STATE of KNOWLEDGE

The Impacts of Dams on the Fisheries of the Mekong

Compiled by Ilse Pukinskis and Kim Geheb

Mekong Fish and Fisheries Basics

The commercially valuable fish species in the Mekong basin are generally divided between 'black fish', which inhabit low oxygen, slow moving, shallow waters, and 'white fish', which inhabit well oxygenated, fast moving, deeper waters (MRC, 2010a). People living within the Mekong River system generate many other sources of food and income from what are often termed 'other aquatic animals' such as freshwater crabs, shrimp, snakes, turtles, and frogs.

Other aquatic animals comprise about 20 percent of the total Mekong catch. When fisheries are discussed, catches are typically divided between the wild capture fishery (i.e. fish and other aquatic animals caught in their natural habitat), and aquaculture (fish reared under controlled conditions).

> "40 million rural people, more than two-thirds of the rural population in the Lower Mekong Basin, are engaged in the wild capture fishery"

Wild capture fisheries play the most important role in supporting livelihoods. Wild capture fisheries are largely open access fisheries, which poor rural people can access for food and income.

Broadly, there are three types of fish habitats in the Mekong: i) the river, comprising all the main tributaries, rivers in the major flood zone and the Tonle Sap, which altogether yield about 30 percent of wild catch landings; ii) rainfed wetlands outside the river-floodplain zone, comprising mainly rice paddy in formerly forested areas, seasonally inundated to about 50 cm and yielding about 66 percent of wild catch landings; and iii) large water bodies outside the flood zone, including canals and reservoirs yielding about 4 percent of wild catch landings (MRC, 2010a).

The Mekong Basin has one of the world's largest and most productive inland fisheries (Baran and Myschowoda, 2009; Baran and Ratner, 2007; ICEM, 2010; Sarkkula et al., 2009). An estimated 2 million tonnes of fish are landed a year, in addition to almost 500,000 tonnes of other aquatic animals (Hortle, 2007). Aquaculture yields about 2 million tonnes of fish a year (MRC, 2010a). Hence, the Lower Mekong Basin [1] yields about 4.5 million tonnes of fish and aquatic products annually. The total economic value of the fishery is between USD 3.9 to USD 7 billion a year (MRC, 2010b). Wild capture fisheries alone have been valued at USD 2 billion a year (Baran and Ratner, 2007). This value increases considerably when the multiplier effect is included, but estimates vary widely.

An estimated 2.56 million tonnes of inland fish and other aquatic animals are consumed in the lower Mekong every year (MRC, 2010a). Aquatic resources make up between 47 percent and 80 percent of animal protein in rural diets for people who live in the Lower Mekong Basin (Baran

1 - The Lower Mekong Basin countries are Cambodia, Lao PDR, Thailand and Vietnam. Myanmar and China are Upper Mekong Basin countries.

and Ratner, 2007; Bush, 2003; Friend and Blake, 2009). Fish are the cheapest source of animal protein in the region and any decline in the fishery is likely to significantly impact nutrition, especially among the poor (Baird, 2009a, 2009b, 2011; Bush, 2003; ICEM, 2010). The size of this impact has not been established (Baird, 2009b, 2011).

It is estimated that 40 million rural people, more than two-thirds of the rural population in the Lower Mekong Basin, are engaged in the wild capture fishery (MRC, 2010b). Fisheries contribute significantly to a diversified livelihood strategy for many people, particularly the poor, who are highly dependent on the river and its resources for their livelihoods (Baran and Myschowoda, 2009; Baran and Ratner, 2007; Baran et al., 2011; Friend and Blake, 2009; World Bank, 2004).

They provide a principal form of income for a large number of people and act as a safety net and coping strategy in times of poor agricultural harvests or other difficulties (Baran and Ratner, 2007; Baran and Myschowoda, 2009; Friend and Blake, 2009; World Bank, 2004). In Lao PDR alone, 71 percent of rural households (2.9 million people) rely on fisheries for either subsistence or additional cash income. Around the Tonle Sap Lake in Cambodia, more than 1.2 million people live in fishing communes and depend almost entirely on fishing for their livelihoods (MRC, 2010b).

"Dams have a significant negative impact on fisheries, in some cases driving them to collapse"

What are the impacts of dams on fisheries?

