STRATEGIC ENVIRONMENTAL ASSESSMENT OF HYDROPOWER ON THE MEKONG MAINSTREAM

MEKONG FISHERIES AND MAINSTREAM DAMS

Eric BARAN
(WorldFish Center)

Fisheries sections of the Strategic Environmental Assessment of hydropower on the Mekong mainstream prepared for the

Mekong River Commission

by ICEM – International Centre for Environmental Management

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ABOUT THE SEA OF HYDROPOWER ON THE MEKONG MAINSTREAM

The Strategic Environmental Assessment of Hydropower on the Mekong mainstream (SEA) was initiated by the Mekong River Commission and coordinated by the MRC's Initiative for Sustainable Hydropower.

Strategic Environmental Assessments address broad strategic issues usually relating to more than one hydropower project. SEAs follow similar steps to Environmental Impact Assessments but have much larger boundaries in terms of time, space and subject coverage. The SEA is a tool to examine the broad strategic concerns which need to be resolved and decided prior to making project specific decisions. In this case, the SEA of hydropower on the Mekong mainstream was asked to provide an understanding of the implications of mainstream hydropower development and recommendations on whether and how the proposed projects should best be pursued. The SEA is intended to feed into the MRC Basin Development Plan (BDP), and ultimately to support national decisions concerning the mainstream proposals.

The SEA was implemented between May 2009 and October 2010 by the International Center for Environmental Management (ICEM) and covered nine themes: Power systems, Economic systems, Hydrology and sediment regime, Terrestrial systems, Aquatic systems, Fisheries, Social systems, Navigation and Climate change.

The SEA team included:
MRCS ISH: Mr Voradeth Phonekeo (Project Manager), Mr Larry Haas (Technical Advisor).
ICEM: Dr Jeremy Carew-Reid (Team Leader), Mr Tarek Ketelsen (Project Coordinator), Mr Peter-John Meynell, Dr Eric Baran, Dr Elizabeth Mann, Prof. Peter Ward, Mr John Sawdon, Dr Benoit LaPlante, Dr Carlos Yermoli, Mr Cong An Tranh, Dr Apichart Annukalumphai, Dr Suppakorn Chinnarvo, Dr Kanokwan Manoram, Ms Piyathip Eawpanich, Dr Nguyen Huu Thien, Dr Nguyen Xuan Nguyen, Dr Nguyen Van San, Ms Nguyen Thi Nga, Mr Meng Monyrak, Mr Try Thuon, Mr Phaknakhone Rattana, Mr Sae Senpaty, Mr Bonheung Phantasith.

The current report is an excerpt of the whole SEA study, and focuses on fish resources only.

The details and conclusions of this SEA are available on the following websites: www.mrcmekong.org/ish/SEA.htm and www.icem.com.au

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Dr. E. Baran is Senior Scientist at the **WorldFish Center** (www. worldfishcenter.org)

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Mekong River Commission, 2010; Zeb Hogan, 2009; Peter-John Meynell, 2010, Peter Ward, 2003

International Center for Environmental Management
32 Xuan Dieu St., Tay Ho, Hanoi, Vietnam
www.icem.com.au

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FISHERIES BASELINE ASSESSMENT

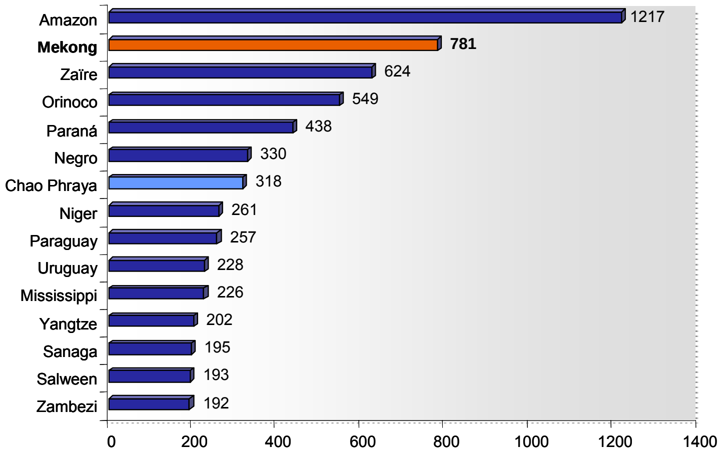
1 FISHERIES BASELINE ASSESSMENT

1.1 STATUS OF MEKONG FISH BIODIVERSITY[1]

1.1.1 FRESHWATER FISH DIVERSITY IN THE MEKONG AND WORLDWIDE

The following analyses focus on species richness, and rely on FishBase (*www.fishbase.org*), the global fish database (32,000 species). Fish species richness was queried from FishBase for 455 ecosystems, out of which 204 rivers and 32 lakes were identified. The top 15 rivers and top 10 lakes are displayed below.

Figure 1: Fish species richness for different rivers of the world.



Source: FishBase, December 2009

Conclusions:

The Mekong River is the second river in the world for its fish diversity, after the Amazon. It was ranked third in 2000 (Dudgeon 2000) but its species list has been substantially updated since then. The Mekong region is thus a biodiversity hotspot, whose magnitude is only being discovered: in the last decade more than 279 new species of fish have been discovered in this basin (WWF 2009). When all animals and plants are considered, it is more than a thousand new species that have been discovered in the basin within a decade.

Notes:

• These numbers originating from the global database do not yet reflect the larger species richness identified during this study and described below.

• Many publications mention fish species richness in the Mekong equal or close to 1,200 species (e.g. Coates *et al.* 2003, Poulsen *et al.* 2004). However, this number originates from the introduction section of W. Rainboth's book "Fishes of the Cambodian Mekong" (Rainboth 1996). According to this taxonomist, "the total number of species recorded or expected from the Mekong, as inferred from the known zoogeography of Southeast Asia, includes about 1,200 species" (p. 5). The author actually details his "method" in an interview to "Catch and Culture" in August 1996[2]. These sources show that the widespread figure of 1,200 fish species in the Mekong is not a factual figure.

[1] This section reflects the on going-work of the project "Scenario-based assessment of the potential effects of alternative dam construction schemes on freshwater fish diversity in the Lower Mekong Basin" implemented by NIES (Japan), WorldFish Center, Ubon Ratchatani University (Thailand) and IFReDI (Cambodia), and Funded by Mitsui Bussan.

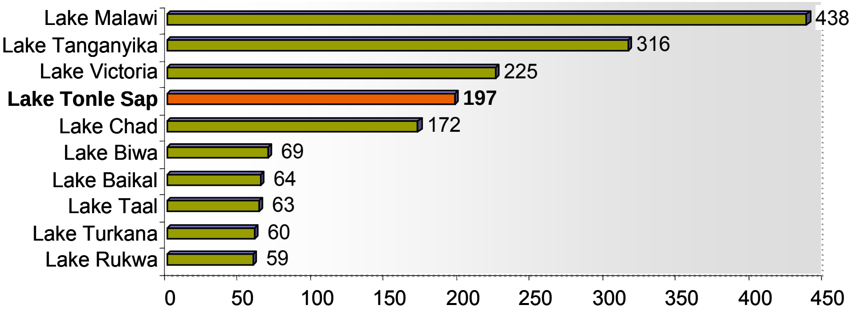
[2] "I included species from parts of adjacent river basins, such as the Chao Phya. Also, I included estuarine and shoreline species. I included about 150 species of goby! Right now, the total number is any body's guess, and the more effort we put into looking, the higher the number will be." W. Rainboth in Catch and Culture, August 1996.

Alternatively, in the Mekong Fish Database produced by the MRC (MFD 2003), 924 species only are listed, 815 species being "confirmed" and 45 species "expected" (the remainder consisting of synonymous or questionable species). In a recent article, Hortle (2009) reviews the issue and concludes that "the available data indicate that there are about 850 freshwater fish species recorded from the Mekong, with a total of about 1,100 if the possible coastal or marine visitors are included".

Unlike all the above figures, the number of Mekong fish species presented here (781 so far) originates from FishBase, the global reference database of fishes worldwide (www.fishbase.org), in which each record is backed by a scientific study or publication. This is certainly an underestimate but is also the most rigorous assessment available so far.

FishBase was also used to compare the Tonle Sap Lake in Cambodia with lake ecosystems worldwide:

Figure 2: Fish species richness for different lakes of the world.



Source: FishBase, December 2009

Conclusions: In terms of fish biodiversity, the Tonle Sap Lake appears, with 197 species recorded so far, as the lake ecosystem having the fourth highest fish diversity in the world, or the richest lake in the world after east-African lakes.

Last, FishBase was used to identify the number of freshwater, brackish, marine and threatened species for 302 countries or territories worldwide. The table below indicates the rank of Mekong countries for each of these categories.

Table 1: Rank of Lower Mekong countries for 4 different categories of fish species out of 302 countries or territories.

	Number of / Rank in freshwater species	Number of / Rank in threatened species
Cambodia	488 / 18	NA
Lao PDR	587 / 14	21 / 16
Thailand	837 / 8	61 / 6
Viet Nam	629 / 12	55 / 7

Source: FishBase, December 2009

So among countries and territories of the world, Lao PDR, Thailand and Viet Nam are among the top 5% for their number of freshwater fish species and number of threatened fish species.

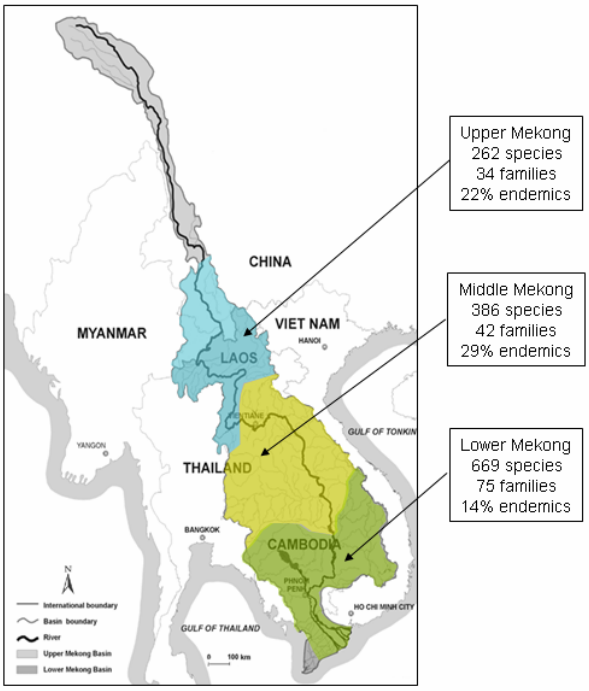
1.1.2 FRESHWATER FISH DIVERSITY IN THE 3 MAIN MIGRATION ZONES

An analysis of the above database allows characterizing the biodiversity in each of the 3 migration zones identified initially by Poulsen *et al.* in 2002.

Table 2: Biodiversity in the 3 main Mekong migration zones.

Migration zones	Location	Species	Families	Endemics	% Endemics
Upper Mekong	Mekong China – lower reach Mekong northern Lao PDR Nam Ou	262	34	57	21.8
Middle Mekong	Mun / Chi Nam Kadinh Nam Mang Nam Ngum Songkhram Xe Bang Fai Xe Bang Hiang	386	42	112	29.0
Lower Mekong	Mekong down Khone Falls Mekong Stung Treng - Kratie Sekong Sesan Srepok **Tonle Sap** **Mekong delta**	669	75	96	14.3

Figure 3: Biodiversity in the 3 main Mekong migration zones



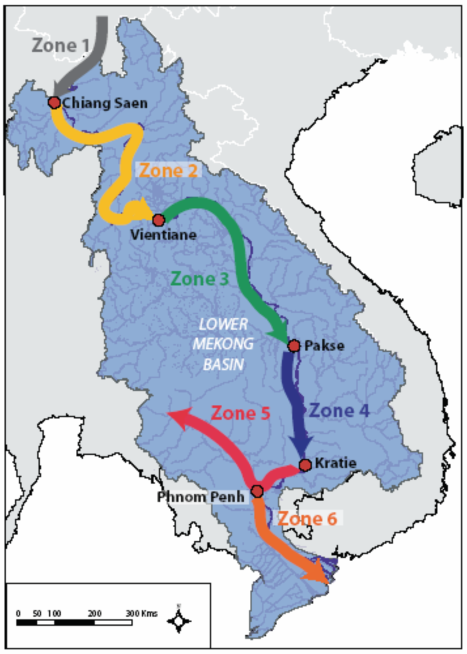
Conclusions: With 669 species, the lower Mekong migration zone is by far the area exhibiting the highest species diversity. This high diversity is largely due to the conjunction of freshwater, estuarine and marine fish faunas, particularly with the incursion of coastal species into the freshwater areas, up to the Tonle Sap or even higher upstream. Since the coastal species are not Mekong-specific, they are not considered as endemics in the classification, which partly explains why the Lower Mekong migration zone also has the lowest endemicity.

1.1.3 FRESHWATER FISH DIVERSITY IN THE SIX MAIN ECOLOGICAL REACHES

In the analysis below we follow the ecological zones or "reaches" of the Mekong mainstream defined in MRC 2005a and originating from the Integrated Basin Flow Management project (report nº 7, unpublished). In this classification based on geomorphological descriptors, six main zones are identified:

Zone 1: Upper Mekong River in China to Chiang Saen: headwaters and mountain river
Zone 2: Chiang Saen to Vientiane: upland river in a steep narrow valley
Zone 3: Vientiane to Pakse: midstream section; large river
Zone 4: Pakse to Kratie: zone including large wetlands (in Siphandone, and Stung Treng)
Zone 5: Kratie to Phnom Penh: downstream section; floodplains and the Great Lake
Zone 6: Phnom Penh to the South China Sea: Mekong delta, tidal zone

Figure 4: Ecological zones in the Mekong Basin.



The biodiversity analysis detailed below allowed the quantification of species diversity for each ecological reach.

Table 3: Number of fish species and families in each ecological zone of the Mekong (mainstream).

	Z1 China	Z2 Chiang Saen - Vientiane	Z3 Vientiane - Pakse	Z4 Pakse-Kratie	Z5 Kratie - PP and TS	Z6 PP - Delta
Number of species	151	140	NA	252	284	486
Endemic species	19	26	NA	40	31	28
Introduced species	7	4	NA	5	4	3
Native species	125	110	NA	207	249	455
Number of families	13	12	NA	36	40	56

Conclusions: This analysis confirms the previous one and shows that species richness is lower in China and northern Lao PDR (although quite high already, with more than a hundred species), increases downstream and culminates in the delta. Conversely, the proportion of endemics is relatively higher upstream and decreases below Khone Falls.

1.1.4 FRESHWATER FISH DIVERSITY IN MEKONG HYDROLOGICAL SUB-BASINS

For this analysis 45 sources of information were reviewed, including substantial lists of fish species in the Mekong mainstream (China included) and in sub-basins. Sources are listed in the Bibliography section. Overall 860 Mekong fish species belonging to 81 families have been identified. This is much more than previously recorded and documented in FishBase (781 so far), and can be explained by the integration of recent species lists from China and from the delta (these recent publications are not reflected in FishBase yet).

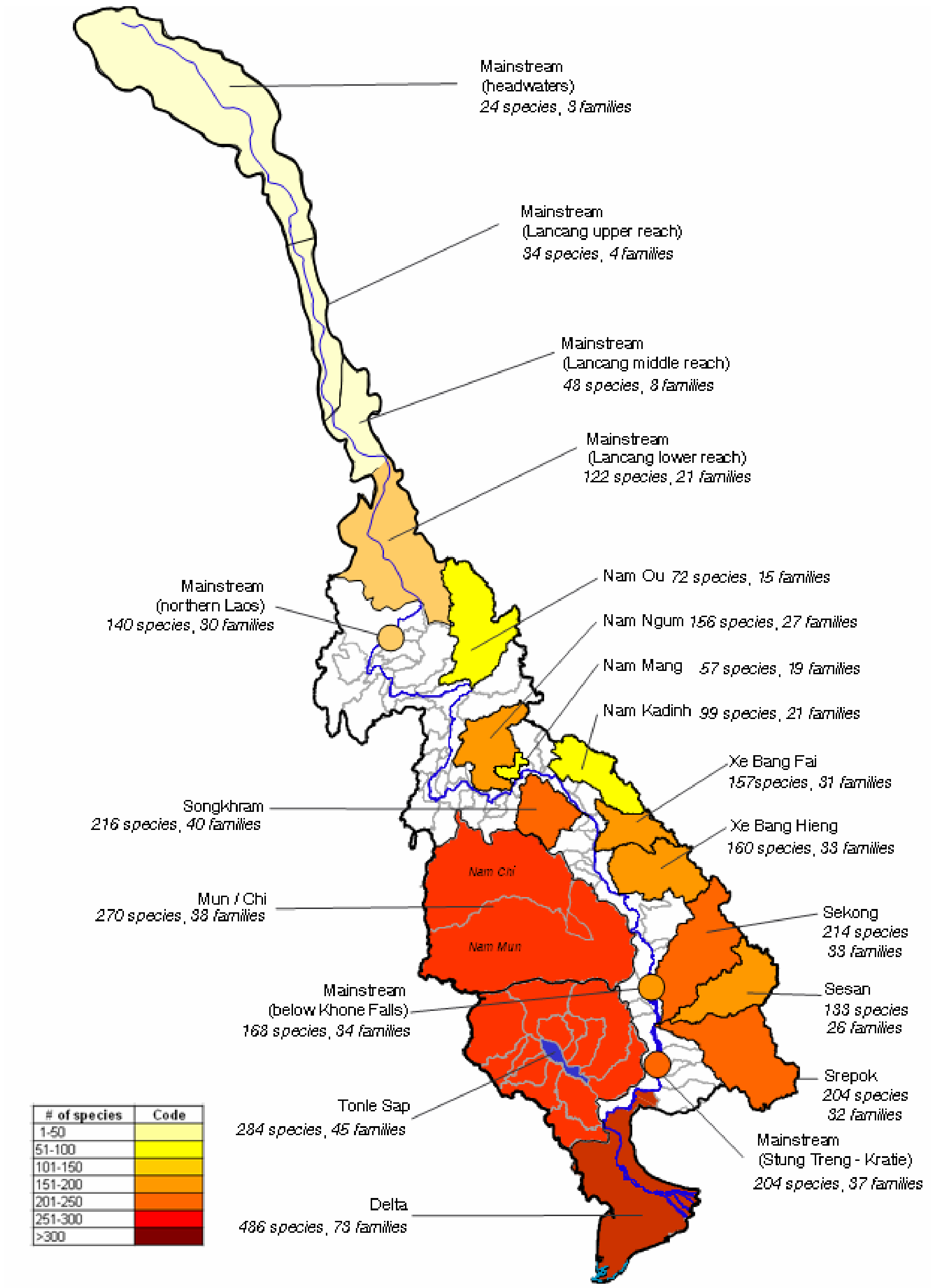
This study resulted in a mapping of species compositions in 20 locations (river basins and mainstream locations), detailed in Table 4 and in Figure 5.

Table 4: Species richness in 20 locations of the Mekong Basin.

Location	Species	Families	Endemic
Mekong China - headwater	24	3	4
Mekong China - upper reach	34	4	4
Mekong China - middle reach	48	8	7
Mekong China - lower reach	122	21	15
Mekong northern Lao PDR	140	30	26
Nam Ou	72	15	29
Nam Ngum	156	27	43
Nam Mang	57	19	17
Nam Kadinh	99	21	38
Songkhram	216	40	39
Xe Bang Fai	157	31	51
Xe Bang Hiang	160	33	47
Mun / Chi	270	38	49
Mekong down Khone Falls	168	34	25
Mekong Stung Treng - Kratie	204	37	33
Sekong	214	33	63
Sesan	133	26	24
Srepok	204	32	38
Tonle Sap	284	45	31
Mekong Delta	486	73	28

Conclusions: This analysis shows a strong gradient of species richness from the headwaters down to the sea, with 24 species in Tibet and 486 in the delta. This phenomenon is standard in big rivers and reflects the fact that hydrological predictability and habitat diversity increase downstream, allowing more species to develop. Another unsurprising finding is that in sub-basins the species richness is roughly proportional to the size of the watershed; thus, the Mun/Chi and Tonle Sap basins feature the highest number of species. The delta is the area characterized by the highest species diversity, because of the combination of estuarine, freshwater and marine faunas, the two latter groups making temporary incursions in the estuarine area.

Figure 5: Species richness in 20 locations in the Mekong Basin.



1.2 STATUS OF MEKONG CAPTURE FISH PRODUCTION

1.2.1 FISH CATCH IN THE MEKONG COUNTRIES

1.2.1.1 FRESHWATER FISH CATCH ACCORDING TO NATIONAL DATA

We present in Table 5 FAO fisheries catch statistics since 2000. These statistics represent a compilation of official statistics provided by the riparian countries. 2008 and 2009 data are not available yet.

Table 5: Freshwater capture fisheries statistics for the four LMB countries according to the FAO (tonnes).

	2000	2001	2002	2003	2004	2005	2006	2007
Cambodia	245,300	384,500	359,800	308,250	249,600	323,500	421,400	419,400
Lao PDR	29,250	31,000	33,440	29,800	29,800	26,560	26,925	26,925
Thailand	201,205	202,200	198,200	197,493	202,600	194,159	208,400	218,010
Viet Nam	180,000	188,542	163,615	148,959	134,075	130,400	136,200	133,600

Source: *http://www.fao.org/fishery/statistics/global-capture-production/en*

In the rest of this review we focus on the 2005-2007 period since these years reflect the latest trends in a sector and an environment evolving rapidly (aquaculture, infrastructure development, market forces, demography, etc.).

Table 6: LMB freshwater capture fisheries production according to national statistics (FAO; average of the 2005-2007 statistics; tonnes).

	2005	2006	2007	Average
Cambodia	323,500	421,400	419,400	388,100
Lao PDR	26,560	26,925	26,925	26,803
Thailand	194,159	208,400	218,010	206,856
Viet Nam	130,400	136,200	133,600	133,400
Total				755,160

Source: *http://www.fao.org/fishery/statistics/global-capture-production/en*

Note: As of December 2009, FAO/national statistics are not yet available for 2008. According to the Cambodian Minister of Agriculture, Forestry and Fisheries (1st July 2009), Cambodian freshwater fisheries production amounted to 365,000 tones in 2008.

Conclusions: According to respective national statistics, the inland fisheries sector in the four countries of the LMB produces around 755,000 tonnes each year. By comparison, the total production of inland capture fisheries worldwide amounted to 10.1 million tonnes in 2006 (FAO 2009); thus, according to national statistics, the Mekong fisheries produce 7% of the world's freshwater fisheries.

1.2.1.2 FRESHWATER FISH CATCH ACCORDING TO FIELD SURVEYS

FAO statistics are disputed and considered much underestimated since they originate from individual countries and are *not based on field studies* (Coates 2002, Barlow *et al.* 2008)[3]. Coates (2002) in particular, in his review of inland fishery statistics in Southeast Asia, argues that the total reported production from inland waters appears to be underestimated by a factor of between 2.5 and 3.6. One can also note an incongruity within FAO statistics between the inland fish catch figures and inland fish consumption, the latter being more than double the catch (see section 1.2.3). At the moment there are three main alternative sources of science-based statistics: studies based on catch monitoring and assessment projects, on wetland productivity and on fish consumption at the household level. We detail below the figures originating from these sources:

Table 7: Estimates of LMB freshwater capture fisheries production, based on fishery surveys.

	Cambodia[1]	Lao PDR[1]	Thailand[1]	Viet Nam[1]	*Total*
Estimated fish yield (tonnes)	682,150	182,700	932,300	844,850	*2,642,000*

Source: Van Zalinge *et al*. 2004.

Table 8: Estimates of LMB freshwater capture fisheries production based on wetland productivity studies.

	Cambodia	Lao PDR	Thailand	Viet Nam	Total
Km^2 of wetland	49,393	10,196	86,734	47,573	193,896
Low fish productivity scenario (50 kg/ha/y)	197,572	20,392	173,468	190,292	581,688
Medium fish productivity scenario (100 kg/ha/y)	395,144	40,784	346,936	380,584	1,163,376
High fish productivity scenario (200 kg/ha/y)	790,288	81,568	693,872	761,168	2,326,752

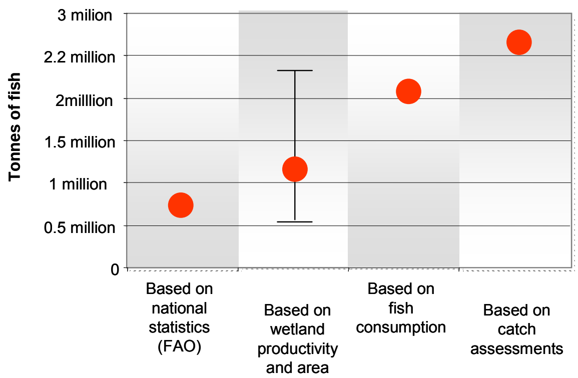
Source: Hortle 2007. Surface of wetlands calculated by GIS, yield per surface area hypothesized, based on a range of 20 field studies.

Table 9: Estimates of LMB fish production, based on fish consumption in households.

	Cambodia	Lao PDR	Thailand	Viet Nam	Total
Estimated yield (tonnes/year) of inland fish in the LMB, based on consumption studies	481,537	167,922	720,501	692,118	2,062,077

Source: Hortle 2007, based on 20 fish consumption surveys.

Figure 6: Estimates of Mekong fish production according to national statistics and scientific assessments.



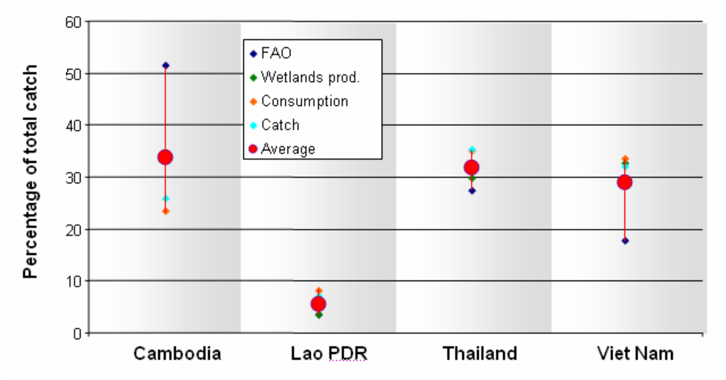
<u>Conclusions:</u> According to scientific estimates alternative to FAO statistics, the fish production of the Lower Mekong amounts to more than one million tonnes, and up to 2.6 million tonnes. The most reliable assessment, based on a synthesis of 20 household consumption studies, estimates fish production at 2.1 million tonnes of freshwater fish. The coastal fish production dependent on Mekong nutrient outflow is not included in these figures.

[3] Furthermore FAO statistics are produced by country, whereas alternative catch assessments focus on the Mekong Basin only. This implies that Mekong catches *sensu stricto* would be even lower according to FAO statistics.

Table 10: Share of each country in the total catch, depending on sources of data considered (cf. Tables 6 to 9)

	Cambodia	Lao PDR	Thailand	Viet Nam
Range in %	23-51	4-8	27-35	18-34

Figure 7: Share of each country in the total catch, depending on sources of data considered

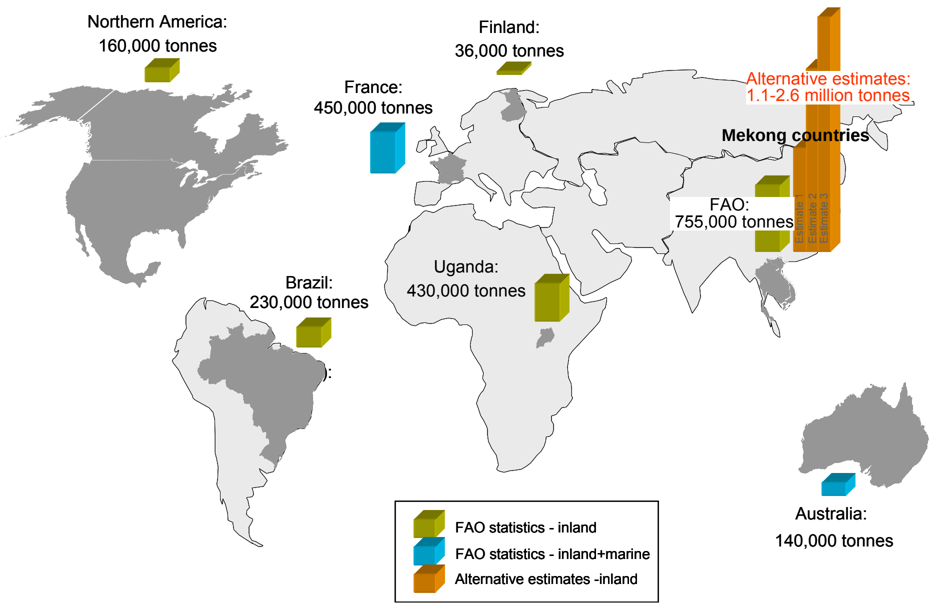


Conclusions: According to all studies and sources of data, Cambodia, Thailand and Viet Nam each produce about one third of the overall Mekong fish catch, and Lao PDR produces around 5%.

1.2.1.3 FRESHWATER FISH CATCH IN THE MEKONG AND WORLDWIDE

As mentioned above, according to FAO statistics, the inland fisheries sector in the four countries of the LMB produces around 755,000 tonnes each year, but according to alternative field-based estimates, this sector produces up to 2.64 million tonnes of fish a year (the most robust assessment being 2.1 million tonnes). Thus, depending on the source of information considered, Mekong fisheries produce between 6 and 22% of the world's freshwater capture fish[4], the most likely estimate being 18% [5].

Figure 8: Comparison of fish production in the Mekong and in other countries worldwide.



Source: FAO statistics: 2005-2007 average. Brazil, Uganda and Finland are the countries with the biggest inland fisheries in South America, Africa and Western Europe respectively. Alternative estimates for the Mekong correspond to the 3 main assessment approaches (wetland productivity, fish consumption and catch estimates).

[4] Minimum: estimate based on low wetland productivity: 0.58/(10.1-0.755+0.58) in million tonnes = 5.8%
Maximum: estimate based on fish catches: 2.64 / [10.1 + (2.64 – 0.755)] in million tonnes = 22%

[5] Most likely estimate based on fish consumption: 2.1 / [10.1 + (2.1 – 0.755)] in million tonnes = 18%

1.2.2 MEKONG FISH CATCH AND POPULATION

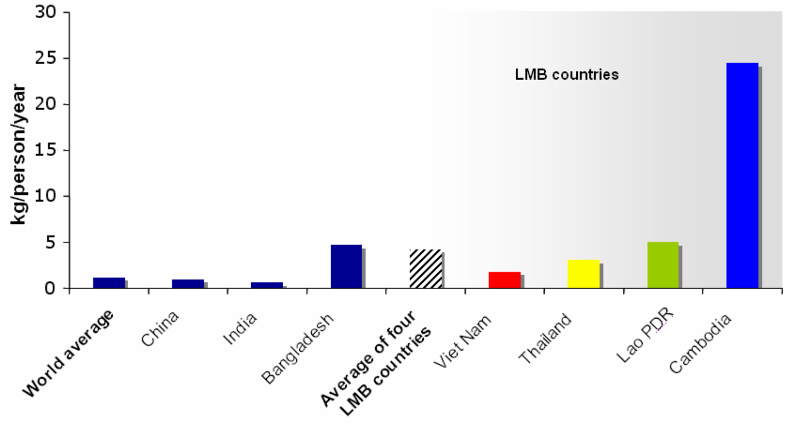
Fish catch figures are compared with population statistics in Table 11.

Table 11: Freshwater capture fisheries and population.

	Average freshwater fish catch 2000-2007 in tonnes	2005 population	catch (kg) per person/y
World	7,556,635	6,512,276,000	1.1604
China	1,309,551	1,312,253,000	0.998
India	703,099	1,130,618,000	0.622
Bangladesh	714,662	153,122,000	4.667
4 LMB Countries	722,889	169,766,000	4.258
Viet Nam	151,924	84,074,000	1.807
Thailand	202,783	65,946,000	3.075
Lao PDR	29,213	5,880,000	4.968
Cambodia	338,969	13,866,000	24.446

Source: Fish catches from FAO, population data from UN World Population Prospects, 2005. (*http://esa.un.org/unpp/index.asp*)

Figure 9: Freshwater fish catch per person and per year (average 2000-2007). LMB countries are compared to the 3 countries having the biggest inland fish production worldwide. Source: FAO data.



<u>Conclusions:</u> According to FAO data, freshwater fish catch per inhabitant of Cambodia, Lao PDR, Thailand and Viet Nam is nearly four times the world average. Cambodia's freshwater fish catch amounts to nearly 25 kg/person/year; this is by far the highest in the world in terms of catch per inhabitant.

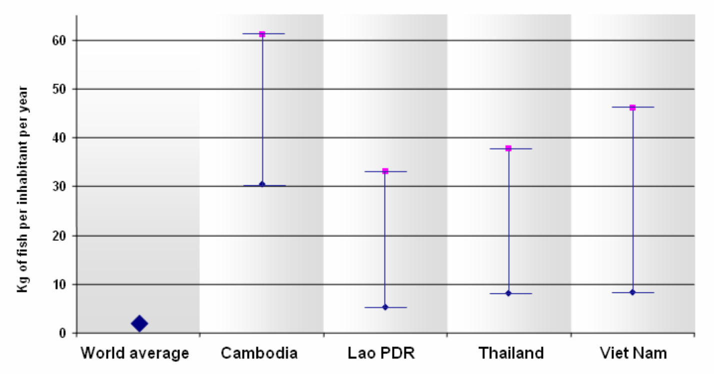
Actually, the above population statistics correspond to the whole population of each country, and a pro-rata calculation needs to be made to assess the proportion of each country's inhabitants found within the boundaries of the Mekong Basin. The latter is calculated following MRC (2003). There is also a wide range in estimates of fish catches, the lower one originating from the production estimate of low productivity wetlands, and the upper one from catch assessment studies. We integrate these figures below and compare the fish catch per inhabitant of the Lower Mekong Basin with the world average.

Table 12: Fish catch per LMB inhabitant, compared to the world average.

	Freshwater fish catch (FAO, tonnes)	Freshwater fish catch (MRC; catch)	Country population in 2005	% of LMB population in the country	LMB population in 2005	Catch per LMB inhabitant (FAO, kg)	Catch per LMB inhabitant (MRC, kg)
World	7,556,635		65,12,276,000			1.2	
Cambodia	338,969	682,150	13,866,000	80.4	11,148,264	30.4	61.2
Lao PDR	29,213	182,700	5,880,000	93.9	5,521,320	5.3	33.1
Thailand	202,783	932,300	65,946,000	37.5	24,729,750	8.2	37.7
Viet Nam	151,924	844,850	84,074,000	21.8	18,328,132	8.3	46.1

Sources: [1] http://www.fao.org/fishery/statistics/global-capture-production/en
[2] http://esa.un.org/unpp/index.asp
[3] MRC 2003a

Figure 10: Range of estimates of catch per inhabitant of the LMB, compared to the world average.



Conclusions: Within the Lower Mekong Basin, in Lao PDR, Thailand and Viet Nam each person produces between 5 and 29 times more freshwater fish than the world average. Cambodia stands out as being the country in the world with the highest fishing intensity: each Cambodian in the LMB harvests 26 to 53 times more freshwater fish than the world average.

1.2.3 MEKONG FISH CATCH AND FOOD SECURITY

1.2.3.1 FISH CONSUMPTION IN THE MEKONG ACCORDING TO FAO DATA

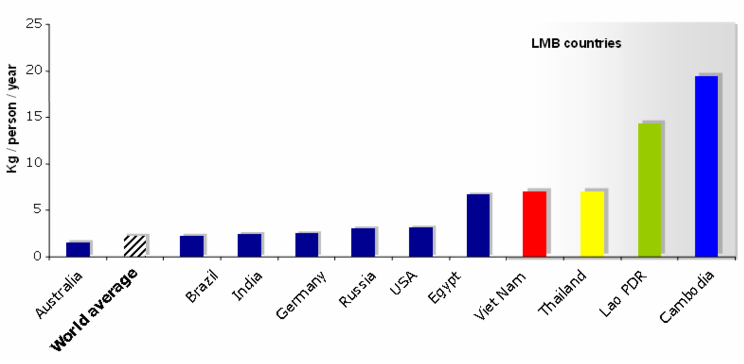
This first analysis is a comparison of freshwater fish consumption in the Lower Mekong Basin based exclusively on FAO data. Data for the countries of the LMB are compared to those of countries having the greatest freshwater fish consumption in their continent or geographic zone.

Table 13: Fish consumption per person in the LMB countries and worldwide.

	2000	2001	2002	2003	2004	2005	Average
Australia	1.51	1.6	1.55	1.66	1.83	1.86	1.57
Brazil	2.26	2.44	2.57	2.42	2.66	2.64	2.28
World average	*2.17*	*2.24*	*2.23*	*2.25*	*2.35*	*2.44*	*2.28*
Germany	2.16	2.65	2.49	2.79	2.85	3.47	2.49
Egypt	6.91	7.39	7.44	8.21	8.03	7.89	6.70
India	2.61	2.79	2.55	2.59	2.8	2.86	2.46
Russian Federation	3.28	3.1	3.19	3.65	3.11	3.72	3.01
United States of America	2.77	3.19	3.33	3.65	3.8	4.05	3.11
Cambodia	17.75	28.78	25.3	21.69	18.09	23.39	19.43
4 LMB countries	*11.51*	*14.73*	*14.45*	*14.00*	*13.11*	*14.98*	*13.80*
Lao PDR	13.65	15.24	17.25	17.26	16.99	19.03	14.35
Thailand	7.76	7.77	7.84	8.4	8.49	8.15	7.06
Viet Nam	6.89	7.11	7.42	8.64	8.86	9.33	7.04

Sources: [1] FAO; *http://faostat.fao.org/site/610/default.aspx*, updated on 18 December 2009;
[2] UN; *http://esa.un.org/unpp/index.asp*

Figure 11: Freshwater fish consumption per person and per year worldwide and in the LMB countries.



Source: FAO data.

Note: in the above figure, the origin of freshwater fish consumed (either from capture fisheries or from aquaculture) is not specified. This figure reflects an update in FAO data on 18 December 2009.

Conclusions: According to the FAO, in the four countries of the LMB:

• the average consumption of freshwater fish per person amounts to 13.8 kg/person/year; by comparison, the global average is only 2.3 kg/person/year, so freshwater fish consumption in the LMB is six times higher than the world average. In Cambodia, the consumption of freshwater fish amounts to 19.4 kg/person/year, i.e. more than 8 times the world average and higher than anywhere else in the world[6]. It should be noted that the above statistics integrate aquaculture fish, but in the Mekong Basin locally consumed fish originates largely from capture fisheries.

• According to FAO consumption figures, people in the LMB countries eat 1.55 million tonnes of freshwater fish per year. Given the absence of massive import of freshwater fish towards the LMB countries, this figure is incompatible with FAO freshwater fish catch statistics in the LMB (0.72 million tonnes per year).

• However, like for capture statistics, these FAO statistics reflect official estimates and are considered largely underestimated. Thus, Hortle (2009) found that official estimates of fish consumption in Mekong provinces of the four countries of the region represented between 86% and 8% only of survey-based estimates.

1.2.3.2 FISH CONSUMPTION IN THE MEKONG ACCORDING TO FIELD SURVEYS

FAO statistics are available by country only; however, a number of studies have been undertaken more specifically within the Lower Mekong Basin. The most recent and comprehensive overview of fish consumption in the Lower Mekong Basin is that of Hortle (2007); it is based on a thorough review and synthesis of 20 fish consumption studies basinwide in 19,139 households.

Conclusions:

Despite differences with FAO figures (by a factor 1.4 to 5.3), twenty food consumption studies undertaken in the LMB lead to the same conclusion as FAO data: the four countries of the Lower Mekong Basin feature the highest consumption of freshwater fish in the world. According to the above studies, this consumption corresponds to around 80 grams of fresh fish per person, each day of the year.

We present Figure 13 a comparison of freshwater fish catch and freshwater fish consumption per person and per year in the LMB. Catch estimates obtained by different methods have been related to population within the Mekong Basin in each country (see Table 12) and to consumption figures according to the FAO and to Hortle 2007.

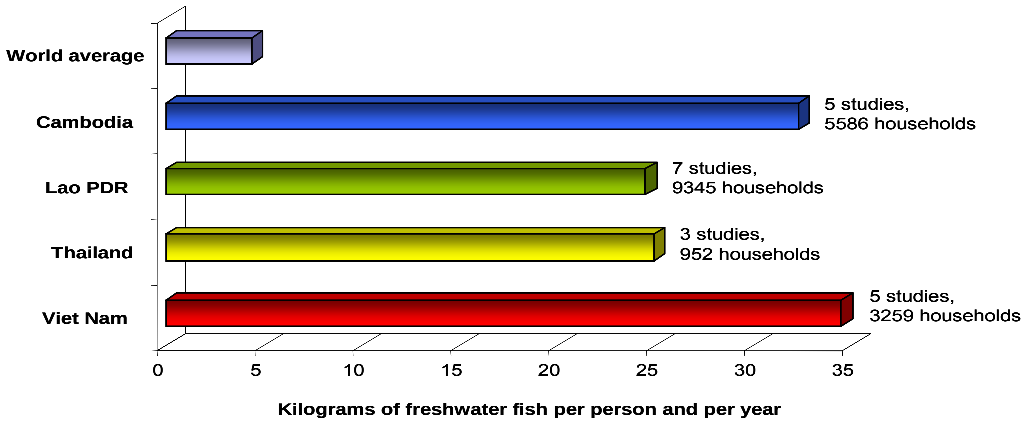
[6] These statistics are focussed on freshwater fish; when marine fishes are also included, then the top-three countries in the world are Japan, Iceland and Portugal (Hortle 2007)

Table 14: Estimated per capita consumption of inland fish (in kg/year) in the LMB, based on consumption studies.

