katon, B. M., and Harkes, I. (1998). Fisheries co-management: Key conditions and principles drawn from Asian experiences. *In* "Crossing Boundaries," The Seventh Annual Conference of the International Association for the Study of Common Property," Vancouver, British Columbia, Canada, 10-14 June 1998, p 15. 23pp.

Poulsen, A. F. and Viravong, S. (2002). Fish migrations and maintenance of biodiversity in the Mekong River Basin. *In* "International Symposium on Biodiversity Management and Sustainable Development in the Lancang-Mekong River Basin," Xishuangbanna, Yunnan Province of China, 4-7 December 2001.

Poulsen, A. F., Ouch, P., Viravong, S., Suntornratana, U., and Nguyen, T. T. (2002a). Fish migrations of the Lower

Mekong River Basin: Implications for development planning and environmental management. *MRC Technical Paper* 8, 1-62.

Poulsen, A. F., Ouch, P., Viravong, S., Suntornratana, U., and Nguyen, T. T. (2002b). Deep pools as dry season fish habitats in the Mekong River basin. *MRC Technical Paper* 4, 1-24.

Prapertchob, P., Kachamart, P., Pakuthai, W., Viratchakul, J., Hornak, A., Thiranggon, P., and Kamsrakaeo, P. (1989). "Summary Report on Analysis of Freshwater Fish Consumption and Marine Product Marketing in Northeast Thailand," Khon Kaen University, Khon Kaen, Thailand, 35pp.

Prasertwattana, P., Manee, N., and Namtum, S. (2006). Culture of Red-tail Mystus, *Hemibagrus wyckioides,* in earthen ponds with different stocking densities. *MRC Conference Series* 6, 213-216.

Ratner, B. D. (2006). Community management by decree? Lessons from Cambodia's fisheries reform. *Society and Natural Resources* 19, 79-86.

Resurreccion, B. P. (2006). Rules, roles and rights: Gender, participation and community fisheries management in Cambodia's Tonle Sap region. *Water Resources Development* 22, 433-447.

Roberts, T. R. (1993). Just another dammed river? Negative impacts of Pak Mun Dam on fishes of the Mekong Basin. *Natural History Bulletin of the Siam Society* 41, 105-133.

Roberts, T. R. (1995). Mekong mainstream hydropower dams: Run-of-the-river or ruin-of-the-river? *Natural History Bulletin of the Siam Society* 43, 3-13.

Roberts, T. R. (2001a). On the river of no returns: Thailand's Pak Mun Dam and its fish ladder. *Natural History Bulletin of the Siam Society* 49, 189-230.

Roberts, T. R. (2001b). Killing the Mekong: China's fluvicidal hydropower cum-navigation development scheme. *Natural History Bulletin of the Siam Society* 49, 143-159.

Roberts, T. R. (2002). Fish scenes, symbolism, and kingship in the bas-reliefs of Angkor Wat and the Bayon. *Natural History Bulletin of the Siam Society* 50, 135-193.

Roberts, T. R. (2004). "Fluvicide: An Independent Environmental Assessment of Nam Theun 2 Hydropower Project in Laos, with Particular Reference to Aquatic Biology and Fishes," http://internationalrivers.org/files/tysonfluvicide0904.pdf, 46pp.

Roger, P. A. and Kurihara, Y. (1988). Floodwater biology of tropical wetland ricefields. *In* "The First International Symposium on Paddy Soil Fertility," International Soil Science Society, Chiang Mai, Thailand, pp 275-300.

Roos, N, Chairman, C, Loeung, D., Jakobsen, J., and Thilsted, S. H. (2007a). Freshwater fish as a dietary source of vitamin A in Cambodia. *Food Chemistry* **103,** 1104-1111.

Roos, N, Thorseng, H., Chamnan, C, Larsen, T., Gondolf, U. H., Bukhave, K., and Thilsted, S. H. (2007b). Iron content in common Cambodian fish species: Perspectives for dietary iron intake in poor, rural households. *Food Chemistry* **104,** 1226-1235.

Schouten, R. (1998). Effects of dams on downstream reservoir fisheries, case of Nam Ngum. *Catch and Culture* 4(2), 1-5.

Schouten, R. (1999). "Rehabilitation of Stung Chinit Diversion Weir in Cambodia and Impacts on Fish Migration and Fisheries," Asian Development Bank, Phnom Penh, Cambodia, 31pp.

Sensereivorth, T., Diep, L., and Nao, T. (1999). Freshwater capture fisheries data collection in 1998. *In* "Present Status of Cambodia's Freshwater Capture Fisheries and Management Implications, 19-21 January 1999," Van Zalinge, N. P., Nao, T., and Deap, L. (eds.), pp 40-53. Mekong River Commission and Department of Fisheries, Phnom Penh, Cambodia, 170pp.