This topic is well researched around the globe. It has been well established that dams affect the ways in which river ecosystems and hydrology work. River damming is a process so intense and dramatic that it results in the creation of a new ecosystem (Agostinho et al., 2008). Globally, dams eliminate 10 to 60 percent of fish species in their vicinity (Baran et al., 2009).

Dams affect fisheries in several significant ways:

* Acting as barriers to fish migrations. Fish migrations are highly complex events and an inherent part of fish breeding cycles. The presence of dams in the Amazon Basin, for example, has halted the long distance migrations of several species of catfish, reducing downstream catches by up to 70 percent (Bergkamp et al., 2000).

* Interrupting natural flood cycles to which fish have adapted over thousands of years.

* Hardening of the riverbed. Dams typically release water in bursts, which removes smaller sediments like silt, sand, and gravel, as well as aquatic plants and animals and debris from vegetation. As a result, the bedrock below the dam becomes exposed and loses its value as a habitat for fish.

* Capturing sediment behind dam walls. Dams are highly effective at trapping sediments. Sediments are a significant source of nutrition for fish.

* Altering water temperature. The water released from a dam is typically of a different (usually lower) temperature than the natural temperature regime downstream. When water is released, downstream water temperatures are rapidly altered, which has a direct impact on fish habitats and populations (WCD, 2000).

Cambodia is likely to bear the brunt of fisheries decline as a result of dam development, but the loss will also be significant for riparian communities in Laos (ICEM, 2010) and Thailand (Baird, 2011), as well as communities in the Vietnamese Mekong Delta (ICEM, 2010). Fisheries degradation will disproportionately impact the poor, but fisheries alone cannot address all development and poverty reduction needs (Friend and Blake, 2009). By 2030, if 11 proposed mainstream dams are built, the animal protein at risk of being lost every year is equivalent to 110 percent of the current annual livestock production of Cambodia and Laos (ICEM, 2010). Fish consumption is expected to rise as the regional population continues to grow and as diets continue to improve as a result of increasing development (Mainuddin and Kirby, 2009).

Conclusion: *There are good examples and verifiable science from around the world to indicate that dams have a significant negative impact on fisheries, in some cases driving them to collapse. The degree of impact will vary and depends on the location of the dam, the specific hydrodynamics of the river system in question, and the ways in which the dam and its water releases are managed.*

How will dams impact the Mekong River's biodiversity?

Aquatic biodiversity in the Mekong river system is the second highest in the world after the Amazon (Ferguson et al., 2011; ICEM, 2010; World Bank, 2004). The Mekong boasts the most concentrated biodiversity per hectare of any river (Valbo-Jørgensen et al., 2009). While estimates of species diversity vary, it is estimated that the Mekong River contains around 850 species of fish (Hortle 2009). Fish biodiversity will decrease over the next 20 years as a result of overexploitation, decreased habitat diversity and (in some locations) declining water quality (Costanza et al., 2011; ICEM, 2010). In the Lower Mekong, mainstream dams will likely lead to the loss of productivity and biodiversity of migratory species that use tributary systems (Costanza et al., 2011).

Conclusion: *The Mekong fisheries are amongst the most biodiverse in the world, and new species are being regularly identified. It is probable that dams will negatively affect biodiversity by creating barriers to fish migration and increasing habitat loss, thereby affecting fish breeding and life cycles.*

Will dams affect the migration of fish in the Mekong?

Any development that directly impedes fish migration in the middle and lower reaches of the river will have significant impacts on fish production (Stone, 2011). Dams act as physical barriers, blocking fish migration and disconnecting spawning and feeding habitats (Baird, 2009a, 2009b; Baran and Myschowoda, 2009; Kirby and Mainuddin, 2009; Sarkkula et al., 2009; Valbo-Jørgensen et al., 2009; World Bank, 2004).

"It is probable that dams will negatively affect biodiversity by creating barriers to fish migration and increasing habitat loss, thereby affecting fish breeding and life cycles"

These barriers will impact fish production and the survival of many species (Baird, 2009a; World Bank, 2004). Given the fact that most long-distance fish migrations include a reach of the Mekong mainstream, dams on the mainstream are expected to have more of an impact on fisheries than dams on tributaries (Dugan, 2008). Dams located higher in the basin will have less of an impact on fisheries, as most fish production comes from the middle and lower reaches of the basin and relatively few species migrate the full distance from lower to upper basin (Baran and Myschowoda, 2009; Ferguson et al., 2011). It should be noted, however, that "The lower Mekong is likely to have proportionally fewer vulnerable species compared to the upper Mekong because the diverse floodplain habitat characteristic of the lower Mekong supports species of fish that do not undertake extensive migrations to upstream habitats." (Halls and Kshatriya, 2009: 73). Run-of-the-river dams are often thought to have less of an impact on fisheries than reservoir dams. This, however, depends on how the dam is designed and operated. Moreover, all run-of-the-river dams act as a barrier to migration (Baran and Myschowoda, 2009).