	Cambodia	Lao PDR	Thailand	Viet Nam
Inland fish (kg/person/year)	32.3	24.5	24.9	34.5

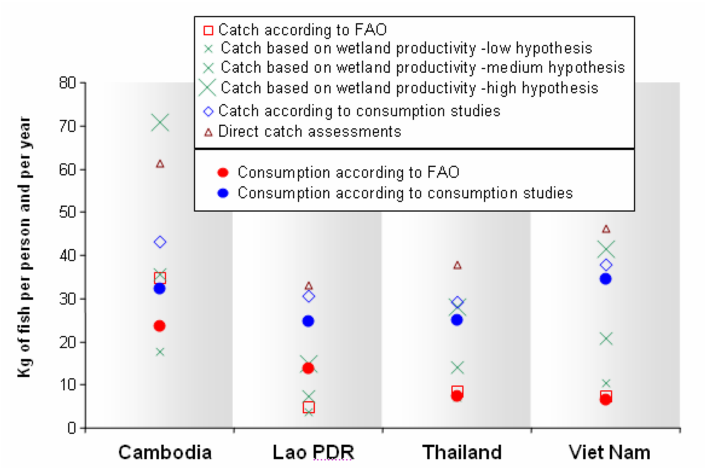
Source: Hortle 2007.

Figure 12: Consumption of freshwater fish per inhabitant and per year.



Source: Hortle 2007.

Figure 13: Comparison of fish catch and fish consumption in the LMB according to different sources.



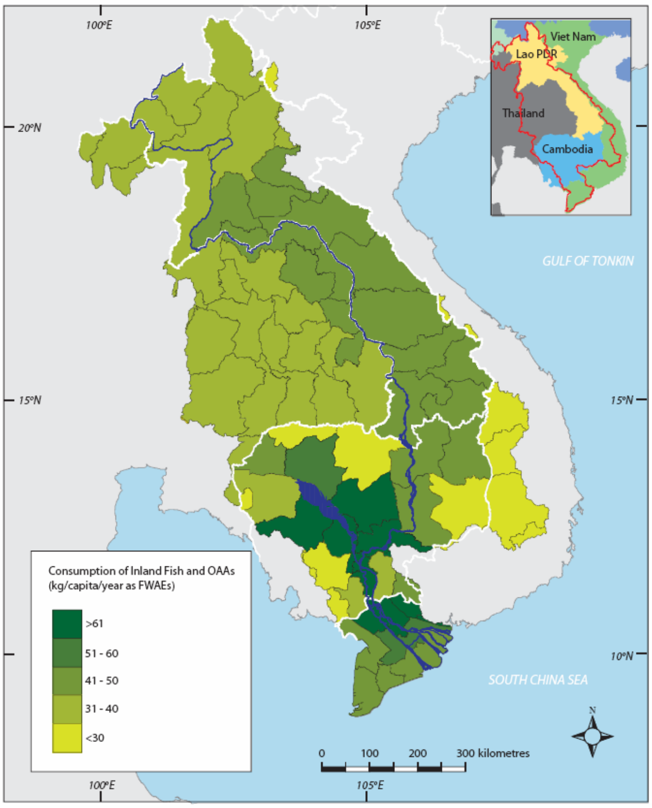
This graph shows that:

- in Cambodia, the fish catch estimate based on low wetland productivity (i.e. the most conservative estimate) is not compatible with any of the fish consumption figures;
- similarly, in Lao PDR the two fish catch estimates based on low and medium wetland productivity assumptions are not compatible with any of the fish consumption estimates;
- more generally, the fish catch estimates based on low and medium wetland productivity assumptions are not compatible, for most countries, with the results of extensive consumption studies detailed in Hortle 2007;
- in Lao PDR, the FAO estimate of fish catch per person is inferior to FAO estimates of fish consumption per person.

The estimate of fish consumption based on 20 studies in more than 19,000 households is robust, leading to the conclusion that fish catch estimates based on low and medium wetland productivity assumptions are too conservative. FAO freshwater fish catch statistics for LMB countries, being in the same range as the above estimates, are also too low; this is confirmed by the fact that they are largely inferior to the FAO's own consumption statistics for the same countries.

Hortle (2007) provides a map of fish consumption by province, based on the above results. This map is a reflection of the importance of fish to the population's food security in the different areas of the Mekong. Basin.

Figure 14: Consumption of inland fish and other aquatic animals per person and per year in Mekong provinces.



Source: Hortle 2007.

1.2.3.3 CONTRIBUTION OF FISH TO PROTEIN SUPPLY IN THE LOWER MEKONG BASIN

In the Mekong region, the bulk of the protein (76%) is derived from rice, but rice is nutritionally incomplete and particularly poor in lysine, an essential amino-acid. With 97.6 mg of lysine per gram of protein, fish provides a nutrient essential to growth, which is lacking in a rice-based diet (Guttman and Funge-Smith 2000).

Several studies have highlighted the high contribution of fish to protein supply in some Mekong countries or in particular locations: between 30% and 50% of total protein consumption in Lao PDR (STEA 2003), and 65% to 75% of the animal protein requirements of households in Cambodia (Ahmed *et al*. 1998), etc. However, most estimates are patchy and relate to specific locations. For this reason, we focused below on the contribution of freshwater fish to the food balance of people in LMB countries, as detailed in FAO data that allow a comparison of Mekong countries together and with the rest of the world.

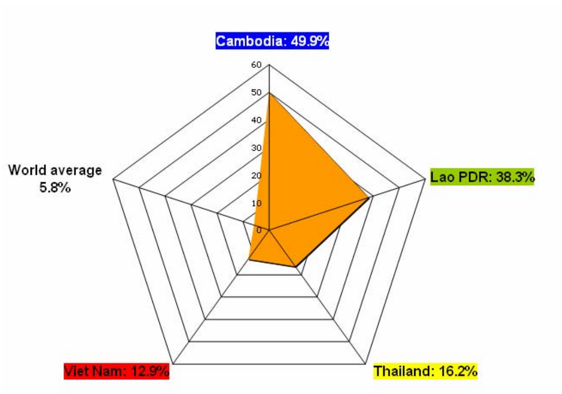
The food balance is based on "all animal proteins", i.e. the sum of freshwater fish + bovine meat + pig meat + poultry meat + other animal products (including dairy, eggs, goat and mutton meat, etc.) + marine fish and seafood.

Table 15: Average consumption of animal protein by source of protein, in grams/person/day (average 2000-2003).

	Cambodia	Lao PDR	Thailand	Viet Nam	World
Freshwater fish	7.21	4.25	2.35	2.09	1.39
Marine fish, seafood	0.70	0.22	7.58	2.73	3.03
Bovine meat	1.93	2.28	1.43	0.85	3.63
Pig meat	2.47	1.76	2.80	5.90	4.40
Poultry meat	0.60	0.82	4.57	1.62	4.01
Other animal products	1.56	1.77	5.69	3.01	12.07
Total	*14.45*	*11.09*	*14.49*	*16.20*	*24.11*
% of freshwater fish protein in total	*49.87*	*38.31*	*16.19*	*12.87*	*5.78*

Source: FAO food balance sheets (*http://faostat.fao.org/site/368/default.aspx).* No data newer than 2003 at the time of query.

Figure 15: Importance of freshwater fish as source of protein in the diet of people in the LMB and worldwide.



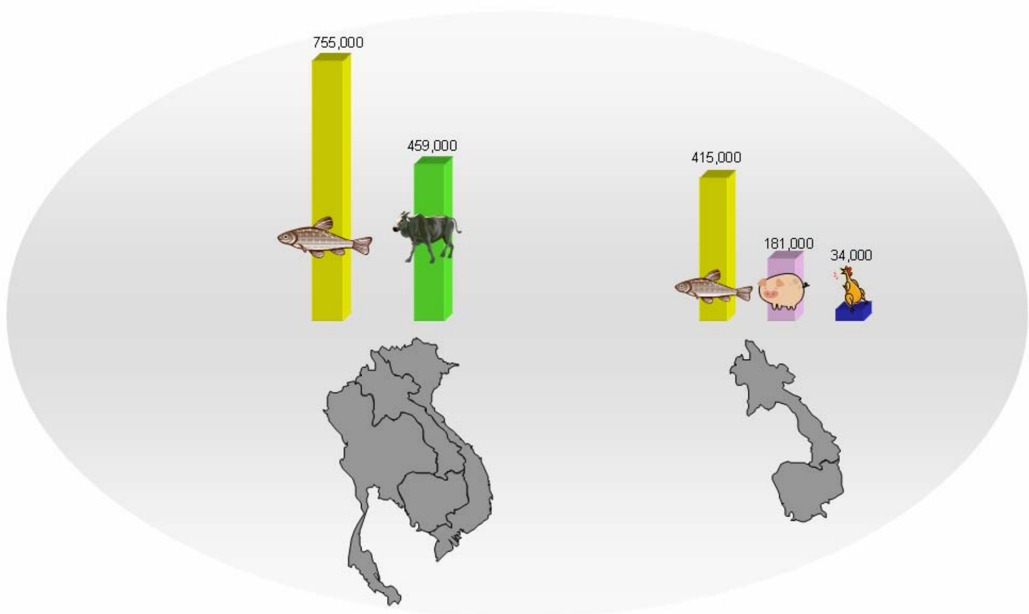
Conclusions:

In the Lower Mekong Basin, fish is a very important part of the protein supply; the share of protein coming from freshwater fish in the diet represents between 2.2 and 8.6 times the world average.

It should be noted that some countries consider that the contribution of fish to food security to be higher than stated by the FAO; thus, in Cambodia, according to the Fisheries Administration, fish (freshwater + marine) contributes 81.5% of the protein supply in the country.

When statistics are focused on some sources of protein or countries, some interesting patterns appear:

Figure 16: Importance of fish compared to other sources of protein in some selected cases.



Source: FAO statistics.

Conclusions: Food production varies by country and is proportional to the population size; there are alternatives to fish in three of the Lower Mekong countries (either chicken or pork), but not in Cambodia where fish is by far the dominant source of protein. Freshwater fish is a commodity whose scale of production is often overlooked: in the whole LMB there is much more freshwater fish harvested than beef produced, and in Cambodia and Lao PDR, fish production amounts to twice the combined production of pork and chicken.

1.2.4 CAPTURE FISHERIES IN THE SIX MAIN ECOLOGICAL REACHES

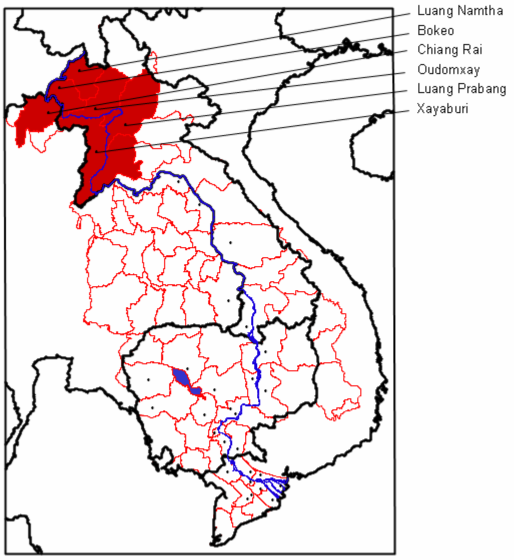
Since the ecological reaches describe the Mekong mainstream, we detail below fish catch, fish consumption and to some extent socioeconomic activities in the provinces bordering the Mekong River, from China down to the sea.

1.2.4.1 ZONE 1: UPPER MEKONG RIVER IN CHINA TO CHIANG SAEN

The upper Mekong Basin in China produces around 25,000 tonnes of fish a year (Xie and Li 2003). This low production, confirmed by Heinonen and Vainio-Mattila (1999), is explained by the fact that the river flows in deep gorges, with subsequent low productivity (no floodplains) and that population density along banks is very low. Given the features of the area, most of the fish catch is expected in the area downstream of Xishuangbanna or in the Simaogangzhen area. No detailed statistics about fish consumption and socioeconomics could be found for this zone; however, Xie and Li (2003) indicate that the capture fisheries in this zone employ about 15,000 persons.

1.2.4.2 ZONE 2: CHIANG SAEN TO VIENTIANE

This zone corresponds to Luang Namtha, Bokeo, Oudomxay, Luangprabang and Sayabouri provinces in Lao PRD and Chiang Rai in Thailand.



According to discussions with district leaders in these provinces, fishing is not considered a significant livelihood option for local people because it is not done on a large scale. People on the Mekong River banks do fish for household consumption, but this goes unrecorded in district or provincial level statistics and is not reflected in social development plans. The table below gives some very low yet official statistics about the yield in some districts of that zone, and about the ratio between the mainstream and some tributaries.

Table 16: Capture fish production in some districts along the Mekong in Zone 2.

District Name	Mekong (tonnes/year)	Tributary (tonnes/yea)	Total (tonnes/yea)	Tributary Name
Paktha (Bokeo)	3.6	1.2	4.8	Nam Tha River
Pakbeng (Oudomxay)	1.8	1.5	3.3	Nam Beng River
Nan (Luang Prabang)	9	1.2	10.2	Nan River
Sayaboury	1.8	1.8	3.6	Houng River,
Paklay (Sayabouri)	3.6	1.2	4.8	Lay River, Phoun, Nham, and Nhang

Sources: Bokeo provincial economic and social development plans of 2008-2009; Oudomxay provincial economic and social development plans of 2009-2010; Luangprabang provincial economic and social development plans of 2008-2010; Sayaboury provincial economic and social development plans 2008-2009.

In contrast with the above estimates, the study of fish consumption and catch in Luang Prabang province done by the MRC in 1999 (Sjorslev *et al.* 2000) and based on actual field work, systematic sampling and seasonal records concludes that the total catch of fish and aquatic animals for Luangprabang Province is within a range of 10,000 to 14,000 tons per year. The authors note that this range is considerably higher than existing government estimates, the latter referring only to the "commercial" catch and not being collected in any systematic way.

A more detailed estimate using fish consumption estimates in the table below, and multiplying these by the population of each province[7], leads to an estimate of 29,000 tonnes consumed, plus the catch sold or exchanged. Lorenzen *et al.* (2003a) and Garaway (2005) estimate around 70% of the share is consumed, 20% sold, and 10% given as gifts or payment in kind. This leads to a final estimate of 41,000 tonnes of fish harvested in this zone.

This estimate is roughly in line with the alternative estimate (60,000 tonnes) resulting from a different calculations detailed in Barlow *et al.* (2008). It can be concluded that the capture fish production in Zone 2 ranges between 40,000 and 60,000 tonnes,

Fish consumption is detailed in a few studies summarized in Hortle (2007):

Table 17: Fish consumption in some provinces along the Mekong in Zone 2.

Province	Total inland fish consumption (kg/person/year)	Source
Oudomxay	16.0 (60% fresh, 40% preserved)	Hortle 2007 based on FAO-PADP 1998
Sayaboury	12.8 (50% fresh, 50% preserved)	Hortle 2007 based on FAO-PADP 1998
Luang Prabang	27.5 (40% fresh, 60% preserved)	Hortle 2007 based on Sjorslev 2000

Fishing occurs year round in the Mekong as well as in tributaries, but in the latter fishing becomes more intensive during the flood season and during transition periods. The main fishing gears include gillnets, cast-nets and traps in tributaries.

Available official data indicate that fishing plays a minor role in the employment of the provinces of Zone 2 (see table below). This reflects the fact that very few people are full-time professional fishers, which is common in the region where fishing is a part time activity and part of a diversified livelihood portfolio.

Table 18: Percentage of people involved in river fishing as the main sources of employment.

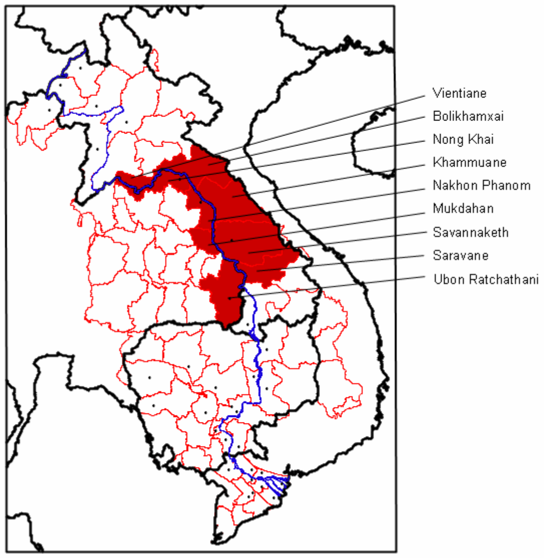
Province	River fishing
Bokeo	3%
Oudomxay	4.47%
Luangprabang	0.50%
Sayaboury	0.20%

Source: Questionnaires to district officials, December 2009 field survey.

[7] Population figures for each province are from the Population & Housing Census 2005. Luang Namtha: pop. = 134,900, 18.6 kg of fish consumed/person/year (average of Oudomxay, Sayaboury and Luangprabang), total annual fish consumption = 2,509 tonnes; Oudomxay: pop. = 276,960, 16 kg of fish consumed/person/year, total annual fish consumption = 4,431 tonnes; Bokeo: pop. = 156,173, 18.6 kg of fish consumed/person/year (average of Oudomxay, Sayaboury and Luangprabang), total annual fish consumption = 2,905 tonnes; Chiang Rai: pop. = 62,000, 18.6 kg of fish consumed/person/year (like Bokeo on the other side of the river), total annual fish consumption = 2,905 tonnes; Luangprabang, pop. = 425,246, 27.5 kg of fish consumed/person/year, total annual fish consumption =11,694 tonnes; Xayaboury: pop. = 360,195, 12.8 kg of fish consumed/person/year, total annual fish consumption =4,610 tonnes. Total for the 6 provinces: 29,000 tonnes of fish consumed.

1.2.4.3 ZONE 3: VIENTIANE TO PAKSE

This zone corresponds to Vientiane, Bolikhamxai, Khammuane, Savannaketh and Saravane provinces in Lao PRD and Nong Khai, Nakhon Phanom, Mukdahan and Ubon Ratchathani provinces in Thailand (Amnat Charoen province was not included because of its limited connection with the Mekong River).



On the Lao side, capture fish production and consumption is poorly known, and we could not find statistics for this specific mainstream zone. The most detailed source of information on fisheries in this zone actually originates from the Lower Songkhram Basin (e.g. Khumsri *et al*. 2006, Tai Baan Research Network Songkhram River Basin 2006, Hortle and Suntornratana 2008) and from the lower Mun River area (e.g. Roberts 1993, Amornsakchai *et al*. 2000), but these sub-basins are not detailed in this review focussing on the mainstream.

In Zone 3 along the mainstream, information is available about fish consumption, thanks to studies by Garaway in Lao PDR (1999, 2005). According to these studies, fish consumption in Savannaketh province amounts to 17.5 kg of fish per person per year (Garaway 1999) or 19.5 kg of fish per person per year (48% fresh fish, 52% preserved fish; details in Hortle 2007). Bush (2003) complements this information by showing that fish and other aquatic animals are present in 85% of all meals.

On the Thai side of this reach (corresponding mostly to Nong Khai and Nakhon Phanom provinces) consumption of inland fish two decades ago amounted to to 25.3 kg/person/year (Prapertchob *et al*. 1989). More recently, Suntornratana (2002) estimated fish consumption in the Lower Songkhram Basin (a tributary reaching the mainstream in Nakhon Phanom Province) at 42 kg/person/year (47% fresh and 53% preserved).

When these figures are related to the population in these provinces[8], this corresponds to a catch of around 116,000 tonnes in Zone 3.

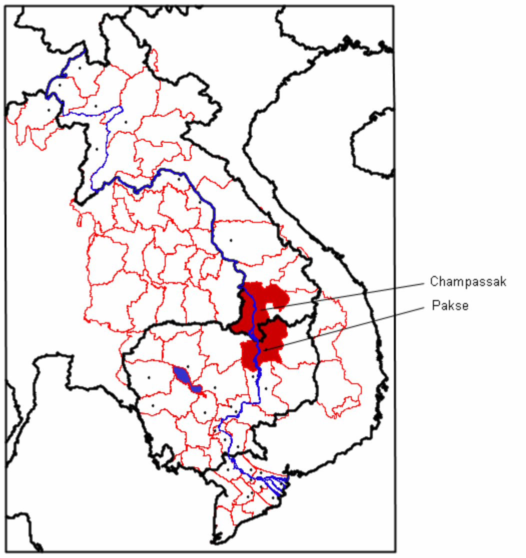
In economic terms, inland fisheries in Thailand's Northeast are officially valued at 3,643 million baht[9], i.e. 0.4 percent of the wealth of the region. This very low value is contradicted by the very high fish consumption rate in this region and by the important role of fishing in livelihoods and household income, as demonstrated by Hortle and Suntornratana (2008) for the Lower Songkhram Basin[10]. In that sense, the fish catch in this zone should be seen as contributing to livelihoods and to food supply rather than as a formal economic driver. An

[8] Vientiane: no detailed figures could be found for this province, where the relationship between fish consumption and catch is blurred by fish imports in the capital city and fish production in the Nam Ngum reservoir; Vientiane is not included in our calculation for this zone. Population figures for each province were obtained from Wikipedia (*http://en.wikipedia.org*). Bolikhamxai: pop. = 215,000, 19.5 kg of fish consumed/person/year (Hortle 2007 in Savannaketh), total annual fish consumption = 42,00 tonnes; Khammuane: pop. = 359,000, 19.5 kg of fish consumed/person/year (Hortle 2007 in Savannaketh), total annual fish consumption = 7000 tonnes; Savannaketh: pop. = 721,000, 19.5 kg of fish consumed/person/year (Hortle 2007), total annual fish consumption = 14,000 tonnes; Saravane: pop. = 337,000, 19.5 kg of fish consumed/person/year (Hortle 2007 in Savannaketh), total annual fish consumption = 65,00 tonnes; Nong Khai: pop. = 884,000, 19.5 kg of fish consumed/person/year like in Bolikhamxai on the other site of the river), total annual fish consumption = 17,000 tonnes; Nakhon Phanom: pop. = 684,000, 42 kg of fish consumed/person/year (Suntornratana 2002), total annual fish consumption = 29,000 tonnes; Mukdahan: pop. = 311,000, 19.5 kg of fish consumed/person/year (like Savannaketh on the other side of the river), total annual fish consumption = 6,000 tonnes; Ubon Ratchathani: pop. = 1,691,000, 19.5 kg of fish consumed/person/year (like Savannaketh), total annual fish consumption = 33,000 tonnes. Total for the 8 provinces: 116,000 tonnes of fish consumed.
[9] National Economic and Social Development Board, 2007
[10] It can also be argued that if the value of inland fish was extremely low, the loss of fishery resources in the Mun River Basin following dam construction would not have triggered social protests during more than a decade and ultimately led to the seasonal opening of that dam.

alternative value of capture fish in Northern Thailand is 23,850 million baht, i.e. about USD 700 million (Na Mahasarakarm 2007).

1.2.4.4 ZONE 4: PAKSE TO KRATIE

This zone corresponds to Champassak Province in Lao PDR and Stung Treng province in Cambodia. Statistics from Kratie Province have been classified under Zone 5 (Kratie to Phnom Penh) since there is an ecological similarity between Champassak and Stung Treng (islands, wetlands) that is not much reflected in Kratie province.



There is much more information available for this zone than for the previous one; this zone includes extensive wetland areas in Siphandone, Khone Falls and around Stung Treng; fishing is intensive in these wetlands and in the mainstream, and migrations are a striking feature in this area, as detailed in more than 30 scientific papers (details in Baran *et al.* 2005). Four publications in particular detail the remarkable importance of aquatic biodiversity and fisheries in this zone:

- "Traditional fisheries and fish ecology on the Mekong River at Khone waterfalls in Southern Laos" (Roberts and Baird 1995)
- "Aquatic biodiversity in the Siphandone wetlands" (Baird 2001)
- "Fisheries bioecology at the Khone Falls" (Baran *et al.* 2005).
- "Biological surveys of the Mekong River between Kratie and Stung Treng" (Bezuijen *et al*. 2008).

An example of frequent and complex fish migration fluxes in this zone is given in Figure 25.

In Champassak province, official statistics mention a river fish production of 8,000 tonnes and a sale of fish amounting to 8,900 tonnes (Champassack provincial economic and social development plans, 2009-2010). However, when consumption figures per capita detailed below are multiplied by the population in Champassak province[11], they give a catch of at least 22,600 tonnes per year, plus the catch sold or exchanged. Assuming that 70% is consumed locally (Baird *et al.* 1998, confirming Lorenzen *et al.* 2003a,b and Garaway 2005) this gives an alternative estimate of 32,000 tonnes of fish harvested in the Lao part of this zone (left bank and Siphandon islands). It should be noted that in Khong district alone, Baird *et al.* (1998) estimated the catch at 4,000 tonnes a year, and in 2001 in this district's fish trade towards Thailand and Pakse was estimated at 435 tonnes/year (Aloun Phonvisay and Bush 2001), for a value of USD 440,000.

Province and district officials reckon that fishing is one of the main occupations for farmers in all Mekong districts, and they estimate that fisherfolk represent 1.3% of the population in Pakse, and 30% in Khong district (December 2009 field survey).

Fish consumption in Champassak province was estimated at 37.2 kg/person/year, made of 69% of fresh fish and 31% of preserved fish (Singhanouvong and Phouthavongs 2003, details in Hortle 2007). Actually fish consumption varied from 28.9 kg/person/year in the highlands of the province to 57 kg/person/year on Khong Island. A district-level study done on Khong Island (Baird *et al.* 1998) gave an alternative figure of 43 kg of fish consumed per person and per year. All these figures are exceptionally high since the average freshwater fish consumption worldwide is 4.4 kg/person/year.

In Cambodia, there is limited knowledge of fisheries in Stung Treng province, the most recent and detailed information coming from Allen *et al.* (2008) and Bezuijen *et al.* (2008), complemented by Israel *et al*. (2005), Try Thuon (2003), Srun Lim Song (2002) and Chea Vannaren (1999). Ecologically, the area around Stung Treng is characterized by the presence of deep pools which are critical dry-season habitats for many migratory fish species. Deep pools can be 10-60 m deep and 100-300 m long (Hill 1995); 19 deep pools have been identified in Stung Treng province and 39 in Kratie province (Poulsen *et al.* 2002a).

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[11] Population of 607,370 (Population & Housing Census 2005, National Statistics Centre) x 37.2 kg/person/year (Singhanouvong and Phouthavongs 2003) = 22,594 tonnes of fish consumed.

According to national statistics, Stung Treng produces around 8,000 tonnes of fish (table below). In the absence of alternatives, these statistics are considered reliable enough since Cambodia is the only country in the region that integrates family and rice field fisheries, which remain unrecorded in Lao statistics. When this production is added to that of Zone 4 above the Cambodian border (i.e. 32,000 tonnes), this leads to a total estimate of 40,000 tonnes of fish harvested in Zone 4[12].

Table 19: Catch statistics in Stung Treng province.

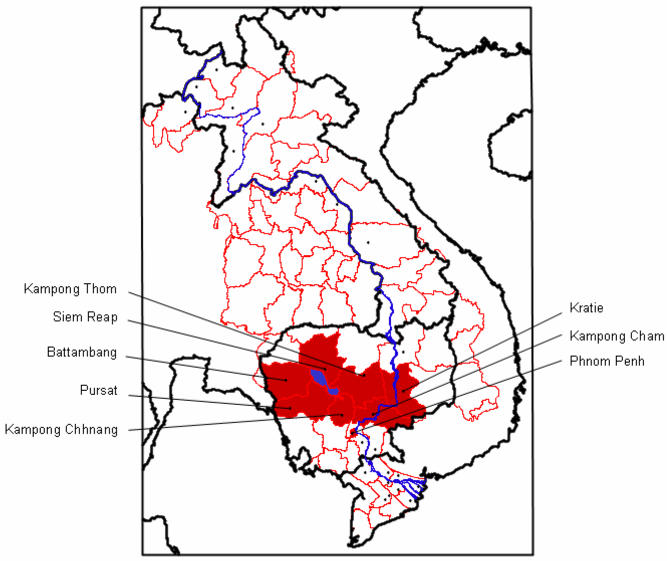
	2006				2007				2008			
	Lots	Family	Rice field	*Total*	Lots	Family	Rice field	*Total*	Lots	Family	Rice field	*Total*
Stung Treng	2,000	5,000	2,000	*9,000*	2,000	3,500	2,100	*7,600*	1,500	3,100	2,300	*6,900*

Source: FiA 2008, 2009

This table shows that professional fisheries actually produce less than a quarter of the catch, three quarters being due to activities (family- and rice-field fishing) that do not qualify as "professional". In Stung Treng, this is confirmed by the fact that in province statistics, only 1% of families are recorded as having fishing as a primary occupation. Allen *et al.* (2008) showed that individual households by the river would catch on average between 0.6 and 1.5 tonnes of fish a year, depending on the location, with peaks in December-January and April-May.

1.2.4.5 ZONE 5: KRATIE TO PHNOM PENH

This zone corresponds to Kratie, Kampong Cham, and Phnom Penh provinces (Kandal stretching mostly south of Phnom Penh in the delta was classified under Zone 6), and the provinces around the Tonle Sap (Kampong Chhnang, Pursat, Battambang, Siem Reap and Kampong Thom).



Downstream of Kratie start the large and hugely productive Cambodian floodplains. This zone, including the Tonle Sap system, is characterized by exceptionally intensive fishing, described in numerous publications, in particular:

- "La pêche dans les eaux douces du Cambodge" (Chevey and Le Poulain 1940)
- "Diversity and spatial distribution of freshwater fish in Great Lake and Tonle Sap river" (Lim *et al.* 1999)
- "Proceedings of the Annual meeting of the Department of Fisheries" (van Zalinge *et al.* 1999, 2000 and 2001).
- "Socio-economic survey of the Tonle Sap Lake" (Keskinen 2003)
- "Cambodian inland fisheries" (Baran 2005)
- "Socioeconomics and livelihood values of Tonle Sap lake fisheries" (Hap Navy *et al.* 2006).

Catches in Zone 5 are detailed below. According to official Cambodian statistics, Zone 5 produces around 230,000 tonnes of fish annually. The large difference between the production of Zone 5 and that of Zones 4 or 3 (respectively 40,000 and 116,000 tonnes) is mainly due to the fact that the surface area of Zone 5, including the Tonle Sap provinces, is much larger than that of the two other zones (in which large tributary basins such as Mun/Chi or 3S rivers are not included). However, the huge production of Zone 5 also results from the huge productivity of floodplains (100 to 200 $kg.ha^{-1}/year^{-1}$; Hortle 2009) that are the dominant environmental feature of the zone.

[12] An estimate based exclusively on fish consumption like the one in the upstream provinces is not possible since there are no consumption studies in Stung Treng; on the basinwide consumption map (Figure 14) Hortle (2007) uses the Svay Rieng figure for Stung Treng, underlining that this is a conservative estimate. This disputable similarity would lead, given the population of the province, to an estimated catch of 3,800 tonnes.

Table 20: Catch statistics in the provinces of Zone 5.

	2006			2007			2008		
	Lots	Family	Rice field	Lots	Family	Rice field	Lots	Family	Rice field
Kratie	2,500	6,500	3,000	2,000	4,500	2,500	1,500	3,100	2,500
Kampong Cham	7,000	13,000	9,500	6,000	11,000	9,000	5,500	9,000	9,500
Phnom Penh	12,000	9,500	2,000	9,500	7,500	1,500	8,400	6,000	1,000
Kampong Chhnang	18,000	16,500	10,000	17,000	16,000	9,000	16,000	13,000	9,000
Pursat	15,000	15,000	8,000	14,000	12,000	8,500	12,000	11,000	9,000
Battambang	10,000	13,000	7,200	10,000	11,000	8,500	9,500	10,500	9,500
Siem Reap	13,000	14,000	8,000	12,000	13,000	9,000	11,000	13,000	9,500
Kampong Thom	11,000	14,500	8,000	10,500	13,000	8,000	11,500	12,000	9,500
		246,200			***225,000***			***212,500***	

Source: FiA 2008, 2009.

When fish consumption statistics per person (see below) are multiplied by the population in each province[13], they give a catch of at least 485,000 tonnes per year in Zone 5, plus the catch sold or exchanged.

Fish consumption in Zone 5 has been reviewed by Hortle (2007), based on detailed surveys by Ahmed *et al.* (1998). Results show that fish consumption in the provinces of Zone 5 varies between 43.4 and 105.2 kg/person/year; the average is 65 kg of inland fish consumed per person and per year in Zone 5, which is a world record. Out of this, 65% is consumed fresh and 35% preserved.

Table 21: Fish consumption in provinces of Zone 5 (kg/person/year).

	Kratie	Kampong Cham	Phnom Penh	Kampong Chhnang	Pursat	Battambang	Siem Reap	Kampong Thom
Fresh fish	22.8	40	51.6	67.9	60.1	22.1	34.5	38.7
Preserved fish	11.7	25.2	19.3	37.3	22.5	21.3	26.8	27
Total	34.5	65.2	70.9	105.2	82.6	43.4	61.3	65.7

Source: Ahmed *et al*. 1998

Note: in the absence of local consumption studies in Kratie, Hortle (2007) applies Svay Rieng's figures to that province.

The economic and livelihoods values of fisheries in Zone 5 are detailed in Ahmed *et al.* (1998), Hap Navy *et al.* (2006) and Baran *et al.* (2007). All authors underline that the vast majority of people living in this zone are involved in small-scale, non-commercial fishing, although this is also an example of occupational pluralism. According to Hap Navy *et al.* (2006) for instance, the 1.25 million people living around the Tonle Sap Lake earn USD 233 million annually from the lake; of this, home consumption of fisheries products is worth USD 13 million. Yet, most households are very poor, with 72% of these making less than USD 1,000 a year. All households are very dependent on aquatic resources for their livelihoods.

[13] Population figures for each province were obtained from the 2008 Population Census and consumption figures from Hortle 2007. Kratie: pop. = 318,500; 34.5 kg of fish consumed/person/year (Hortle 2007), total annual fish consumption = 11,000 tonnes; Kampong Cham: pop. = 1,680,000, 65.2 kg of fish consumed/person/year, total annual fish consumption = 109,000 tonnes; Phnom Penh: pop. = 2,000,000, 70.9 kg of fish consumed/person/year, total annual fish consumption = 142,000 tonnes; Kampong Chhnang: pop. = 472,000, 105.2 kg of fish consumed/person/year (Hortle 2007), total annual fish consumption = 50,000 tonnes; Pursat: pop. = 397,000, 82.6 kg of fish consumed/person/year, total annual fish consumption = 33,000 tonnes; Battambang: pop. = 1,024,000, 43.4 kg of fish consumed/person/year, total annual fish consumption = 44,000 tonnes; Siem Reap: pop. = 896,000, 61.3 kg of fish consumed/person/year, total annual fish consumption = 55,000 tonnes; Kampong Thom: pop. = 631,000, 65.7 kg of fish consumed/person/year, total annual fish consumption = 41,000 tonnes. Total for the 8 provinces: 485,000 tonnes of fish consumed.

1.2.4.6 ZONE 6: PHNOM PENH TO THE SOUTH CHINA SEA

This zone between Phnom Penh and the seashore corresponds to Kandal and Prey Veng Provinces in Cambodia, and An Giang, Đồng Tháp, Cần Thơ / Hậu Giang, Tiền Giang, Vĩnh Long, Bến Tre, Sóc Trăng and Trà Vinh provinces in Viet Nam. Although they formally belong to the Mekong Basin, Bạc Liêu, Cà Mau and Kiên Giang provinces were not integrated into this review since they are not related to the Mekong mainstream.

Zone 6 is characterized by a deltaic environment and a tidal influence. Catch statistics for this zone are detailed in the table below.

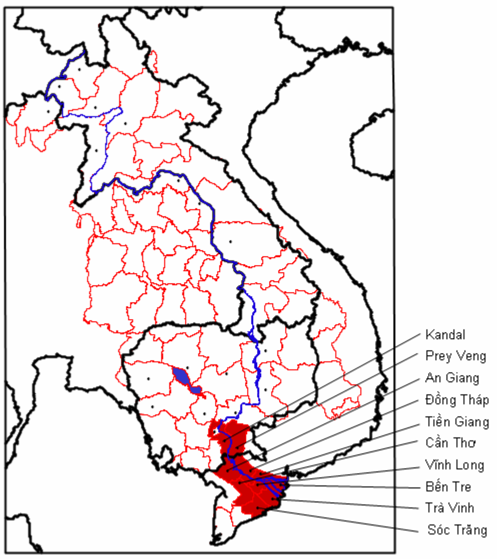


Table 22: Catch statistics in the provinces of Zone 6.

	2006	2007	2008
Kandal	72,500	71,000	61,500
Prey Veng	20,500	19,500	18,700
An Giang	53,403	51,851	40,650
Đồng Tháp	21,756	16,030	16,428
Sub-total	*168,159*	*158,381*	*137,278*
Cần Thơ / Hậu Giang	10,276	9,893	9,325
Tiền Giang	75,155	75,637	75,789
Vĩnh Long	80,48	7,937	7,853
Bến Tre	75,699	76,226	81,389
Sóc Trăng	31,870	31,370	31,316
Trà Vinh	58,008	58,385	60,821
Sub-total	*259,056*	*259,448*	*266,492*

Source: FiA 2008, 2009; General Statistics Office of Viet Nam (*http://www.gso.gov.vn/default_en.aspx?tabid=491*)

However, these statistics do not distinguish between freshwater and marine fish catches; the sub-total restricted to Kandal, Prey Veng, An Giang and Đong Tháp corresponds to provinces located between 130 and 350 km away from the sea and that do not have a marine fishing fleet. The proportion of freshwater fish in these provinces is considered insignificant.

Once again, detailed fish consumption studies are the best alternative to official statistics. When fish consumption statistics per person (see below) are multiplied by the population in each province, the conclusion is that at least 520,000 tonnes of freshwater fish are harvested each year in Zone 6.

Table 23: Population, freshwater fish consumption and corresponding catch in Zone 6 provinces

Province	Total population	Proportion in the LMB	Population in the LMB	Freshwater fish consumption (kg/person/year)	Source	Total consumption (tonnes)
Kandal	1,075,000	100	1,075,000	67.7	Hortle 2007	72,778
Prey Veng	946,000	65	567,600	26.9	Hortle 2007	15,268
An Giang	2,250,573	100%	2,250,573	49.5	Hortle 2007	111,403
Dong Thap	1,682,725	100%	1,682,725	49.5	Like An Giang	83,295
Can Tho	1,171,069	100%	1,171,069	29.6	Like Tien Giang	34,664
Tien Giang	1,742,140	70%	1,219,498	29.6	Hortle 2007	36,097
Vinh Long	1,069,081	100%	1,069,081	29.6	Like Tien Giang	31,645
Ben Tre	1,360,272	100%	1,360,272	36.2	Like Tra Vinh	49,242
Soc Trang	1,301,710	100%	1,301,710	36.2	Like Tra Vinh	47,122
Tra Vinh	1,062,010	100%	1,062,010	36.2	Hortle 2007	38,445
Total						***519,958***

Note: population figures are from the Social Atlas of the Lower Mekong Basin (MRC 2003c).

In Zone 6, freshwater fish consumption is high but variable; the table below, from Hortle (2007) who summarised 5 fish consumption studies in this zone, shows that it varies between 26.9 and 67.7 kg/person/year.

Table 24: Fish consumption in provinces of Zone 5 (kg/person/year).

	Kandal	Prey Veng	An Giang	Tien Giang	Tra Vinh
Fresh inland fish	45.5	21	36.8	29.6	22.7
Preserved inland fish	22.2	5.9	12.7	-	13.5
Total consumption of inland fish	67.7	26.9	49.5	29.6	36.2

Sources: Ahmed *et al.* 1998 (Kandal), Setboonsarng, *et al.* 1999 (Kandal and Prey Veng), Sjorslev 2001(An Giang), Setboonsarng *et al.* 1999 (Tien Giang), and Phan *et al.* 2003 (Tra Vinh).

On the socioeconomic ground, capture fisheries remain an important part of local livelihoods in provinces of Zone 6 in Viet Nam, even though there are few full-time fishers (Table 25).

Table 25: Role of fishing in people's activities.

	An Giang	An Giang	Dong Thap	Whole delta
	Phan and Pham 1999	Sjorslev 2000	Nguyen Van Trong, Pham Mai Phuong 2004	Pham Trong Thinh 2009
Full time fishers	3%	7%	4.7%	8.1%
Part-time fishers	37%	66%	22.1%	43.8%

According to the recent study of Pham Trong Thinh (2009) in this zone, of the total catch 17% is used for consumption and 83% is sold. Ninety-two percent of households estimated that the catch had been decreasing, but people's impression was that their overall well-being had increased, thanks to factors outside the fishery sector. This being said, the level of dependence upon aquatic resources remains very high among the 32% of the population qualifying as poor or very poor.

Table 26: Weath status and dependence on fish in the Vietnamese provinces of Zone 6. Source: Pham Trong Thinh 2009.