Setboonsarng, S., Le, H. H., and Pham, C. T. (1999). "Report of Baseline Survey of Tien Giang Province," Mekong River Commission Fisheries Programme, Rural Extension for Aquaculture Development in the Mekong Delta (Phase 1) Cambodia and Vietnam, Phnom Penh, Cambodia, 113pp + Annexes.

Shoemaker, B., Baird, I. G., and Baird, M. (2001). "The People and Their River. A Survey of River-Based Livelihoods in the Xe Bang Fai River Basin in Central Lao PDR," Lao PDR/Canada Fund for Local Initiatives, Vientiane, Laos, 79pp.

Singsee, S., Udomkarn, C, Prasertwattana, P., and Sukumasavin, N. (2003). Development of techniques for induced oocyte maturation and ovulation in *Pangasius bocourti. MRC Conference Series* 4, 151-154.

Sitthichaikasem, S. (1990). Thermal and chemical stratification phenomena in Srinagarind Reservoir. *In* "2nd National Seminar on Water and Wastewater Technology," Panwad, T. and Nayomtoon, I. (eds.), pp 93-107. College of Engineering, Chulalongkorn University, Chulalongkorn, Thailand.

Sjorslev, J. G. (2000). "Fisheries Survey, Luangprabang Province, Lao PDR," NAFRI and MRC Fisheries Program AMFC Component, Vientiane, Lao PDR, 45pp.

Sjorslev, J. G. (ed.). (2002). "An Giang Fisheries Survey. An Giang Province;—Viet Nam," Draft Report. RIA2, Department of Fisheries An Giang, Fisheries Department, Can Tho University, AMFC of MRC Fisheries Programme, Vientiane, Laos, 70pp.

Smith, H. M. (1945). The fresh-water fishes of Siam, or Thailand. *Bulletin of the Smithsonian Institution* 188,1-577.

So, N, Ouch, V., Hao, V., and Nandeesha, M. C. (1998). Women in small-scale aquaculture development in Cambodia. *Aquaculture Asia* 3, 20-22.

Soukhaseum, V., Viravong, S., Sinhanouvong, D., Phounsavath, S., and Warren, T. (2007). Fish migration studies and CPUE (catch per unit effort) data collection in southern Lao PDR from 1994 to 2006. Paper presented in "8th Asian Fisheries Forum," Kochi, India, 20-23 November 2007, Asian Fisheries Society, Manila, Philippines, 19pp.

Sprenger, G. (2006). Out of the ashes. Swidden cultivation in Laos. *Anthropology Today* 22, 9-13.

Sretthachau, C, Nungern, K., and Olsson, A. (2000). "Social Impacts of the Rasi Salai Dam, Thailand: Loss of Livelihood Security and Social Conflict," Submission to the World Commission on Dams, East/South-East Asia Regional Consultation, Hanoi, Vietnam. 26-27 February 2000. Southeast Asia Rivers Network (SEARIN), Thailand, 14pp.

Sricharoendham, B., Leelapatra, W., Ratanachamnong, D., Kaewjaroon, P., and Aimsab, M. (1999). "Variation on Fish Community and Catch of Sirindhorn Reservoir, Ubon Ratchathani Province," National Inland Fisheries Institute, Department of Fisheries, Ministry of Agriculture and Cooperatives, Thailand, Bangkok, Thailand, 30pp.

Suwannapeng, N. (2002). Induced spawning of Jullien's **mud** carp, *Henicorhynchus siamensis. MRC Conference Series* 2, 253-256.

Sverdrup-Jensen, S. (2002). Fisheries in the lower Mekong Basin: Status and perspectives. MRC *Technical Paper* 6, 1-95.

Taki, Y. (1978). An analytical study of the fish fauna of the Mekong Basin as a biological production system in nature. *Research Institute of Evolutionary Biology Special Publications* 1, 1-77.

Tep, C, Sinuon, M., Doung, S., and Odermatt, P. (2006). Intestinal parasites in school-aged children in villages bordering Tonle Sap Lake, Cambodia. *Southeast Asian Journal of Tropical Medicine and Public Health* 37(5), 859-864.

Thach, P., Chea, T., and Hortle, K. G. (2006). Drift of fish fry and larvae in five large tributaries of the Tonle Sap-Great Lake system in Cambodia. MRC *Conference Series* 6, 289-294.