Not all fish species will be threatened by mainstream dams. Species that undertake significant migration as part of their life cycle are most likely to be impacted (Halls and Kshatriya 2009). Estimates for the number of migratory fish species in the Mekong vary. Approximately 87 percent of species whose migration status is known (about 165) are migratory (Baran, 2006; Baran and Ratner, 2007; Baran and Myschowoda 2009).

Long distance migratory fish represent at least one third of the fish biomass harvested in the Lower Mekong Basin, including a large percentage of important commercial species (ICEM, 2010; World Bank, 2004). It is estimated that migratory species comprise more than 37 percent of the overall yield in the basin (Ferguson et al., 2011). Fifty-eight species in the ecological zone upstream of Vientiane are highly vulnerable to mainstream dam development and a further 26 species are at medium risk of impact as a result of their migratory behavior (ICEM, 2010).

Conclusion: *Mekong fish catches are comprised in large part of migratory fish species. The impact of dams on their migration routes will vary from place to place, but will in general significantly impact fish migration routes and therefore, fish catches. Experience from elsewhere around the world provides evidence of significant negative impacts on fisheries as a result of barriers to fish migration. While more research is needed in the Mekong on the magnitude of the impact that would result and the fish species that would be affected, it is expected that dams will present insurmountable barriers to fish migration.*

Will dams affect the Mekong's flood pulse?

It is well established that dams will alter the Mekong's seasonal variation in water levels, known as the 'flood pulse'. The presence of dams may result in an increase in dry season discharges (Friend and Blake, 2009) and reduce the severity of the flood pulse, hence reducing flooding (Stone, 2011). But floods are beneficial to fisheries as they open up new areas for fish to feed. Many Mekong fish species rely on hydrological triggers to start them on their migrations. If dry season flows are increased, this may prevent fish that are sensitive to these triggers from migrating, thereby reducing population size (Baird 2011; Baran and Myschowoda, 2009; Baran and Ratner, 2007; Friend and Blake, 2009: Halls and Kshatriya, 2009; Hogan et al., 2004, 236; Jutagate et al., 2003; Valbo-Jørgensen et al., 2009). Even run-of-the-river projects can potentially alter flow patterns, depending on how they are constructed (Baran and Ratner, 2007). The estimates for the number of species that could potentially be impacted by altered flood pulses vary widely (Baran and Ratner, 2007). Flow modifications will have other impacts, including diminished feeding and refuge opportunities, as well as unfavorable environmental conditions (Halls and Kshatriya, 2009; Kirby and Mainuddin, 2009; Sarkkula et al., 2009; World Bank, 2004).

The stabilization of the Tonle Sap as a result of alterations to the natural flood pulse will disrupt the ecosystem, where current fisheries production is correlated to the magnitude of the flood (Kirby and Mainuddin, 2009; Stone, 2011).

Conclusion: *Dams will reduce the magnitude of the Mekong's flood pulse, although by how much is not well established. It is probable that this will have knock-on impacts on fish migrations and breeding cycles, thereby reducing fisheries productivity.*

Will dams affect the Mekong's fish habitats?

It is well established that deep pools are important fish habitats throughout the basin, serving as dry season/low water refuges (i.e. where fish can hide from predators) (Bush, 2003; Baird, 2009b). Deep-water pools in the Sesan River have become increasingly shallow as a result of erosion and sedimentation caused by the Yali Falls Dam, thereby negatively impacting fisheries (Baird, 2009b). If all 11 planned mainstream dams are built, in 2030 more than 81 percent of the Lower Mekong Basin watershed will be obstructed, and therefore inaccessible to floodplain migratory fish (Baran, 2010). Additionally, 55 percent of the Mekong River between Chiang Saen and Kratie will be converted to reservoirs, completely changing the environmental features of the region (Baran, 2010). At least 250,000 hectares of floodplain, 5 percent of the Lower Mekong Basin floodplain area, will be lost by 2030 if all planned tributary dam projects go ahead (ICEM, 2010; Roberts, 2004).