	Weath Status			
Percentage in the population	**Very poor**	**Poor**	**Middle**	**Well-off**
% of the population	6.8	25.3	59.7	8.2
Level of dependence on fish and other aquatic animals	59.4	31.2	5.5	3.8

According to the province stastistics and to interviews gathered during December 2009 field surveys, this fish production is in decline compared to 10 or 30 years ago (see table below). The reasons given are that up to 1975, aquatic resources were abundant, but after 1978, canal systems were dug, agriculture developed, and with it chemicals used that are toxic for fish. In the 1990's the spreading of electric fishing gears had a negative impact on fish abundance, and after 2006 dykes and sluice gates aimed at protecting against saline intrusion contributed to reducing fish abundance further. This trend subsequently led to a decline in employment and income from fisheries, especially among poor households.

Table 27: Catch statistics in An Giang and Dong Tap provinces, 1996-1998 and 2006-2008 periods.

An Giang				trend (%)
1996	72004	*2006*	53403	-26
1997	74300	*2007*	51851	-30
1998	76577	*2008*	40650	-47

Dong Thap				trend (%)
1996	28292	*2006*	21756	-23
1997	26705	*2007*	16030	-40
1998	27118	*2008*	16428	-39

Sources: Tong Cuc Thong Ke *et al*. 1999 and General Statistics Office of Viet Nam (*http://www.gso.gov.vn/default_en.aspx?tabid=491*)

Overview:

Table 28: Main characteristics of fisheries in the 6 ecological reaches of the Mekong

	Number of fish species	**Freshwater fish catch** (tonnes)	**Percentage of the catch**	**Freshwater fish consumption** (kg/person/year)
Zone 1 (China)	151	25,000	2.0	-
Zone 2 (Chiang Saen -Vientiane)	140	50,000	4.0	16 - 27.5
Zone 3 Vientiane - Pakse	NA	116,000	9.4	17.5 - 42
Zone 4 Pakse-Kratie	252	40,000	3.2	28.9 - 57
Zone 5 Kratie -PP and TS	284	485,000	39.2	43.4 - 105.2
Zone 6 PP-Delta	486	520,000	42.1	29.6 - 67.7
		1,236,000		

According to the above review, around 1.2 million tonnes of fish are harvested and consumed each year along the Mekong River in the 6 main ecological reaches. This is lower than the 2.1 million tonnes of fish harvested estimated from consumption studies basinwide, but is explained by the fact that 35 other provinces not included here[14] also contribute the overall catch.

Most of this catch is realized in the three lower zones (Zones 4 to 6 totalling 85% of the overall catch), and these zones are also those where fish species richness and fish consumption are the highest. Zone 4 (Pakse-Kratie) does not exhibit such high fish production and consumption, but is characterized by its high fish biodiversity, which can be related to the diversity of specific habitats (waterfalls, islands and wetlands).

Keeping in mind that in a system characterized by intense migrations, fish harvest in Zones 4 and 5 is largely conditioned by the connexion of these zones with other zones and tributaries (see Figure 22), and Zone 5 would be the zone in which mainstream dam construction would have the most dramatic impact on fish production.

[14] The provinces having a majority of their territory lying within the Mekong Basin are: Attapeu, Phongsaly, Sekong, Vientiane, Xaysomboun and Xiengkhuang Provinces in Lao PDR; Amnat Charoen, Burirum, Chaiyaphum, Kalasin, Loei, Maha Sarakham, Nakhon Ratchasima, Nong Bua Lamphu, Phayao, Roi Et, Sakon Nakhon, Si Saket, Surin, Udon Thani and Yasothon provinces in Thailand; Banteay Meanchey, Kampong Speu, Kong Pailin, Mondul Kiri, Otdar Meanchey, Preah Vihear, Ratana Kiri and Takeo provinces in Cambodia; Bac Lieu, Ca Mau, Dak Lak, Kien Giang and Kon Tum provinces in Vietnam.

1.3 STATUS OF MEKONG AQUACULTURE PRODUCTION

The aquaculture sector is full of promise. As detailed by Dugan *et al.* (2006), cultivating fish has the potential to improve water productivity, through aquaculture in ponds, but also integration of fish into irrigation systems, rice-fish culture and integrated aquaculture-agriculture. After several years of expansion, aquaculture is still considered as having tremendous potential for expansion in Asia (Dey *et al.* 2005, 2008); aquaculture is very beneficial to the income and food security of rural households, particularly in the case of integrated agriculture-aquaculture and rice-field fisheries (Prein and Ahmed 2000, Dey and Prein 2005).

1.3.1 STATUS OF AQUACULTURE PRODUCTION IN THE MEKONG BASIN COUNTRIES15

In terms of biomass produced, we analyzed FAO data for national freshwater and brackish water aquaculture production in 2007, and compared them to Mekong fish production figures detailed in section 1.2.[16].

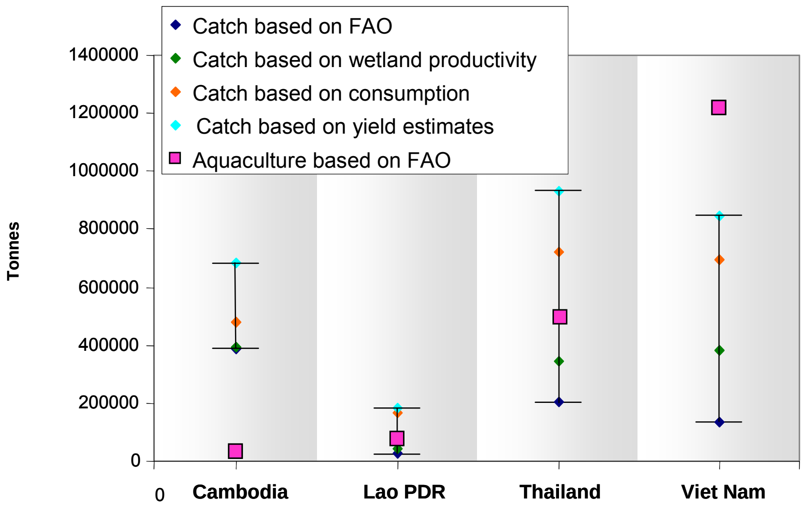
Table 29: Production of freshwater aquaculture fish in tonnes.

	2005	2006	2007	Average 2005-2007
Cambodia	25,500	33,570	33,570	30,880
Lao PDR	78,000	78,000	78,000	78,000
Thailand	506,331	498,392	475,751	493,491
Viet Nam	961,100	1,157,045	1,530,300	1,216,148
				1,818,520

Source: FAO Figis (*http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en*; query on Environment = inland+ brackishwater, Species = freshwater fish; query done in October 2009; FAO statistics have been slightly and retroactively modified since then.

Note: According to the Minister of Agriculture, Forestry and Fisheries (1st July 2009), aquaculture production in Cambodia amounted to 40,000 tonnes in 2008.

Figure 17: Comparison of capture fisheries estimates (bars indicate the range, depending on different approaches) and aquaculture figures. Averages by country for the 2005-2007 period



Sources: data from Tables 6 to 9 and Table 29

Conclusions: The freshwater aquaculture sector produces more than Mekong capture fisheries in Viet Nam only. In Thailand and Lao PDR, production of both sectors is in the same range, and in Cambodia the production of the aquaculture sector is 12 to 22 times *inferior* to the production of the capture fishery sector.

[15] This section is an update superseding the corresponding section in the April 2009 working paper.
[16] Thus, aquaculture figures here cover the whole country, whereas capture fisheries statistics are restricted to the Mekong Basin, which represents a substantial bias in favour of aquaculture. In 2000 for instance, aquaculture in the Mekong Delta represented only 65% of aquaculture in the whole of Viet Nam.

1.3.2 DOMINANT SPECIES IN THE AQUACULTURE SECTOR

National statistics compiled by the FAO indicate the species dominant in the inland aquaculture sector of each Lower Mekong country.

Table 30: Fish species dominant in the inland aquaculture sector of LMB countries.

Scientific name	2005	2006	2007
CAMBODIA			
Siluroidei	13,200,000	17,600,000	17,600,000
Pangasius spp	10,000,000	16,000,000	16,000,000
Barbonymus gonionotus	10,620,000	12,600,000	12,600,000
Cyprinus carpio	8,400,000	10,000,000	10,000,000
Hypophthalmichthys molitrix	2,100,000	2,618,000	2,618,000
Ctenopharyngodon idellus	1,500,000	1,800,000	1,800,000
Clarias batrachus	1,050,000	1,400,000	1,400,000
Leptobarbus hoeveni	880,000	1,100,000	1,100,000
Hypophthalmichthys nobilis	750,000	900,000	900,000
Oreochromis mossambicus	440,000	660,000	660,000
Oreochromis niloticus	440,000	660,000	660,000
Total	49,380,000	65,338,000	65,338,000
LAO PDR			
Oreochromis niloticus	22,920,000	25,467,000	25,467,000
Probarbus jullieni	9,000,000	10,000,000	10,000,000
Cirrhinus microlepis	8,640,000	9,600,000	9,600,000
Hypophthalmichthys molitrix	7,155,000	7,950,000	7,950,000
Barbonymus gonionotus	6,739,000	7,488,000	7,488,000
Cyprinus carpio	6,264,000	6,960,000	6,960,000
Cirrhinus molitorella	6,138,000	6,820,000	6,820,000
Hypophthalmichthys nobilis	5,281,000	5,868,000	6,520,000
Catla catla	5,400,000	6,000,000	6,000,000
Ctenopharyngodon idellus	5,400,000	6,000,000	6,000,000
Labeo rohita	4,770,000	5,300,000	5,300,000
Cirrhinus mrigala	4,230,000	4,700,000	4,700,000
Total	91,937,000	102,153,000	102,805,000
THAILAND			
Oreochromis niloticus	146,392,000	172,018,000	164,824,000
C.gariepinus x C.macrocephalus	114,846,000	124,539,000	117,075,000
Barbonymus gonionotus	44,208,000	44,343,000	46,787,000
Trichogaster pectoralis	35,624,000	41,043,000	41,056,000
Channa striata	18,910,000	16,054,000	15,444,000
Pangasius hypophthalmus	14,041,000	14,144,000	17,285,000
Osteichthyes	6,720,000	6,850,000	12,372,000
Osphronemus goramy	7,561,000	8,379,000	8,068,000
Cyprinus carpio	4,195,000	3,852,000	4,350,000
Anabas testudineus	3,741,000	1,574,000	3,549,000
Labeo rohita	1,960,000	1,450,000	2,790,000
Cirrhinus mrigala	981,000	868,000	859,000
Oxyeleotris marmorata	699,000	576,000	696,000
Channa micropeltes	252,000	390,000	290,000
Hypophthalmichthys molitrix	219,000	261,000	275,000
Oreochromis mossambicus	122,000	194,000	181,000
Nonopterus albus	106,000	94,000	102,000
Trichogaster spp	23,000	25,000	115,000
Notopterus spp	25,000	1,000	4,000
Total	400,625,000	436,655,000	436,122,000
VIET NAM			
Osteichthyes	877,650,000	955,568,000	1,020,450,000
Pangasius spp	564,000,000	780,000,000	1,275,000,000
Total	1,441,650,000	1,735,568,000	2,295,450,000

Source: FAO data in FishBase (*www.fishbase.org*)

The above statistics are synthesized in terms of percentages in the table below.

Table 31: Percentage of each species in the inland aquaculture production of LMB countries

	Percentage of national production				Annual total production
	Cambodia	Lao PDR	Thailand	Viet Nam	(average 2005-2007, tonnes)
Osteichthyes (= various fish species)			1.3	52.1	640,496
Pangasius spp	22.0			47.9	588,500
Oreochromis niloticus	0.8	25.1	40.5		219,553
C.gariepinus x C.macrocephalus			29.0		143,113
Barbonymus gonionotus	21.8	8.0	11.5		69,489
Trichogaster pectoralis			7.2		35,687
Pangasius hypophthalmus			5.0		24,648
Cyprinus carpio	15.6	7.4	1.0		15,245
Channa striata			2.0		9,956
Hypophthalmichthys molitrix	5.7	10.2	0.1		9,948
Labeo rohita		6.8	0.6		8,097
Hypophthalmichthys nobilis	1.9	8.4			7,070
Siluroidei (= various catfishes)	23.7				7,000
Ctenopharyngodon idellus	3.7	6.4			6,100
Cirrhinus mrigala		6.0	0.2		5,869
Osphronemus goramy			1.1		5,195
Catla catla		6.4			5,000
Cirrhinus microlepis		6.2			4,800
Probarbus jullieni		5.1			4,000
Cirrhinus molitorella		4.0			3,100
Anabas testudineus			0.4		2,208
Clarias batrachus	2.4				700
Oreochromis mossambicus	0.8		0.04		454
Leptobarbus hoeveni	1.5				450
Channa micropeltes			0.1		249
Trichogaster spp			0.02		96
Oxyeleotris marmorata			0.02		85
Monopterus albus			0.01		56
Notopterus spp			0.002		11

Source: FAO data in FishBase (www.fishbase.org). Red, orange and yellow colors highlight respectively the first, second and third most abundant species in each country.

Conclusions: Pangasiid catfishes are the dominant fish group produced in aquaculture. This group actually includes a majority of *Pangasianodon hypophthalmus* and P*angasius bocourti* whose cycles are well mastered. The second dominant species is the introduced tilapia *Oreochromis niloticus*, coming first in Thailand and Lao PDR. This species is followed by a number of other catfishes (Silurids), in particular the hybrid "*Clarias gariepinus x C. macrocephalus*" famous for its high growth rate. The first native Cyprinid farmed in the region is the Java/silver barb *Barbonymus gonionotus*, present in particular in Cambodia where *O. niloticus* farming is not developed. The carp *Cyprinus carpio* is also present in several countries, but its rank is quite variable. All together, 24 freshwater fish species are grown in the Mekong aquaculture sector. Cambodia and Lao PDR have not contributed statistics to the FAO for 2 and 3 years respectively, and Viet Nam does not provide details about the species raised. It can also be noted that some species farmed at a substantial scale in some countries are not reflected in these statistics (e.g. hybrid "*Clarias gariepinus* x *C. macrocephalus*" or *Channa spp* in Cambodia).

1.4 SOCIOECONOMIC STATUS OF MEKONG FISH RESOURCES

The values of Mekong fish resources (economic valuation analyses with direct use and indirect use values, economic impact analyses, socio-economic analyses and livelihood analyses) were comprehensively reviewed in 2007 by Baran *et al.* This review is freely available on the internet[17] and we will not paraphrase it here. The statistics proposed below are updates and additional notes.

1.4.1 ECONOMIC VALUE OF CAPTURE FISHERIES

The economic value of capture fish harvested in the Lower Mekong Basin has been estimated at between USD 1.4-2 billion per year (first sale value; Sverdrup-Jensen 2002, Van Zalinge *et al*. 2004, MRC 2008a). Actually the economic value of Mekong fisheries is derived from catch estimates multiplied by an average price per kilogram; the latter is supposed to integrate the variability between species, countries and seasons. The problem is that despite numerous economic valuation projects over the years (e.g. Sultana *et al.* 2003[18], Israel *et al.* 2005, MRC 2008b), no transparent price per kilo or tonne has ever been produced, and economic valuation of fish resources remains a much neglected issue in the Mekong Basin.

The most "detailed" pricing system is that used in Sverdrup-Jensen (2002; Table 32)

Table 32: Value of fish production in the LMB according to Sverdrup-Jensen (2002).

	Quantity (tonnes)	Price (US$ per kg)	Value (US$ millions)
Riverine capture fisheries	1,533,000	0.68	1,042
Aquaculture	260,000	1.05	273
Reservoirs	240,000	0.68	163
Total	*2,033,000*		*1,478*

The most recent estimate is that of Hortle (2009) who, integrating inflation, has valued Mekong fish resources at USD 2.1-3.8 billion on first sale and between USD 4.2-7.6 billion on retail markets[19].

The contribution of fisheries resources to GDP is detailed in Table 33:

Table 33: Contribution of the fisheries sector (capture + aquaculture) to GDP.

Country	Share of GDP	Sources
Cambodia	11.7%-16% 8% - 12%	Starr 2003 - Van Zalinge *et al*. 2004 Kurien *et al*. 2006
Lao PDR	6.8%	FAO statistics (http://www.fao.org/fishery/countrysector/FI-CP_LA/en#fn7)
Thailand	NA	
Viet Nam	7%	Thai Thanh Duong 2003

Kirby and Mainuddin (2009) recently showed, in a conservative assessment, that the economic value of capture fish in the Lower Mekong is at least as important as that of livestock. In Thailand, the contribution of aquaculture to the GDP was estimated at 2.07% GDP (Sugiyama *et al*. 2004).

[17] http://www.worldfishcenter.org/v2/pubs.html, keyword "values".
[18] This very comprehensive and poorly known analysis is available at http://www.fmsp.org.uk/FTRs.htm
[19] In the original publication the author actually values a production of "3.6 million tonnes" at USD3.6-6.5 billion, for a price per kilogram varying between USD 1 and 1.8 at first sale and USD 2-3.6 on retail markets. Assuming a catch of freshwater fish of 2.1 million tonnes (see section 1.1.2) this corresponds to a total value of USD 2.1-3.8 billion at first sale and USD 4.2-7.56 on retail markets.

1.4.2 ECONOMIC VALUE OF AQUACULTURE FISH

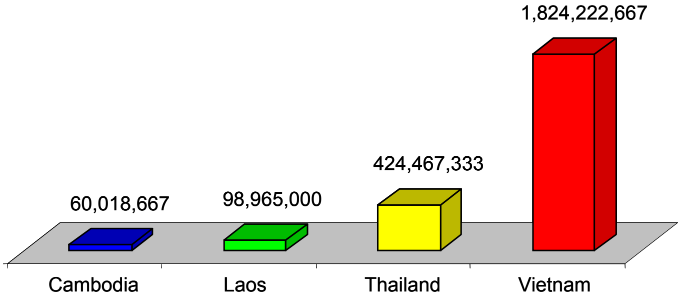
FAO statistics indicate the value of the inland and brackish water aquaculture production:

Table 34: Value of species produced in the LMB aquaculture sector.

Species	2005	2006	2007
CAMBODIA			
Barbonymus gonionotus	10,620,000	12,600,000	12,600,000
Clarias batrachus	1,050,000	1,400,000	1,400,000
Ctenopharyngodon idellus	1,500,000	1,800,000	1,800,000
Cyprinus carpio	8,400,000	10,000,000	10,000,000
Hypophthalmichthys molitrix	2,100,000	2,618,000	2,618,000
Hypophthalmichthys nobilis	750,000	900,000	900,000
Leptobarbus hoeveni	880,000	1,100,000	1,100,000
Oreochromis mossambicus	440,000	660,000	660,000
Oreochromis niloticus	440,000	660,000	660,000
Pangasius spp	10,000,000	16,000,000	16,000,000
Siluroidei	13,200,000	17,600,000	17,600,000
Total	*49,380,000*	*65,338,000*	*65,338,000*
LAO PDR			
Barbonymus gonionotus	6,739,000	7,488,000	7,488,000
Catla catla	5,400,000	6,000,000	6,000,000
Cirrhinus microlepis	8,640,000	9,600,000	9,600,000
Cirrhinus molitorella	6,138,000	6,820,000	6,820,000
Cirrhinus mrigala	4,230,000	4,700,000	4,700,000
Ctenopharyngodon idellus	5,400,000	6,000,000	6,000,000
Cyprinus carpio	6,264,000	6,960,000	6,960,000
Hypophthalmichthys molitrix	7,155,000	7,950,000	7,950,000
Hypophthalmichthys nobilis	5,281,000	5,868,000	6,520,000
Labeo rohita	4,770,000	5,300,000	5,300,000
Oreochromis niloticus	22,920,000	25,467,000	25,467,000
Probarbus jullieni	9,000,000	10,000,000	10,000,000
Total	*91,937,000*	*102,153,000*	*102,805,000*
THAILAND			
Anabas testudineus	3,741,000	1,574,000	3,549,000
Barbonymus gonionotus	44,208,000	44,343,000	46,787,000
C.gariepinus x C.macrocephalus	114,846,000	124,539,000	117,075,000
Channa micropeltes	252,000	390,000	290,000
Channa striata	18,910,000	16,054,000	15,444,000
Cirrhinus mrigala	981,000	868,000	859,000
Cyprinus carpio	4,195,000	3,852,000	4,350,000
Hypophthalmichthys molitrix	219,000	261,000	275,000
Labeo rohita	1,960,000	1,450,000	2,790,000
Nonopterus albus	106,000	94,000	102,000
Notopterus spp	25,000	1,000	4,000
Oreochromis mossambicus	122,000	194,000	181,000
Oreochromis niloticus	146,392,000	172,018,000	164,824,000
Osphronemus goramy	7,561,000	8,379,000	8,068,000
Osteichthyes	6,720,000	6,850,000	12,372,000
Oxyeleotris marmorata	699,000	576,000	696,000
Pangasius hypophthalmus	14,041,000	14,144,000	17,285,000
Trichogaster pectoralis	35,624,000	41,043,000	41,056,000
Trichogaster spp	23,000	25,000	115,000
Total	*400,625,000*	*436,655,000*	*436,122,000*
VIET NAM			
Osteichthyes	877,650,000	955,568,000	1,020,450,000
Pangasius spp	564,000,000	780,000,000	1,275,000,000
Total	*1,441,650,000*	*1,735,568,000*	*2,295,450,000*

Source: FAO in FishBase (*www.fishbase.org*)

Figure 18: Value of the inland aquaculture sector in LMB countries. US dollars. Yearly average, 2005-2007 period.



Source: FAO data in FishBase (www.fishbase.org)

Conclusions: During the 2005-2007 period, aquaculture generated around USD 60, 100, 400 and 1800 million each year in Cambodia, Lao PDR, Thailand and Viet Nam respectively, i.e. around USD 2.4 billion all together.

1.4.3 EMPLOYMENT VALUE OF CAPTURE FISHERIES AND AQUACULTURE

Figures about the number of people involved in the fishery sector are scarce. This is partly due to the lack of assessment, but also to the elusive nature of involvement in fishing, since a minority of people are full-time fishers, while a majority of farmers spend time fishing. Thus, in Cambodia, Keskinen (2003) stated that around the Tonle Sap Lake, fishing was a primary occupation for 17.1% of people only, but a secondary occupation for 28.5%. Fish related activities make up to two thirds of income in the villages of the Tonle Sap system, (Rab *et al*. 2004, 2006). In Lao PDR, full time fishers account for only a few percent of the Lao population, but fishing is central to livelihoods in the southern provinces of the country (Roberts and Baird 1995, Baird 1996, MRAG 2002).

Table 35: Number of people involved in the fishery sector (inland capture fisheries + aquaculture).

	Number of Households/People	**Sources**
Cambodia	1,640,000 people 4 million people or 29% of Cambodia's population derive employment from fisheries	FAO and WorldFish Center 2008 Kurien *et al*. 2006
Lao PDR	NA	
Thailand	50,198 households 3.13 million fishers	FAO statistics (www.fao.org/fishery/countrysector/naso_thailand/en Lymer *et al*. 2008
Viet Nam	2,834,238 people In the Mekong delta, fisheries and aquaculture contributed to 10% of the national labor force.	FAO and WorldFish Center 2008 FAO statistics www.fao.org/fishery/countrysector/FI-CP_VN/en

Table 36: Number of people involved in the aquaculture sector (inland + marine).

	People involved	**Farms**	**Sources**
Cambodia		53,800 farms in 2008	Minister of Agriculture's speech 01/012009
Lao PDR	5,5200 families or 8.3% of rural households	503,460 ha	FAO statistics (www.fao.org/fishery/countrysector/FI-CP_LA/en#fn7 Souvannaphanh *et al*. 2003
Thailand	80,704 households	Freshwater aquaculture: 390,853 farms and 131,500 ha in 2002; more than 440,000 farms in 2004	FAO statistics (www.fao.org/fishery/countrysector/naso_thailand/en)
Viet Nam	670,000 people	327,092 ha of freshwater farms (36.3%) 575,137 ha of marine and brackish water farms (63.7%)	FAO statistics (www.fao.org/fishery/countrysector/FI-CP_VN/en)

1.5 FISH ECOLOGY AND RISKS IN RELATION TO DAM DEVELOPMENT

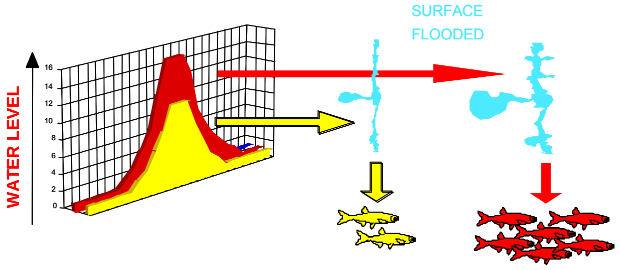
In general dams constitute a threat to fish because of i) modification of flows and subsequent impacts on water and habitat quality/quantity, and ii) a barrier effect making fish migrations difficult or impossible for adult or juvenile fish (WCD 2000). Flow modifications result in particular in changes in downstream discharge (volume, timing and amplitude), changes in downstream habitats, nutrient trapping in reservoirs, and deterioration of water quality. The sections below show that flows and migrations are the main drivers of the Mekong fish production.

1.5.1 FACTORS DRIVING FISH PRODUCTION

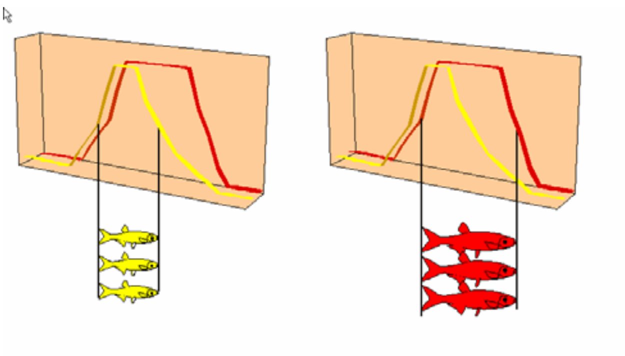
The analysis of factors driving fish production in the Mekong Basin has been done mostly in relation to an attempt to model that production, in view of better assessing the consequences of environmental modifications. The initial identification of factors driving fish production is given in Baran *et al.* (2001; unpublished report whose excerpts are presented here), developed further in Baran and Cain (2001) and in Baran *et al.* (2003), and summarized in Kurien *et al.* (2006). All these factors have been analyzed further for the Tonle Sap (e.g. Baran and Jantunen 2005).

A summary of these studies is presented graphically below:

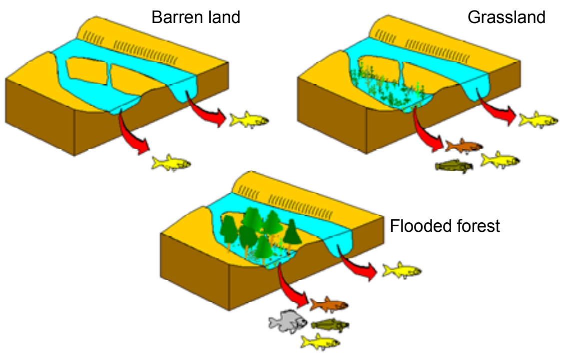
1) a bigger flood is correlated with higher fish production



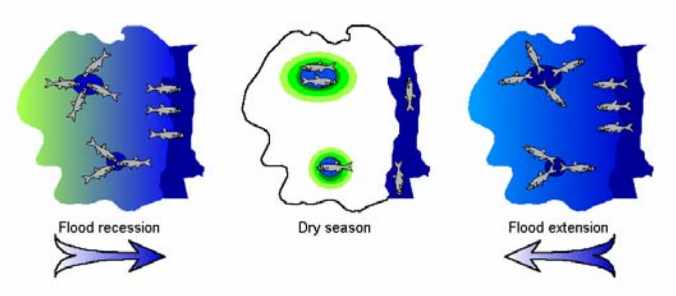
2) a longer flood is correlated with higher fish production



3) the nature and diversity of the vegetation in the flooded areas is most probably correlated with the diversity and abundance of fish production



4) the sustainability of the fish resource is dependent upon the presence and accessibility of refuges for fish in the dry season. These refuges consist of ponds in floodplains and deep pools in the Mekong mainstream. Almost no literature is available about ponds, but the role and functioning of deep pools has been much more studied (e.g. Poulsen *et al.* 2002a, Baran *et al.* 2005, Baird 2006).

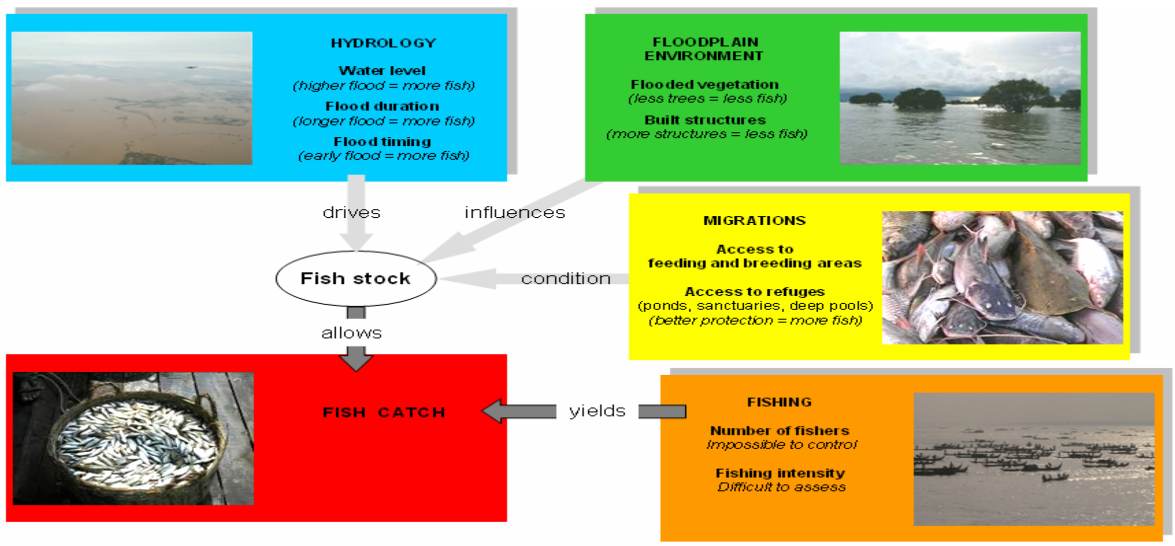


5) in a system driven by migrations, connectivity is an essential feature; the possibility for fish to move between their breeding and feeding zones is central to fish production sustainability. This issue has led to several analyses, in particular the study of the influence of built structures on Tonle Sap fisheries (Baran *et al.* 2007), and the role of dams on migrations (Halls and Kshatriya 2009).

6) last, the presence of an active fishery sector is a condition for converting the natural productivity of the system into tangible production; when it does not reach overfishing, this fishery sector contributes to enhancing the natural productivity of the system (Baran and Myschowoda 2008).

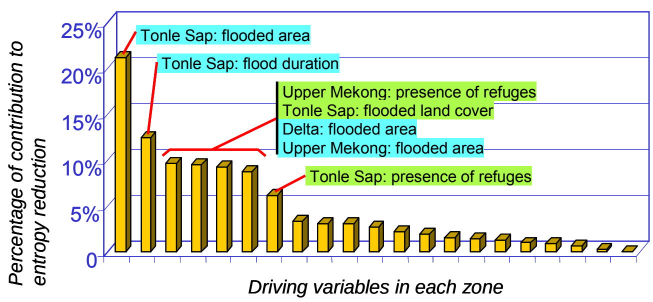
The interactions between these different factors are summarized below:

Figure 19: Overview of main factors driving fish production in the Mekong Basin.



In their model of environmental factors driving fish production in the Lower Mekong Basin, Baran *et al.* (2003) considered three groups of fishes (black fishes, white fishes and opportunists) and three geographic sectors (Upper Mekong, Tonle Sap system and Mekong Delta). The conclusion of their modelling work – based on expert consultations only – is summarized in Figure 20.

Figure 20: Factors driving fish production basinwide.



Source: Baran *et al*. 2003

According to the model developed, the area of flooding around the Tonle Sap is the most influential parameter driving fish production; among 7 influential factors, the area flooded is present 3 times, highlighting the importance of natural flooding for natural fish production. It should be noted however that this model, developed in 2001, is based on the evidence available at that time; it did not encompass built structures or access to breeding sites. The importance of the latter issues was highlighted subsequently.

1.5.2 FISH GROUPS IN THE MEKONG

Three main fish groups (or "guilds") having very different migration patterns are to be distinguished. The group of "*black fish*" is made of species with limited lateral migrations and no longitudinal migrations; these tough fish do not leave floodplains and wetlands, and spend the dry season in local ponds; this group includes *Channidae* (Snakeheads), *Clariidae*, *Bagridae* or *Anabantidae.* The group of "*white fish*" undertakes long distance migrations, in particular between lower floodplains and the Mekong mainstream. This group includes many cyprinids (e.g. *Henicorhynchus spp.* and *Cirrhinus sp*.) but also most *Pangasidae* catfishes. A third group, that of "*grey fish*", was defined later on (Lévêque and Paugy 1999, Poulsen *et al.* 2002; Table 37):

Table 37: Characteristics of main fish groups migrating

	White fish	Black fish	"Grey" fish
Migrations	Long distance longitudinal migrations	Local movements	Short range longitudinal migrations, lateral migrations
Body form	Round or fusiform	Body vertically compressed; no scales or long scales or armored body	Body laterally compressed, spiny, usually with strong scales
Color	Silvery or light	Very dark, often black	Rather dark, usually ornamented and coloured
Reproduction guild	Non-guarders; open substrate spawners	Guarders; build complex nests	Guarders; nest builders or open substrate spawners
Dry season habitat	Main channel, lake or sea	Floodplain ponds	Tributaries or edges of main streams
Wet season habitat	Main channel or floodplain	Floodplain or swamps	Floodplain

This "grey fish" group, made of fish that are not grey in colour but ecologically intermediate between the two previous groups, corresponds to fishes that do not spend the dry season in floodplain ponds, but do not undertake long distance migrations either. When the flood recedes they leave the floodplain and tend to spend the dry season in local tributaries; their ecological and physiological characteristics are intermediate between those of black and white fish.

Figure 21: Examples of fish species belonging to the main fish migration groups.

White fish is the group of fish most sensitive to dam development, because of the need to migrate over long distances. Black fish is the group most resilient to the impact of dams and tend to replace, to a certain extent, vanishing white fish. Grey fish are intermediate between these the two previous ones.

1.5.3 SPECIES GUILDS

Going beyond these three simple fish groups, Halls and Kshatriya (2009), drawing on Welcomme *et al.* (2006), proposed a series of 10 fish groups of similar migratory ecology (i.e. guilds) relevant to the Mekong. These guilds are detailed below.

Table 38: Migratory guilds for the Mekong and mainstream dam impact forecasting.

Migratory guild	Potential range of habitat utilized	Typical characteristics*	Likely impact of mainstream dams on migrations.
1. Rithron resident guild	Running river upstream	• Resident in rapids, torrents, rocky areas and pools upstream • Limited migrations.	Little or no impact
2. Migratory main channel (& tributaries) resident guild	Sea to running river upstream	• Long distance migrants; spawning in the main channel upstream. • May migrate to deep pools in the main channel during the dry season. • Adults do not enter floodplains. • Vulnerable to overexploitation and sensitive to damming. • May respond favorably to fish passage facilities.	Medium
3. Migratory main channel spawner guild	Floodplains to running river upstream	• Spawn in the mainstream, in tributaries and around floodplains. • Adults and drifting larvae return to floodplains to feed. • May migrate to deep pools in the mainstream during the dry season. • Sensitive to damming.	Very high
4. Migratory main channel refuge seeker guild	Floodplains to slow river downstream	• Spawn in floodplains. • Migrations between floodplains and mainstream deep pools in the dry season. • Sensitive to damming.	Very high
5. Generalist guild	Floodplains and slow river downstream	• Limited non-critical migrations in mainstream. • Highly adaptable, often tolerant of low oxygen concentrations. • May be semi-migratory often with sedentary local populations; may seek refuge in deep pools during dry season. • May undertake lateral migrations to floodplains. • This guild is well represented in most rivers.	Little or no impact
6. Floodplain resident guild (blackfish)	Floodplains	• Limited migrations between floodplains, pools, river margins, swamps, and inundated floodplains. • Tolerant to low oxygen concentrations or complete anoxia.	Little or no impact
7. Estuarine resident guild	Estuary	• Limited migrations within the estuary in response to daily and seasonal variations in salinity. • Usually confined to the brackish part of system.	Little or no impact
8. Semi-anadromous guild	Estuary and lower slow river downstream	• Enters fresh/brackish waters to breed. • Enters freshwaters as larvae and juveniles (obligate or opportunistic). • Impacted by river mouth dams that stop migration into the river.	High (for dams located in river mouths or lower part of the river)
9. Catadromous guild	Marine to running river upstream	• Reproduction, early feeding and growth at sea. • Juvenile or sub-adult migration to freshwater habitats. • Vulnerable to overexploitation and tend to disappear when river is dammed preventing longitudinal upstream migration. • May respond favorably to fish passage facilities.	Very high
10. Marine guild	Estuary	• Enter estuaries opportunistically.	Little or no impact

Source: adapted from Halls and Kshatriya (2009)

According to these authors, Mekong mainstream dams are likely to have a significant impact on at least 58 migratory Mekong fish species.

1.5.4 FISH MIGRATIONS

Fish migrations in the Mekong Basin have been identified as a major feature several decades ago (e.g. Chevey and Le Poulain 1940) and subject since then to numerous publications: in 2006, Baran reviewed 26 studies dealing with Mekong fish migrations. The major features of these migrations are presented below, as well as new developments.

Northcote (1984) defines migrations as “movements that result in an alternation between two or more separate habitats, occur with a regular periodicity, and involve a large proportion of the population”. From a spatial perspective fish migration can be lateral, longitudinal or vertical, and the movements can be either active or passive (in particular in the case of eggs and larvae).

Fish migrate when they cannot complete their lifecycle in a single habitat: when requirements for reproduction and for feeding at different life stages cannot be met in the same place, then fish have to move between places to survive. This process also optimizes survival, growth and reproduction. Fish also sometimes migrate to avoid unsuitable water quality; e.g. out of the Great Lake in the dry season when the water is warm and has low oxygen content. Generally speaking, breeding and feeding are the two main factors that drive fish migrations in the Mekong system.

• *Feeding migrations*: extensive wetlands and floodplains in the basin (185,000 and 50,000 km^2 respectively according to Hortle *et al.* 2008 and TKK and SEA START-RC 2008), and their multiple resources (vegetation debris, invertebrates, algae, etc.) constitute a rich feeding place for both adults and juveniles. Thus, in the lower stretches of rivers almost all fish species at all life stages temporarily migrate to floodplains at the beginning of the rainy season. This process, which involves long or short distance migrations, contributes to increased growth and survival of individuals, and thus to the very high productivity of the system.

• *Breeding migrations*: the Mekong is the river with the highest discharge variability in the world: rainy season flows can be 30 fold higher than dry season flows. If fish did not migrate this huge pulse would wash larvae and juveniles away; actually it forces adult fish to move upstream for spawning, so that their larvae and juveniles can drift down to floodplains with the flood and grow there, in good conditions, during the wet season.

Most species combine feeding and breeding migrations, so it is almost impossible to dissociate these two patterns. Thus, in the case of the Mekong upstream migrations are mainly breeding migrations undertaken by larger, often adult fish; downstream migrations are mainly feeding migrations undertaken at both life stages. Fish movements also include lateral migrations between the mainstream or tributaries and floodplains. Migration however has a high mortality cost (predation, fishing) and if the conditions remain locally suitable, there are instances where some species or sub-populations stop migrating over long distances (e.g. in man-made brush parks where species like *Henicorhynchus sp.* can be found year round; Hortle, pers. comm.). Brush parks that contribute to deforestation are an illegal fishing method.

1.5.4.1 MIGRATIONS IN SPACE

Three major migration systems can be distinguished in the Mekong Basin (Poulsen *et al.* 2002), as detailed in Figure 22.

• The Lower Mekong migration system, characterized by its extensive floodplains, is limited downstream by the sea (although in reality the extent and volume of migrations between the river and the sea is not known), and upstream by the Khone Falls bottleneck on the mainstream. Khone Falls is only a partial bottleneck for fish, as demonstrated for instance by the intensive local fishery almost exclusively based on migrations, or by the migration of species such as the giant catfish that feeds in the Tonle Sap and breeds in upper Lao PDR/Thailand; however the role of the Khone Falls as a bottleneck has not been quantified so far. The proportion of Lower Mekong species that can breed in northern Cambodian tributaries without crossing the falls is also unknown.

• The Middle Mekong migration system is characterized by big tributaries and local wetlands; fish tend to migrate between these two habitats and the Mekong mainstream. Few publications detail the ecology of this area (Ubolratana Suntornratana *et al.* 2002, Jutagate *et al.* 2007) and the location of the upper boundary of this zone (approximately around Vientiane) is unclear.

• In the Upper Mekong migration system (which includes to some extent the Chinese Mekong or Lancang) fish migrate upstream to spawning habitats during the wet season. The upper limit of this ecological zone and the role of the local short tributaries in migrations are unknown.

We detail below these areas, and an estimate of their fish biomass (excerpt from Barlow *et al.* 2008)

1. Fish resources in the Lower Mekong migration system correspond to 100% of the Mekong yield in Cambodia and in Viet Nam. One estimate (Van Zalinge *et al.* 2004) based on fisheries catch studies amounts to 682,000 tonnes in Cambodia and 845,000 tonnes in Viet Nam. A second estimate, based on household consumption studies (Hortle 2007), amounts to 481,000 tonnes in Cambodia and 692,000 tonnes in Viet Nam. These estimates thus give a range for the fish production in the Lower Mekong Migration System:

• Estimate 1: (Cambodia: 682,000 tonnes x 100%) + (Viet Nam: 845,000 tonnes x 100%) = 1.53 million tonnes

• Estimate 2: (Cambodia: 481,000 tonnes x 100%) + (Viet Nam: 692,000 tonnes x 100%) = 1.17 million tonnes

Thus, the Lower Mekong migration system produces between 1.2 and 1.5 million tonnes of fish annually.