Thai, N. C, Sollows, J. D., Nguyen, Q. A., Phan, D. P., Nguyen, Q. N, and Truong, H. P. (2001). Is Lak Lake overfished? *ACIAR Proceedings* 98, 71-80.

Touch, S. T. and Todd, B. H. (2003). "The Inland and Marine Fisheries Trade of Cambodia," Economic, Social and Cultural Observation Unit, Royal Government of Cambodia and Oxfam America, Phnom Penh, Cambodia, 147pp.

Tran, T. V., Do, T. L., Nguyen, N. V., Phan, D. P., Phan, T. H., Thai, N. C, Nguyen, Q. A., and Sollows, J. D. (2001). An assessment of the fisheries of four stocked reservoirs in the Central Highlands of Vietnam. *ACIAR Proceedings* 98, 81-92.

Trinh, Q. T., Huynh, H. N, Thi, T. V., Nguyen, M. T., and Hoang, Q. B. (2006). Preliminary results of domestication of *Pangasius krempfi. MRC Conference Series 6,* 217-222.

Troeung, R., Aun, S., Lieng, S., Deap, L., and van Zalinge, N. (1999). A comparison of fish yields and species composition between one fishing lot in Battambang province and two fishing lots in Prey Veng Province. MRC *Conference Series* 4,9-16.

Trong, T. Q., Nguyen, V. H, and Griffiths, D. (2002). Status of Pangasiid aquaculture in Viet Nam. *MRC Technical Paper* 2, 1-16.

Truong, T. T., Do, Q. T. V., and Nguyen, V. H. (2008). Fisheries and aquaculture statistics for the Mekong River Delta in Viet Nam. *MRC Conference Series* 7, 65-81.

Tubtim, N. and Hirsch, P. (2005). Common property as enclosure: A case study of a backswamp in southern Laos. *Society and Natural Resources* 18, 41-60.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, I. R., and Cushing, C. E. (1980). The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37, 130-137.

van Zalinge, N. and Nao, T. (1999). Summary of project findings: Present status of Cambodia's freshwater capture fisheries and management implications. *In* "Present Status of Cambodia's Freshwater Capture Fisheries and Management Implications," Van Zalinge, N. P., Nao, T., and Deap, L. (eds.), pp 11-20. Mekong River Commission and Department of Fisheries, Phnom Penh, Cambodia, 150pp.

van Zalinge, N. and Touch, S. T. (1996). Catch assessment and fisheries management in the Tonle Sap Great Lake and River. *In* Paper presented in "Workshop on Fisheries Statistics," 18 September 1996, Department of Fisheries, Phnom Penh, Cambodia, 21pp.

van Zalinge, N. P., Lieng, S., Ngor, P. B., Heng, K., and Valbo-Jorgensen, J. (2002). Status of the Mekong *Pangasianodon hypophthalmus* resources, with special reference to the stock shared between Cambodia and Viet Nam. MRC *Technical Paper* 1,1-29.

van Zalinge, N. P., Degen, P., Pongsri, C, Nuov, S., Jensen, J. G., Nguyen, V. H., and Choulamany, X. (2004). The Mekong River system. *In* "Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries," Phnom Penh, Cambodia, 11-14 February 2003, Volume 1, pp 335-357. RAP Publication 2004/16. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand, 357pp.

Virapat, C. and Mattson, N. (2001). Inventory of reservoir fisheries in Thailand. ACIAR *Proceedings* 98, 43-47.

Voeun, V. (2001). "Fishbones from Archaeological Remains from Angkor Borei," Heinrich-Boli-Foundation, Phnom Penh, Cambodia, lp.

Vromant, N., Nam, C. Q., HChau, N. T., and Ollevier, F. (2004). Survival rate and growth performance of *Cyprinus carpio* L. in intensively cultivated rice fields. *Aquaadture Research* 35, 171-177.

Walker, K. F. and Yang, H. Z. (1999). Fish and fisheries in western China. *FAO Fisheries Technical Paper* 385,237-278.

Warren, T. J. (1999). "A Monitoring Study to Assess the Localized Impacts Created by the Nam Theun-Hinboun Hydro-scheme on Fisheries and Fish Populations," Theun-Hinboun Power Company, Vientiane, Laos, 68pp.

Warren, T. (2000). Impacts to fish populations and fisheries created by the Nam Theun-Hinboun Hydropower Project, Lao PDR. *In* "Summary of Presentation at Conference on "Accounting for Development," University of Sydney, 23-24 June 2000, 7pp.

Watson, S. P. and Schouten, R. (2001). "Nam Song Diversion Project." Draft Impact Analysis Report and Action Plan. Asian Development Bank, Vientiane, Laos.