"Experience from elsewhere around the world provides evidence of significant negative impacts on fisheries as a result of barriers to fish migration"

Conclusion: *It is probable that dams will have a significant negative impact on fish habitats, reducing fish reproduction and interrupting fish life cycles, thereby reducing fish landings. More research is, however, required to determine the extent of habitat loss, and the likely impact of this on fish landings.*

Will dams affect ecosystem benefits in the Mekong?

The degradation of Mekong fisheries has the potential to impact the ecosystem integrity and functioning of the entire basin (Halls and Kshatriya, 2009; Baird 2009a). At risk will be the economic, nutritional and social benefits of ecosystem services (Dugan et al., 2010). If all planned dams are built in the basin, the worst-case scenario loss of ecosystem services is valued at USD 274 billion (Stone, 2011).

Conclusion: *Dams will inevitably affect ecosystem services. The magnitude of losses to ecosystem services will vary depending on the number of dams built and where they are built. Because the poor rely disproportionately on ecosystem services, they will bear most of the impact.*

Will dams affect fisheries production in the Mekong?

If, by 2030, eleven dams are built on the Lower Mekong Basin mainstream, forecasted total fish losses would amount to 550,000 to 880,000 tonnes compared to the baseline year 2000 (a 26-42 percent decrease). This is a loss of approximately 340,000 tonnes compared to a situation in 2030 without mainstream dams (ICEM, 2010). Estimates of the cost of lost fish production range from USD 200 million (Baird, 2011) to USD 476 million (ICEM, 2010) a year. Mainstream dams located upstream of Vientiane would have less impact on fisheries resources than those located further downstream.

The impacts of mainstream dams on fisheries production varies from project to project, depending on distance from the major Mekong floodplains and position in relation to its important tributaries (ICEM, 2010). Tributary dams will also have a considerable impact on fisheries production. Together, the 78 constructed or planned tributary dams of the Lower Mekong Basin would produce less energy and pose greater risk to the environment, including catastrophic impacts on fish productivity and biodiversity, than the planned upper six Lower Mekong Basin mainstream dams (Ziv et al., 2012).

The planned tributary dams that will yield the greatest impact on fisheries production are the Lower Sesan 2 in Cambodia, which will reduce basin-wide fish biomass production by 9.3 percent; the Sekong 3 downstream in Lao PDR, which will reduce basin-wide fish biomass production by 2.3 percent; the Sekong 3 Upstream in Lao PDR, which will reduce basin-wide fish biomass production by 0.9 percent; and the Sekong 4 in Lao PDR, which will reduce basin-wide fish biomass production by 0.75 percent (Ziv et al., 2012).

Conclusion: *Dam developments on the Mekong will significantly affect the fisheries production of the system, whether those dams are built on the mainstream or its tributaries.*

Can wild capture fisheries losses as a result of dam development be mitigated?

In 2008, seventeen experts on fisheries and fish passes met at the Mekong River Commission Secretariat in Vientiane and concluded that, "existing mitigation technology cannot handle the scale of fish migration on the Mekong mainstream…The meeting also recognized that the ability to provide the partial mitigation measures seen in North America and Europe has been dependent on substantive research and development over several decades and on teams of highly qualified biologists and fish passage engineers. Similar investments will be needed in the Mekong before any level of certainty on their effectiveness can be determined" (Dugan, 2008: 14). There is no evidence from the region, or globally, that these mitigation measures prevent the negative impacts of hydropower on fisheries completely. They can, however, reduce them.

Conclusion: *While technical, managerial and ecological applications can help to mitigate fisheries losses to a limited extent, they cannot restore them to levels associated with an un-dammed river.*

Can intensified aquaculture production compensate for potential future fisheries losses, in addition to increased regional demand for fish?

Dam development has been recognized as a potential catalyst for aquaculture in the region (Friend and Blake, 2009). Data on aquaculture production in the Mekong River Basin is generally poor. It is known that aquaculture production has increased in recent years, with the majority of growth occurring in the Mekong Delta (Kirby and Mainuddin 2009; Mainuddin et al., 2011). A large portion of aquaculture production is, however, for export and does not therefore benefit regional diets (Friend and Blake, 2009; ICEM, 2010; Mainuddin et al., 2011).