2. Fish resources in the Middle Mekong Migration System correspond to 100% of the yield in the Thai Mekong Basin, and by our estimate 80% of the yield in the Lao Mekong. According to Van Zalinge *et al.* (2004) (Estimate 1), the Mekong Basin produces annually 932,000 tonnes in Thailand and 183,000 tonnes in Lao PDR; according to Hortle (2007) (Estimate 2), Thailand produces 720,000 tonnes a year and Lao PDR 168,000 tonnes. This leads to the following estimates of fish production for the middle system:

• Estimate 1: (Thailand: 932,000 tonnes x 100%) + (Lao PDR: 183,000 x 80%) = 1.08 million tonnes

• Estimate 2: (Thailand: 720,000 tonnes x 100%) + (Lao PDR: 168,000 x 80%) = 850,000 tonnes

Thus, the Middle Mekong migration system produces between 850,000 and 1 million tonnes annually. In this system, the environmental impact of dams will be spread between many more tributaries than in the lower system.

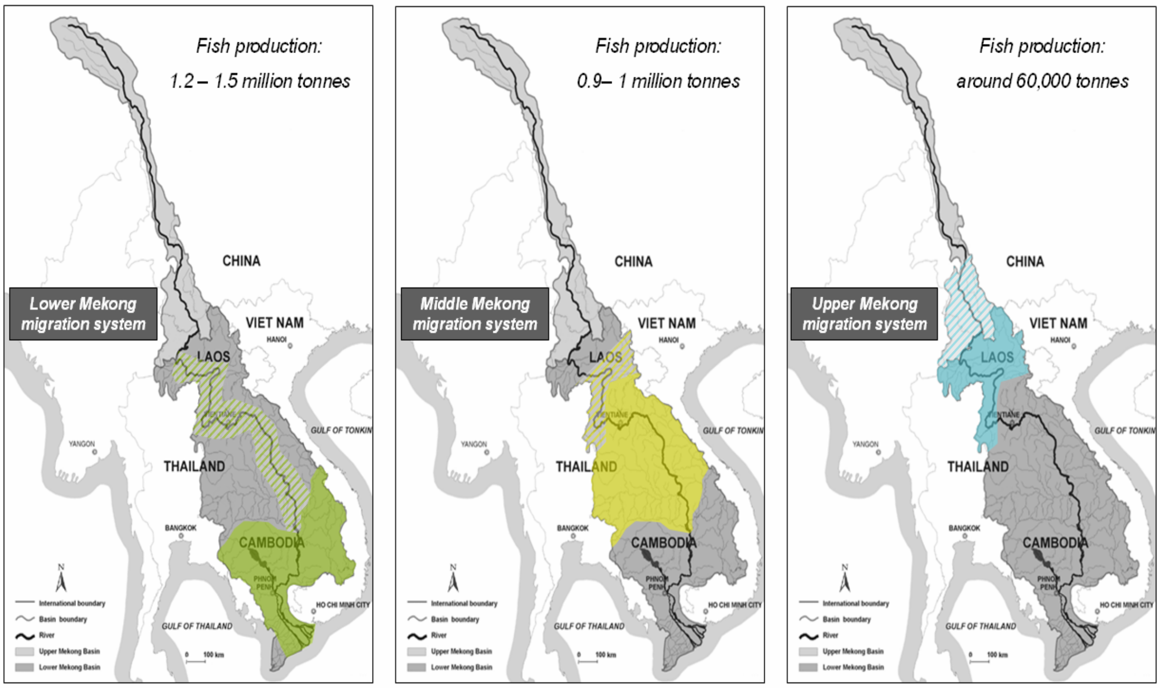
3. Fish resources in the Upper Mekong migration system correspond to 100% of the yield in the Chinese-Langcang Mekong (25,000 tonnes according to Xie and Li 2003) and 20% of the yield in the Lao section of the Mekong Basin. Hence, the estimates of fish production for the Upper Mekong Migration System are:

• Estimate 1: (China: 25,000 tonnes x 100%) + (Lao PDR: 183,000 x 20%) = 62,000 tonnes

• Estimate 2: (China: 25,000 tonnes x 100%) + (Lao PDR: 168,000 x 20%) = 58,000 tonnes

Thus, the Upper Mekong system produces around 60,000 tonnes of fish a year; this makes it the zone where there is the least to lose from hydropower development; however, this is a region of specific biodiversity, with a number of local species characteristic of headwaters, rapids and high streams. It should also be noted that this calculation of local yields at risk does not reflect far-fetched impacts, such as sediment retention in upstream dams and its impact on overall fish and river productivity.

Figure 22: Main migration systems within the Lower Mekong Basin.

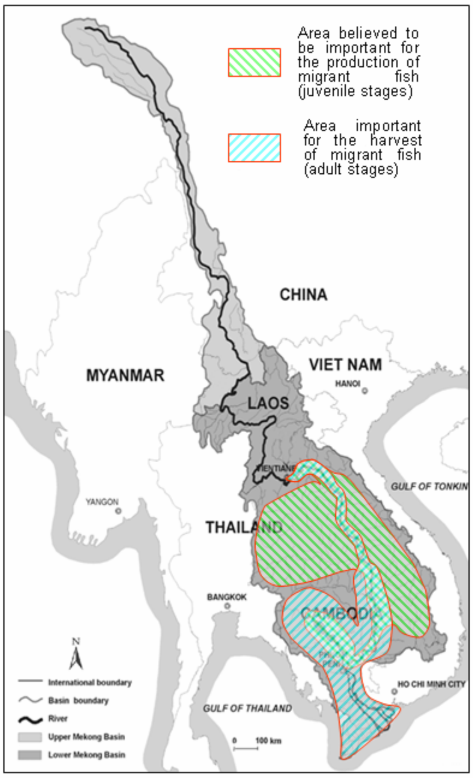


Note: a recent paper by Bin Kang *et al*. (2009) clarified the northern extent of the Upper Mekong migration system: the latter should be limited to the lower reach of the Lancang (from the Lao border to the Hiaohei sub-basin).

It is important to note that these estimates reflect studies and papers available *before* the present SEA undertook a revision of the production figures by zone; therefore, the latest and most detailed estimates by zone are to be found in the Fisheries Impact Assessment of the SEA.

Last, given the large-scale migration phenomenon, it must be highlighted that the southern area of the Mekong Basin (Lower Mekong migration system, Ecological Zone 5) is productive because of its connection with the adjacent zones upstream. In particular, large tributaries in the Middle Mekong migration system are, for many migratory species, breeding areas or migration corridors allowing the downstream area to harvest the adult fish originating from upstream as juveniles (Figure 23).

Figure 23 Components of the fish production based on migratory fishes: production area for larvae and juveniles (originating from upstream breeding sites) and production area for adults (harvested downstream in floodplains).



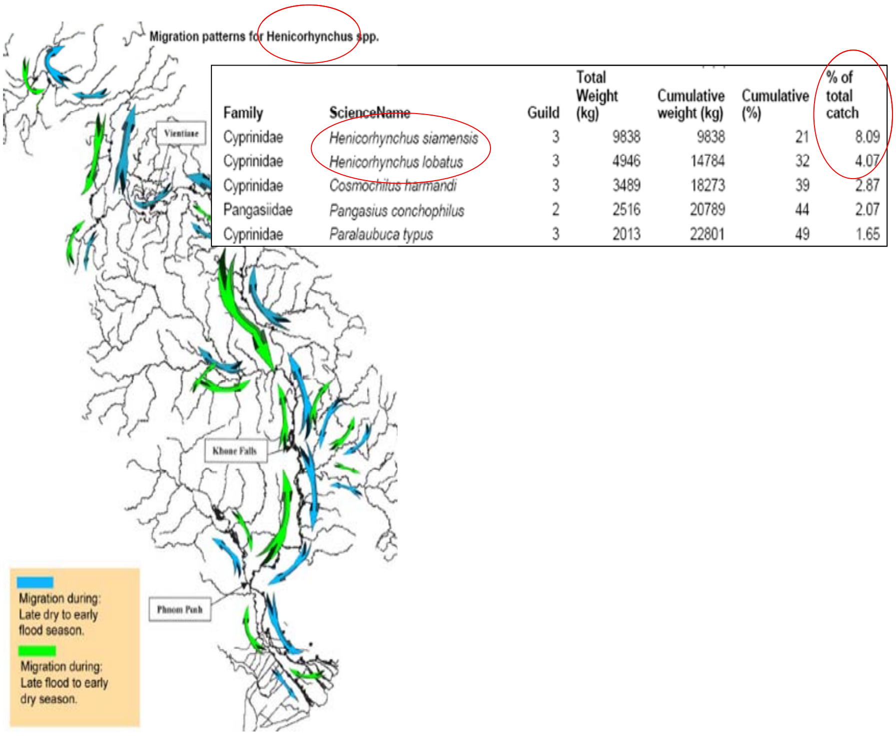
This map reflects dominant hypotheses about the functioning of the system but is not backed by data, and the limits of each area, although based on those of major watersheds, are arbitrary.

<u>Migrations in tributaries:</u>

In the analysis below we combine i) the results of fish migration surveys done by Poulsen and his team (Poulsen *et al.* 2002, 2004) and documented in two CD-ROMs (MRC 2001 and MFD 2003), and ii) the only assessment of fish abundance basinwide based on a standardized field sampling (protocol based on gill nets described in Starr 2008, with preliminary results published in Halls and Kshatriya (2009)).

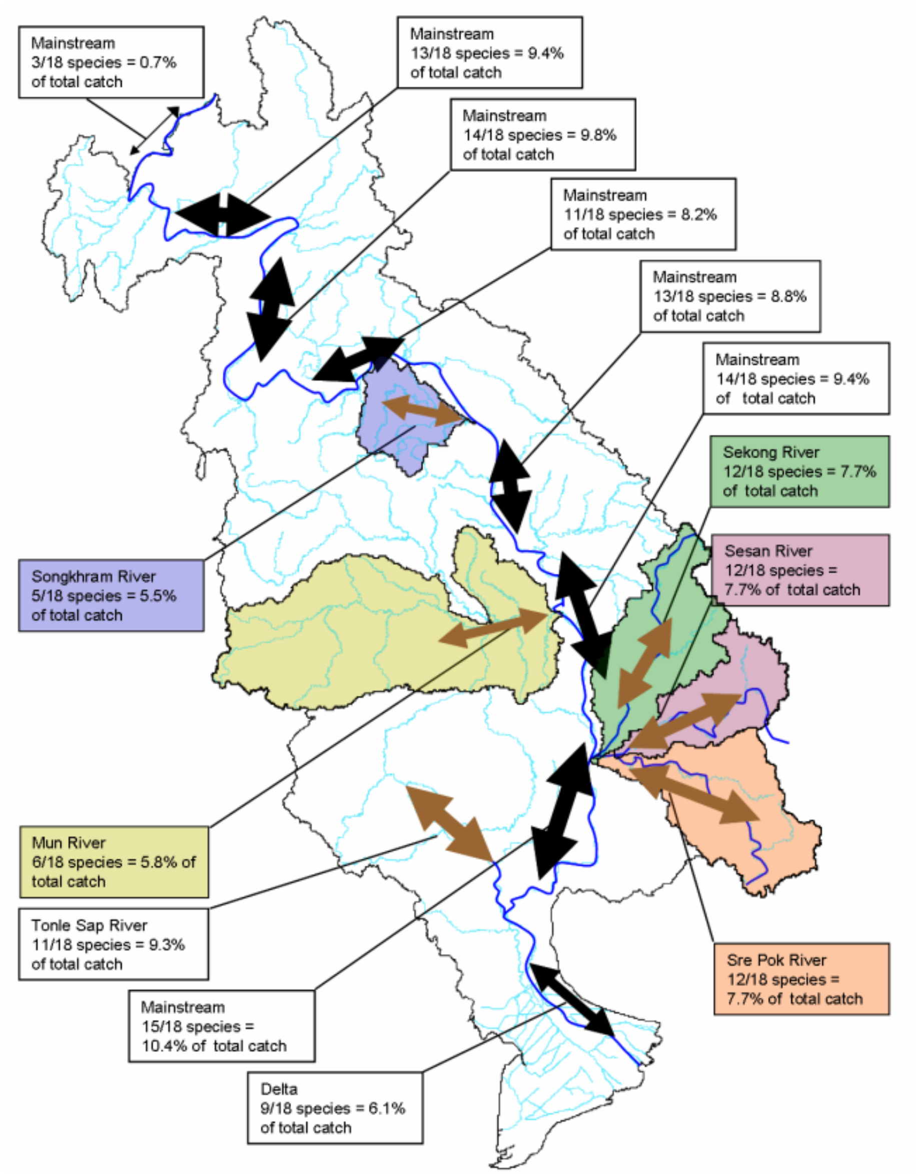
Migration studies based on local knowledge systematically gathered throughout the basin resulted in a description of migration patterns for 23 species. Figure 24 shows an example of such a description for one particular species.

Figure 24: Combination, for one given species, of migration map produced by the MRC and of biomass estimates resulting from gillnet monitoring basinwide.



This information was then compiled for all the sub-basins of the Mekong, and weighted by the relative importance of each species in catches basinwide. The resulting map shows the main migration corridors in the Mekong Basin and, for the first time, the relative biomass involved (as indicated by the width of arrows). It should be noted that this map is based only on 18 species for which migration maps are available *and* relative importance in catches of gillnets is known; thus it should be taken as an indication of main migration corridors based on information available, but not as a precise summary of overall migrations basinwide.

Figure 25: Main migration corridors and their relative importance

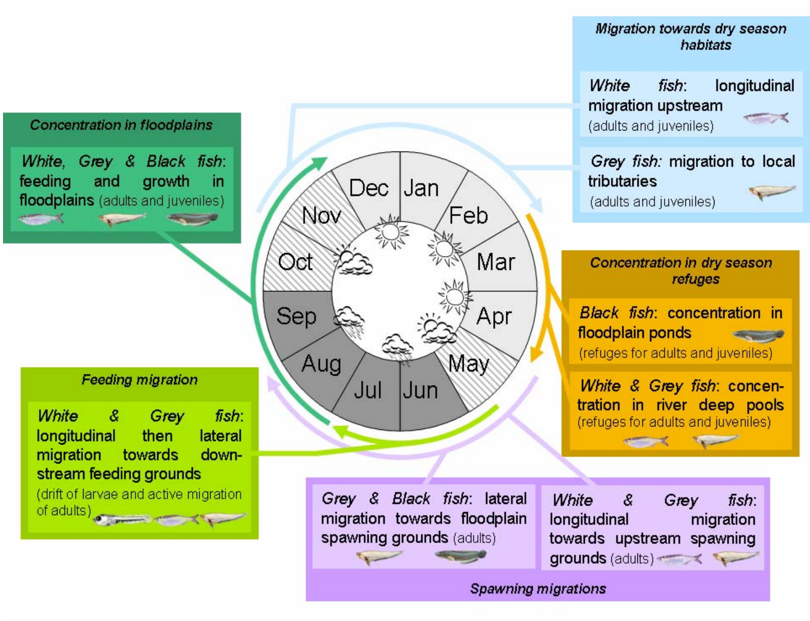


Conclusions: The main migration corridor is the Mekong mainstream, and the area between Phnom Penh and Stung Treng features the highest number of migratory species for which migration maps exist. There are relatively far fewer species migrating in the delta, but a surprisingly steady number of species migrating all along the mainstream up to northern Lao PDR. This latter location is the place of least migration in the LMB. With 12 out of 18 species for which migration maps exist, the 3S system (Sesan, Srepok, Sekong Rivers) seems to play an important role (as important as the Tonle Sap River) among migratory species.

1.5.4.2 MIGRATIONS IN TIME

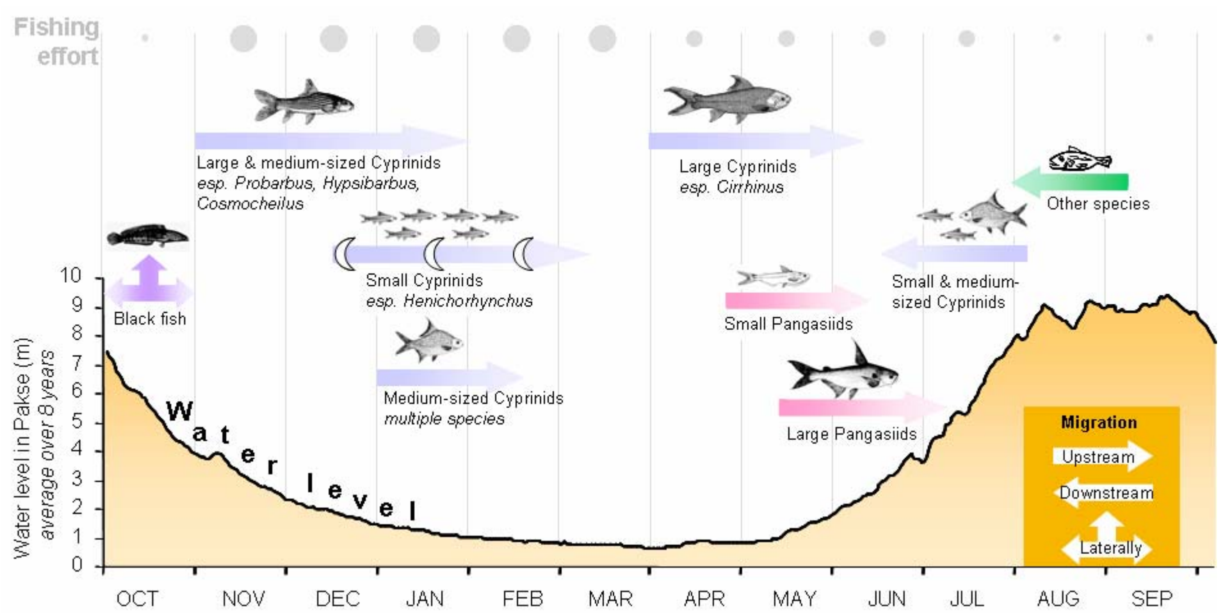
• In the Lower Mekong migration system most migrations take place during the rising flood and drawdown period (Figure 26). For many fish species the spawning season occurs during rising water levels. White fish species generally migrate upstream for spawning, and subsequently the river transports the eggs and larvae downstream and onto floodplains. Black fish species, of which several are piscivores, often breed relatively early, so that by the time the larvae of the white fish arrive on the floodplain, the black fish are ready to exploit these for food.

Figure 26: Lifecycle and migrations of fishes in the Lower Mekong migration zone



• In the Middle Mekong migration system, Khone Falls (southern Lao PDR) is a special and well studied area characterized by a series of waterfalls between the Lao plateaux and the southern lowlands of the Lower Mekong migration zone. In this ecological corridor, multiple studies (Warren *et al.* 1998, Baird 2001, Baran *et al.* 2005) allowed the identification over time of eight distinct waves of fish migrations per year (Figure 27)

Figure 27: Migration patterns at Khone Falls



Source: Baird 2001

1.5.5 DAMS AND DISRUPTION OF MIGRATIONS

In the analysis below, we illustrate the area of the basin in which movements of long-distance migrants are already obstructed by existing dams. The map produced results from a superimposition of the map of migrations (Figure 22) and of a map of dams in hydrological basins.

A recent paper by Barlow *et al.* (2008) reviewed the possible consequences of mainstream dam development on fish production. The paper compares the conclusions based on three different approaches: the first one is based on interviews of a panel of experts (Dugan 2008); the second is based on analyses of published literature (Baran and Jutagate 2008); and the third one (Halls and Kshatriya 2009) categorizes different species of fish into guilds based on their biology and then uses a fisher catch survey to determine the proportion of the catch that is highly threatened by dam construction.

The results from the three studies indicate that the migratory fish resources at risk from mainstream dam development in the Mekong range from 0.7 to 1.6 million tonnes per year (Table 39).

Again, this review reflects studies and papers available *before* the present SEA undertook a revision of the production figures by zone and updated the assessment of impacts; therefore, the latest and most detailed estimates of fish production at risk from mainstream dam development are to be found in the Fisheries Impact Assessment of the SEA.

Figure 28: Areas where long-distance fish migrations between the mainstream and upper reaches are already obstructed by dams.

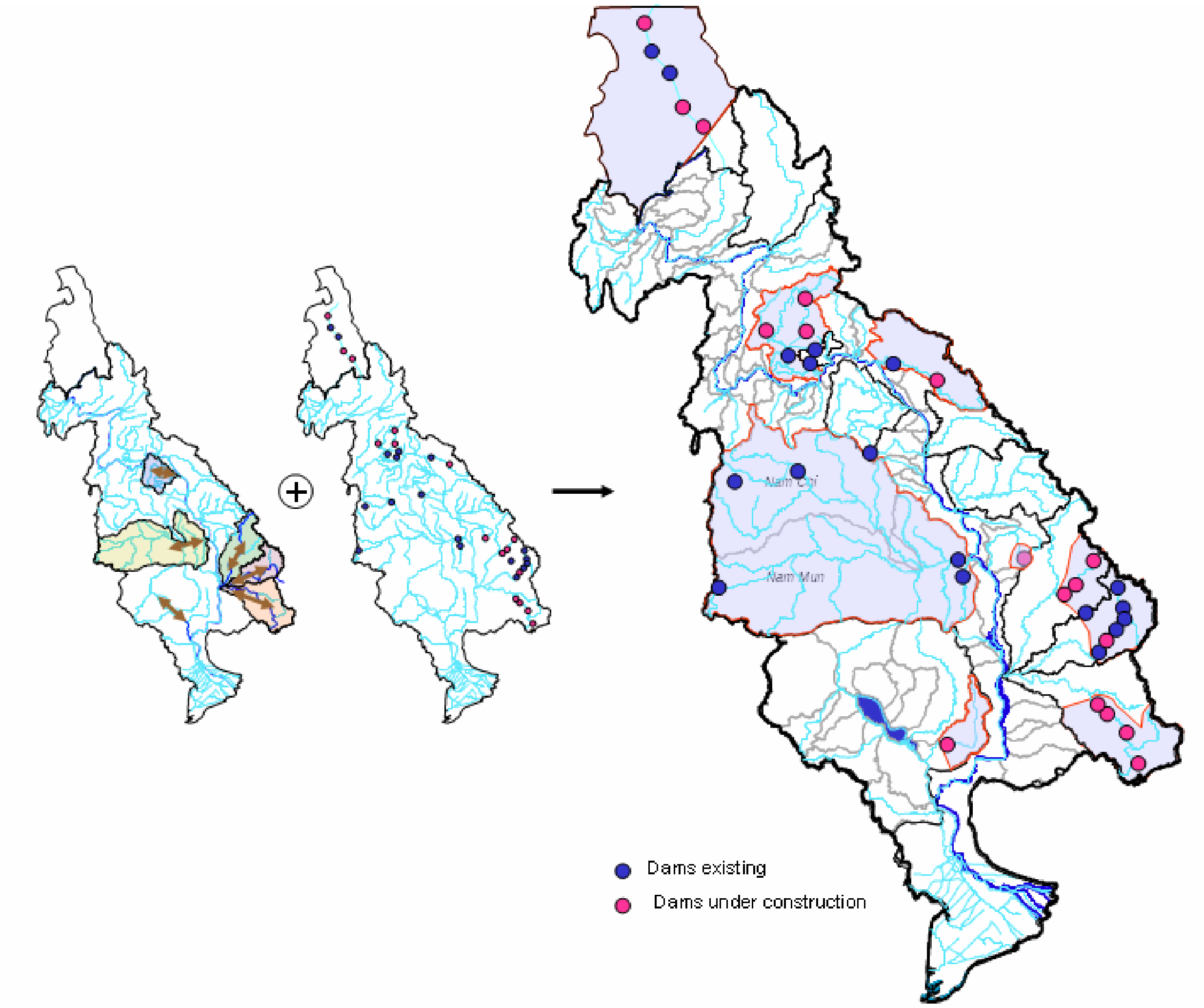


Table 39: Migratory fish resources at risk from mainstream dam development in the Mekong.

Method	Estimate Derived	Annual Yield (tonnes)	Annual Value (USD million)
1	Highly migratory fish resources in the LMB	1,320,000	2,500*
2	Highly migratory fish resources in the LMB	1,270,000 – 1,570,000	2,400 – 3,000*
	- Lower Mekong Migration System (Viet Nam to Khone Falls)	*750,000 – 950,000*	*1,400 – 1,800**
	- Middle Mekong Migration System (Khone Falls to Vientiane)	*500,000 – 600,000*	*950 – 1,100**
	- Upper Mekong Migration System (Vientiane to China border)	*20,000*	*37**
3	Highly vulnerable migratory fish groups in the LMB	744,000	1,400*

The size of the migratory fish resources in the Lower and Middle Migrations Systems (between the delta and Vientiane) is far larger than the resource in the Upper Migration System (northern Lao PDR). Therefore, dams built in the Lower and Middle Migration Systems are likely to have a greater impact on fisheries production in the LMB than dams built in the Upper Migration System.

Barriers to migration do not have the same effect on all fish species. An analysis of studies worldwide (Welcomme *et al.* 1989) shows that:

- obligate migratory fish species tend to disappear when the main channels are blocked, despite mitigation measures such as fish passes or fish stocking;
- floodplain spawners are selected against when the annual flood is reduced or eliminated;
- fish assemblages tend to shift from floodplain spawners toward main channel spawners.

In Africa, a review of case studies (Lévêque 1997) concludes that the closure of a dam is generally followed by two phases: i) an increase in fish populations fit to lacustrine conditions such as small clupeids, then ii) a subsequent increase of predators that sharply reduces the previous populations. Overall the change in species composition is marked and hard to predict, but native riverine species often disappear.

In South America, three main generic fishery states have been identified: i) in undisturbed, unregulated rivers, catches are dominated by high value large silurids and characins; ii) in developed, regulated rivers, fisheries are still supported by migratory fish of decreasing size, but there is an increasing contribution of less valuable species and appearance of exotics; iii) in dammed rivers with reservoir fisheries, the proportion of migratory fish in catches descends well below 50%, catches become dominated by "black fish" species, and the number of exotic species rises further.

In the Mekong River system, white fish that undertake long-distance longitudinal migrations of several hundred kilometres will be much more impacted by barriers to migrations than black fishes whose home range is much smaller. The "white fish" guild includes in particular Cyprinidae (many species), Balitoridae, Cobitidae and Pangasiidae. That latter family will be among those severely impacted since a majority of its species migrates over long distances with complex migration patterns such as the Mekong giant catfish (*Pangasianodon gigas*) and the anadromous *Pangasius krempfi*.

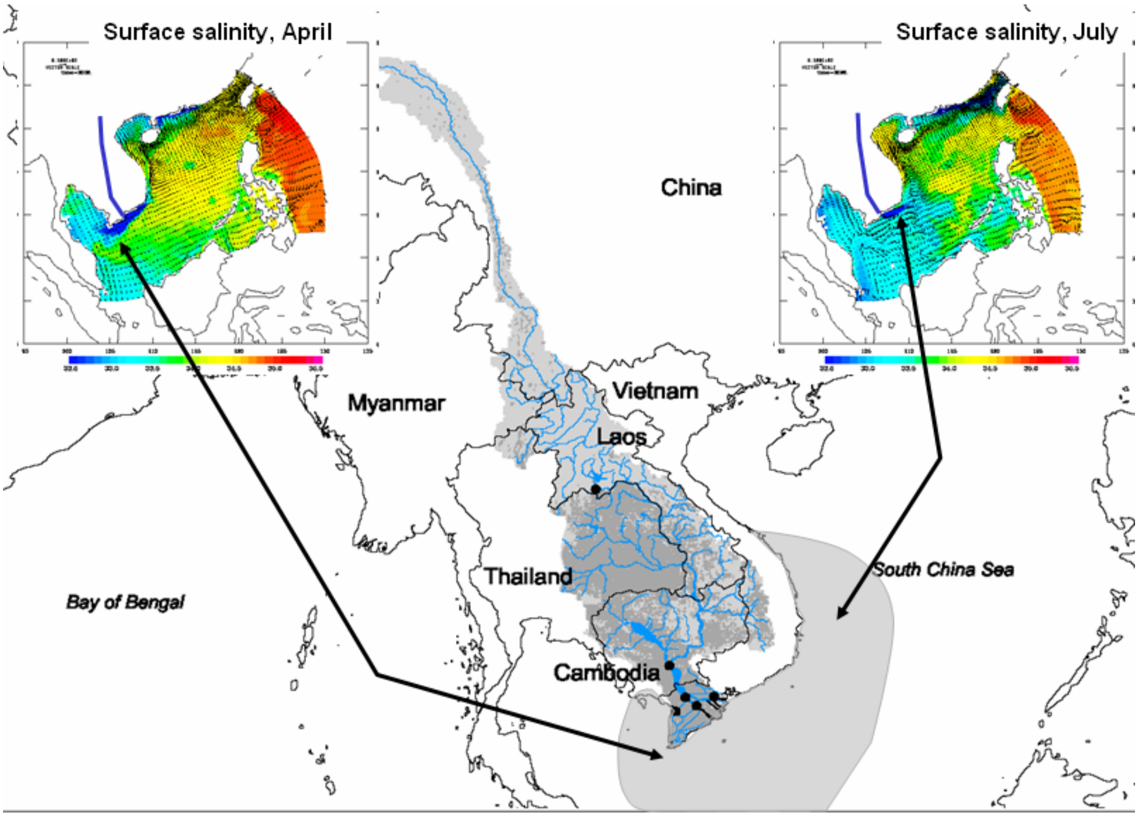
The "grey fish" guild is a rather heterogeneous group composed of species having in common the need to migrate between floodplains and local tributaries. Thus, they will not be sensitive to the physical barrier constituted by mainstream dams, but might be as sensitive as "white fish" to dams built on local tributaries. Overall the characteristics of "grey fish" species vary a lot from species to species, and it is difficult to predict an overall response for that guild.

The "black fish' guild is characterized by adaptations that allow individuals to endure adverse conditions on the floodplain, such as low dissolved oxygen. These fishes are able to better survive in lacustrine conditions and are believed to be able to somehow adapt to altered hydrographs. This guild includes families such as Channidae, Clariidae, Bagridae and Anabantidae. It is believed that robust black fishes might do well in reservoirs; this actually reflects confusion between the robustness of adult individuals and an assumed similar robustness throughout their life history that would enable them to breed in and adapt to reservoirs. Such robustness at all life history stages remains to be demonstrated.

1.5.6 INTERACTIONS BETWEEN THE RIVER AND THE COASTAL ZONE

The importance and richness of the estuarine and coastal areas, which constitute an intrinsic part of the Mekong system, should be highlighted. In tropical systems the connexions between rivers outflows and coastal productivity are well known (review in Loneragan and Bunn 1999) and in the Mekong the importance of river inputs to the fisheries productivity of the coastal zone has been known for a long time (Chevey 1933, Lagler 1976, Poulsen *et al.* 2002). The extent of the Mekong's influence on the coastal zone and of the subsequent coastal estuary whose productivity depends upon Mekong discharge and sediments is illustrated below.

Figure 29: Extent of brackish areas around the Ca Mau peninsula, depending on the season.



Source: Xue *et al.* 2000.

A remarkable concentration of fish can be noticed at the mouths of the Bassac and Mekong Rivers at the beginning of the dry season. The fish are attracted by the enormous concentration of nitrogenous material coming from the Mekong and their scales register the sharp acceleration of growth that results.

Chevey 1933

The loss of nutrients, either dissolved or in organic silt, from the plume of the Mekong/Bassac will certainly diminish productivity in the near-shore areas and to a lesser extent in the off-shore areas. The fishery of the Mekong plume in the South China Sea also will be subject to impacts of the controlled and augmented low-flow regime.

Lagler 1976

Unfortunately the rivers outflow - coastal productivity connection has been poorly recognized in research and development agendas (Blaber 2002) and as far as we know there is no information to be reviewed on that topic. This highlights an important gap in research regarding the impact of Mekong mainstream dams on fish resources.

1.6 FUTURE TRENDS WITHOUT MAINSTREAM HYDROPOWER DEVELOPMENT

1.6.1 TRENDS IN AQUACULTURE AND CAPTURE FISHERIES

The only statistics available on a yearly basis and allowing an assessment of trends over years are those of the FAO, originating from riparian line agencies. We present below the trends in fisheries and aquaculture for the countries of the Lower Mekong Basin.

Table 40: Production in the capture fisheries and aquaculture sectors in the four LMB countries since 2000. Inland capture fisheries, inland and brackish aquaculture production, in tonnes.

	2000	2001	2002	2003	2004	2005	2006	2007
Aquaculture Cambodia	14,002	13,463	14,133	17,886	20,200	25,500	33,570	33,570
Aquaculture Lao PDR	42,066	50,000	59,716	64,900	64,900	78,000	78,000	78,000
Aquaculture Thailand	259,885	262,815	275,262	329,006	486,397	506,331	498,392	475,751
Aquaculture Viet Nam	365,015	383,186	441,827	599,824	761,566	961,100	1,157,045	1,530,300
Capture Cambodia	245,300	384,500	359,800	308,250	249,600	323,500	421,400	419,400
Capture Lao PDR	29,250	31,000	33,440	29,800	29,800	26,560	26,925	26,925
Capture Thailand	201,205	202,200	198,200	197,493	202,600	194,159	208,400	218,010
Capture Viet Nam	180,000	188,542	163,615	148,959	134,075	130,400	136,200	133,600

Source: FAO Figis (*http://www.fao.org/fishery/statistics/global-aquaculture-production/query/en*)

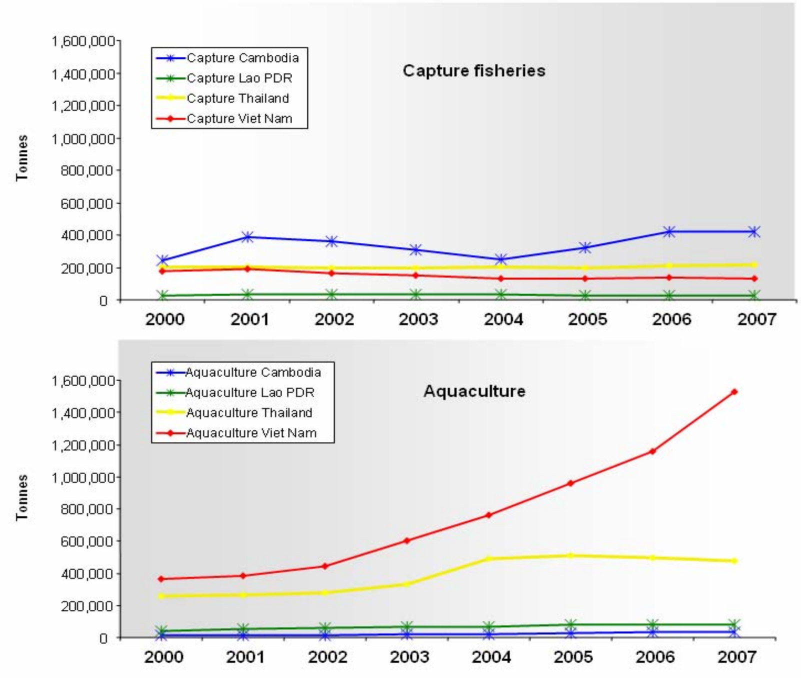
Table 41: Growth in the inland/brackish aquaculture sector (percentage of growth compared to the previous year).

	2001	2002	2003	2004	2005	2006	2007
Cambodia	-3.8	5.0	26.6	12.9	26.2	31.6	0.0
Lao PDR	18.9	19.4	8.7	0.0	20.2	0.0	0.0
Thailand	1.1	4.7	19.5	47.8	4.1	-1.6	-4.5
Viet Nam	5.0	15.3	35.8	27.0	26.2	20.4	32.3

Source: FAO Figis.

Capture fisheries: While many press articles refer to declining catches among fishermen, there is no evidence from national statistics that the yield from capture fisheries is declining in the four LMB countries. However, recent reviews emphasize the fact that capture fisheries yields are becoming static and that little or no growth is to be expected from that sector in the years to come (Lymer *et al*. *2008*; Kirby *et al.* 2008). In Cambodia the only long-term database of field-based catch records, from the *dai* fishery in Cambodia, indicates no upward or downward trend in yields between 1995-96 and 2007-08 (Halls *et al*. 2008). Baran and Myschowoda (2008) examined long-term trends in catches in the Tonle Sap area and concluded that over the last 60 years there has been a decline in the catch per fisherman because the fish biomass, although it increased substantially over time, did not increase as fast as the human population.

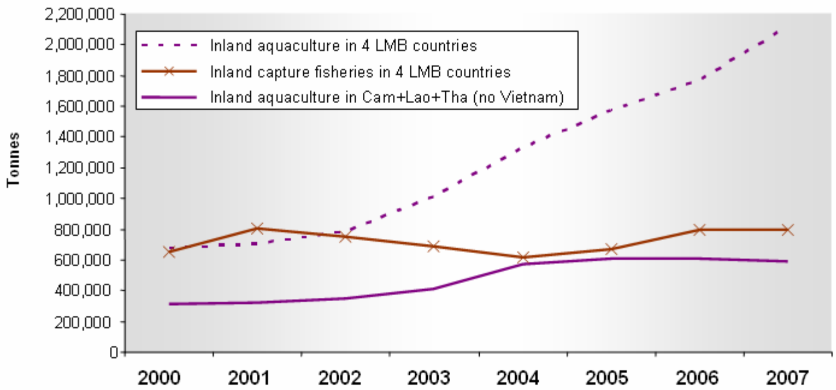
Figure 30: Production in inland capture fisheries and in inland/brackish aquaculture sectors in the four LMB countries since 2000.



Source: FAO Figis.

Aquaculture sector: in inland/brackish water aquaculture, only one country, Viet Nam, features a high annual growth (+28% a year over the last 5 years) and high production levels (1.5 million tonnes in 2007). In Cambodia, annual growth is substantial but the production level is very low; in Lao PDR figures are erratic but low; and in Thailand the inland/brackish aquaculture production, having reached a high level – around 500,000 tonnes/year – is showing signs of stabilization if not decline.

Figure 31: Comparative trends in inland/brackish water aquaculture and capture fisheries.



Source: see Table 40.

Conclusions: According to national statistics, when all countries are lumped together, the production of the inland/brackish aquaculture sector in the LMB is more than double that of the inland fisheries sector (respectively 1.82 and 0.75 million tonnes on average over the last 3 years). However, when the exceptional case of Viet Nam is put aside, the production of the inland aquaculture sector in Cambodia, Lao PDR and Thailand remains inferior to the production of the inland fisheries sector in these countries.

1.6.2 PERSPECTIVES ON AQUACULTURE AND CAPTURE FISHERIES

Tentative forecasts are proposed below; they are based on a projection of growth observed in the past 7 years in both capture and aquaculture sectors (inland and brackish aquaculture, freshwater fisheries; Table 42).

Table 42: Average growth rate in aquaculture and capture fisheries for the LMB countries.

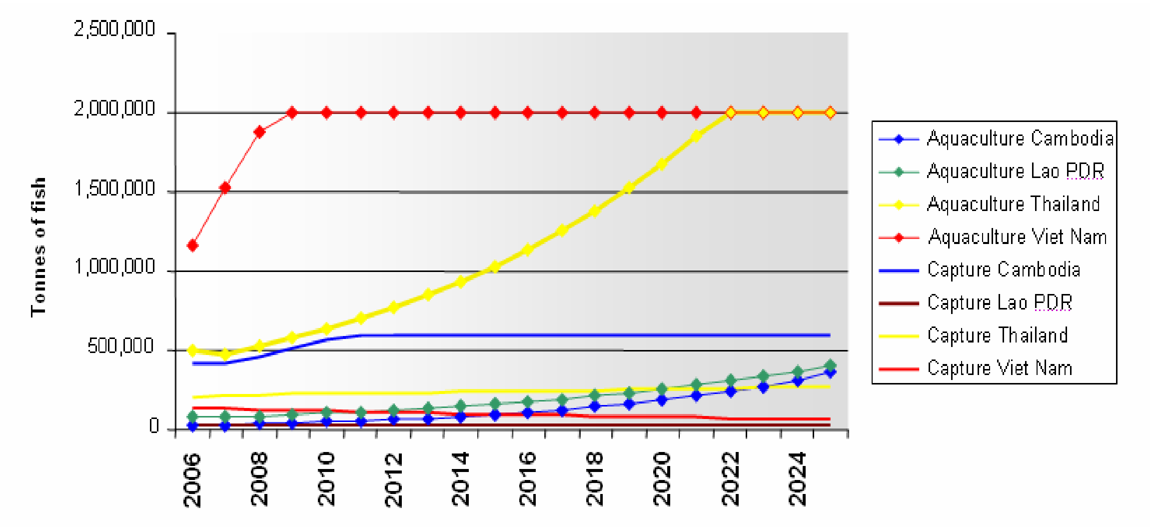
	Average growth between 2000 and 2007 (%)
Aquaculture Cambodia	14.1
Aquaculture Lao PDR	9.6
Aquaculture Thailand	10.2
Aquaculture Viet Nam	23.1
Capture fisheries Cambodia	10.9
Capture fisheries Lao PDR	-0.9
Capture fisheries Thailand	1.2
Capture fisheries Viet Nam	-3.9

Some assumptions are made:

- aquaculture production in Viet Nam and Thailand cannot grow beyond 2 million tonnes a year, because of i) market pricing making fish production less valuable when production doubles, ii) space available, and iii) risk of diseases at very high production levels;
- capture fish yield in Cambodia cannot go beyond 600,000 tonnes (record annual yield so far has been 421,000 tonnes) because 2 million tonnes of fish caught basinwide corresponds to the maximum estimate accepted (and to a baseline situation, in good environmental conditions) and Cambodia harvests approximately a third of this total biomass (section 1.2.)