Welcomme, R. L. (1985). River fisheries. *FAO Fisheries Technical Paper* 262, 1-358.

Welcomme, R. L. (2001). "Inland Fisheries Ecology and Management," Fishing News Books, Oxford, UK, 358pp.

Welcomme, R. L. and Halls, A. (2004). Dependence of tropical river fisheries on flow. RAP Publication 2004/16, pp 267-283.

Westing, A. H. (1976). "Ecological Consequences of the Second Indochina War," Stockholm International Peace Research Institute and Amqvist and Wiksell, Stockholm, Sweden, 119pp.

Whitmore, T. J., Brenner, M., Jiang, Z., Curtis, J. H., Moore, A. M., Engstrom, D. R., and Wu, Y. (1997). Water quality and sediment geochemistry in lakes of Yunnan Province, southern China. *Environmental Geology* 32, 45-55.

Wongstitwilairoong, B., Srijan, A., Serichantalergs, O., Fukuda, C. D., McDaniel, P., Bodhidatta, L., and Mason, C. J. (2007). Intestinal parasitic infections among preschool children in Sangkhlaburi, Thailand. *American journal of Tropical Medicine and Hygiene* 76, 345-350.

Wyatt, A. B. and Baird, I. G. (2007). Transboundary impact assessment in the Sesan River Basin: The case of the Yali Falls Dam. *International journal of Water Resources Development* 23(3), 427-442.

Xie, P. and Chen, Y. (2001). Invasive carp in China's Plateau lakes. *Science* 224, 999-1000.

Xie, S. and Li, Z. (2003). "Inland Fisheries Statistics in China." RAP Publication 2003/01: 20-26. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Xie, P. and Liu, J. (2001). Practical success of biomanipulation using filter-feeding fish to control cyanobacteria blooms. *The Scientific World* 1, 337-356.

Xie, Y., Li, Z., Gregg, W. P., and Li, D. (2001). Invasive species in China—An overview. *Biodiversity and Conservation* 10, 1317-1341.

Yan, Y. Z. and Chen, Y. F. (2007). Changes in the life history of *Abbottina rivularis* in Lake Fuxian. *Journal of Fish Biology* 70, 959-964.

Yang, J. X. (1996). The alien and indigenous fishes of Yunnan: A study on impact ways, degrees and relevant issues. *In* "Conserving China's Biodiversity," Wang, S., Peter, J. S., and Xie, Y. (eds.), pp 129-138. China Environmental Science Press, Beijing (in Chinese).

Yang, Y., Tian, K., Hao, J., Pei, S., and Yang, Y. (2004). Biodiversity and biodiversity conservation in Yunnan, China. *Biodiversity and Conservation* 13, 813-826.

Yap, S. Y. (2002). On the distributional patterns of Southeast-East Asian freshwater fish and their history. *Journal of Biogeography* 29, 1187-1199.

Yim, C. and McKenney, B. (2003). "Domestic Fish Trade: A Case Study of Fish Marketing from the Great Lake to Phnom Penh—Working Paper 29," Cambodia Development Resource Institute, Phnom Penh, Cambodia, 24pp.

York, R. and Gossard, M. H. (2004). Cross-national meat and fish consumption: Exploring the effects of modernisation and ecological context. *Ecological Economics* 48, 293-302.

Zhou, D. (2001). "The Customs of Cambodia," Edited and translated by Michael Smithies. The Siam Society, Bangkok, 147pp.

Academic Press is an imprint of Elsevier

360 Park Avenue South, New York, NY 10010-1710
30 Corporate Drive, Suite 400, Burlington, MA 01803, USA
525 B Street, Suite 1900, San Diego, CA 92101-4495, USA
32 Jamestown Road, London NW1 7BY, UK
Radarweg 29, PO Box 211, 1000 AE Amsterdam, The Netherlands

First edition 2009

Library of Congress Cataloging-in-Publication Data
The Mekong: biophysical environment of an international river basin / edited by Ian Campbell. - 1st ed.
p. cm. - (Aquatic ecology series)
ISBN 978-0-12-374026-7
1. Environmental management-Mekong River Watershed-International cooperation.
2. Mekong River Watershed-Environmental conditions. 3. Natural history-Mekong River Watershed. 4. Physical geology-Mekong River Watershed. 5. Aquatic ecology-Mekong River Watershed. I. Campbell, Ian C, 1950-GE320.M47M45 2009
333.91'62130959-dc22
2009022377

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN 978-0-12-374026-7

For information on all Academic Press publications
visit our web site at elsevierdirect.com

Printed and bound in USA
09 10 10 9 8 7 6 5 4 3 2 1