In 2008, aquaculture production was estimated to be about 2 million tonnes, equivalent to 78 percent of wild fisheries consumption (MRC, 2010a). Aquaculture in the Mekong is heavily concentrated in the Mekong Delta. As the Mekong Basin's population grows, demand for aquatic resources will increase, hence driving up prices and improving investment opportunities for aquaculture. By 2015, it is predicted that aquaculture will be able to meet the extra demand for fish products, which is expected to exceed the capacity of wild capture fisheries (MRC, 2010a). By 2020, it is expected that aquaculture production will no longer be able to keep up with demand, and pressure will return to wild capture fisheries to make up the shortfall (MRC, 2010a).

"Seventeen experts on fisheries and fish passes concluded that existing mitigation technology cannot handle the scale of fish migration on the Mekong mainstream"

It should be noted that production is not the same as consumption. As has been well demonstrated elsewhere, the availability of large amounts of food does not necessarily equate with consumption if it is not distributed to those who need it, and the latter cannot afford to buy it (Sen, 1981). This is an important distinction between wild capture fisheries and aquaculture – aquaculture production must be paid for by those who consume it; this is not necessarily the case for wild capture fisheries.

Whether or not aquaculture can replace lost production from wild capture fisheries as a result of dams is uncertain. Scenario studies suggest that it can, under best case scenarios. Under mid-case assumptions there will also be excess yield, except when all mainstream dams are built. In the worst case scenarios, there would be a significant basin-wide deficit after 2015 of 436,000 tonnes per year. Most of this deficit would accrue in Cambodia. Thailand and the Vietnamese highlands would also suffer a deficit, and in Lao PDR there would be a small deficit in the worst case (MRC, 2010a). The Mekong delta would be in excess under any scenario due to its large aquaculture production capacity.

Even if current trends to intensify aquaculture production continue, if nothing is done to mitigate and manage capture fisheries impacts, there will be a significant basin-wide deficit that could not be replaced by aquaculture. It should be noted that these figures do not include the large quantities of aquaculture products produced in the Mekong Delta that are or will be exported out of the Lower Mekong Basin. If kept in the basin, these could compensate for any basin-wide deficit, but it is not necessarily the case that increased production will benefit poor people. Therefore, the most-affected people would also be least able to pay for such products (MRC, 2010a).

Aquaculture requires significant investment in addition to the technical and political support required to sustain it (Friend and Blake, 2009; Ferguson et al., 2011; ICEM, 2010; World Bank, 2004) and its future expansion has not been adequately assessed (Friend and Blake, 2009; Ferguson et al., 2011). Large-scale aquaculture does have significant ecological impacts, particularly through the accidental introduction of non-native species to rivers or the overharvest of fry populations from the wild for fish feed (Costanza et al., 2011; Friend and Blake, 2009: Mainuddin et al., 2011). Small-scale aquaculture may, however, be able to contribute to increased food security in rural areas (Friend and Blake, 2009; World Bank, 2004).

Conclusion: *Intensified, large-scale aquaculture can probably compensate for wild capture fish production deficits, but this is not certain. This option comes at a price, however. Rural people cannot harvest aquaculture fisheries 'for free'. In addition, the ecological impacts of large-scale aquaculture intensification need to be factored into any cost-benefit analysis of such a strategy.*

Do dam reservoirs represent new opportunities for fisheries development?

Currently, reservoir fisheries account for approximately 10 percent of Mekong fishery production (Baran et al., 2007). Reservoirs will not be able to support the same levels of fish diversity as the present riverine system (ICEM, 2010; Roberts, 1996). Only nine Mekong fish species are known to breed in reservoirs (Baran, 2006). In the past, reservoir stocking has not been able to compensate for the level of capture fisheries losses (Friend and Blake, 2009). Reservoirs may become eutrophic and deoxygenated as well as sites of increased outbreaks of fish disease experienced after dam construction (Roberts, 1996); such cases have been reported from some Mekong dam reservoirs (Baird, 2009b). It is highly unlikely that reservoir fisheries will be able to compensate for fisheries losses (Baran and Myschowoda, 2009; Friend and Blake, 2009).

"Whether or not aquaculture can replace lost production from wild capture fisheries as a result of dams is uncertain"

Conclusion: *Fisheries production from dam reservoirs cannot compensate for losses in capture fisheries arising from dam development.*

Are the benefits resulting from hydropower production large enough to offset the costs associated with the impacts on fisheries?