Under these assumptions, the fish production expected by 2025 is illustrated in Figure 32.

Figure 32: Status of fisheries and aquaculture production predicted on the basis of the growth rate experienced since 2000.

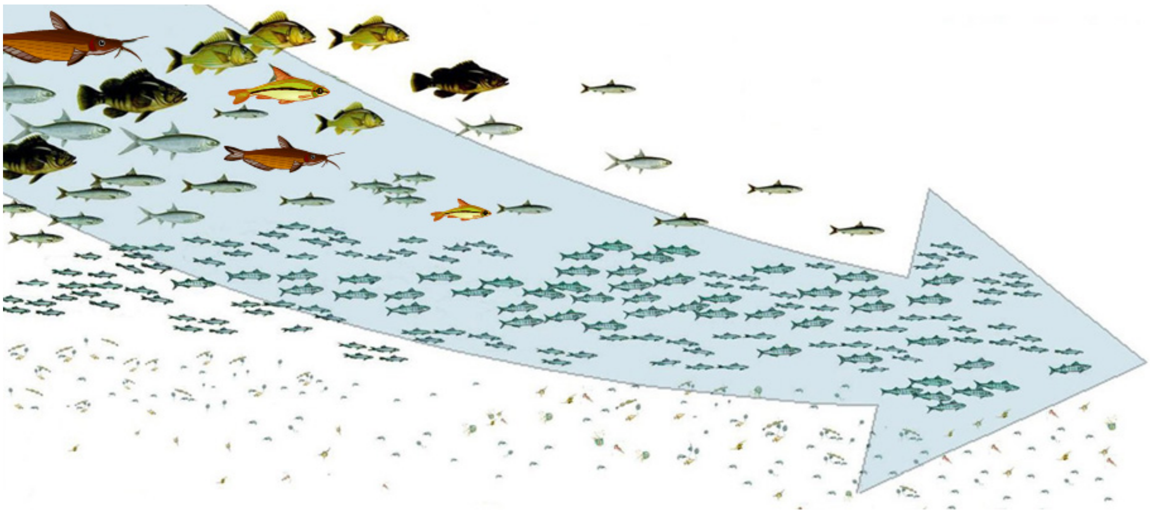


Conclusions:

If the average growth rate of the past 7 years is sustained, Viet Nam is expected to reach a plateau in aquaculture production (an arbitrary 2 million tonnes a year) a few years from now, while Thailand would reach the same plateau around 2020. At the same period aquaculture production in Cambodia and Lao PDR would reach around 200,000 and 300,000 tonnes respectively. As for capture fisheries, Cambodia would reach a plateau (an arbitrary 600,000 tonnes) a few years from now, while the catch in the three other countries would remain steady and close to their current levels. These predictions are of course very hypothetical since they depend completely on economic and governance factors currently not accounted for.

Two qualitative predictions can also be made about capture fisheries: i) a progressive reduction over years of the size and quality of fish harvested, and ii) an increased variability and unpredictability of catches from year to year. The first trend, due to the progressive disappearance of big species particularly targeted by fishers, corresponds to the process of "fishing down food webs" (Pauly *et al.* 1998) and has already been described in the case of Mekong fisheries by Van Zalinge *et al.* in 2001; it is largely confirmed by fishermen. The second trend is the consequence of the first one: big species that live several years and are not very sensitive to annual hydrological variability are replaced by small opportunistic species whose abundance is largely driven by the annual flood pattern, as they grow quickly and die young. This will create a boom-and-bust cycle, with years of high abundance followed by years of shortage.

Figure 33: Fishing down food webs, or the progressive replacement, by intensive fishing, of large long-life species by small short-life species.



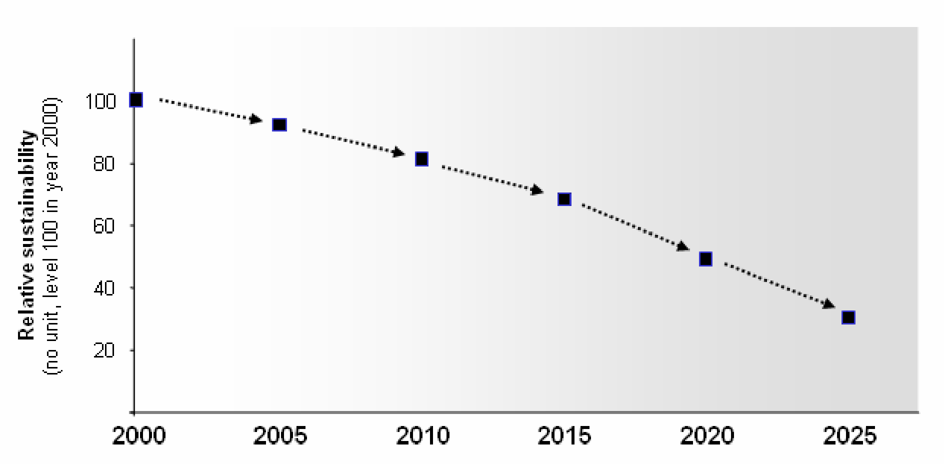
Since accurate predictions cannot be made based on growth rates only, we detail below a more detailed semi-quantitative approach for capture fisheries. This approach integrates the BDP2 "Definite future" scenario for 2015.

This prediction of trends is based on the factors driving fish catch; these factors are the flood level, the flood duration, the flood timing, the presence and nature of flooded vegetation, the number of built structures reducing hydrological connectivity, the availability of refuges, the number of fishers and the fishing intensity (i.e. fish mortality rate due to the evolution of gears).

Trends are expressed by a number (-2 for strong decrease, -1 for moderate decrease, 0 if unchanged, +1 for moderate increase, +2 for strong increase) and a brief justification; then each factor is given a weight depending on its impact on the sustainability of the catch (1 if small, 2 if moderate, 3 if important). Ultimately for each factor the trend and the weight are multiplied, and the resulting number is a number of units expressing the impact on fish catch. For each period of five years between 2000 and 2025 all units are summed; the sum is a number expressing, in relative terms, the overall trend related to the fish catch. The result of this process is presented in Figure 34.

Thus, the overview, assuming a level 100 in 2000, results in the conclusion that there has been a loss – quantified in relative units – of sustainability between 2000 and 2005, and another loss between 2005 and 2010. This leads to the prediction, in the case of the definite future scenario, of a progressive erosion of sustainability over the next 15 years, for the reasons detailed in the table. In 2025 and in absence of mainstream dams, the prospects of sustainability of Mekong fisheries would be approximately a third of what they are now, for a combination of reasons pertaining to fishing pressure, dams existing and under construction on tributaries, and changes in the floodplain environment.

Figure 34: Trend in sustainability of Mekong fisheries. Figure based onTable 43, with a baseline in 2000 (level 100).



1.6.3 AQUACULTURE AS A REPLACEMENT FOR CAPTURE FISHERIES?

The above results show that the production of capture fisheries is exceptionally high and is not declining (the apparent decline in catch per unit of effort being attributed to an increase in population and fishing effort rather than to a decrease in biomass harvested). However, in some discourses the decline of capture fisheries is already framed in relation to dam construction basinwide (Bush and Hirsch 2005, Friend *et al.* 2009), and aquaculture is presented as a means of replacing the losses of capture fisheries. Although this strategy is not part of official policies in the Mekong countries, it is recurrently mentioned in multiple reports, EIAs, discussions and fora.

Replacing capture fisheries production by aquaculture production is not realistic, for several reasons detailed below.

• As currently practiced, an unclear but large proportion of the aquaculture sector depends on capture fisheries for feed. According to Nuov and Nandeesha (1993), 4 kg of fresh low value fish are needed as feed during the fishing season to produce one kilogram of cage culture fish. The use of inland wild fish as aquafeed is not significant in Northern Thailand and Lao PDR, but very substantial in Cambodia and Viet Nam (FAO 2005). In Viet Nam, farm-made feed uses on average 13.6% of freshwater fish and 86% of marine species (FAO 2005). The demand for capture fish creates a competition between the aquaculture sector and rural communities: in Cambodia, 16% of low value fish is used for aquaculture and 84% for human consumption (So *et al.* 2007); this competition led to the ban of snakehead culture in Cambodia in 2004. However, at the scale of the Lower Mekong Basin a precise assessment of the role of low value capture fish versus imported pellet feed in the aquaculture sector remains to be done.

• Producing aquaculture fish is much more costly than capturing wild fish (although the market price of capture fish can be higher because wild fish is favored by consumers). From an all-inclusive economic viewpoint, the cost of one tonne of fish is much lower in the fisheries sector than in the aquaculture sector, since capture fishes are grown at almost no cost (no hatcheries, no installations, no feed, no maintenance, only the cost of gears and the fishers' time).

Table 43: Trends in fish catch defined and predicted for the 2000-2005 period.

	2000-2005				2005-2010				2010-2015				2015-2020				2020-2025			
	Trend	Reason	Weight	Impact	Trend	Reason	Weight	Impact	Trend	Reason	Weight	Impact	Trend	Reason	Weight	Impact	Trend	Reason	Weight	Impact
Flood level	0	Flow close to baseline	3	0	0	Flow close to baseline	3	0	0	Beginning of a reduction of flood level	3	0	-1	Progressive reduction of flood level	3	-3	-1	Flood level reduced by 15% in northenn Laos, down to -3% in Vietnam	3	-3
Flood duration	0	Flow close to baseline	2	0	0	Flow close to baseline	2	0	0	Beginning of a small change in duration	2	0	-1	Modelling predicts a small shortening (5-10%) of duration	2	-2	-1	Modelling predicts a small shortening (5-10%) of duration	2	-2
Flood timing	0	Flow close to baseline	1	0	0	Flow close to baseline	1	0	0	Flow close to baseline	1	0	0	Modelling predicts a marginal change (a few days) in timing	1	0	0	Modelling predicts a marginal change (a few days) in timing	1	0
Flooded vegetation	-1	Increased deforestation for rice cultivation	1	-1	-1	Increased deforestation for rice cultivation	1	-1	-1	Deforestation, first irrigation schemes (pollutants)	1	-1	-2	Deforestation, more irrigation schemes (pollutants)	1	-2	-2	Deforestation, more irrigation schemes (pollutants)	1	-2
Built structures	0	No major infrastructure development	3	0	-1	More floodplain roads and dykes	3	-3	-1	More floodplain roads and dykes	3	-3	-2	More floodplain roads and dykes, more dams; reservoirs won't compensate	3	-6	-2	More floodplain roads and dykes, more dams	3	-6
Refuges	-1	More pumping in floodplains, deep pools unchanged	2	-2	-1	Systematic pumping in floodplains, deep pools unchanged	2	-2	-2	Systematic pumping in floodplains, deep pools unchanged	2	-4	-2	Systematic pumping in floodplains, sediments in deep pools because of reduced flushes	2	-4	-2	Systematic pumping in floodplains, deep pools unchanged	2	-4
Number of fishers	1	Population growth, more demand	3	-3	1	More demand, economic crisis, women involved	3	-3	1	More population but more urban alternatives; slight augmentation	3	-3	0	More urban alternatives; CPUE decreasing	3	0	0	More urban alternatives; more agriculture; CPUE bad	3	0
Fishing intensity (technology)	1	Gear size increases and mesh size decreases progressively	2	-2	1	Gear size increases and mesh size decreases progressively	2	-2	1	Gear size increases and mesh size decreases progressively	2	-2	1	Gear size increases and mesh size decreases progressively	2	-2	1	Gear size increases and mesh size decreases progressively	2	-2
Overall trend (arbitrary units):		**-8**				**-11**				**-13**				**-16**				**-16**		

• Intensive aquaculture does not contribute much to food security in rural areas (although this sector provides employment and income to workers) and extensive aquaculture is not very productive. Intensive aquaculture (e.g. catfish production in the delta) is very technical, usually based on high value carnivorous species, and accessible only to better-off individuals having land, access to information and sufficient capital; this production mode targets the export market and generates income. More generally intensive aquaculture has a history of environmental impacts and social conflicts (Bush 2008). Extensive aquaculture on the contrary is based on herbivorous or omnivorous species; it is neither capital nor technology intensive and, like capture fisheries, it does provide substantial income at the household or village level and a contribution to food security. However, this system, which could locally replace the loss of capture fish, is not very productive for several reasons: no or few inputs are used; the supply of fingerlings is always a bottleneck; and without genetic maintenance, it tends to lose 20-40% productivity over a few years (Brummett and Ponzoni 2009). In fact, studies have shown that technically a higher productivity is possible, through the use of manures or farm wastes for instance (Prein and Ahmed 2000, IIRR *et al*. 2001) but it is mainly socio-economic and institutional reasons (e.g. land availability, access to quality fry, tenure issues) that have impeded aquaculture development in some of the LMB countries (Phillips 2002, Lebel *et al*. in press).

• Under current practices, a significant proportion of the aquaculture sector depends on capture fisheries for fingerlings. Viet Nam being an exception in terms of aquaculture infrastructure and technology, in the rest of the basin cage fish aquaculture remains largely dependent on fish seed caught in the wild. In Cambodia for instance, in 2001 the culture of 19 species out of 33 (57%) was based on supply of fingerlings from the wild (DoF 2001). More generally the level of dependency of the artisanal aquaculture sector on wild fry in unknown, and this is an area where research is needed.

In Viet Nam the catfish production has recently soared, but this is largely an export commodity (although increasing living standards progressively make this commodity more affordable for the local market). Given the considerable investment in promoting aquaculture development in Cambodia, Lao PDR and Thailand over the last decades, it is difficult to conceive, in the years to come, development of the extensive aquaculture sector leading to production able to replace losses from the fisheries sector. In Cambodia for instance, at a growth rate of 20% per year, it would take 27 years for aquaculture to produce as much as local fisheries. Thus aquaculture can *ameliorate* fish supply from capture fisheries but cannot replace it.

ASSESSMENT OF IMPACTS OF MAINSTREAM DAMS ON FISHERIES

2 FISHERIES IMPACT ASSESSMENT

2.1 CLUSTERS OF MAINSTREAM DAMS

The superimposition of maps of migration zones (see Fisheries Baseline Assessment) and of mainstream dam development leads to the identification of three clusters of potential dams of significance to fish production: i) Upper Mekong, from China down to Vientiane (mountainous part of the river, altitude > 200 masl); ii) Middle Mekong, from Vientiane down to Pakse (Khorat plateau; altitude between 100 and 200 masl); iii) from Pakse down to the sea (extensive wetlands and floodplains; altitude <100 masl). The first cluster includes all Chinese dams and 6 projects in the Lower Mekong Basin (from Pak Beng to Pakchom); the second cluster includes 2 dam projects in the mainstem (Ban Koum and Latsua); the last cluster includes Don Sahong and the two Cambodian mainstream projects.

This clustering corresponds largely to the BDP2 scenarios for 2015 and 2030 (BDP 2010): “2015 definite future” (no mainstream dams), “2030 w/o MS” (no mainstream dams), “2030 w. LMD” (only 6 Lao mainstream dams); “2030 w/o CMD” (no Cambodian mainstream dams, 9 mainstream dams upstream of Cambodia) and “2030 20 year plan” (11 mainstream dams).

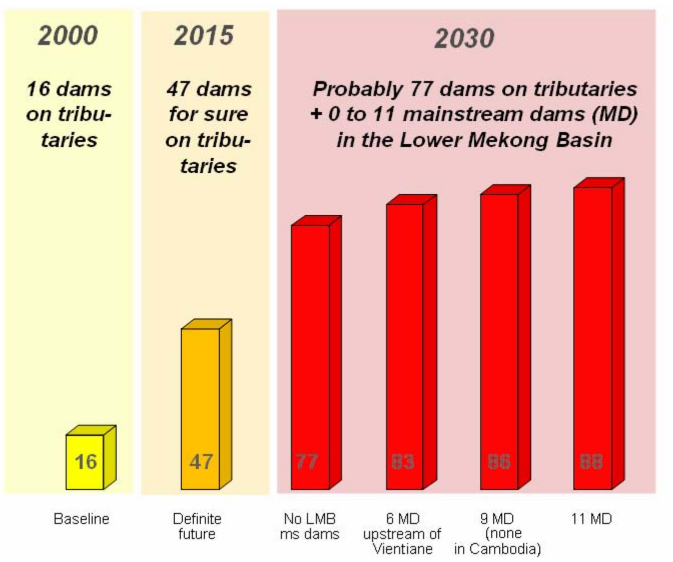
Table 43: Clusters of dams considered in the analysis of fisheries impacts.

Area	Cluster	Fish migration zone	Dam	Installed capacity (MW)	Operation (?)	Reservoir area (km^2)	Length (m)	Height (m)
Upper Mekong	Up-stream cluster	Upper migration zone	Gonguoqiao	750	-	3	-	130
			Xiaowan	4,200	2010	37.14	-	300
			Manwan	1,500	1993	4.15	-	126
			Dachaoshan	1,350	2003	8	-	110
			Nuoshadu	5,500	2017	45	-	254
			Jinhong	1,500	2009	5.11	-	118
			Ganlanba	750	-	0	-	-
			Mengsong	400	-	0.58	-	-
Lower Mekong			Pak Beng	1,230	2016	87	943	76
			Luang Prabang	1,410	2016	90	1,106	68
			Xayaburi	1,260	2016	49	810	32
			Pak Lay	1,320	2016	108	630	35
			Sanakham	700	2016	81	1,144	38
			Pakchom	1,079	2017	68	1,200	55
	Middle cluster	Middle migration zone	Ban Koum	1,872	2017	40	780	53
			Latsua	686	2018	13	1,300	27
	Down-stream cluster	Lower migration zone	Don Sahong	240	2013	2.9	720	10.6
			Stung Treng	980	-	211	10,884	22
			Sambor	2,600	2020	620	18,002	56

Figure 35: Clusters of dams considered in the analysis of fisheries impacts.

These mainstream dams are to be considered in relation to development scenarios; these scenarios, developed by the MRC BDP2, are summarized below:

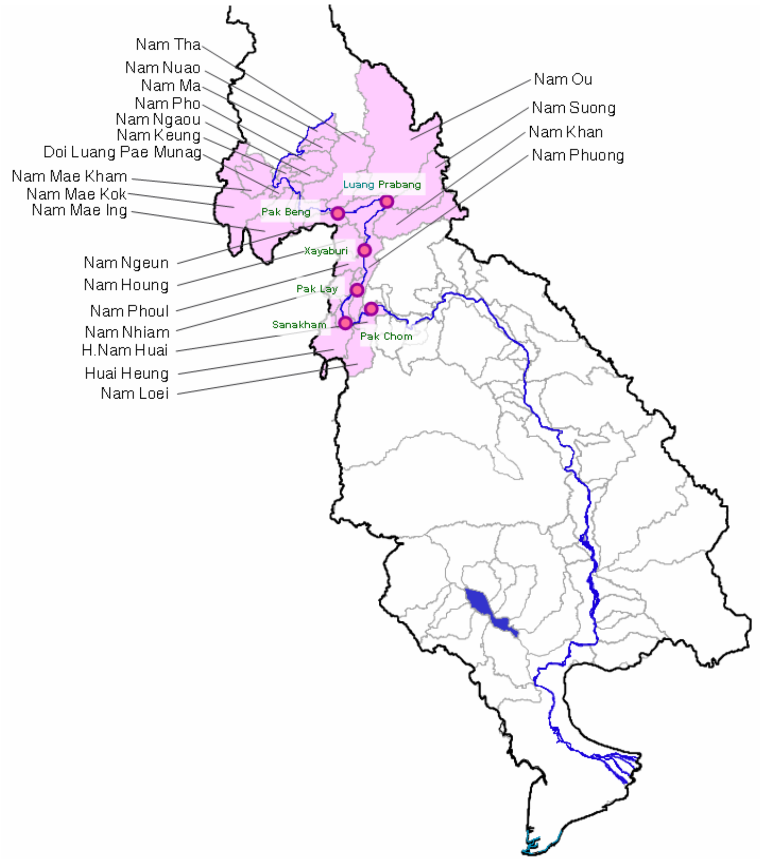
Figure 36: Mainstream dams and development scenarios (BDP2 scenarios dated 21-12-2009).



2.1.1 UPSTREAM CLUSTER OF DAMS

The upstream zone is mostly within China, and contains 262 species, including 22% of endemics (see Fisheries Baseline Assessment). The analysis below focuses more specifically on the IBFM Zone 2 (Chiang Saen to Vientiane). This zone is bounded by the Chinese border (upstream) and the Pak Chom dam (downstream), and corresponds to the upstream cluster of dams. In this zone the barrier effect on migrations will apply to 36 sub-basins[20], in particular the large Nam Ou, Nam Mae Kok, Nam Tha, and Nam Khan basins.

Figure 37: Main river basins in the upstream cluster zone.

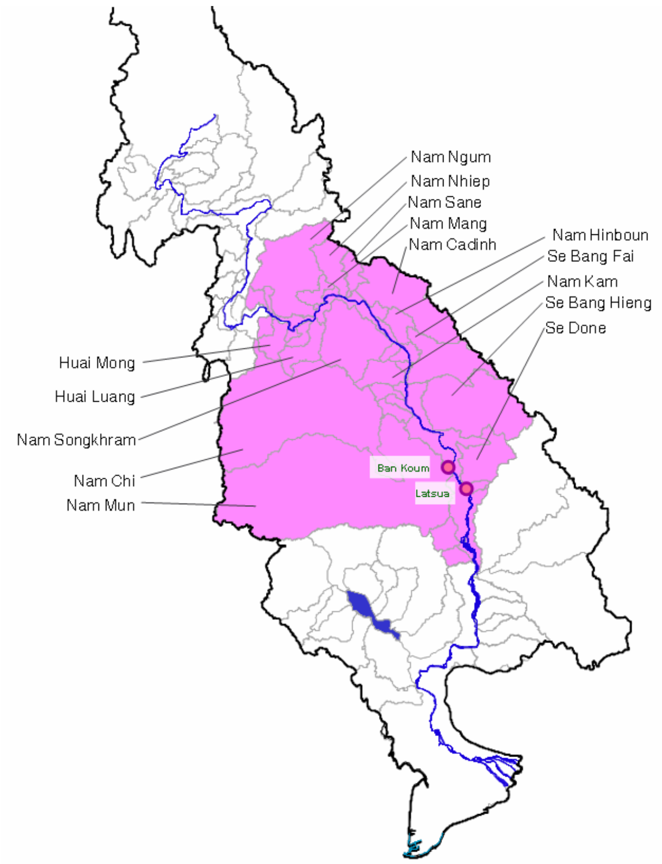


[20] Nam Ou: 26,033 km²; Nam Mae Kok: 10,701 km²; Nam Tha: 89,18 km²; Nam Khan: 7,490 km²; Nam Mae Ing: 7,267 km²; Nam Suong: 6,578 km²; Nam Heung: 4,901 km²; Nam Phuong: 4,139 km²; Nam Mae Kham: 4,079 km²; Nam Loei: 4,012 km²; Nam Houng: 2,872 km²; Nam Pho: 2,855 km²; Nam Sing: 2,681 km²; Nam Nuao: 2,287 km²; Nam Beng: 2,131 km²; Nam Phoul: 2,095 km²; Nam Nhiam: 1,990 km²; Nam Ngeun: 1,819 km²; H.Nam Huai: 1,755 km²; Nam Tam: 1,548 km²; Nam Khop: 1,521 km²; Nam Ngaou: 1,495 km²; Nam Ma: 1,141 km²; Nam Mi: 1,032 km²; Nam Nago: 1,008 km²; B.Khai San: 778 km²; Doi Luang Pae Muang: 688 km²; Nam Phone: 664 km²; Nam Keung: 633 km²; Nam Kai: 602 km²; Phu Luong Yot Huai Dua: 491 km²; Nam Ngam: 489 km²; Muang Liep: 488 km²; Nam Mae Ngao: 485 km²; Nam Nhah: 316 km²; B.Nam Song: 138 km².

2.1.2 MIDDLE CLUSTER OF DAMS

The middle migration zone is characterized by 386 species and 29% of endemics (see Fisheries Baseline Assessment). This zone corresponds to the middle cluster of dams (Pak Chom dam upstream, Don Sahong dam downstream) and is composed of 44 sub-basins[21], in particular Nam Mun, Nam Chi, Se Bang Hieng, Nam Ngum, Nam Cadinh, Songkhram, Se Bang Fai and Se Done basins.

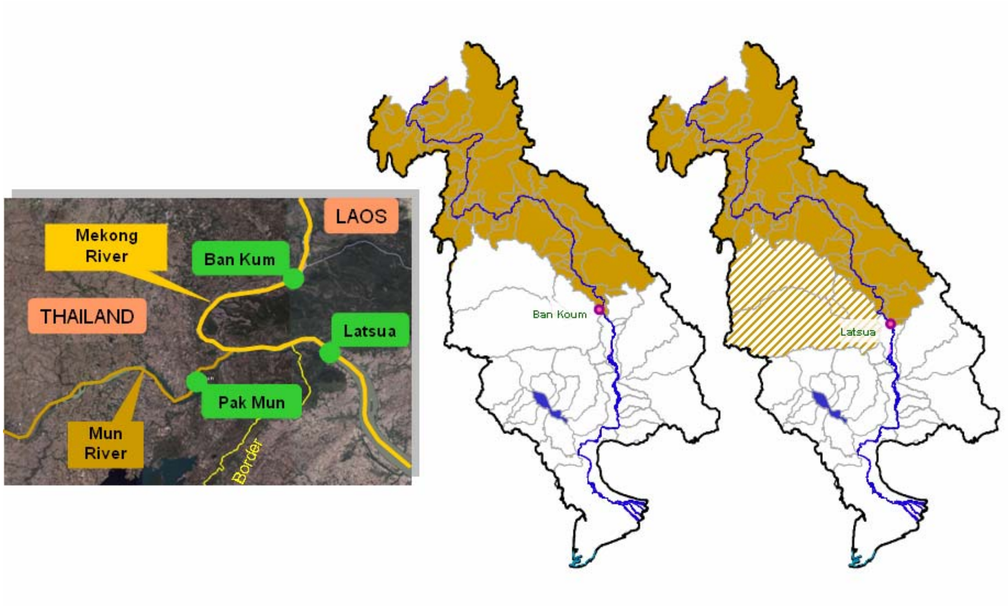
Figure 38: Main river basins in the middle cluster zone.



The two dams of the middle cluster will have very different impacts on fish, since Latsua and Ban Kum dams are located upstream and downstream, respectively, of the mouth of the Pak Mun tributary (Figure 39). With an area of 119,707 km^2, the Mun/Chi River is the biggest hydrological basin the Mekong.

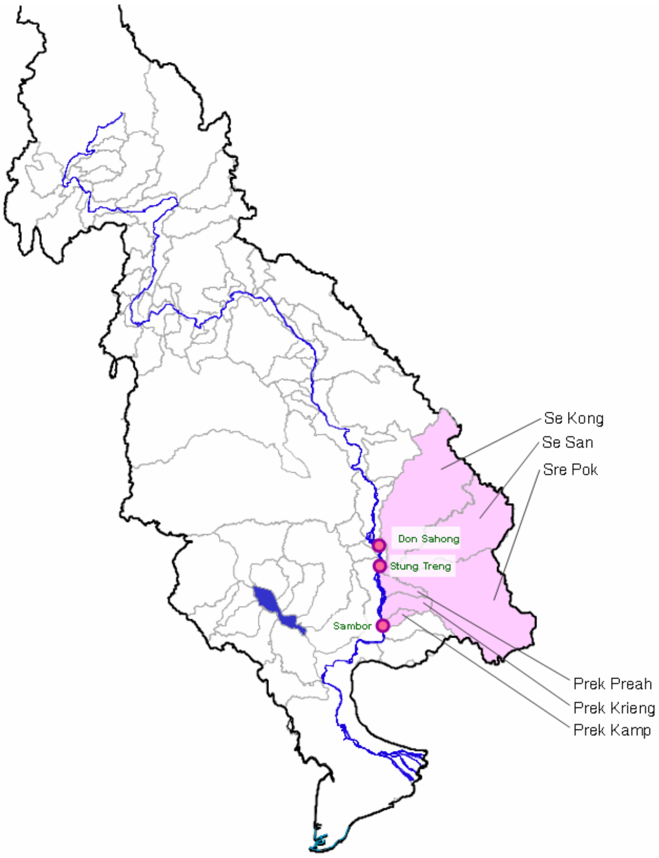
[21] Nam Mun: 70,574 km^2; Nam Chi: 49,133 km^2; Se Bang Hieng: 19,958 km^2; Nam Ngum: 16,906 km^2; Nam Cadinh: 14,822 km^2; Nam Songkhram: 13,123 km^2; Se Bang Fai: 10,407 km^2; Se Done: 7,229 km^2; Nam Nhiep: 4,577 km^2; Huai Luang: 4,090 km^2; Huai Khamouan: 3,762 km^2; Nam Kam: 3,495 km^2; H.Bang Koi: 3,313 km^2; Se Bang Nouan: 3,048 km^2; Huai Mong: 2,700 km^2; Huai Tomo: 2,611 km^2; Nam Hinboun: 2,529 km^2; Huai Som Pak: 2,516 km^2; H.Bang Bot: 2,402 km^2; Tonle Repon: 2,379 km^2; Nam Sane: 2,226 km^2; Nam Mang: 1,836 km^2; Huai Bang I: 1,496 km^2; O Talas: 1,448 km^2; Huai Bang Sai: 1,367 km^2; Nam Sang: 1,290 km^2; Nam Suai: 1,247 km^2; Huai Nam Som: 1,072 km^2; H.Ma Hiao: 990 km^2; Nam Mang Ngai: 944 km^2; Huai Bang Haak: 938 km^2; Nam Thon: 838 km^2; Huai Muk: 792 km^2; Huai Thuai: 739 km^2; Huai Bang Lieng: 695 km^2; Huai Ho: 691 km^2; Hoaag Hua: 626 km^2; Nam Ton: 587 km^2; H. Khok: 538 km^2; Prek Mun: 476 km^2; Nam Kadun: 456 km^2; Nam Thong: 455 km^2; H.Sophay: 186 km^2; Phu Pa Huak: 132 km^2

Figure 39: Location of Ban Kum and Latsua dams and barrier effect on the Mun/Chi sub-basins.



2.1.3 DOWNSTREAM CLUSTER OF DAMS

Figure 40: Main river basins in the middle cluster zone.



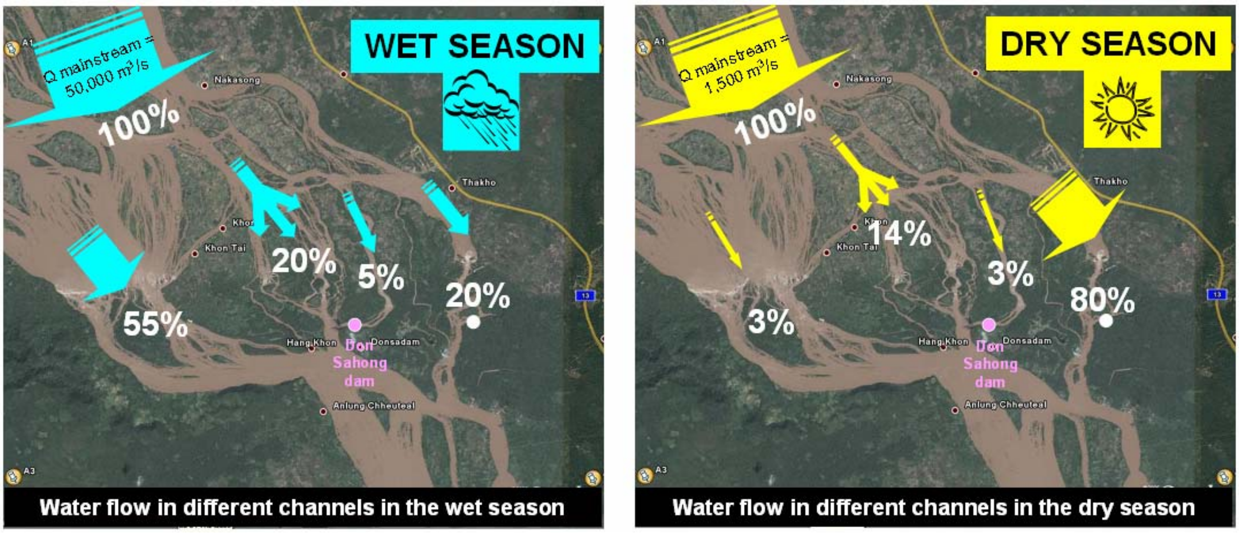
The lower migration zone contains 669 species and 14% of endemics (see Fisheries Baseline Assessment). This zone corresponds to the downstream cluster of dams (Don Sahong dam upstream, Sambor dam downstream) and is composed of 24 sub-basins[22]. However, in this lower migration zone only six sub-basins will be subject to the barrier effect of mainstream dams: Se Kong, Se San, Sre Pok, Prek Preah, Prek Krieng, and Prek Kamp basins. The Sekong-Sesan-Srepok system, converging upstream of Stung Treng, is the second largest hydrological sub-basin in the Mekong after the Mun/Chi system and has an area of 78648 km^2. The area downstream of Sambor dam, including the delta and the Tonle Sap sub-basin, is not affected by the barrier effect, only by the hydrological modifications induced by these dams.

CASE OF THE DON SAHONG DAM:

This project has been criticized as potentially having an impact on regional fishery resources by blocking fish migrations in Hou Sahong, the only channel passable by fish migrating through Khone Falls in the dry season. The SEA team recently obtained a copy of the Feasibility Study of the Don Sahong dam project, and copies of the public consultations of the Thakho hydropower project, whose site is also located in Khone Falls, less than 4 km away from Don Sahong. The comparative analysis of these documents revealed some new elements relevant to this fisheries impact assessment:

• Hydrological analyses presented by the developer of the Thakho project highlighted the fact that very little water flows through Hou Sahong channel (3 to 5% of the Mekong flow depending on the season):

Figure 41: Water flows in Khone Falls in wet and dry season.



Source: Thakho project feasibility study.

• The Don Sahong feasibility study confirms the insufficient natural level of water in Hou Sahong channel[23] to operate the dam at the expected level of 360 MW. As a consequence **the Don Sahong project made plans for excavation upstream of Hou Sahong, in order to divert and attract water naturally flowing in the other channels**. This excavation would be 5-6 meters deep and 1,200 to 1,800 meters long.

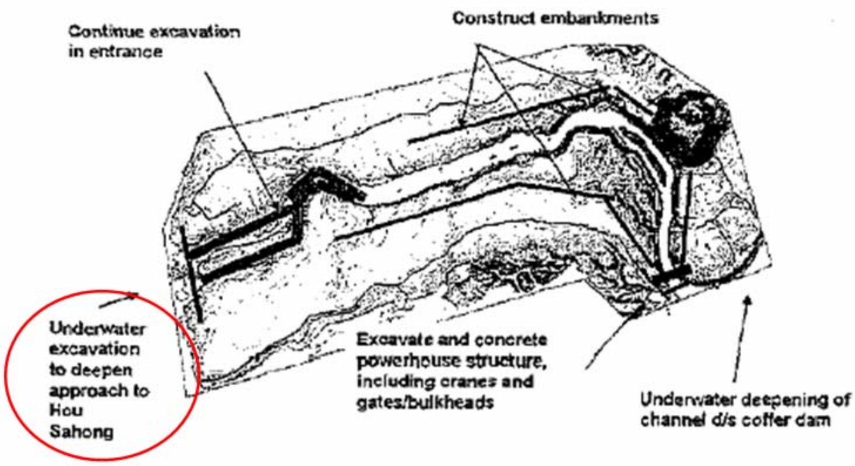
> *In the low season with a water level at the entrance to Hou Sahong of RL 71.0, say, the existing channel might have a discharge of 250 m3/s or even less. Clearly, therefore, it would be necessary to introduce appreciable changes to the entrance geometry (including lowering of the channel bed over hundreds of metres) to achieve the major increases in discharge in the Hou Sahong. (Don Sahong feasibility study report, page 3-11)*

[22] Delta: 48,235 km^2; Sre Pok: 30,942 km^2; Se Kong: 28,815 km^2; Se San: 18,888 km^2; Stung Sen: 16,360 km^2; Stung Mongkol Borey: 14,966 km^2; Stung Sreng: 9,986 km^2; Siem Bok: 8,851 km^2; Stung Chinit: 8,237 km^2; Stung Baribo: 7,154 km^2; Prek Thnot: 6,124 km^2; Stung Pursat: 5,965 km^2; Prek Chhlong: 5,957 km^2; Prek Te: 4,364 km^2; Stung Staung: 4,357 km^2; Stung Battambang: 3,708 km^2; Stung Dauntri: 3,696 km^2; Stung Siem Reap: 3,619 km^2; Prek Krieng: 3,332 km^2; Tonle Sap: 2,744 km^2; Stung Chikreng: 2,714 km^2; Prek Preah: 2,400 km^2; Stung Sangker: 2,344 km^2; Prek Kamp: 1,142 km^2

[23] "hou" = "channel" in Lao language

In its natural state, the high bed levels in the upper reaches of the Hou Sahong would restrict flow into the channel, particularly in the low flow periods, and the power station would not be able to operate at its design capacity. To overcome this, the bed of the Hou Sahong will be excavated a maximum of 5 m deep for a length of about 2 km and there will also be a similar depth of excavation into the Mekong around the entrance to the Hou Sahong. (Don Sahong Environmental Impact Assessment, page 2-3)

Figure 42: Earthworks planned upstream of Hou Sahong by the Don Sahong project (Don Sahong feasibility study report, figure 12-1, sheet 2).



• These earthworks would generate more than 1.9 million cubic meters of excavation material:

> *The excavation will be carried out in the following stages: Stage 1 (estimated volume of 1,600,000 cu. m.); Stage 2 (estimated volume of 300,000 cu. m); Stage 3 (estimated volume of 60,000 cu. m.) (Don Sahong feasibility study report, page 12-10)* [1.9 million cubic meters of excavation material represent about 95,000 truckloads. A fraction of this material will be used for the construction of the dam and embankments but] *there will be a requirement to dispose of more than a million cubic meters of surplus rock from these excavations. (Don Sahong Environmental Impact Assessment, page 2-98).*

As a comparison, one million cubic meters represent approximately a height of 150m of excavation material spread over the surface area of the Vientiane airport building (6,500 m^2).

• At the excavation site, the river bed is made of hard rock. This is confirmed by geological surveys of the Thakho project. Excavating such hard riverbed implies the use of dynamite or explosives.

> *At the upstream entrance to the Hou Sahong channel, a wide bar of massive rhyolite is present as seen on the aerial photographs. This also strikes east-west across the entrance and dips to the south. Drilling has confirmed its massive and hard nature. (Don Sahong Environmental Impact Assessment, page 4-3).*

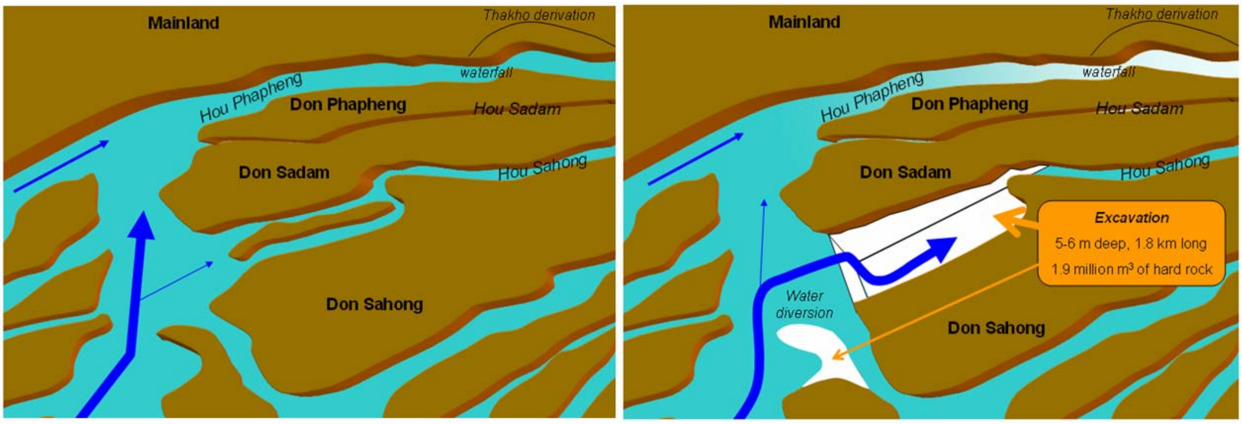
• The consequence of these works will be a diversion of water from the other channels into Hou Sahong.

> *If it is as high as 1,500 m3/s (for RL 71 at the entrance to Hou Sahong), clearly diversion of a discharge of a similar magnitude into Hou Sahong would i) account for virtually all of the main river discharge; ii) reduce the discharge over Phapheng Falls to a very low value (Don Sahong feasibility study report, page 3-11).*

> *While it is recognized that the Khone Phapheng waterfall is best viewed at lower flows, the amount of reduction in low season flows, the peak tourism months, is critical. (Don Sahong Environmental Impact Assessment, page 4-6).*

The figure below illustrates approximately the intended earthworks at the mouth of Hou Sahong:

Figure 43: Water diversion and earthworks planned by the Don Sahong project.



As a part of its assessment of impacts of mainstream dams, this SEA notes that:

- the ecological impact on fisheries and aquatic ecology of blasting and excavating more than 1.9 million cubic meters from the river bed has not been mentioned in the Environmental Impact Assessment of the Don Sahong project;
- the ways to dispose of more than one million cubic meters of excavation material have not been specified;
- the impact of the water diversion planned on the discharge in Hou Phapheng and on Khone Phapheng waterfall has not been detailed. Will the reduced discharge in Hou Phapheng be enough to keep, in the dry season, the visual aspect of a site known as the biggest waterfall in Southeast Asia? Will the reduced discharge in other channels be enough to allow fish migrations and fishing at critical times of the year?
- the impact of the above plans on tourism and downstream areas has not been discussed.

2.1.4 OVERVIEW

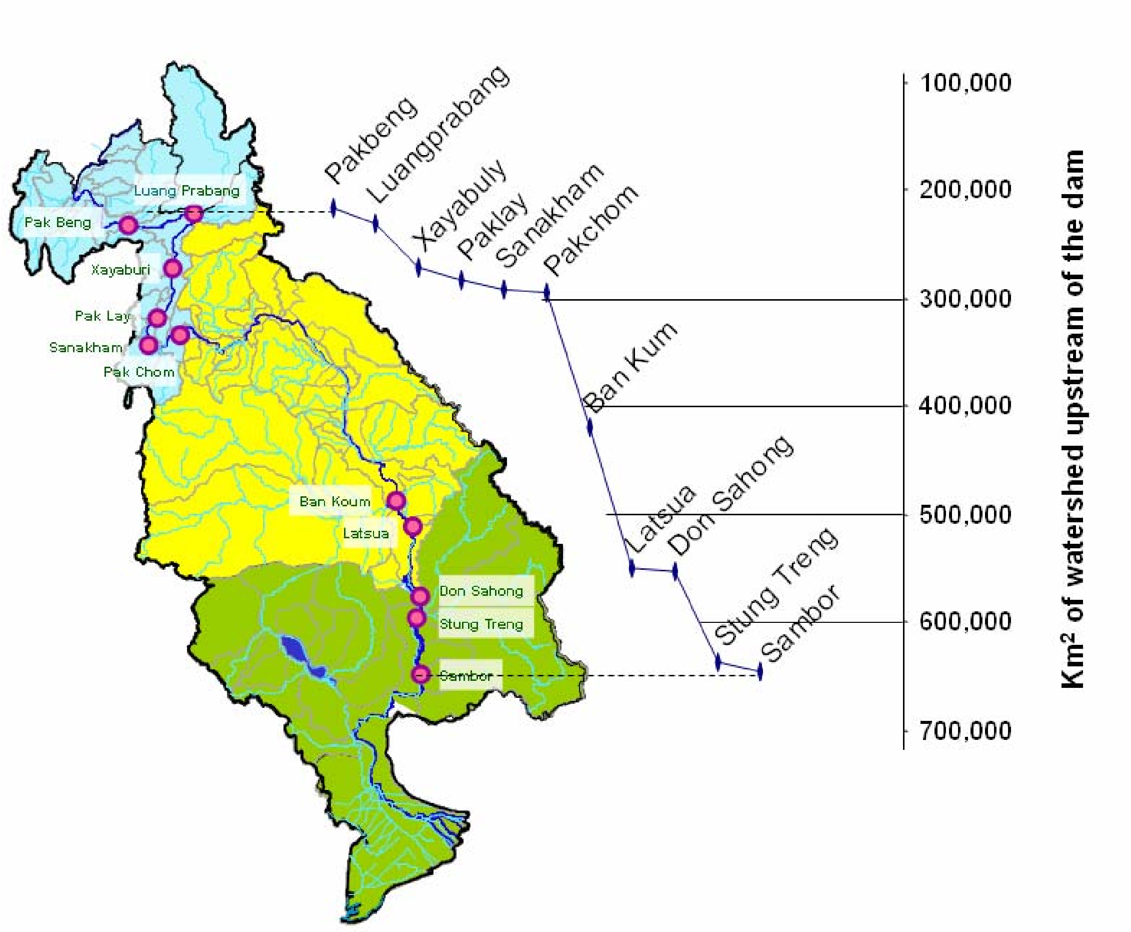
Table 44 shows the proportion of the Lower Mekong watershed located upstream of the dams being considered. This confirms that three dams, namely Ban Kum, Latsua and Stung Treng, have a proportionally greater share of watershed than others.

Table 44: Watershed area upstream of each mainstream dam.

Cluster	Project name	Watershed area upstream (km^2)	% of LMB watershed upstream of the dam
1	Pakbeng	218,000	27.4
1	Luangprabang	230,000	28.9
1	Xayabuly	272,000	34.2
1	Paklay	283,000	35.6
1	Sanakham	292,000	36.7
1	Pakchom	295,500	37.2
2	Ban Kum	418,400	52.6
2	Latsua	550,000	69.2
2	Don Sahong	553,000	69.6
3	Stung Treng	635,000	79.9
3	Sambor	646,000	81.3
	LMB	795,000	

Source: MRC data (BDP2)

Figure 44: Mainstream dams and corresponding upstream watershed area.



In the Mekong Basin long-distance fish migrations occur on a large scale between downstream floodplains and the upstream sections of the Mekong and its tributaries. For this reason the proportion of the upstream section of the Mekong watershed blocked by dam gives an indication of the surface area or habitat that will become inaccessible to migrant fish. BDP2 data indicate the watershed area upstream of each dam; in order to assess the surface area blocked for upstream migrations, dams have been classified by watershed then by river, and *for each river* the area upstream of the dam located most downstream has been kept as the area being blocked for that river. This area was quantified for each basin and for 3 periods of time: 2000 (baseline), 2015 (Definite future) and 2030. For 2030, the scenarios detailed are i) no mainstream dams; ii) 6 mainstream dams in the upstream cluster; iii) no mainstream dams in Cambodia, and iv) 11 mainstream dams (details in ANNEX 1: Dam projects in the BDP2 scenarios and corresponding characteristics). The table below summarizes the findings:

Table 45: Surface area of the Lower Mekong Basin blocked by dams under different scenarios.

	2000		2015		2030	
	S1. Baseline	**Area S1**	**S2. Definite future**	**Area S2**	**S3. No MS dams**	**Area S3**
Nb of dams / km^2 obstructed for migrations	*16*	164,148	*47*	187,695	*77*	296,568
% of LMB obstructed for migrations	20.6		23.6		37.3	
LMB area (km^2) = 795,000			**2030**			
	S4. 6 MS dams in upper LMB	**Area S4**	**S5. No Cam MS dams**	**Area S5**	**S6. All 11 MS dams**	**Area S6**
Nb of dams / km^2 obstructed for migrations	*83*	545,901	*86*	621,998	*88*	646,000
% of LMB obstructed for migrations	68.7		78.2		81.3	
Km^2 obstructed specifically by LMB mainstream dams	S4 - S3 =	249,333	S5-S3 =	325,430	S6 - S3 =	349,432
% of LMB obstructed specifically by mainstream dams	31		41		44	

Sources: Description of BDP2 scenarios dated 21-12-2009

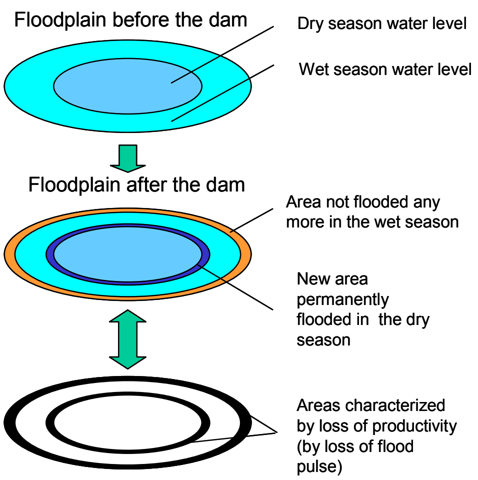
<u>Conclusions</u>: In 2000, 20.6% of the Lower Mekong Basin was already barred by 16 dams and was inaccessible to fish species having to migrate to the upstream parts of the river network. In 2015, this area will have increased by 14% (from 164,000 to 188,000 km^2). In 2030, if 11 mainstream dams are constructed, 81.3% of the watershed will be obstructed and floodplain migratory fish will not be able to migrate further than Kratie (Sambor dam). If no mainstream dams are built in Cambodia, then 78.8% of the basin will not be accessible to long distance migratory fish. If mainstream dam development is limited to the 6 dams of the upstream cluster, then 68.7% of the basin will be barred. If no mainstream dams are built, the surface area inaccessible to long distance migratory fish is reduced to 37.3% of the watershed, despite the presence of 77 other dams on tributaries.

Since many dams on tributaries already exist or are planned, mainstream dams will not be the only cause of the barrier effect on fish migrations. The proportion of the total impact attributable to mainstream dams can be quantified by subtracting the area barred by tributary dams from the overall area barred. These results indicate that the cluster of 6 mainstream dams in upper Lao PDR would obstruct 31% of the migration routes (but not of the migrations themselves), that all LMB mainstream dams would obstruct 44% of the Lower Mekong Basin, and that in the presence of 9 other mainstream dams the Cambodian mainstream dams alone would obstruct only 3% of the basin, because most of the basin area between Sambor and Latsua (5 watersheds including Sekong, Sesan and Srepok watersheds) would already be obstructed by 21 tributary dams.

2.2 HYDROLOGICAL CHANGES FORECASTED IN RELATION TO FISHERIES

The dams planned will bring about a number of hydrological changes of importance for fish: i) flow reduction in the wet season and floodplain area: the Mekong system has the most productive fishery of the world because of its large floodplain and its hydrological variability. If the flow is lower in the wet season, in some places water might not reach the level of the banks and thus not spill over in plains, or not spill as far as before, which would mean a loss of habitat for fish; ii) flow increase in the dry season: some land areas that used to be dry in the dry season will become permanently flooded, and thus will lose the productivity that results from the seasonal inundation (Junk *et al.* 1989). As a consequence, the yearly loss in floodplain habitat and in productivity resulting from dam construction should be computed as the sum of losses in wet *and* in dry season (loss in variability). This corresponds to the surface area that will not be flooded any more in the wet season *plus* the surface area that will be permanently flooded in the dry season (double ring illustrated in Figure 45).

Figure 45: Change in flooding due to dams and loss of productivity. Source: Baran *et al.* in press.



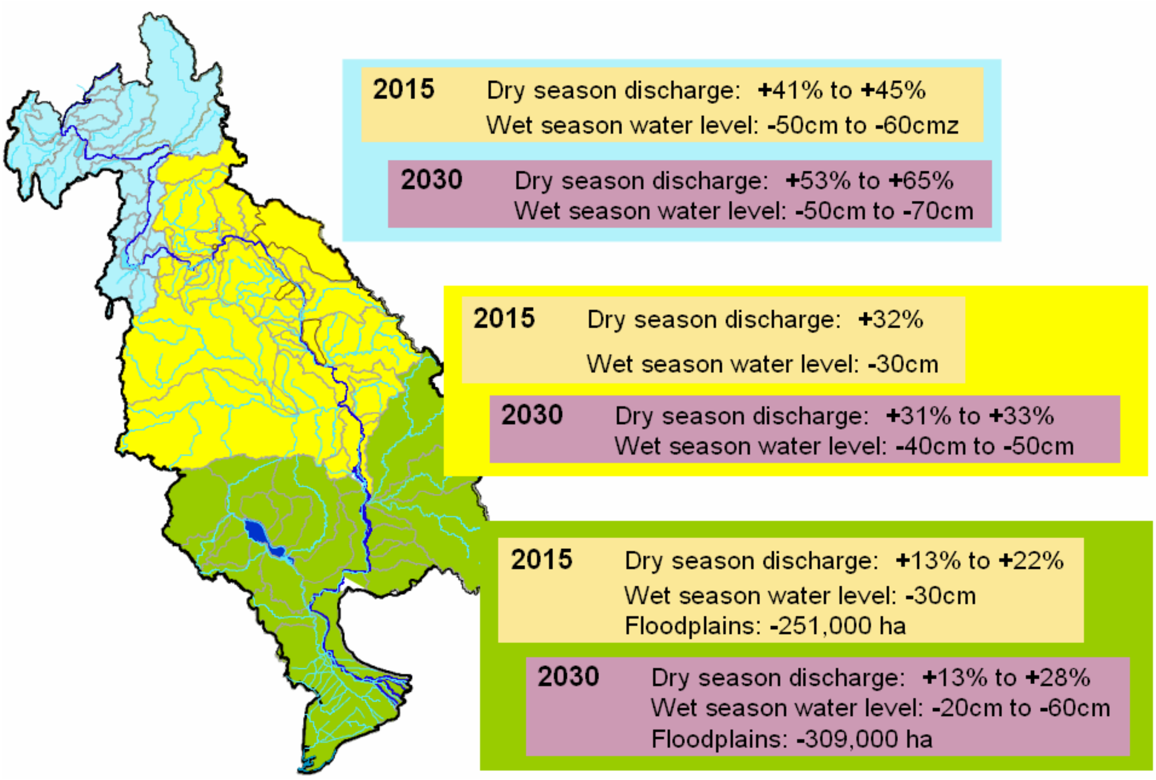
In the past years a number of studies have attempted to quantify these changes. For this SEA the reference predictions used are those of the on-going BDP2 analysis, since they are based on the most updated and accurate set of scenarios. However, we also included, for information, the predictions from three other large modelling studies: i) the *WorldBank* Mekong development scenarios (Podger *et al.* 2004); ii) the *Nam Theun 2* Cumulative Impact Analysis (Norplan and Ecolao 2004); and iii) the *BDP 1* scenarios for strategic planning (MRC 2005b). The results of these respective studies are summarized below for comparison with the BDP2 scenarios. All former studies are characterized by a small number of dams, and thus can only be compared with the BDP2 2015 scenario.

Table 46: Development scenarios in recent hydrological modelling studies

	WorldBank 2004	Nam Theun 2 2004	BDP 1 2005	BDP 2 2009/2010
Scenarios	High development (25 dams basinwide)	2025 (28 dams basinwide)	High development (21 dams basinwide)	2015 Definite future (47 dams basinwide)
				2030 no LMB mainstream dams (77 dams basinwide) 2030 with 6 Lao mainstream dams (83 dams basinwide) 2030 with 9 mainstream dams not in Cambodia (86 dams basinwide) 2030 with 11 mainstream dams (88 dams basinwide)

The hydrological consequences forecasted by the different studies are detailed in the table and figure below. The results from the on-going BDP2 modelling work have been extracted from detailed hydrological forecasts provided, from Technical notes 1, 2 and 4 dated February 2010 and corresponding presentations (www.mrcmekong.org/programmes/bdp/BDP-submissions.asp).

Figure 46: Summary of hydrological changes forecasted by different studies for 5 scenarios.



Conclusions:

In the Definite Future scenario, when compared to the 2000 baseline, BDP2 (technical notes 1 and 2 and presentations dated February 2010) predicts that dry season discharge will increase by 45% in Luang Prabang, 32% in Pakse, 22% in Kratie and 13% in Viet Nam. These estimates are close to estimates from BDP1 and WorldBank studies, within a range of about 10%. This is surprising since the number of dams integrated in the BDP1 and WorldBank studies is only about half of those integrated in the BDP2 studies, which would indicate that an additional 19 to 26 dams in the basin would not make much difference for discharge levels in the dry season. Changes predicted by the Nam Theun 2 study are much more dramatic, with a dry season discharge doubling in Pakse and Kratie. In the wet season, the variable common to all studies is the water level, not discharge. According to BDP2, wet season water level is expected to be reduced by 30 to 60 cm maximum, depending on places. Previous studies tend to forecast that the reduction of water level will be higher by 10 to 90 cm.

None of the former studies analyzed scenarios for 2030, and thus cannot be compared to the BDP2 study. BDP2 forecasts that twenty years from now, in the absence of mainstream dams, discharge in the dry season will be between 13% and 65% higher than in 2000 (higher values upstream). With 6, 9 or 11 mainstream dams in the Lower Mekong Basin the range will be approximately the same (13% to 58%) because most of these mainstream dams are considered run-of-the-river. The same applies to water level in the wet season, with a decrease of between 20 cm and 70 cm maximum depending on the location (more losses upstream), for all scenarios.

The latest BDP2 scenarios for 2015 predict a loss of 1,040 km^2 of floodplains in Cambodia compared to the situation in 2000, and of 2,510 km^2 for the whole Mekong Basin (-5%). In 2030, with 11 mainstream dams, a total loss of 1,420 km^2 and 3,090 km^2 is forecasted in Cambodia and in the whole basin respectively (-7%). It is not clear whether the loss of floodplain area forecasted by the BDP2, which seems relatively limited (7% loss maximum after the total number of dams has increased from 16 dams in 2000 to 88 in the 2030 11 MD scenario), includes the double ring detailed above.

Table 47: Detailed hydrological changes forecasted by different studies for 5 scenarios.

	Definite Future 2015			20Y w/o MD 2030, no mainstream dams		20Y with LMD 2030, 6 mainstream dams			20Y no CMD 2030, 9 mainstream dams			20Y 2030, 11 mainstream dams		
	Discharge in dry season (% change from baseline)	**WL in wet season** (change from baseline in m)	**FA, wet season** (% change from baseline)	**Discharge, dry season** (% change from baseline)	**WL, wet season** (change from baseline in m)	**Discharge in dry season** (% change from baseline)	**WL, wet season** (change from baseline in m)	**FA, wet season** (% change from baseline)	**Discharge, dry season** (% change from baseline)	**WL, wet season** (change from baseline in m)	**FA ,wet season** (% change from baseline)	**Discharge in dry season** (% change from baseline)	**WL in wet season** (change from baseline in m)	**FA in wet season** (% change from baseline)
Luang Prabang	**BDP1:** +55 **BDP2:** +45.4	**BDP1:** -1.5 **BDP2:** -0.6		**BDP2:** +65.2	**BDP2:** 0	**BDP2:** +58.3	**BDP2:** -0.7		**BDP2:** 59.7	**BDP2:** ?		**BDP2:** +59.7	**BDP2:** -0.7	
Nong Khai/ Vientiane	**WB:** +47 to 73 **BDP2:** +41.4	**WB:** -0.5 to 1.0 **BDP2:** -0.5		**BDP2:** +52.7	**BDP2:** -0.5	**BDP2:** +54	**BDP2:** -0.5		**BDP2:** 54.8	**BDP2:** ?		**BDP2:** +55.2	**BDP2:** -0.5	
Savannakhet/ Pakse	**WB:** +30 to 52 **NT2:** +135 **BDP1:** +33 **BDP2:** +31.6	**WB:** -0.4 to 0.7 **NT2:** -1.6 **BDP1:** -0.7 **BDP2:** -0.3		**BDP2:** +31	**BDP2:** -0.4	**BDP2:** +32.1	**BDP2:** -0.5		**BDP2:** 32.6	**BDP2:** ?		**BDP2:** +33.3	**BDP2:** -0.5	
Kratie	**WB:** +22 to 45 **NT2:** +125 **BDP1:** +27 **BDP2:** +22.4	**WB:** -0.4 to 0.8 **BDP1:** -0.8 **BDP2:** -0.3		**BDP2:** +25.3	**BDP2:** -0.6	**BDP2:** +26.1			**BDP2:** 27.4	**BDP2:** ?		**BDP2:** +28	**BDP2:** -0.6	
Tonle Sap	**NT2:** +0.63 **BDP2:** ?	**NT2:** -0.54 **BDP1:** -0.4 **BDP2:** -0.26	**NT2:** -8.7 **BDP1:** -3.4 **BDP2:** -5 (Cambodia and LMB)	**BDP2:** ?	**BDP2:** ?		**BDP2:** ?	**BDP2:** ?	**BDP2:** ?			**BDP2:**	**BDP2:** -0.46	**BDP2:** -7 (Cambodia and LMB)
Tan Chau	**BDP1:** +26 **BDP2:** +13.3	**WB:** -0.2 to 0.3 **BDP1:** -0.2 **BDP2:** -0.3		**BDP2:** +13.1	**BDP2:** -0.2	**BDP2:** +13.8	**BDP2:** -0.2		**BDP2:** 13.7	**BDP2:** ?		**BDP2:** +14.9	**BDP2:** -0.2	
Whole Cambodia			**BDP2:** -104,000 ha											**BDP2:** -142,000 ha
Whole Basin			**BDP2:** -251,000 ha											**BDP2:** -309,000 ha

BDP1: Basin Development, phase 1**; BDP2:** Basin Development Plan phase 2; **NT2:** Nam Theun 2; **WB:** WorldBank Q: discharge; **WL:** Water level; **FA:** Flooded area

Regarding the Tonle Sap area (an area that generates 60% of the Cambodian fish production), some additional forecasts are proposed by the BDP2 (BDP2 2010):

- Reduction of the total flooded area by 60,000 ha (4.5%) in an average year, and as much as 100,000 ha (9%) in a dry year;
- Reduction of the area of flooded forest by 5,000 ha (1.1%) in an average year to 23,000 ha (5.3 %) in a dry year;
- Reduction of the area of inundated grasslands by 8,500 ha (3.2%) in an average year to 25,000 ha (10%) in a dry year;
- Reduction of the area of flooded marshes by 3,000 ha (1.0%) in an average year to 5,500 ha (1.8 %) in a dry year;
- Reduction of the area of flooded rice fields of 41,000 ha (18%) in an average year and 48,000 ha (28%) in a dry year;
- Reduction of flood depth of just over 0.5 m in an average and dry year;
- Reduction of flood duration of the flooded forest area by generally less than 2 weeks in an average year, but up to 1 month in a dry year;
- Reduction in flood duration by generally less than 1 month in an average year in 70% of the inundated grassland area, but an increase of flood duration with up to 1 month in 25% of the area;
- Increase of the water level in the dry season with about 30 cm, resulting in a volume increase of 780 MCM, or an increase of over 50%;
- Reduction of sediment inflow in the system of at least 8 to 13%.

It is important to note that hydrological changes forecasted by the BDP2 are averages by season which do not reflect daily variations. Important daily variability in downstream water level following peak operation is a major problem for river ecology, fisheries and riverine livelihoods, as shown by the Yali dam. Downstream of Yali dam in Cambodia, until at least 2003, daily fluctuations ranging between 50 cm and one meter have resulted in dramatic losses in habitat, fish resources, livestock, and at least 39 casualties (Fisheries Office of Ratanakiri Province, 2000, McKenney 2001, Baird *et al*. 2002, Lerner 2003, Baird and Meach 2005, Wyatt and Baird 2007). Data on daily variations in flows downstream of planned mainstream dams are not available; however, expected daily fluctuations in the level of the reservoir (i.e. upstream) are indicated for some projects and give an indication of the daily variability in downstream flows. In the case of Luang Prabang, Latsua and Stung Treng dams, two meters of daily fluctuation correspond respectively to 87, 23 and 428 million cubic meters (see Table 48). Such level of variability is expected to have major effects on fish resources and on the environment in general and cannot be ignored. However the complete absence of data about this phenomenon did not allow factoring it into the current impact analysis.

Table 48: Mode of operation of the planned mainstream dams and expected daily fluctuation in the reservoir level (Source: SEA Inception Report Vol 2).

	Mode of operation	Daily fluctuations in the reservoir (m)
Pak Beng	NA	NA
Louang Prabang	peak load 12-15 h/day	-2m
Xayaburi	NA	0
Pak Lay	Peak load 8-10 hours/day	1-2 m
Sanakham	NA	NA
Pakchom	Continuous	- 2m
Ban Koum	Continuous	NA
Latsua	Peak load >16 hours/day	-2m
Don Sahong	Continuous	NA
Stung Treng	Continuous	2m
Sambor	NA	small

2.3 WETLANDS, FLOODPLAINS AND FISH PRODUCTIVITY

Changes in floodplain areas highlighted above imply changes in related fish production. This relationship between wetland or floodplain area and fish yield has been studied in detail and the comprehensive reviews done by Hortle (2007) and Hortle *et al.* (2008) are summarized below.

Welcomme (1985) estimates that floodplain area can be used to predict 70% of floodplain river productivity, and 40-60 kg/ha/year is a typical range for tropical floodplain rivers. In the LMB, however, natural productivity exceeds that of many other tropical floodplains, and is estimated to range between 25 and 630 kg/ha/year, with a mean yield of 119 ± 25 kg/ha/year (average of 18 studies, details in Hortle *et al.* 2008, p. 39). This value is lower and more accurate than the 230 kg/ha/year mentioned in Baran *et al*. 2001 and Sverdrup-Jensen 2002[24]). To reflect the variability in floodplain productivity, Hortle (2007) used low, medium, and high values of productivity per hectare (respectively 50, 100, and 200 kg/ha/year) and confirmed this range later on (Hortle *et al*. 2008), insisting on the middle value (119 ± 25 kg/ha/year) as the most likely average figure.

<u>Notes:</u>

- When relating floodplain productivity, floodplain area and total production, the most recent wetland surface area estimates available and published are those detailed in Hortle *et al.* (2008, p. 40), updating those of Hortle 2007.

- In the unofficial IBFM report nº 8 (King *et al.* 2005), fish productivity per hectare is not detailed, but a non-linear relationship is assumed and it is estimated that a 10% reduction in floodplain area would result in a 20-30% reduction in fisheries productivity. This study also points out that loss of production in due to reduced floodplain area can be exacerbated by a delayed flood duration (issue highlighted and detailed in Baran *et al.* 2001, 2005, and Kurien *et al.* 2006)

In the Lower Mekong Basin, freshwater fishes originate from wetlands in general. Wetlands are made of permanent water bodies (rivers and lakes) + floodplains + rice fields (floodplain rice fields + rainfed rice fields) + aquaculture areas + swamps + flooded forest/grassland/shrubs. Thus, wetlands are made of much more than just floodplains, but fishery studies tend to focus on floodplains, and multiple authors do not clearly differentiate wetlands, floodplains and rice fields. Hortle *et al.* (2008) published the first study in which the fish productivities of rice fields, swamps, flooded natural vegetation and permanent water bodies were distinguished[25]. Although floodplains are the dominant habitat mentioned in the fishery literature, the surface area of floodplains in the LMB amounts to 50,152 km^2 (TKK & START-RC 2009) while that of wetlands is more than three times larger, reaching 184,900 km^2 (Hortle *et al.* 2008). The implications of this fact in relation to fish production and the impact of dams are detailed in section 2.5.4. (Method 4).

[24] Yet figures of total production in these studies are close to Hortle's figures because the surface area of wetlands was updated.
[25] However, in the surface areas detailed by these authors, rainfed rice fields (RRF) are lumped with flooded rice fields, although it is acknowledged that the productivity of the latter (around 200 kg/ha/y) is double that of the former.

2.4 LONG-DISTANCE MIGRATORY FISH SENSITIVE TO MAINSTREAM DAM DEVELOPMENT

A number of Mekong fish species migrate between floodplains and tributaries, but details about where they migrate to have never been summarized. For this study we reviewed existing information to characterize the migration of as many species as possible, and combined this information with the contribution of these species to total catches. The methods are detailed below, and results will be detailed for each dam cluster in a later section.

This synthesis is initially based on migration maps available for 23 species in the Mekong Fish Database (MFD 2003, see ANNEX 2: Migration patterns of 23 migratory fish species). On each map five barriers have been represented: i) Sambor blocking migrations upstream and towards the 3S system; ii) Stung Treng/Don Sahong blocking migrations through Khone Falls; iii) Latsua blocking migrations towards the Mun/Chi system; iv) Ban Kum blocking migrations towards Vientiane, and v) the upstream cluster blocking access to the upstream migration zone.

This analysis of 23 fish taxa was complemented by a synthesis of all ecological information published in Mekong Fish Database and in FishBase, obtained by merging these two databases (FishBase having more information on the taxonomy and biology of the species, and Mekong Fish Database on their ecology and distribution). This combination provides information (with more or less detail depending on how well a given species is known) for 768 species. An example of the information synthesized is given in ANNEX 3: Ecological information on two species dominant in Mekong catches for two well-known migratory species. The analysis focused on six main upstream migration patterns : i) fish migrating from floodplains up to Kratie/Sambor; ii) fish migrating to the 3S system (Sekong-Sesan-Srepok); iii) fish migrating through Khone Falls; iv) fish migrating to the Mun/Chi system; v) fish migrating upstream of Pakse; vi) fish migrating upstream of Vientiane. Ultimately a total of 46 species displaying particular migration patterns or critical habitats in the different zones describe above were identified. The matrix of species by zone (ANNEX 4: Dominant species in Mekong catches and their migration patterns) was complemented by the contribution of each species to total catches basinwide). A summary of that information is detailed in Table 49.

Table 49: Summary of the migration patterns of 43 species dominant in catches[26]

	All species reviewed	Migration up to Kratie	Migration to the 3S system	Migration through Khone Falls	Migration to the Mun/Chi system	Migration up to Vientiane	Migration upstream of Vientiane
Number of species	43	43	25	41	15	28	27
% of species reviewed	100	100	58	95	35	65	63

Notes:

- This review only reflects the status of our knowledge about migrations in relation to a few key locations in the basin, as summarized in the scientific literature and in the two databases cited; additional raw information about migrations exists (e.g. migration timing of *Hypsibarbus malcolmi* in multiple locations in the Basin) but could not be analyzed within the 15 days of work granted for the current impact assessment. The above conclusions are therefore an underestimate of actual migrations.
- Some other species living in the mainstream such as *Gyrinocheilus aymonieri* might be at risk of mainstream dam development although they do not exhibit long-distance migration patterns; they have not been covered in the present analysis (another underestimate).

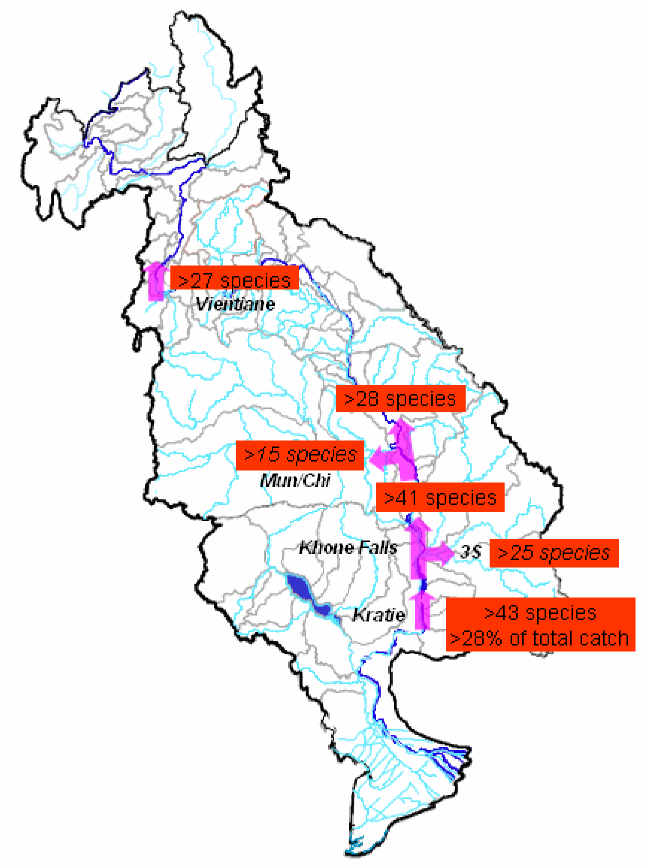
[26] This analysis assumes that the downstream floodplains in Cambodia and Viet Nam are a starting point, and considers only upstream long distance migrations. Migration within sub-systems, from floodplains to local tributaries or lateral migrations between close habitats are not reflected here.

Conclusions:

This analysis focused on 43 white fish species whose long-distance migration patterns are well known, and making up to a third of the fish catch basinwide. Out of these species, all exhibit a migration pattern between downstream floodplains and the Mekong mainstream by Kratie; 95% of them (= 28.5% of the catch basinwide) migrate through Khone Falls; and about two-thirds undertake a migration between Khone Falls and upstream (towards tributaries of the middle Mekong migration system, or upstream of Vientiane).

Several limitations to this approach must be highlighted: i) upstream of Kratie it is impossible to assess how much of the catch the migratory species identified represent (what is known is only their contribution to the overall catches); to do so it would be necessary to know the catch per river stretch; this information is available in raw MRC data but has never been analysed so far; ii) the fact that a species migrates to a certain zone does not mean that it is specific to that zone (thus 22 of the 25 species migrating to the 3S system are also found upstream of Vientiane) nor that access to this zone is absolutely necessary to the reproduction of that species; iii) for some species there could be sub-populations able to complete their lifecycle within segments of the basin (e.g. between Cambodian floodplains and the 3S system, between Thai floodplains and the upstream Mekong) without having to migrate through the whole basin.

Figure 47: Number of species of long-distance migrants found in the sections of the LMB possibly barred by mainstream dams.



Halls and Kshatriya (2009) identified 58 fish species as being highly vulnerable to mainstream dam development; their findings are detailed in the next section and the 58 species are identified in ANNEX 5: Mainstream fish species highly vulnerable to dam development. An additional 26 species were identified as being at medium risk of impact. It should be noted that in a tropical system characterized by a few dominant species and many rare ones, the proportion of species at risk (58 + 26 out of 781 = 11% or more) does not reflect the fraction of harvest at risk (35% or more, see below). Furthermore these 58 or 84 species represent species at risk because of their migratory behaviour; the figure does not include the many species at risk because of environmental changes brought about by dams (e.g. another 41 species found only in the mainstream upstream of Vientiane are at risk if a cluster of 6 dams turns 90% of this river section into a reservoir). Overall the total number of species at risk of mainstream dam development is greater than 100 but is not precisely known.

2.5 IMPACT OF DAMS ON MIGRATORY FISH AND ON CAPTURE FISH PRODUCTION

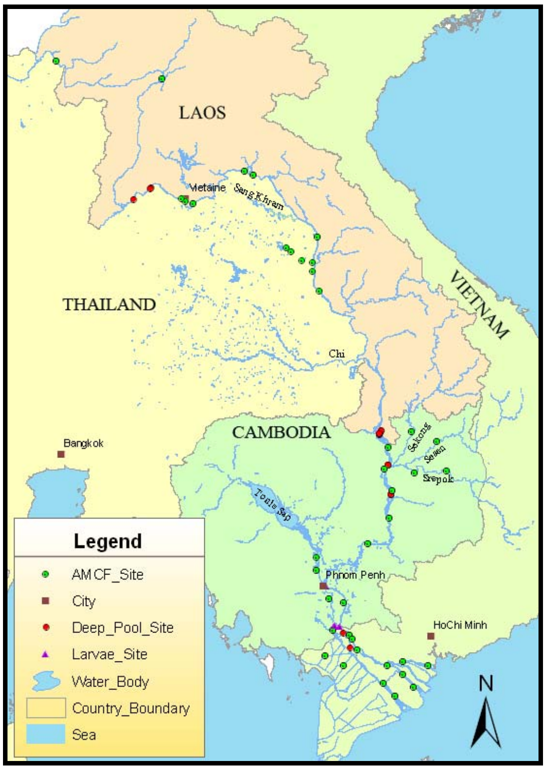
The dominant approach in quantifying the impact of dams on fish production has long consisted of representing the amount of fish at risk as the proportion of long-distance migrants ("white fish") in the total fish production basinwide, because these long distance migrants basically need to complete their lifecycle between downstream floodplains where they grow and upstream tributaries where they breed (see Baseline Assessment. In this approach, it is implicit that non-migratory fish (the sturdy floodplain "black fish") will not be impacted by dams because they do not need to migrate over long distances and can adapt to environmental changes[27]. As a consequence a debate has recently surfaced about the species composition in catches basinwide, and the relative proportion of black fish – or white fish – in the overall catch. We review below four approaches that either identified dominant species in overall catches, or quantified the share of black/white fishes in overall catches.

An alternative approach consists of i) assessing the surface area of different types of wetland habitat basinwide (some of them, like rivers, being impacted by dam development while others, like rainfed rice fields, are not) ; ii) estimating the annual productivity of these different habitats; and iii) calculating fish production in each case and basinwide. This alternative approach is also reviewed.

2.5.1 METHOD 1: CATCH MONITORING IN THE MAINSTREAM

Fish abundance and diversity have been monitored basinwide based on gillnets operated by local fishermen (Starr 2008). This monitoring undertaken by the MRC Assessment of Mekong Capture Fisheries Project was carried out in the four LMB countries between 2002 and 2005. At each selected site three fishermen using different gears (mainly gillnets) recorded species caught daily, in different types of habitats: the main channel of the Mekong River, deep pools in the mainstream and along three tributaries, and in the delta. Data used in the analysis below correspond to the December 2003 – November 2004 period. Data from this monitoring have been processed and made public for the first time in Halls and Kshatriya (2009).

Figure 48: Site locations of the AMCF fishermen's catch monitoring survey.



[27] This binary classification of fishes into two guilds only is simplistic and tends to underestimate the impact of local dams on "grey fish", the guild that needs to complete migrations between floodplains and local tributaries. Also, the term "black fish" refers, strictly speaking, to floodplain fishes only, and thus to species found in floodplain or wetlands; this term should not be used for non-migratory species found upstream of tributaries and in stream environments.

The AMCF survey resulted in reports about a total of 233 species of fish belonging to 55 families. Twenty-two species (9.4% of the species richness sampled) were identified as *black fish* and 150 species (64.4%of the total richness) were identified as *white fish.* Among those, 58 white fish species (24.9% of the species richness sampled) representing 38.5% of the catch in the mainstream and large tributaries were considered highly vulnerable to dam development (the criteria for classification, the 58 species, and their share in catches basinwide are detailed in ANNEX 5: Mainstream fish species highly vulnerable to dam development. From this assessment it can also be deduced that 100 - 38.5 = 61.5 % of the catch in large rivers is made of species that are not highly vulnerable to dam development (this latter category includes black fish and other species).

This study is by far the most detailed source of information available to date when dealing with fish catches at the species level *and* basinwide. However, it is restricted to large rivers (mainstream and 4 large tributaries), without covering the extensive floodplains and wetlands of the basin. This constitutes a major bias regarding the importance of black fish in the overall fish production basinwide, since Hortle (2009) highlighted the fact that wetlands outside the flooded area (and thus considered independent from rivers and from mainstream dam development) feature high black fish productivity and represent 71% of wetlands basinwide. For this reason the catch estimates resulting from the AMCF study will be kept as an indication but will not be used for the assessment of the impact of mainstream dams on Mekong fish production (although it was used in the 2008 review by Barlow *et al.* and in the June 2010 working version of the present Fisheries Impact Assessment).

2.5.2 METHOD 2: SURVEYING EXPERTS

In the first half of 2007, the MRC Fisheries Programme gathered an expert panel consisting of 13 fisheries scientists from Lao PDR, Cambodia and international research organizations operating in the LMB to provide an estimate of the size and value of the migratory fish resource in the LMB (details in Barlow *et al.* 2008). Experts were asked "*What percentage of the total yield from the capture fishery in the LMB is 'white fish' (that is, those that are highly migratory)?"* The combined answer was that migratory fish resources vulnerable to mainstream dam development comprise 71% of the fisheries yield in the LMB.

However, this approach can be questioned because the experts consulted were not identified and did not detail the analyses, figures and reasons underpinning their respective conclusions. Furthermore the results from the 13 experts (some working at the national level, some other at the regional level) were simply averaged, without analysis or weighing of local disparities. The whole process was not public and thus could not be reviewed, and only the summary was reported in Barlow *et al.* (2008). As a consequence the results of this consultation were not integrated into the current review (as opposed to the June 2010 working version of this Fisheries Impact Assessment).

2.5.3 METHOD 3: CATCH STATISTICS IN CAMBODIA

In 2000, van Zalinge and his colleagues, summarizing several years of fish monitoring by the MRC/DoF/DANIDA project "Management of the Freshwater Capture Fisheries in Cambodia" (Diep Loeung *et al.* 1998), reached the conclusion that "longitudinal migrants constitute about 63 % of the total catch taken by fisheries in the Tonle Sap area" (van Zalinge *et al.* 2000). However, this proportion can be considered an overestimate for several reasons: i) the fishery best monitored was the *dai* fishery targeting white migratory fish, whereas the species composition in dispersed small-scale and familial fisheries and in the non-transparent large scale fishing lots was not well known; ii) since then additional studies have led to the conclusion that "rice fields probably produce a much larger share of the total yield of inland fisheries in Cambodia than is generally recognized" (Hortle *et al.* 2008); iii) these catches reflecting the floodplain system typical of Cambodia and Viet Nam are not identical to those of the Thai and Lao systems where wetlands and water bodies are more common than floodplains, and the 63% of longitudinal migrants identified in Cambodia might not be generalized to the whole LMB. For these reasons the results of this assessment have not been integrated to the conclusions of the current review (although they were in its June 2010 working version of this Impact assessment).