A 2006 World Bank and Asian Development Bank joint study found that the Mekong Basin's capacity for flexibility and tolerance indicated sustainable and integrated development could lead to widespread benefits. It recommended that policies related to water management be founded on economic, environmental and social trade-offs (Friend and Blake, 2009). It is likely that the economic costs associated with lost fisheries production as a result of dam development will outweigh the expected economic benefits of these structures (Baran and Myschowoda, 2009; Baran and Ratner, 2007; Friend and Blake, 2009).

Conclusion: *Initial studies on the trade offs between the environmental and social impacts of dams development with their economic gains, suggest that the economic benefits of dams are unlikely to outweigh the environmental and social costs of dams development (Kirby and Mainuddin, 2009).*

References

Agostinho, A.A., Pelicice, F.M. and Gomes, L.C. 2008. Dams and the fish fauna of the Neotropical region: impacts and management related to diversity and fisheries. *Brazilian Journal of Biology* 68(4): 1119-1132.
Baird, I.G. 2009a. The Don Sahong Dam: Potential Impacts on Regional Fish Migrations, Livelihoods and Human Health. http://polisproject.org/PDFs/Baird%_Don%20Sahong.pdf. Accessed on 30 January 2012.
Baird, I.G. 2009b. Best Practices in Compensation and Resettlement for Large Dams: The Case of the Planned Lower Sesan 2 Hydropower Project in Northeastern Cambodia. Rivers Coalition in Cambodia, Phnom Penh.
Baird, I.G. 2011. The Don Sahong Dam. *Critical Asian Studies* 43(2): 211-235.
Baran, E. 2006. Fish migration triggers in the Lower Mekong Basin and other tropical freshwater systems. *MRC Technical Paper* No. 14, Vientiane, Lao PDR, Mekong River Commission.
Baran, E. 2010. Mekong fisheries and mainstream dams. Fisheries sections in: ICEM 2010. Mekong River Commission Strategic Environmental Assessment of hydropower on the Mekong mainstream, International Centre for Environmental Management, Hanoi, Vietnam. p. 67. Accessed on February 20, 2012. http://www.worldfishcenter.org/resource_centre/WF_2736.pdf.
Baran, E., Jantunen, T., Chong, C.K. 2007. Values of inland fisheries in the Mekong River Basin. WorldFish Center, Phnom Penh, Cambodia.
Baran, E., Meynell, P.-J., Kura, Y., Agostinho, A.A., Cada G., Hamerlynck, O., Nao T. and Winemiller K., 2009. Dams and Fish: Impacts and Mitigation. Unpublished draft report from WorldFish Center to the MRC.
Baran, E. and Myschowoda, C. 2009. Dams and fisheries in the Mekong Basin. *Aquatic Ecosystem Health and Management*, 12(3): 227-234.
Baran, E. and Ratner, B. 2007. The Don Sahong Dam and Mekong Fisheries. *Science Brief*. WorldFish Center. p. 3.
Baran, E., Samadee, S., Shwu Jiau, T. and Thanh Cong T. 2011. Fish and fisheries in the Sesan River Basin: Catchment baseline, fisheries section. Project Report. Mekong Challenge Program Project MK3.
Berkamp, G., McCartney, M., Dugan, P., McNeely, J. and Acreman, M. 2000. Dams, Ecosystem Functions and Environmental Restoration: Thematic Review II.1. Prepared as an input to the World Commission on Dams. Cape Town, South Africa, World Commission on Dams.
Bush, S. 2003. "Give a man a fish…" Contextualising Living Aquatic Resources Development in the Lower Mekong Basin. Australian Mekong Resource Centre Working Papers No. 8.