2.5.4 METHOD 4: UPDATE INTEGRATING BLACK FISH PRODUCTION IN RICE FIELDS

In 2008, Hortle *et al.* looked in detail that the production of rice field fisheries in Cambodia, and found that 87.7% of the catch in rice fields is made of black fish, and that rice fields represent 86.1% of wetlands in the Lower Mekong Basin[28]. We used this update to determine the contribution of black fish to fish production basinwide; the steps of this assessment are detailed below:

• Wetlands = floodplains + rice fields + other wetland types

• Rice fields = floodplain rice fields (high fish productivity) + rainfed rice fields (RRF, lower fish productivity)

• Other wetland types = permanent water bodies + aquaculture areas + swamps + flooded forest/grassland/shrubs

Surface area of wetlands = surface area of floodplains (including floodplain rice fields) + rainfed rice fields + permanent water bodies + aquaculture + swamps + flooded forest/grassland/shrubs

Surface area of rainfed rice fields = surface area of wetlands - floodplains - permanent water bodies - aquaculture - swamps - flooded forest/grassland/shrubs

Surface area of Wetlands in the LMB: 184,900 km^2 (Hortle *et al.* 2008 p. 40)
Surface area of floodplains in the LMB: 50,152 km^2 (TKK & START-RC 2009 p. 22).
Surface area of rice fields: 159,200 km^2 (Hortle *et al.* 2008 p. 40)
Surface area of permanent water bodies: 13,800 km^2 (Hortle *et al.* 2008 p. 40)
Surface area of aquaculture zones: 2,400 km^2 (Hortle *et al.* 2008 p. 40)
Surface area of swamps: 2,200 km^2 (Hortle *et al.* 2008 p. 40)
Surface area of flooded forest/grassland/shrubs: 7,300 km^2 (Hortle *et al.* 2008 p. 40)

→ Surface area of rainfed rice fields = 109,000 km^2

• Production of RRF = productivity of RRF x surface area of RRF = Y% of (black fish)$_{RRF}$

Productivity of RRF: around 100 kg/ha/y (Hortle *et al.* 2008 p.41)
Surface area of RRF: 109,000 km^2 = 10,900,000 ha

Fish production of rainfed rice fields = 1,090,000 tonnes

Percentage of black fish in rainfed rice fields: 88% (Hortle et al,. 2008 p. 19)
Percentage of white fish in rainfed rice fields = 100 – 88 = 12% (Hortle et al,. 2008 p. 19)

→ Production of black fish in rainfed rice fields = 1,090,000 x 0.88 = 959,000 tonnes
→ Production of white fish in rainfed rice fields = 1,090,000 x 0.12 = 131,000 tonnes

• **Production of fish basinwide: 2.1 million tonnes** (based on consumption studies; see Fisheries Baseline Assessment)

• Production (tonnes) of fish basinwide = production of Flood Plains + production of Rainfed Rice Fields

Production of Flood Plains = Production basinwide (2,100,000 t) - Production of RRF (1,090,000 t)

→ Production of Rainfed Rice Fields = 1.01 million tonnes (made of white fish and black fish)

• In the Tonle Sap (i.e. floodplain system), the proportion of *white* fish reaches 63% (van Zalinge *et al.* 2000) and thus the proportion of black fish is 100-0.63 = 37%

→ Production of white fish in floodplains = 1,010,000 x 0.63 = 636,000 tonnes
→ Production of black fish in floodplains = 1,010,000 x 0.37 = 374,000 tonnes

• Total production of black fish: 959,000 tonnes from rainfed rice fields + 374,000 tonnes from floodplains = 1.33 million tonnes, out of 2.1 million tonnes = 63%

→ Production of black fish basinwide = 1,010,000 x 0.63 = 636,000 tonnes
→ Percentage of black fish basinwide = 63%

So based on estimates of black fish proportion in rainfed rice fields and in actual floodplains, and on the respective proportion of each habitat type in the LMB, there would be 63% of black fish in the total fish production of the Mekong Basin. As a consequence, according to this approach, migratory fish resources vulnerable to mainstream dam development would represent 37% of the fisheries yield in the LMB[29] (figure rounded up to 35%).

[28] However, a detailed analysis of productivity by wetland type, based on the reviews detailed in Hortle (2007) and Hortle *et al.* (2008), and detailed in another section of this report, leads to the conclusion that rice fields produce around 100 kg of fish per hectare and per year, whereas floodplains produce around 200 kg per hectare and per year.

[29] The existence of grey fish, i.e. species migrating over short distances between floodplains and local tributaries is to be kept in mind as a caveat to this conclusion and percentage. However the current absence of

2.5.5 METHOD 5: ASSESSMENT BASED ON HABITAT TYPES

This approach, producing the most detailed forecasts and influencing substantially the overall results and conclusions of the present fisheries impact assessment, was not part of the June 2010 working version of this assessment.

2.5.5.1 ASSESSMENT OF THE MRC BDP2

This approach, derived from the previous one, has been developed as the "BDP2 fisheries assessment" and presented by K. Hortle at the MRC's Third Regional Forum on Mekong Basin Development Plan (29-30 July 2010). The approach is based on the surface area of different fish habitats, on yields per unit area (i.e. productivity per habitat) and changes in both habitats and productivity depending on dam development scenarios. Although white and black fish are present in the different habitats and reflected in findings, this method, unlike the previous ones, does not explicitly mention these guilds. The method details instead the proportion of 3 main habitat types (mainly rainfed rice fields, rivers/floodplains and water bodies/reservoirs/canals) and the proportion of each in the LMB (respectively 67%, 30% and 3%). This method differs radically from the previous ones by highlighting the importance of rainfed rice fields and their high black fish productivity (50-100 kg/ha/year), whereas the other methods tend to focus on rivers and floodplains and their high white fish productivity (100-200 kg/ha/year). This approach also considers that rainfed rice fields and their fish production will not be seriously impacted by dams, but that dam development will modify the surface area of each habitat type and subsequently the total fish production. Figures are calculated for each scenario, and detailed in the upcoming BDP2 fisheries impact assessment report. It should be noted that the latter integrates the production of non-finfish aquatic animals in the total fishery production

A summary of findings is presented below, and the BDP2 results are processed further to reflect divergences in hypotheses between the SEA and the BDP2 assessments.

Table 50: Annual fishery production (in tonnes of fish and other aquatic animals) expected based on habitat changes (BDP2 Fisheries Impact Assessment, July 2010).

	Rainfed rice fields			Rivers / Floodplains	Reservoirs	
	Best case	Intermediate	Worst case		Best case	Worst case
Baseline (2000)	1,044,000	1,044,000	1,044,000	1,035,000	226,000	226,000
2015 Definite Future	1,015,000	1,010,000	649,000	902,000	241,000	229,000
2030 without mainstream dams	1,270,000	1,010,000	649,000	830,000	258,000	234,000
2030 with Lao mainstream dams only (6 dams)	1,270,000	1,010,000	649,000	759,000	265,000	235,000
2030 without Cambodia mainstream dams (9 dams)	1,270,000	1,010,000	649,000	673,000	276,000	238,000
2030 with 11 mainstream dams	1,270,000	1,010,000	649,000	450,000	290,000	242,000

This method allows a more detailed assessment of impacts than the previous ones in case of different scenarios, and the report is rigorously presented with best/intermediate/worst hypotheses in combination with the respective dam development scenarios. However some caveats are to be considered:

Non-fish aquatic animals: this analysis includes non-fish aquatic animals, i.e. snails, frogs, crabs or mollusks, as being part of fisheries. The production of Other Aquatic Animals is indeed substantial in Mekong wetlands, explaining the difference between the BDP2 baseline (fisheries production of 2.305 million tonnes in 2000) and the SEA baseline (fisheries production of 2.1 million tonnes in 2000), i.e. a 0.911 factor between both assessments. However, the productivity of these animals, in particular their response to environmental changes (creation of reservoirs, agriculture intensification, etc.) is not well known. For this reason, and because

any data about the quantitative importance of grey fish basinwide did not allow moving beyond the back vs. white fish calculations.

the SEA chose to focus on fisheries *sensu stricto*, non-fish aquatic animals are excluded from the analyses below.

Rice fields: in the BDP2 analysis, the best case hypothesis is that dam development generates additional water level in the Mekong in the dry season, which translates into additional irrigated fields, leading to additional rice field fish production (+226,000 tonnes/year). This hypothesis is unrealistically optimistic because i) higher discharge in the Mekong in the dry season is not synonymous with additional irrigation schemes, since the latter depend on an economically – and politically – driven development process largely independent from hydrology; ii) increased rice productivity resulting from more crops per year implies intensive use of herbicides and pesticides, which translates into a drastic reduction of the fish productivity (case of Viet Nam). This problem is reflected in the Worst Case scenario, but is not reflected in the Best Case scenario. For this reason the Best Case hypothesis in irrigation can be dismissed.

Reservoirs: in the BDP2 analysis the Best Case scenario of all reservoirs created producing 200 kg/ha is highly unrealistic when i) a large number of studies show that a productivity higher than 200 kg/ha/year is reached only by a few highly managed reservoirs usually characterized by the stocking of exotic species (Marshall and Maes 1994, Bernacsek 1997, Amornsakchai *et al.* 2000, Jackson and Marmulla 2001, De Silva 2001, De Silva and Funge-Smith 2005, Hortle 2009), whereas many other reservoirs perform at a few kilograms per hectare and per year (e.g. 10 kg/ha/year for Pak Mun). For this reason the Best Case hypothesis in reservoirs can be dismissed.

Aquaculture: in the BDP2 analysis findings are based on an updated estimate of aquaculture consumption in the LMB in 2008 (K. Hortle, pers. comm.). According to this estimate the volume of freshwater + brackish fish produced in 2008 amounts to i) 100,000 tonnes in Lao PDR, consumed 100% locally, but the FAO mentions a total production limited to 78,000 tonnes since 2005**;** ii) 111,000 tonnes in Cambodia, consumed 100% locally, but 38,365 tonnes only were officially reported to the FAO in 2008. These estimates used in the BDP2 analysis are not backed by any detailed publication we are aware of, and vary substantially from official estimates (by 290% in the case of Cambodia), which calls for a cautious review of these figures before aquaculture is promoted as an alternative source of fish in the region.

2.5.5.2 REVISION OF THE MRC BDP2 ASSESSMENT

The above reservations have been integrated and a revised assessment of the finfish production to be expected for each scenario has been calculated (see table below).

Table 51: Annual fishery production (tonnes of finfish) expected based on habitat changes (revised estimates based on the July 2010 BDP2 Fisheries Impact Assessment).

	Rainfed rice fields		Rivers / Floodplains	Reservoirs	Total	
	High end	*Low end*			*High end*	*Low end*
Baseline (2000)	951,000	951,000	943,000	206,000	2,100,000	2,100,000
2015 Definite Future	920,000	591,000	822,000	209,000	1,950,000	1,622,000
2030 without mainstream dams	920,000	591,000	756,000	213,000	1,889,000	1,561,000
2030 with Lao mainstream dams only (6 dams)	920,000	591,000	691,000	214,000	1,826,000	1,497,000
2030 without Cambodia mainstream dams (9 dams)	920,000	591,000	613,000	217,000	1,750,000	1,421,000
2030 with 11 mainstream dams	920,000	591,000	410,000	220,000	1,551,000	1,222,000

Deducting annual production expected for each scenario from the baseline or from the situation in 2015 (definite future) allows calculating expected losses in each case:

Table 52: Annual fishery losses (in tonnes) expected for different scenarios (estimates based on the July 2010 BDP2 Fisheries Impact Assessment)

Baseline (2000)	**2,100,000**	
	High end	***Low end***
2015 Definite future		
Loss in tonnes compared to Baseline	150,000	480,000
2030 without mainstream dams		
Loss in tonnes compared to Baseline	210,586	539,457
Loss in tonnes compared to Definite future	60,586	59,457
2030 with Lao mainstream dams only (6 dams)		
Loss in tonnes compared to Baseline	274,356	603,227
Loss in tonnes compared to Definite future	124,356	123,227
Loss compared to 2030 with no mainstream dams	63,770	63,770
2030 without Cambodia mainstream dams (9 dams)		
Loss in tonnes compared to Baseline	349,969	678,840
Loss in tonnes compared to Definite future	199,969	198,840
Loss compared to 2030 with no mainstream dams	139,383	139,383
2030 with 11 mainstream dams		
Loss in tonnes compared to Baseline	549,478	878,349
Loss in tonnes compared to Definite future	399,478	398,349
Loss compared to 2030 with no mainstream dams	338,892	338,892

2.5.6 SYNTHESIS

- Approach based on the share of long distant migratory fish sensitive to the barrier effect of dams:
  Around 35% of the fish production basinwide is made of long-distance migratory species vulnerable to mainstream dam development and around 2.1 million tonnes of fish are currently harvested in the LMB (see Baseline assessment). This results in an estimate of 2,100,000 x 0.35 = 700,000 tonnes of fish at risk from dam development in the LMB.

- Approach based on habitats and their productivity:

Table 53: Annual fishery losses (in tonnes) expected for different scenarios (summary).

	2000: 16 dams on tributaries, 2.1 million tonnes of fish produced				
	2015	**2030**			
	47 dams on tributaries	**77 dams on tributaries**			
	No mainstream dams	**No mainstream dams**	**6 MS dams**	**9 MS dams**	**11 MS dams**
Losses in 2015 compared to 2000 (t)	150,000 - 480,000	-	-	-	
Losses in 2030 compared to 2000 (t)	-	210,000 - 540,000	270,000 - 600,000	350,000 - 680,000	550,000 - 880,000
Losses in 2030 compared to 2015 (t)	-	~60,000	~120,000	~200,000	~400,000
Losses in 2030 compared to 2030 without mainstream dams (t)	-	-	~60,000	~140,000	~340,000

In 2015 the loss of fish compared to the 2000 baseline is expected to range between 150,000 and 480,000 tonnes annually. This fish loss will be due to 31 new dams on tributaries and to other factors such as loss of floodplains, habitat fragmentation, fishing intensification, etc. This corresponds to 50 - 160% of the total cumulated livestock production of Cambodia and Lao PDR in 2008.

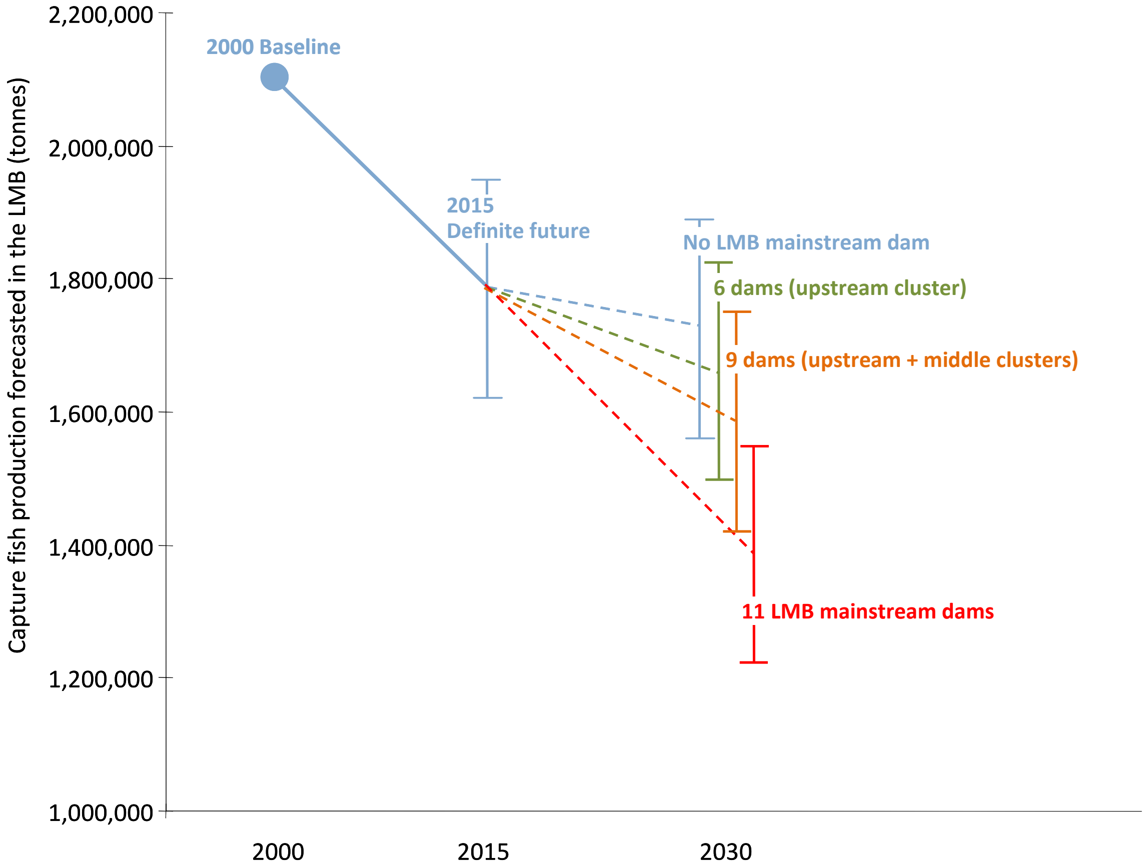
In 2030, with development basinwide and a total of 77 dams on tributaries, the loss of fish compared to year 2000 is expected to amount to 210,000 – 540,000 tonnes *in the absence of mainstream dams*. This represents a loss of 10 to 26% of the baseline production or 3-4% of the 2015 production, even though mainstream dams are not built.

In 2030, *if 6 dams are built upstream of Vientiane*, a loss ranging between 270,000 and 600,000 tonnes is expected compared to the situation in 2000 (i.e. minus 13 – 29%). The additional loss compared to the situation in 2030 without mainstream dams would represent about 60,000 tonnes. In the latter case this amount of protein at risk of being lost annually if 6 mainstream dams are built by 2030 represents 60% of the current livestock production in Lao PDR. This assessment is *very* conservative and corresponds only to the loss of catch in the habitats modified. It does not reflect the loss of recruitment, i.e. the loss of larvae and juveniles bred upstream and harvested downstream as adults. For this reason the actual impact of the upstream group of mainstream projects is likely to be substantially higher than 60,000 tonnes - but at this time it cannot be quantified.

In 2030, *if 9 mainstream dams are built upstream of Khone Falls*, the loss in fish resources forecasted would amount to 350,000 – 680,000 tonnes compared to 2000 (i.e. minus 17 – 32%), or to around 200,000 tonnes compared to 2015. This would also represent a loss of about 140,000 tonnes compared to the situation in 2030 without mainstream dams. Again, this is a very conservative estimate. This biomass at risk of loss between 2015 and 2030 corresponds to the whole annual freshwater fish production of Brazil or to the whole annual meat production in Cambodia.

In 2030, *if 11 mainstream dams are built in the LMB*, the total fish loss forecasted would amount to 550,000 – 880,000 tonnes compared to the baseline (i.e. minus 26 – 42%) and to about 400,000 tonnes compared to the situation in 2015. It would also correspond to a loss of ~340,000 tonnes compared to the situation in 2030 without mainstream dams. This latter amount of protein at risk of being lost annually if 11 mainstream dams are built by 2030 represents more (110%) than the current cumulated annual livestock production of Cambodia and Lao PDR. 550,000 – 880,000 tonnes of fish at risk is a huge number; by comparison the annual freshwater fish production of the whole West Africa (15 countries) amounts to around 600,000 tonnes. This fish loss would have critical consequences on food security in the LMB countries, in particular in Cambodia and Lao PDR.

Figure 49: Potential impact of mainstream dams on fish production basin-wide.



The above figures are based on the most detailed estimates available, produced by the MRC Fisheries Programme for the BDP2, and based on changes in habitats and the productivity of each habitat. **These estimates are very conservative** since they are a sum of local situations (*before* and *after)* but do not reflect the impact that a change in a given place (e.g. a breeding site upstream) can have on another place (e.g. a fishing ground downstream). In other words, this approach undervalues the loss of upstream sites where fisheries are not intensive but where juveniles of migratory species are generated before they migrate downstream where they get caught.

Thus, fish production would decline even in the absence of mainstream dams, but mainstream dams would exacerbate the trend, resulting in extremely high losses.

Applying these global figures to the estimates of total fish production by country as detailed in the Baseline Assessment —with a focus on catch estimates based on consumption studies since they are the most robust— shows that the total fish production at risk of full dam development basinwide by 2030 would range between 220,000 – 350,000 tonnes for Cambodia, 30,000 – 40,000 tonnes for Lao PDR; 160,000 – 260,000 tonnes for Thailand and 140,000 – 220,000 tonnes for Viet Nam.

Table 54: Annual fishery losses (in tonnes) expected between 2000 (baseline) and 2030 (11 mainstream dams) for each country.

	Contribution to LMB catch in %	Amount of fish at risk basinwide		Amount of fish at risk in each country	
Cambodia	23-51 ≈ 40%	550,000	880,000	220,000	350,000
Lao PDR	4-8 ≈ 5%			30,000	40,000
Thailand	27-35 ≈ 30%			160,000	260,000
Viet Nam	18-34 ≈ 25%			140,000	220,000

Note: these figures integrate the high production of rice field fisheries, in particular rainfed rice field fisheries, which are not currently reflected in the national statistics of the riparian countries.

An alternative approach consists of calculating losses based on the fact that 35% of the global Mekong catch is made of long-distance migrants. When applied to each country, this method indicates that the biomass of fish at risk of being lost in Cambodia, Lao PDR, Thailand and Viet Nam amounts to respectively 170,000, 60,000, 250,000 and 240,000 tonnes. All these values are close to the previous figures based on habitat changes, and both approaches provide very conservative estimates. Thus the extensive South American experience of dam construction in large river basins summarised by Quiros (2004) indicates that the loss in capture fish production amounts to at least 50%[30].

Table 55: Catch of migratory white fish vulnerable to mainstream dam development.

	Cambodia	Lao PDR	Thailand	Viet Nam	*Total*
Total catch (estimate based on fish consumption studies)	481,537	167,922	720,501	692,118	2,062,077
Yield at risk under the assumption of 35% of vulnerable species	168,500	58,800	252,200	242,200	721,700

[30] Quiros indicates that after a decade the fish production drops "well below 50%" of its original state.

2.6 GAINS IN FISH PRODUCTION FROM DAM RESERVOIRS

Utilization of dam reservoirs for fish stocking is often mentioned as a way to increase fish production; this production depends on the characteristics of the reservoir considered. Table 56 details the specifications of reservoirs created behind each of the 11 mainstream dams; it was generated by the SEA GIS team, based on a digital terrain model and the specifications of each dam.

Table 56: Characteristics of each mainstream dam reservoir.

Reservoir	Area (km^2)	Average depth (m)	Maximum volume (mcm)	% of total volume at depth	
				< 2 m	< 5 m
Pak Beng	87.77	3.1	275.3	22.94	53.28
Louang Prabang	62.38	12.9	802.1	10.84	26.93
Xayaburi	50.43	7.4	374.7	86.57	93.69
Pak Lay	76.65	5.1	388.7	19.74	47.68
Sanakham	70.46	53.7	3783.6	3.29	8.16
Pakchom	55.76	1.7	97.2	78.23	92.33
Ban Koum	133.69	4.7	634.3	10.8	25.95
Latsua	13.33	9	119.4	19.43	45.96
Don Sahong	2.89	10.6	30.5	16.36	40.58
Stung Treng	234.23	6.6	1548.9	27.62	64.72
Sambor	715.89	4.9	3488.4	31.3	63.07

The proportion of the total volume of the reservoir between the surface and -2m or -5m characterizes the shape of the reservoir, and subsequently its fish productivity since the latter is concentrated in the water closest to the surface, with deeper waters being less productive (Bernacsek, 1997).

According to Bernacsek (1997), assessing production potential requires data about annual affluent flow volume in each reservoir. This information was derived, for each main scenario, from annual discharge volumes in dry and wet seasons in the upstream hydrological station nearest each reservoir.

Table 57: Annual effluent flow volume in each reservoir (million cubic meters).

Reservoir	Upstream station	Baseline	Definite future	2030
Pak Beng	Chiang Saen	83.1	82.9	82.7
Luang Prabang	Luang Prabang	120.1	119.7	122.6
Xayaburi	Luang Prabang	120.1	119.7	122.6
Pak Lay	Luang Prabang	120.1	119.7	122.6
Sanakham	Luang Prabang	120.1	119.7	122.6
Pakchom	Chiang Khan	132.4	132.0	134.7
Ban Koum	Mukdahan	238.4	236.8	228.6
Latsua	Pakse	296.6	294.5	285.7
Don Sahong	Pakse	296.6	294.5	285.7
Stung Treng	Pakse	296.6	294.5	285.7
Sambor	Kratie	296.6	294.5	285.7

The yields obtainable from reservoir fisheries vary considerably between reservoirs and depend on size and on multiple other factors. Small and shallow reservoirs are considerably more productive than large and deep ones (Bernacsek 1997). Productivity of reservoirs in Southeast Asia ranges between a maximum yield of 200 kg/ha/year (China, Viet Nam) and a few kilograms per hectare per year in Thailand, Indonesia or in Malaysia (Bernacsek 1997, Jackson and Marmulla 2001). Even with regular stocking, yields from large reservoirs in Thailand have been consistently below 200 kg/ha/year (Amornsakchai *et al.* 2000). In Pak Mun the reservoir fish production was expected to amount to 220 kg·ha^{-1} but it actually reached only about 10 kg.ha^{-1} (Amornsakchai *et al.* 2000, Jutagate *et al.* 2001) In India, large- and medium-size reservoirs have been found unsuitable for self-sustaining production, and depend on continuous stocking (Bernacsek 1997; Jackson and Marmulla 2001). Overall, the large uncertainty throughout Asia in yields achievable in newly created reservoirs seriously hampers the credibility of reservoir fish production predictions (Bernacsek 1997).

Generally speaking, during the first ten years after impoundment, fish in reservoirs benefit from a high primary production and catches are very high, but this period is followed by a progressive then sharp decline (review in Baran *et al.* in press). In addition to biological issues, varying degrees of reservoir management (Jutagate *et al.* 2006) and socio-economic issues (access rights, availability of fingerlings, market competition, etc.) are often another major reason behind the failure of reservoir fish production systems (De Silva and Funge-Smith 2005). For instance, South America has a long experience of dam development and results from stocking in large reservoirs in South America have been meager or null (review in Quirós, 1999). Nam Ngum in Lao PDR seems to be an exceptional case: the reservoir is still productive (13.8 kg/ha/year, around 600 tonnes/year, Bernacsek 1997) after three decades of exploitation. The reasons behind this sustained productivity are not well understood. Other reservoir fisheries in the region have on the contrary been quite disappointing, and there is a risk that a “success story” such as Nam Ngum will give a false impression that reservoir fisheries are a very productive option likely to compensate for the loss of capture fish resources.

2.6.1 ESTIMATES OF PRODUCTIVITY BASED ON SURFACE AREA, DEPTH AND FLOW

Bernacsek, in his extensive review of more than 26 large dam fisheries in the Lower Mekong commissioned by the MRC in 1997, showed that the potential productivity of a reservoir was best predicted by its surface area, its depth, and the water inflow in that reservoir.

$$\mathbf{C = 1.877A - 12D + 0.03835I + 126.8}$$

where C = catch (tonnes/year), A = surface area (km^2), D = depth (m) and I = affluent flow (cmc/year)

Productivities calculated in this manner for mainstream dam reservoirs, using information summarized in the above tables of dam characteristics, ranged from 390 to >>1000 kg/ha/year, which are very high values inconsistent with those previously observed (Hortle, 2007). This may be due to the fact that the dataset used to derive the formula included dams characterized by flows much lower than those of mainstream dams. This result indicates that due to their large annual flow volumes, mainstream dam reservoirs appear to fall outside the linear range of this formula.

2.6.2 ESTIMATES OF PRODUCTIVITY BASED ON SURFACE AREA ALONE.

By default, the surface area alone is the best single predictor of reservoir productivity. The total production of each mainstream reservoir was estimated using surface areas (Table 56) and three productivity levels: low (20 kg/ha/year), medium (50 kg/ha/year), and high (200 kg/ha/year). This large range reflects experience throughout Asia (Sricharoendham *et al*., 2000; Mattson *et al*., 2000; Jutagate *et al*., 2001) and underscores the largely unpredictable nature of reservoir fisheries detailed above. The corresponding estimates for mainstream dam reservoirs, weighed by the shape of the reservoir (deep reservoirs having a low productivity by hectare) are presented in Table 58.

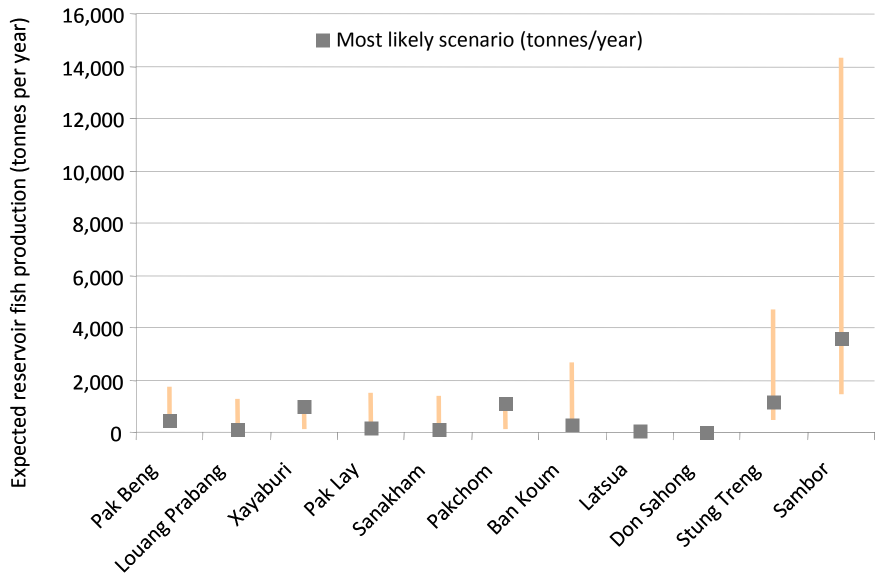
<u>Conclusions</u>: At best the maximum fish production to be expected from reservoir fisheries amounts to 30,000 tonnes basinwide. In fact when the shape of reservoirs is taken into account, **the most likely production represents about 10,000 tonnes of reservoir fish per year**[31] for the 1,500 km^2 of reservoir area created by mainstream dams. This value should be compared with to the 550,000 – 880,000 million tonnes of capture fish production at risk because of mainstream dam development.

[31] 8,072 t/year rounded up to 10,000 tonnes/year.

Table 58: Predicted production range in mainstream dam reservoirs. The most likely production, based on reservoir depth and shape, is highlighted in yellow. The most likely scenario is based on the assumption that reservoirs having more than 50% of their volume between 0 and 2 m are very productive (200 kg/ha/year), whereas reservoirs have a medium productivity (50 kg/ha/year) if 20-50% of their volume is between 0 and 2 m, and they are poorly productive (20 kg/ha/year) if less than 20% of their volume lies within the 0-2 m layer.

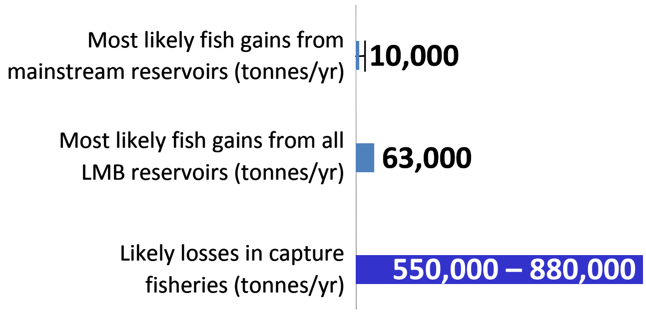
Reservoir	Area (km2)	Average depth (m)	% of total volume at depth <2m	Low productivity scenario (t/year)	Medium productivity scenario (t/year)	High productivity scenario (t/year)	Most likely scenario (t/ year)
Pak Beng	87.77	3.1	22.94	175.5	438.9	1755.4	438.9
Louang Prabang	62.38	12.9	10.84	124.8	311.9	1247.6	124.8
Xayaburi	50.43	7.4	86.57	100.9	252.2	1008.7	1008.7
Pak Lay	76.65	5.1	19.74	153.3	383.3	1533	153.3
Sanakham	70.46	53.7	3.29	140.9	352.3	1409.3	140.9
Pakchom	55.76	1.7	78.23	111.5	278.8	1115.2	1115.2
Ban Koum	133.69	4.7	10.8	267.4	668.5	2673.8	267.4
Latsua	13.33	9	19.43	26.7	66.6	266.6	66.6
Don Sahong	2.89	10.6	16.36	5.8	14.4	57.8	5.8
Stung Treng	234.23	6.6	27.62	468.5	1171.2	4684.6	1171.2
Sambor	715.89	4.9	31.3	1431.8	3579.5	14317.9	3579.5
Total	*1503.49*			*3007*	*7517.5*	*30069.9*	***8072.3***

Figure 50: Reservoir fish production expected from the 11 mainstream projects.



As for dam reservoirs on tributaries, the average surface area of the 36 LMB reservoirs listed in Bernacsek (1997) amounts to 143 km^2. For 77 dams, the cumulated surface area would be around 11,000 km^2. Depending on the level of productivity, the corresponding reservoir fish production would range between 22,000 and 220,000 tonnes, the most likely estimate (at 50 kg/ha/year) being 55,000 tonnes. When added to the most likely production of mainstream dam reservoirs (i.e. 8,000 tonnes), a total of 63,000 tonnes of reservoir fish per year is reached for the whole LMB.

Figure 51: Reservoir fish production compared to capture fish production at risk from dam development.

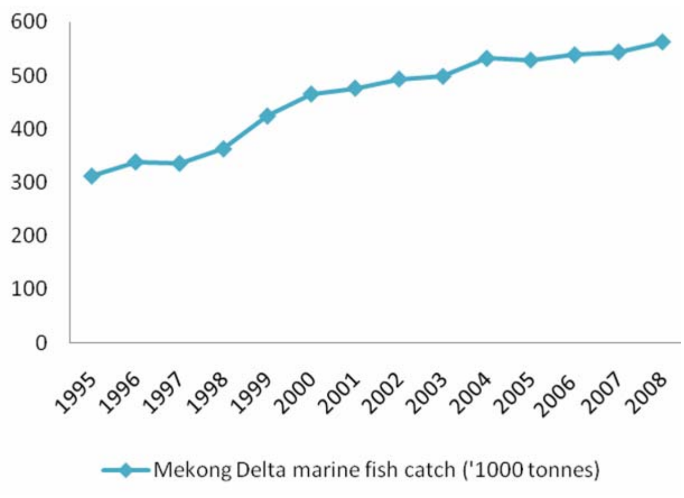


In addition to reservoir fisheries, aquaculture can complement the Mekong capture fisheries sector but cannot replace it in terms of food security. Aquaculture has shown rapid growth in all LMB countries but does not significantly contribute to rural food security. Intensive aquaculture (e.g. Viet Nam) produces fish for export and income but is not accessible to the poor; extensive aquaculture (e.g. Cambodia) feeds local people but is not very productive (see review in the Baseline Impact Assessment[32]). This sector is also dependent on (i) substantial investment, which excludes the poor; (ii) land/water management (i.e. infrastructure development, access rights issues), and (iii) capture fisheries to provide fish farms with protein feed (all countries) and juveniles (Cambodia in particular). With management for multiple uses, the LMB mainstream projects could provide investment and water resources for continued growth in aquaculture; however, these projects would also reduce the productivity of capture fisheries, diminishing the supply of feed to the aquaculture sector.

2.7 MEKONG MARINE FISHERY

The Mekong marine fishery, although seldom mentioned, is producing more than half a million tonnes of fish per year. Past trends indicate that the sector has grown by 80% in the last 15 years. The Mekong marine fishery is thus a significant component of the Vietnamese delta economy, utilizing almost 6,000 fishing boats**.**

Figure 52: Marine fish catch totals for 8 coastal provinces in the Mekong delta (Long An, Tien Giang, Ben Tre, Tra Vinh, Kien Giang, Soc Trand, Bac Lieu, Ca Mau).



[32] Excerpts from the SEA Fisheries Baseline:
- The freshwater aquaculture sector produces more than Mekong capture fisheries in Viet Nam only. In Thailand and Lao PDR, production of both sectors is in the same range, and in Cambodia the production of the aquaculture sector is 12 to 22 times *inferior* to the production of the capture fishery sector.
- Only one country, Viet Nam, features a high annual growth (+28% a year over the last 5 years) and high production levels (1.5 million tonnes in 2007). In Cambodia, annual growth is substantial but the production level is very low; in Lao PDR figures are erratic but low; and in Thailand the inland/brackish aquaculture production, having reached a high level - around 500,000 tonnes/year - is showing signs of stabilization if not decline.
- Replacing capture fisheries production by aquaculture production is not realistic.

The nutrient inputs to the coastal zone represent an approximate 100 Mt of sediments and at least 16,000 tonnes of attached nutrients (very conservative estimate) which are deposited by the Mekong plume in the shallow near coastal shelf of the delta. The Upper Mekong Basin and tributary dams will induce a 50% to 75% reduction in the arrival of sediments and nutrients to the coastal zone by 2030. The mainstream dams would be directly responsible for an average loss of 27 million tonnes per year of sediments and 4,500 tonnes per year of nutrients to the marine environment (SEA Hydrology Impact Assessment).

This sediment and nutrient retention by dams is expected to have a major impact on coastal fish production, and subsequently on the Vietnamese fishing sector and fish trade. This would also impact the delta aquaculture sector which is dependent on protein from marine "trash-fish" to feed the aquaculture fish for feedstock. However, the timescales and extent of the decline remain unknown because the marine fishery is poorly studied and little understood.

Experience from other dams and coastal fisheries worldwide indicates that sediment retention by dams can have a significant impact on coastal fish production. However, agricultural development and urbanization are alternative sources of phosphates, organic matter and other fertilizers. A thorough analysis of expected nutrient inputs from these anthropogenic sources and their positive impact on coastal fisheries remains to be done.

2.8 ANALYSIS BY DAM CLUSTER

2.8.1 UPSTREAM CLUSTER OF DAMS

2.8.1.1 CHANGES IN HYDROLOGY

Upstream of Vientiane, in 2015 as well as in 2030, discharge will be 40 to 60% higher in the dry season than in 2000. However, most of the change is due to Chinese dams and the additional changes due to Lower Mekong mainstream dams are limited. In the wet season water level will be around 50 cm lower than compared to the baseline (again, no major difference between 2015 and 2030). So from a seasonal perspective, mainstream dams in the upstream cluster will not have a major impact on the hydrology of that area already driven by Chinese and tributary dams. However, the daily variability in water levels created by several of these dams operation in peak mode might be very substantial, but could not be documented here due to lack of data.

2.8.1.2 EXPECTED LOSSES WITHOUT MAINSTREAM DAMS

This section of the river is characterized by typical stream species living in riffles and fast flowing waters (Balitoridae, Cobitidae, etc; see Fisheries Baseline Assessment). In case of the Definite Future scenario (absence of LMB mainstream dams), the increased dry season discharge due to Chinese dams is expected to alter riffles and shallow habitats used by species for breeding and as nurseries. The construction of 17 dams on tributaries in the upstream cluster (-46,000 km^2, see ANNEX 1: Dam projects in the BDP2 scenarios and corresponding characteristics) will also reduce fish habitat. As a consequence, a drop in the recruitment of local species is expected even in absence of mainstream dams in the upstream cluster. The contribution of these upstream species to the fish biodiversity of the basin is very important: with 93 species, Balitoridae represent the second most species-rich family in the Mekong, after Cyprinidae. The analysis based on habitat loss (BDP2 approach) predicts that in 2030, in absence of mainstream dams, there would be a loss of 210,000 to 540,000 tonnes of fish per year compared to the 2000 baseline, this loss being due to the degradation of various environmental factors.

2.8.1.3 EXPECTED LOSSES WITH MAINSTREAM DAMS

POSSIBLE FISH BIODIVERSITY LOSSES: LMB mainstream dams in the upstream cluster will have two main consequences: they will act as a barrier to fish migration and modify riverine habitats by creating reservoirs. The 6 upstream dams would create 403 km^2 or 715 linear kilometers of reservoirs, i.e. slow lacustrine, largely deoxygenated and stratified water in lieu of the former running waters (the two deepest reservoirs of the basin, Luang Prabang and Sanakham – average depth of 13 m and 54 m respectively, see Table 59, would be located in this zone).

Table 59: Length of reservoir created in the upstream cluster in relation to river length.

Dam	Reservoir length (km)	Total length of reservoirs (km)	River Length (km)	% of mainstream turned into a reservoir
Pak Beng	180	715	795	90
Luang Prabang	150			
Xayaburi	100			
Pak Lay	110			
Xanakham	90			
Pak Chom	85			

According to existing species records (MFD 2003, Dubeau 2004), the zone between Vientiane and the Chinese border includes 189 fish species. Out of these, an analysis of the MRC Mekong Fish Database records shows that at least forty-one species are not found elsewhere in the LMB (ANNEX 5: Mainstream fish species highly vulnerable to dam development). Mainstream dams will trigger a significant change in habitat, but stream species will also be subject to the impact of the other dams on tributaries. One species (*Acheilognathus deignani*) provides an extreme example of the outlook for some stream fishes in this zone: this species is found in the mainstream *and* in the Nam Ou River only; regardless of plans in the mainstream, in the Nam Ou Basin there are plans for 11 other dams (projects Nam Ou 1 to 7, to be operational between 2013 and 2015, with a height comprised between 47 and 147 m, plus Nam Nga, Nam Phak, Nam Ngao and Nam Pok projects, planned after 2017, 5 - 69 m high).

Conclusions: In the upstream migration zone biodiversity is clearly at risk. Following the construction of 6 mainstream dams in this area, 90% of the river stretch between the Chinese border and Vientiane would be turned into a reservoir. At least 41 species are threatened by a severe alteration of their habitat. By comparison this number corresponds for instance to about half the total freshwater fish fauna of the United Kingdom (99 species). The family most exposed would be Balitoridae (river loaches), with about 10% of its 93 Mekong species at risk. The iconic, endemic and critically endangered Mekong Giant Catfish would also be at great risk of total extinction since its main breeding area is located in this area, near Chiang Saen. However, since 17 other dams blocking access to 46,000 km^2 upstream of tributaries are also planned in the area, habitat alteration and impact on fish biodiversity are not specifically due to mainstream dams. There is no information as to whether any of the 41 species specifically threatened can survive in reservoirs.