Costanza, R., Kubiszewski, I., Paquet, P., King, J., Halimi, S., Sanguanngoi, H., Bach, N.L., Frankel, R., Ganaseni, J., Intralawan, A. and Morell, D. 2011. Planning approaches for water development in the Lower Mekong Basin. Portland State University, Portland, Oregon, USA, and Mae Fa Luang University, Chiang Rai, Thailand.
Dugan, P. 2008. Mainstream dams as barriers to fish migration: international learning and implications for the Mekong. *Catch and Culture* 14(3): 9-15. Vientiane, Lao PDR, Mekong River Commission.
Dugan, P.J., Barlow, C., Agostino, A.A., Baran, E., Cada, G.F., Chen, D., Cowx, I.G., Ferguson, J.W., Jutagate, T., Mallen-Cooper, M., Marmulla, G., Nestler, J., Petrere, M., Welcomme, R.L., Winemiller, K.O. 2010. Fish Migration, Dams, and Loss of Ecosystem Services in the Mekong Basin. Ambio 39: 344-348.
Ferguson, J.W., Healey, M., Dugan, P. and Barlow, C. 2011. Potential Effects of Dams on Migratory Fish in the Mekong River: Lessons from the Fraser and Columbia Rivers. *Environmental Management* 47: 141-159.
Friend, R., Arthur, R. and Keskinen, M. 2009. Songs of the Doomed: The Continuing Neglect of Capture Fisheries in Hydropower Development in the Mekong. In Molle, F., Foran, T. and Kakonen, M. (eds) *Contested Waterscapes in the Mekong Region: Hydropower, Livelihoods and Governance*. London, Earthscan: 307-331.
Halls, A.S. and Kshatriya, M. 2009. Modelling the cumulative barrier and passage effects of mainstream hydropower dams on migratory fish populations in the Lower Mekong Basin. MRC Technical Paper No. 25. Mekong River Commission, Vientiane.
Hogan, Z.S., Moyle, P.B., May, B., Jake Vander Zanden, M., and Baird, I.G. 2004. The Imperiled Giants of the Mekong: Ecologists struggle to understand - and protect - Southeast Asia's large migratory catfish. *American Scientist*, 92 (2004): 228–237.
Hortle, K.G. 2007. Consumption and the yield of fish and other aquatic animals from the Lower Mekong Basin. MRC Technical Paper No. 16, Mekong River Commission, Vientiane.
Hortle, K.G. 2009. Fishes of the Mekong—How many species are there?. Catch and Culture 15(2): 4-12. Vientiane, Lao PDR, Mekong River Commission.
ICEM (International Centre for Environmental Management). 2010, *MRC Strategic Environmental Assessment (SEA) of hydropower on the Mekong mainstream*. Vientiane, Mekong River Commission, Hanoi, Viet Nam.
Jutagate, T., Krudpan, C., Ngamsnae, P., Payooha, K. and Lamkom, T. 2008. *Fisheries in the Mun River: A One-Year Trial of Opening the Sluice Gates of the Pak Mun Dam, Thailand*. *Kasetsart* Journal: Natural Science 37 (1): 101-116.
Friend, R.M. and Blake, D.J.H, 2009. Negotiating trade-offs in water resources development in the Mekong Basin: implications for fisheries and fishery-based livelihoods. *Water Policy Supplement I* (2009): 13-30
Kirby, M. and Mainuddin, M. 2009. Water and agricultural productivity in the Lower Mekong Basin: trends and future prospects. *Water International* 34 (1): 134-143.
Mainuddin, M. and Kirby, M. 2009. Agricultural water productivity in the lower Mekong Basin: trends and future prospects for food security. *Food Security* 1 (1): 71-82.
Mainuddin, M., Kirby, M. and Chen, Y. 2011. Fishery productivity and its contribution to overall agricultural production in the Lower Mekong River Basin. *CPWF Research for Development* Series 03. Colombo, Sri Lanka, CGIAR Challenge Program on Water and Food (CPWF).
MRC (Mekong River Commission), 2003. State of the Basin Report: 2003. Mekong River Commission, Phnom Penh.

MRC (Mekong River Commission), 2010a. Impacts on Fisheries. Assessment of Basin-wide Development Scenarios: Technical Note 11. Basin Development Plan Programme Phase 2. Vientiane, Lao PDR, MRC.

MRC (Mekong River Commission), 2010b. State of the Basin Report 2010. Vientiane, Lao PDR, MRC.

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://www.irn.org/programs/mekong/tysonfluvicide0904.pdf (19 February 2006). Accessed on 30 January 2012.

Sarkkula, J., Keskinen, M., Koponen, J., Kummu, M., Richery, J.E., and Varis, O. 2009. Hydropower in the Mekong Region: What Are the Likely Impacts Upon Fisheries? In Molle, F., Foran, T. and Kakonen, M. (eds) *Contested Waterscapes in the Mekong Region: Hydropower, Livelihoods and Governance*. London, Earthscan: 227-249.

Sen, A. 1981. *Poverty and famines: an essay on entitlement and deprivation*. Oxford, Clarendon Press.

Stone, R. 2011. Mayhem on the Mekong. Science 333: 814-818.

Valbo-Jørgensen, J., Coates, D., Hortle, K.G. 2009. Fish diversity in the Mekong River Basin. In: Campbell, I.C. (ed.) *The Mekong: Biophysical Environment of an International River Basin*. Amsterdam, Elsevier Publishers: 161-196.

WCD (World Commission on Dams), 2000. Dams and Development: A New Framework for Decision-Making. The Report of the World Commission on Dams. London, Earthscan.

World Bank, 2004. Modeled Observations on Development Scenarios in the Lower Mekong Basin. Prepared for the World Bank with MRC Cooperation. Technical assessment by Geoff Podger and Richard Beecham. Review, observations and conclusions by Don Blackmore, Chris Perry and Robyn Stein. Vientiane, Lao PDR, World Bank.

Ziv, G., Baran, E., Rodríguez-Iturbe, I., and Levin, S.A. 2012. Trading-off Fish Biodiversity, Food Security and Hydropower in the Mekong River Basin. In press, Proceedings of the US Academy of Science.

What is the State of Knowledge (SOK) Series?

The SOK series sets out to evaluate the state of knowledge on subjects related to the impact, management and development of hydropower on the Mekong, including its tributaries. Publications in the series are issued by the CGIAR Challenge Program on Water and Food – Mekong Programme. The series papers draw on both regional and international experience. Papers seek to gauge what is known about a specific subject and where there are gaps in our knowledge and understanding. All SOK papers are reviewed by experts in the field. Each section in a SOK papers ends with a conclusion about the state of knowledge on that topic. This may reflect high levels of certainty, intermediate levels, or low certainty.

The SOK series is issued on CD-ROM and in print. The versions that appear on CD-ROM also include the source material on which conclusions are based.

Citation: Pukinskis, I. and Geheb, K. 2012. The Impact of Dams on the Fisheries of the Mekong. State of Knowledge Series 1. Vientiane, Lao PDR, Challenge Program on Water and Food.

This SOK has been reviewed by Eric Baran (WorldFish Centre), Kent Hortle (fisheries consultant), Yumiko Kura (WorldFish Centre), Chris Barlow (ACIAR) and Robert Arthur (MRAG Ltd). Reviewers cannot be held responsible for the contents of any SOK paper, which remains with the CPWF and associated partners identified in the document.

This SOK has been edited by Terry Clayton at Red Plough (**clayton@redplough.com**).
Design and lay-out by Remy Rossi (**rossiremy@gmail.com**).

The Challenge Program on Water and Food was launched in 2002 as a reform initiative of the CGIAR, the Consultative Group on International Agricultural Research. CPWF aims to increase the resilience of social and ecological systems through better water management for food production (crops, fisheries and livestock). CPWF does this through an innovative research and development approach that brings together a broad range of scientists, development specialists, policy makers and communities to address the challenges of food security, poverty and water scarcity. CPWF is currently working in six river basins globally: Andes, Ganges, Limpopo, Mekong, Nile and Volta. More information can be found at **www.waterandfood.org**.

In the Mekong, the CPWF works to to reduce poverty and foster development by optimizing the use of water in reservoirs. If it is successful, reservoirs in the Mekong will be: (a) managed in ways that are fairer and more equitable to all water users; (b) managed and coordinated across cascades to optimize benefits for all; (c) planned and managed to account for environmental and social needs; (d) used for multiple purposes besides hydropower alone; (e) better governed and the benefits better shared. More information can be found at **www.mekong.waterandfood.org**.

The CPWF is part of the CGIAR Research Program on Water, Land and Ecosystems. This new research program combines the resources of 14 CGIAR centers and range of international, regional and national partners to provide an integrated approach to natural resource management (NRM) research, and to the delivery of its outputs. The program focuses on the three critical issues of water scarcity, land degradation and ecosystem services, as well as sustainable natural resource management. It will also make substantial contributions to improved food security, poverty alleviation and, to a minor extent, health and nutrition. More information can be found at **www.iwmi.cgiar.org/CRP5**.

Want to know more?
Contact us at **cpwf.mekong@gmail.com.**

CGIAR Challenge Program on
WATER & FOOD
Andes • Ganges • Limpopo • Mekong • Nile • Volta

Research Program on Water, Land and Ecosystems
CGIAR