POSSIBLE FISH PRODUCTION LOSSES (2030, 6 MAINSTREAM DAMS IN THE UPPER LMB): In this upstream cluster zone, the local fish production amounts to 40,000 – 60,000 tonnes per year (see Fisheries Baseline Assessment), which represents 2-3% of the most likely fish production basinwide (i.e. 2.1 million tonnes) or 3-5% of the fish production along the mainstream (Fisheries Baseline Assessment, Table 28).

At the local level, in absence of other mainstream dams and based on the assumption of a 50% loss in capture fisheries (Quiros 2004), the fish losses in catches of the local fishery would amount to of 20,000 to 30,000 tonnes of capture fish.

At the basin level, in the absence of other mainstream dams, but in the presence of the other tributary dams planned by 2030, 31% of the basin will be specifically obstructed by the dams of the upstream cluster. The (conservative) BDP2 analysis of fish losses based on habitat changes indicates that by 2030, if 6 dams are built upstream of Vientiane, a loss of about 120,000 tonnes of fish per year is to be expected compared to the situation in 2015, as well as a specific loss of about 60,000 tonnes compared to the situation in 2030 without these 6 mainstream dams.

POSSIBLE FISH PRODUCTION GAINS DUE TO DAMS: The mainstream dams of the upstream cluster will create 403 km^2 of reservoir. This area can be expected to produce between 800 and 8,000 tonnes of reservoir fish, the most likely estimate being 3,000 tonnes. This production will be supplemented by that from dam reservoirs on tributaries, but there is no information about the cumulative surface area of these projects on tributaries, so their potential reservoir production cannot be precisely assessed. As a crude alternative estimate, one can note that the surface area of exisiting reservoirs in northern Lao PDR and Thailand ranges between 10 and 80 km^2 (Bernacsek 1997); if we take 40km^2 as an average, this corresponds to around 700 km^2 for the 17 dams planned, and depending on the level of productivity, the corresponding reservoir fish production would range between 1,400 and 14,000 tonnes, which, added to the production of mainstream reservoirs, would represent between 2,000 and 20,000 tonnes of fish, the most likely estimate being around 7,000 tonnes of reservoir fish per year in this zone.

Conclusions:

In the upstream cluster zone, the local fish production represents 5% maximum of the Mekong fish production. In this area covering 123,700 km^2 there might be 23 hydropower projects by 2030 [33], which means that the river network would be largely obstructed by dams, and that the local habitat of the 189 local fish species will change drastically. Following dam development a loss of fish production and of fish biodiversity is to be expected.

At the local level, the loss of capture fish (20,000 – 30,000 tonnes) and the additional production of reservoirs (most probably around 7,000 tonnes) would result in a net loss of 13,000 to 23,000 tonnes of fish supply. This would be a very substantial risk for food securlity, corresponding to 15% to a third of the whole annual meat production of the country[34].

2.8.2 MIDDLE CLUSTER OF DAMS

2.8.2.1 CHANGES IN HYDROLOGY

In 2015, according to the BDP2, between Vientiane and Pakse, discharge will be one third higher in the dry season than in 2000. These forecasts are roughly in line with those of BDP1 and the WorldBank, but not with those of the Nam Theun 2 project that predicts more than doubling of the flow in the dry season. BDP2 forecasts are almost identical for the other scenarios (2030 with 0, 6, 9 and 11 mainstream dams), with just a few percent variation in wet season discharge compared to the situation forecasted in 2015, i.e. dry season discharge increased by a third compared to 2000.

During the monsoon season, according to BDP2, the water level will be 30 cm lower in 2015, although there is a discrepancy with other studies that forecast between -40 cm to -1.6 m. For the 2030 scenarios the wet season water level is expected to decrease by 40 to 50 cm maximum, whatever the number of dams on the mainstream.

Like in the upstream cluster, the very substantial daily variability in flows to be expected from Latsua dam planned to operate in peak mode (2 m daily variability in its reservoir level) could not be detailed nor analyzed by lack of data.

[33] Nam Beng (30 MW; 2014), Nam Dong (1 MW; 1970), Nam Ko (2 MW; 1996), Nam Long (5 MW; 2013), Nam Nga (98 MW; 2017), Nam Ngay (1 MW; 2002), Nam Ou 1 (180 MW; 2013), Nam Ou 2 (90 MW; 2014), Nam Ou 3 (300 MW; 2013), Nam Ou 4 (75 MW; 2014), Nam Ou 5 (108 MW; 2013), Nam Ou 6 (210 MW; 2014), Nam Ou 7 (180 MW; 2015), Nam Pha (147 MW; 2016), Nam Suang 1 (40 MW; 2016), Nam Suang 2 (134 MW; 2016), Nam Tha 1 (168 MW; 2013), plus the 6 mainstream projects

[34] http://faostat.fao.org/site/610/DesktopDefault.aspx?PageID=610#ancor

2.8.2.2 EXPECTED LOSSESS WITHOUT MAINSTREAM DAMS

Given the absence of taxonomic records in the mainstream between the two dam projects and Vientiane, it is difficult to identify species that are dependent on the mainstream in this section of the river.

In the absence of mainstream dams, in 2015 188,000 km^2 (23.6% of the LMB) would be barred by dams on tributaries anyway, and in 2030 296,000 km^2 of watershed, i.e. 37.3% of the LMB, would be obstructed (see ANNEX 1: Dam projects in the BDP2 scenarios and corresponding characteristics). This would represent a loss of 4 and 17% of connectivity compared to the baseline situation in 2000. This loss implies a loss of access to breeding areas upstream of tributaries, and a subsequent loss of productivity to be expected even without mainstream dams. A variety of other factors detailed in the Fisheries Baseline Assessment and unrelated to LMB mainstream dams (e.g. loss of connectivity in floodplains, increased fishing pressure, etc.) will contribute to fish catch reduction.

The analysis based on habitat loss predicts that in 2030, in the absence of mainstream dams, there would be a loss of 210,000 to 540,000 tonnes of fish per year basinwide compared to the 2000 baseline, this loss being due to the worsening of other environmental factors.

2.8.2.3 EXPECTED LOSSESS WITH MAINSTREAM DAMS

POSSIBLE FISH BIODIVERSITY LOSSES: With the 2 dams of the middle cluster, 165 kilometers of river, i.e. 23% of the mainstream between Pakse and Vientiane, would be turned into a reservoir. This would have a definite impact on biodiversity, although the magnitude of this impact could not be quantified here.

Table 60: Length of reservoir created in the middle cluster in relation to river length.

Dam	Reservoir length (km)	Total length of reservoirs (km)	River length (km)	% of mainstream turned into a reservoir
Ban Koum	155	165	713	23
Lat Sua	10			

The Latsua dam, although located only 34 km below the Ban Kum dam, would have much more negative impact on fish migrations and production than the latter because it would block access to the Mun/Chi system (70,000 km2). With 270 species (see Fisheries Baseline Assessment), biodiversity in the Mun/Chi system is very high and this basin is subject to intensive fish migrations. The Latsua dam would have the same impact than the Pak Mun dam on Mun-dependent fish species, plus additional impact on species migrating up the mainstream, and the construction design does not mention sluice gates.

Given the absence of taxonomic records in the mainstream between the two dam project and Vientiane, it is difficult to identify species that are dependent on the mainstream in this section of the river. However, some species identified thanks to the analysis detailed in the Fisheries Baseline Assessment are specifically at risk.

If Ban Kum dam is built, 28 of the long distance migratory species have an alternative in the 3S system (except if Lower Sesan 4 is built) and in the Mun/Chi system (except if the Pak Mun dam is closed). Four species do not migrate towards the 3S system: *Boesemania microlepis, Cyclocheilichthys enoplos, Pangasius polyuranodon, Pangasius sanitwongsei*; they represent at least 1.7% of the fish production. If Latsua or Stung Treng dams are built, 26 of these species have an alternative in the 3S system (except if Lower Sesan 4 or the 20 other dams considered in these 3 watersheds are built).

Table 61: Some particular fish species related to the Mun / Chi system.

	Family	Scientific Name	Information available
Species closely associated with the Mun / Mekong confluence	Cyprinidae	*Aaptosyax grypus*	Found only in large rivers of the Middle Mekong Basin. Most common along the Thai-Lao border at the mouth of the Mun River; it also used to occur in Mun and Songkhram Rivers, but is now an extremely rare species.
	Cyprinidae	*Cyclocheilichthys heteronema*	An uncommon fish in the Mekong. Occurs just upstream from Khone Falls at the mouth of the Mun River. Also recorded in the Great Lake.
	Cyprinidae	*Mystacoleucus chilopterus*	Distribution: Mekong Basin in Lao PDR and Thailand (mouth of Nam Mun) and possibly in Yunnan. Recorded from the Mae Kok at Chiang Rai and Mae Poon.
	Pangasiidae	*Helicophagus waandersii*	In the Mun River, the species migrates upstream from the beginning of the rainy season to the end of August and move back downstream from late September to November. Distribution: found basinwide in the mainstream of the Mekong.
	Pangasiidae	*Pangasius kunyit*	This species is impacted by the Pak Mun dam, because it blocks its migration route. The fish pass is not working properly, and the rapid habitats where the fish used to spawn have been inundated by the head pond. Distribution: the northern boundary for this species is at Chiang Saen, however the main distribution range is from Nakhon Phanom to Kandal Province in Cambodia. Now very rare in the Mun River.
Species related to the Mun system	Cyprinidae	*Cyclocheilichthys furcatus*	Known from the Middle Mekong along the Thai-Lao border to the Tonle Sap. Recorded from the confluence between the Mun and the Mekong Rivers and from the Mekong at Ban Tha Kai 21 kilometres downstream from Mukdaharn.
	Cyprinidae	*Mekongina erythrospila*	In the Mun River, the species migrates upstream from the beginning of the rainy season to the end of August and move back downstream from late September to November. Occurs from Chiang Saen to Pak Lay, but was not reported from Chiang Khan to Paksan. Occurs again at Thakhek and downstream to Sambor. Also recorded from Xe Bangfai, Nam Theun, and Chi Rivers.
	Pangasiidae	*Pangasianodon gigas*	May spawn in the delta or mouth of the Mekong; other spawning grounds have been identified in the mainstream of the Mekong River near Chiang Rai, and in the Mun River at Ubon Ratchathani.
	Pangasiidae	*Pangasius conchophilus*	An important spawning ground appears to be in the Mekong mainstream somewhere between Kompong Cham and Khone Falls and in rapids and riffles of the Mun River. Distribution: the distribution range is from the Mekong Delta all the way along the Mekong to Chiang Saen.

Source: MFD 2003

POSSIBLE FISH PRODUCTION LOSSES (2030, 9 DAMS, NO CAMBODIAN MAINSTREAM DAMS): Under this scenario 78% of the basin would not be accessible to migratory fish coming from downstream floodplains, and 41% of the Basin would be specifically obstructed by mainstream dams (ANNEX 1: Dam projects in the BDP2 scenarios and corresponding characteristics).

At the basin level, the analysis of fish losses based on habitat changes indicates that i) by 2030, if 9 dams are built in the LMB, a specific loss of about 140,000 tonnes of fish per year is to be expected compared to the situation in 2030 without mainstream dams. The losses inherent to the 6 upstream dams of the Lao cluster should not be deducted from those attributable to the middle cluster since the area impacted by the latter would encompass the area impacted by the upstream cluster.

The above estimate is very conservative and is subject to uncertainties such as, for instance, the future management of the Pak Mun dam (6 Km upstream of the confluence with the Mekong River). Until 2001 dam gates were permanently closed, then open until 2002, then open 4 months a year until 2007, then they were permanently closed again. The Pak Mun dam controls access to the Mun/Chi sub-basin (120,000 km^2) and blocks migrations between the mainstream and this basin, and its significant impact on fish production has been reviewed in Amornsakchai *et al.* (2000). According to this study, the closure of the Mun River impacted in particular 17 migratory fish species, including 15 catfish species, whose migration routes were blocked, and whose spawning ground habitats upstream were modified. Jutagate *et al.* (2001) also found that after Pak Mun dam closure, only 96 fish species remained out of the previous 265 species.

POSSIBLE FISH PRODUCTION GAINS DUE TO DAMS: The Ban Koum and Latsua mainstream dams would create 147 km^2 of reservoir. This area can be expected to produce between 300 and 3,000 tonnes of reservoir fish, the most likely estimate being 330 tonnes.

<u>Conclusions</u>: The Latsua dam would have a much more negative impact on fish migrations and production than the Ban Kum dam because if would block access to the Mun/Chi system. It would then repeat the impacts of the Pak Mun dam on the Mun River, in addition to those on the mainstream. Under this scenario 78% of the basin would not be accessible to migratory fish coming from downstream floodplains. The risk of capture fish production losses in case the dams of the middle cluster are built amounts to 350,000 – 680,000 tonnes per year compared to the baseline situation (in 2000), and to about 140,000 tonnes a year compared to the situation in 2030 without mainstream dams. The amount of reservoir fish to be expected from this cluster amount to about 300 tonnes per year only.

2.8.3 DOWNSTREAM CLUSTER OF DAMS

2.8.3.1 CHANGES IN HYDROLOGY

In 2015, according to the BDP2, in the downstream migration zone of the LMB, from Pakse down to the sea, the dry season discharge would be 13 to 22% higher than in 2000. Like in other comparisons, these results are similar to those of the WorldBank and BDP1 forecasts, but much lower than the Nam Theun 2 predictions (+125%). In the wet season in 2015, average water level would be around 30 cm lower than in 2000.

In terms o f discharge or water level, BDP2 forecasts are almost identical for the other scenarios (2030 with 0, 6, 9 and 11 mainstream dams), with just a few percent variation compared to the situation forecasted in 2015.

In terms of changes in floodplains, when compared to 2000, BDP2 predicts a loss of 250,000 ha of floodplains in the whole Basin by 2015 and a loss of 309,000 ha of floodplains by 2030 (-5 and -7% respectively). It is not clear whether this forecast integrates the notion of double ring (detailed in Figure 45) due to the increase of 30 cm of water level in the dry season. Additional forecasts include, for the Tonle Sap area, a reduction of flood duration by 2 weeks to 1 month and a reduction of sediment inflow in the system of at least 8 to 13%.

2.8.3.2 EXPECTED LOSSESS WITHOUT MAINSTREAM DAMS

The factors that apply to the downstream cluster of dams are the same as those previously detailed:

- in the absence of mainstream dams, in 2015 188,000 km^2 (23.6% of the LMB) would be barred by tributary dams; in 2030 296,000 km^2, i.e. 37.3% of the LMB, would also be obstructed by dams on tributaries (see ANNEX 1: Dam projects in the BDP2 scenarios and corresponding characteristics). This loss of 4 and 17% of connectivity compared to the baseline situation in 2000 implies a loss of natural fish productivity even without mainstream dams.

- multiple factors detailed and unrelated to LMB mainstream dams (e.g. loss of connectivity in floodplains, increased fishing pressure, agricultural development in the Tonle Sap and subsequent pesticide inputs, reduced sediment inflow due to 77 tributary dams modifying productivity of the estuarine and costal zone, etc.) will contribute to fish catch reduction. The fact that 250,000 ha of floodplains will be lost by 2015 is a third main factor influencing fish production even in the absence of mainstream dams. This loss corresponds to a loss of capture fish production of between 13,000 and 50,000 tonnes[35].

The analysis based on habitat loss (BDP2 approach) predicts that in 2030, in the absence of mainstream dams, there would be a loss of 210,000 to 540,000 tonnes of fish per year basinwide compared to the 2000 baseline, this loss being due to the worsening of other environmental factors.

2.8.3.3 EXPECTED LOSSESS WITH MAINSTREAM DAMS

POSSIBLE FISH BIODIVERSITY LOSSES: The Fisheries Baseline Assessment has shown that 204 species are found in the mainstream at the level of Kratie, and 168 species are found below of Khone Falls. Out of these, the analysis of migration patterns described in the Mekong Fish Database (ANNEX 4: Dominant species in Mekong catches and their migration patterns) has identified 43 species undertaking long-distance migrations through the mainstream. It is clear that a number of additional species would be impacted by the transformation, between Kratie and Pakse, of 42% of the mainstream into reservoirs, but the exact number of species at risk could not be specified during this study.

Table 62: Length of reservoir created in the downstream cluster in relation to river length.

Dam	Reservoir length (km)	Total length of reservoirs (km)	River length (km)	% of mainstream turned into a reservoir
Don Sahong	5	140	330	42
Stung Treng	45			
Sambor	90			

Overall, the analysis of lengths of reservoirs created in each cluster shows that if 11 reservoirs are built, 55% of the mainstream will be turned into a dam reservoir. If Cambodian dams are not built, “only” 48% of the mainstream would be turned into a lake.

Table 63: Linear length of reservoirs and total length of the mainstream.

Total length of reservoirs (km)	1,020
River length (km)	1,838
% of mainstream turned into a reservoir (between Chiang Saen and Kratie)	55

POSSIBLE FISH PRODUCTION LOSSES (2030, 11 MAINSTREAM DAMS): following this scenario 81.3% of the Basin river network and fish migration routes would be obstructed by dams, 44% of this obstruction being due specifically to mainstream dams

Overall, *at the Basin level*, the analysis of fish losses based on habitat changes indicates that i) by 2030, if 11 dams are built in the LMB, an annual loss of 550,000 to 880,000 tonnes of fish is to be expected compared to the situation in 2000, and a specific loss of around 330,000 tonnes is forecasted compare to the situation in 2030 without mainstream dams. The losses inherent to the dams of the middle and upstream clusters should not be deducted from those attributable to the downstream cluster since the area impacted by the latter would encompass the area impacted by the former clusters.

POSSIBLE FISH PRODUCTION GAINS DUE TO DAMS: The Stung Treng and Sambor mainstream dams would create 950 km^2 of reservoir. This area can be expected to produce between 2000 and 19,000 tonnes of reservoir fish, the most likely estimate being around 4,700 tonnes.

[35] [250,000 x 50 kg/ha/y] – [250,000 x 200 kg/ha/y]

2.8.3.4 EXPECTED LOSSESS IN BIODIVERSITY

If all LMB mainstream dams proceed, 55% of the Mekong River between Chiang Saen and Kratie would be converted into reservoir, shifting the environment from riverine to lacustrine[36]. This would have major impacts on species composition and productivity, since reservoirs would not be able to support the same fish species diversity as the more diversified natural riverine system, and would result in a loss of the number of Mekong fish species. An additional 58,000 hectares of floodplain habitat would be lost due to dam development and subsequent changes in flooding.

At least 41 mainstream species out of 262 species in the ecological zone upstream of Vientiane are threatened by a severe alteration of their habitat. There is no information as to whether any of these species threatened can complete their life cycle in reservoirs. The family most exposed would be Balitoridae (river loaches), with about 10% of its 93 Mekong species at risk. The iconic, endemic and critically endangered Mekong Giant catfish would become extinct in the wild since its main breeding area is located in this area, near Chiang Saen. However, beyond these 41 mainstream species, it is not possible to separate the impacts of the 6 proposed mainstream dams from the 17 proposed tributary dams.

Impacts of the middle and lower clusters of dams on biodiversity are unclear. Fish biodiversity in these zones is high (386 and 669 species respectively) and would decrease, but the specific impact of mainstream dams compared to that of other drivers such as land use changes, habitat fragmentation or agricultural intensification could not be quantified.

[36] This corresponds to 43% of the length of the Mekong between the Chinese border and the sea.

AVOIDANCE AND MITIGATION MEASURES

3 AVOIDANCE AND MITIGATION MEASURES

3.1 INTRODUCTION

The current report is purposely titled "*Avoidance and mitigation*" to highlight the fact that instead of just focussing on *a posteriori* mitigation, avoidance measures can also be taken to reduce both impacts and the costs of mitigation. The impact of dams on fish resources can in fact be best minimized by integrating fisheries considerations in a dam project *before* it is designed or even before its location is decided.

We detail below 9 types of measures aimed at reducing the impact of dams on fish resources and subsequently on fisheries. They pertain to three main categories: i) before dam construction (location and design of the hydropower project); ii) during dam construction (clearance of reservoir vegetation, reservoir filling schedule, fish passes); and iii) after dam construction (reservoir aeration, environmental flows and mitigation of downstream impacts)

It is important to note that not all of these methods will be effective to mitigate the impacts of the Mekong mainstream dams, so the presentation of main measures will be followed by a discussion of potential uses and limitations of each.

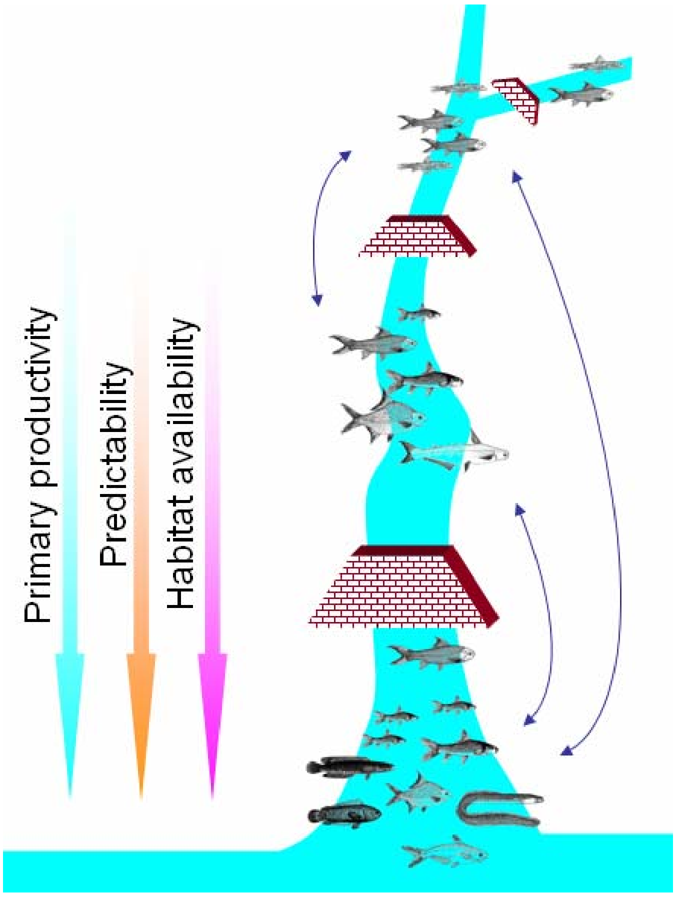
3.2 AVOIDANCE MEASURES BEFORE DAM CONSTRUCTION

3.2.1 DAM LOCATION

Dam location is most often based on water head considerations (hydropower generation requires a significant difference in water level between the upstream and the downstream parts of the site), landscape (deep valleys are more suitable than flat lands for dam construction), and geological factors (the dam needs to be built on solid ground). Ultimately, dam sites are often selected solely for their suitability for hydro-electric power generation, though this criterion may often be balanced with social considerations (i.e. the number of people displaced). Given the importance of fish resources in the Mekong, potential effects on fisheries should be integrated into the analysis of potential dam location.

It generally holds among biologists that dams located high on tributaries are less damaging to fish resources than those located downstream and on the mainstream. Upstream sections of rivers are characterized by fish assemblages made of fewer permanent species and less biomass than downstream assemblages (Illies and Botosaneanu 1963, Amoros *et al.* 1982). In addition, downstream habitats receive nutrients transported by the river from upstream and are characterized by higher productivity.

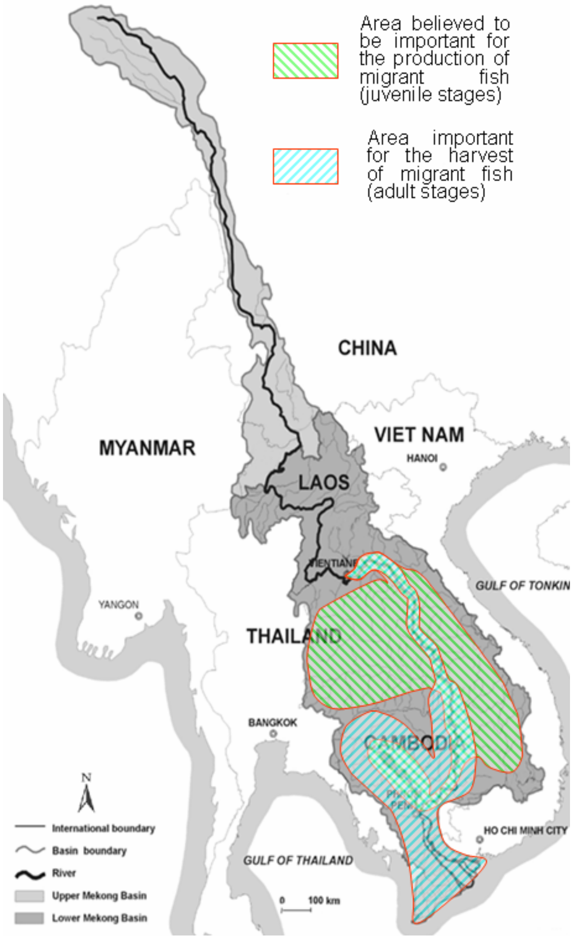
Figure 53: Fish communities, migrations and dams along a standard river gradient.



However, in a system like the Mekong that is also characterized by long-distance migrations, analyses based only on total harvested biomass would be misleading, since such analyses would not integrate the larval phase of the fish production that depends, for many species, on upstream tributaries. Integrating the requirements of the larval phase is possible through an analysis of migration ranges (at least for dominant or commercially important species).

In the case of the Mekong, Halls and Kshatriya (2009) consider that data and information concerning both the distribution of spawning habitat in the basin and the population structure are currently inadequate to determine if the hypothesis that dams built in the upper reaches of rivers have less impact than those built in downstream is reasonable. According to these scientists all dams, regardless of their location, should be regarded as a significant threat to the viability of fish population in the Mekong, particularly those of large species.

Figure 54: Components of the fish production in the Mekong system. It is necessary to integrate larvae and juveniles originating from upstream breeding sites with adults harvested downstream.

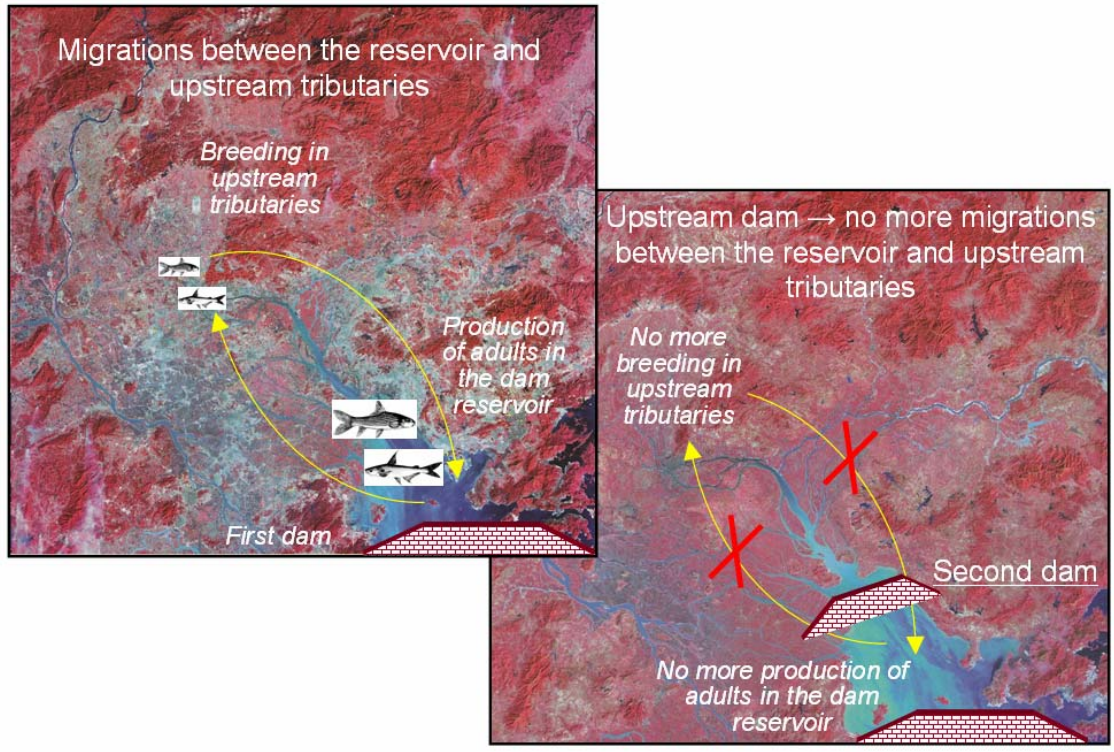


The location of dams on upstream sections of a river system also influences fish production in downstream dam reservoirs. In a number of cases, including the Nam Ngum 1 reservoir in Lao PDR (Dubois 2008), natural reservoir fish productivity can remain relatively high as long as fish (that initially lived in a riverine system and had to adapt to a newly created lake environment) can continue migrating upstream to breed in upstream tributaries under unmodified conditions. A second dam placed upstream prevents such migrations. This applies to the Nam Ngum 1 reservoir in Lao PDR, where new dam projects upstream of the Nam Ngum River and on upstream tributaries can be predicted to result in a decline of the Nam Ngum 1 reservoir fish production[37] .

Therefore, the decline or loss of reservoir fish production can be avoided by *not* locating a new dam on a tributary flowing into an existing dam reservoir.

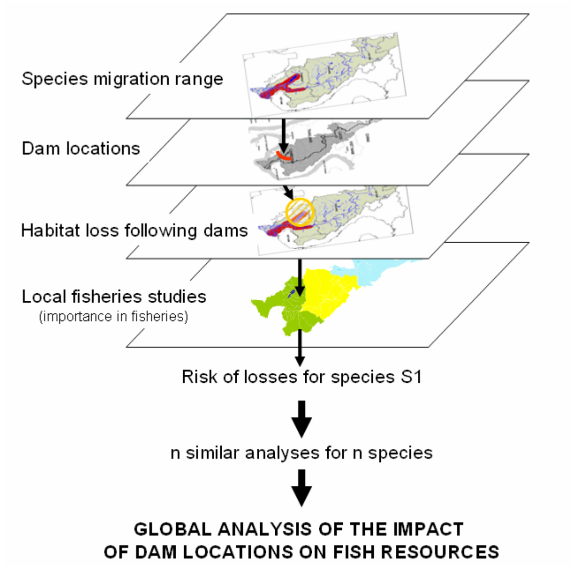
[37] "Directly associated with the productivity of the Nam Ngum 1 reservoir is the role that the Nam Bak plays in supporting many of the more than forty species of indigenous fish species requiring migration into and out of the reservoir for part or parts of their life cycles".
"3rd- and 4th-order stream, including e.g. Nam Bak, Nam Xan and Nam Xong, are of importance specifically in their role as spawning and feeding areas, particularly for the productivity of the Nam Ngum 1 reservoir". Dubois 2008.

Figure 55: Impact of an upstream dam on a downstream dam reservoir production.



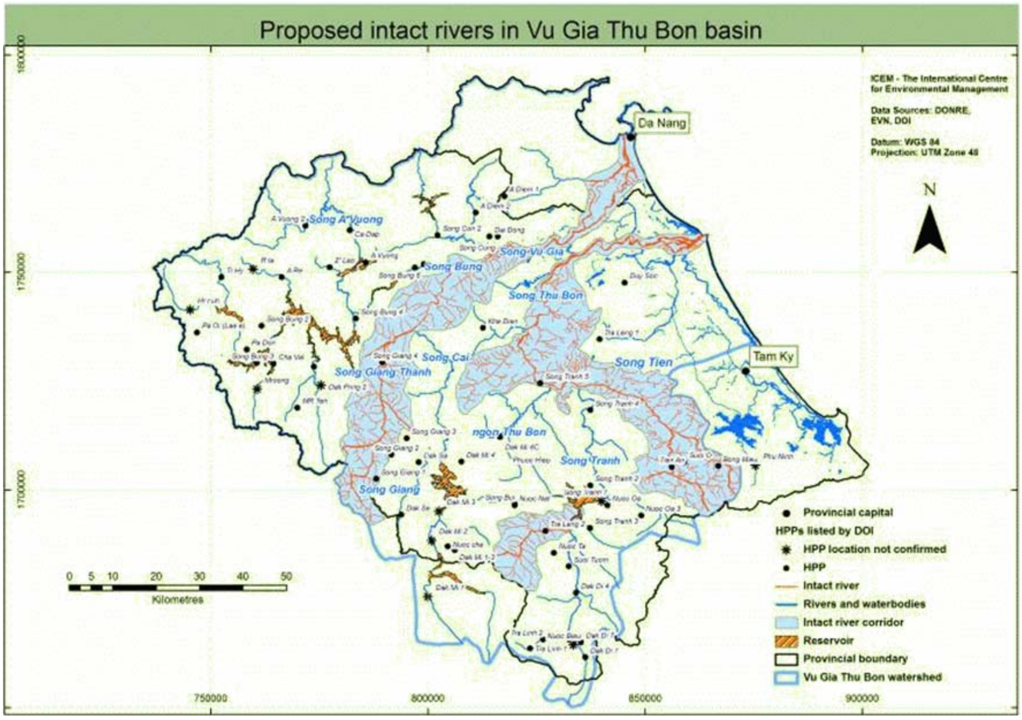
When choosing the location of a dam, or selecting between several possible hydropower projects, multi-criteria approaches should be used. The figure below shows how an analysis of impacts of dam locations on fish species can be undertaken.

Figure 56: Multi-criteria analysis of dam locations to minimize impacts on fish resources.



Above all else, when considering the location of a dam in a river basin from a fisheries perspective, it is critical to maintain at least one intact migration system for fish, from the sea to the mountains (e.g. Vu Gia - Thu Bon system in Viet Nam, upstream of Da Nang, ICEM 2008). Integrating this concept of the intact river into the dam planning stage is an important step in preserving migratory fish populations in the LMB.

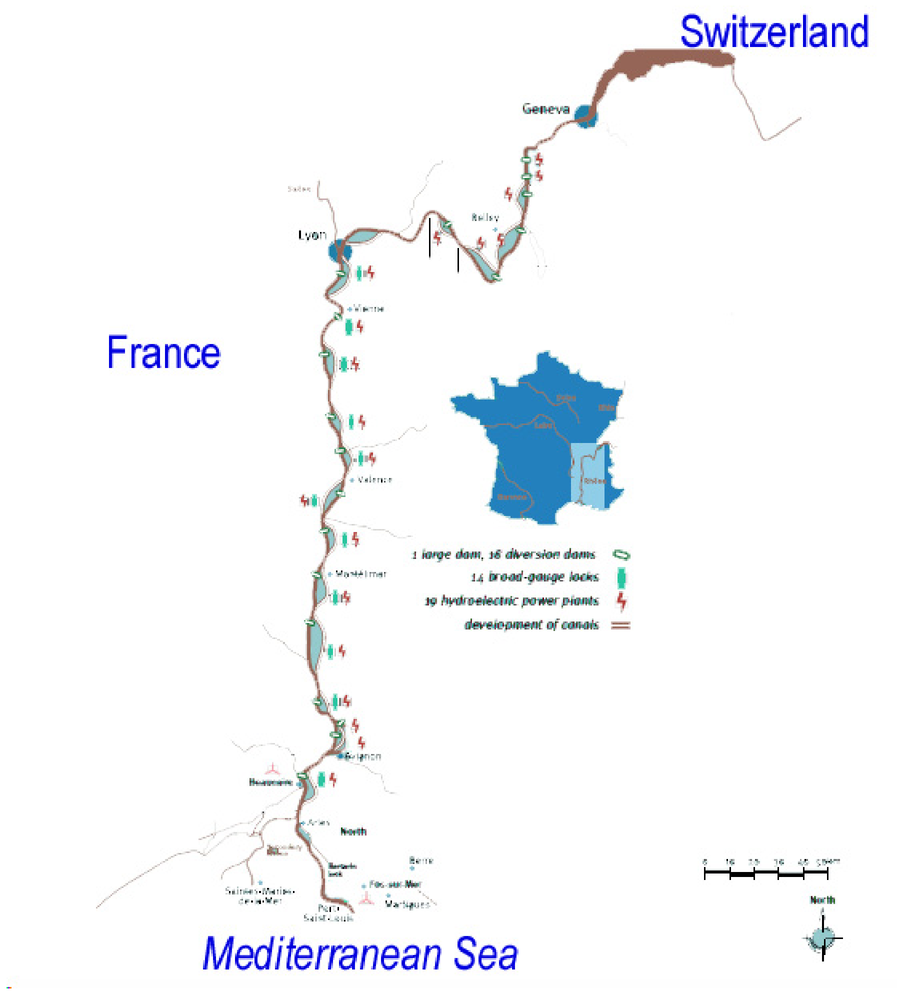
Figure 57: SEA of the Vu Gia - Thu Bon river system in Viet Nam and identification of the river to be left dam-free (in blue) for fisheries considerations. Source: ICEM 2008.



3.2.2 INTEGRATED HYDROPOWER PROJECTS

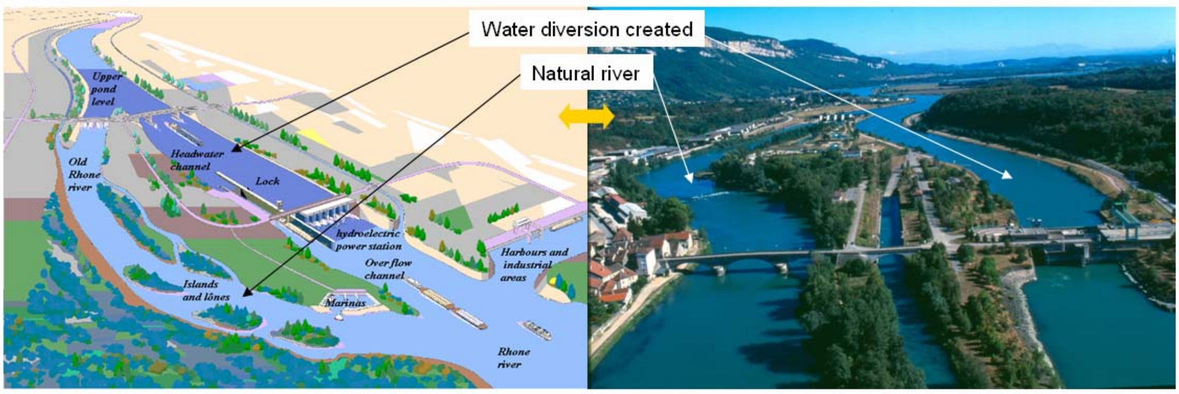
Hydropower schemes do not always consist of dams across rivers, as illustrated by some projects in which a water diversion canal was created in order to use a fraction of the river water and leave the original river available for natural functions, including fish migrations and breeding sites. This is illustrated, for instance, on the Rhone River in Switzerland and France, where 18 hydropower plants producing 3,000 MW have been constructed on 18 river diversions over 500 km of river.

Figure 58: Rhone River: derivation canals (highlighted in blue) created to produce 3000 MW of electricity while minimizing impacts on the natural river. Source: Compagnie Nationale du Rhône.



These hydropower schemes coupled with derivation canals combine a variety of features (preserved natural habitats for fish, navigation locks, tourism facilities, etc) and illustrate an integrated approach of hydropower generation combining several social and environmental dimensions.

\Figure 59: Multi-purpose river management downstream of Lyon (France). The original river keeps flowing on the left, while the newly created water diversion produces electricity and integrates facilities for industrial development, navigation and tourism. Source: CNR

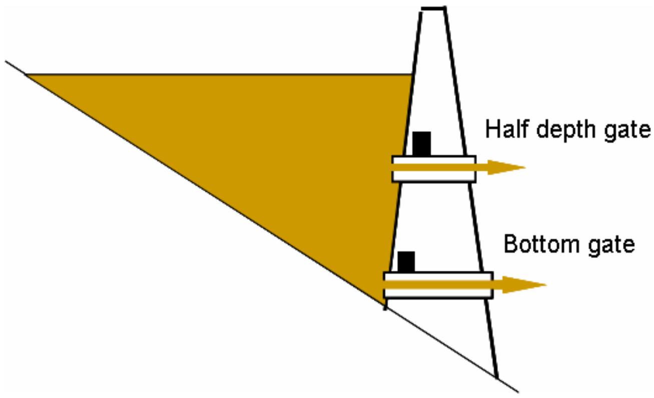


3.2.3 OFFTAKE MANAGEMENT

At a much more specific level, some other measures minimizing the impact of dams can be integrated to their design phase; these measures include offtake management and spillway design. We present here simple conceptual outlines for each, technical details being out of the scope of this brief overview.

Because offtake of anoxic reservoir water can result in fish mortality downstream (Agostinho *et al*. 2007), the use of multiple offtake levels is suggested. This can help to control the quality of discharges, and reduce the thermal gradient across the reservoir. This measure can also improve the control of discharge turbidity. As this is a relatively straightforward mitigation measure, it should be included at the planning stage of dams (IEA 2000).

Figure 60: Reservoir offtake at 2 different levels.



3.2.4 SPILLWAY DESIGN AND DOWNSTREAM AERATION

The design of spillways is often based mainly on hydrological and engineering considerations; however, the shape of the spillway also influences water quality downstream. Therefore in order to integrate an environmental perspective and minimize impact on fish resources, the design of spillways should also be discussed at the dam design stage.

Proper design of spillways can increase downstream turbulence, improving gas exchange and methane release from reservoir waters of poor quality. However, as is always the case, improvements in downstream water quality can never fully replicate pre-development conditions (IEA 2000). Re-aeration downstream can be also achieved via downstream re-aeration weirs or by river morphology engineering (Richard *et al.* 2005). The creation of rocky meanders downstream can improve aeration as well as slow the force of flows and reduce bank erosion. This measure is very site-specific, but is a promising option where appropriate.

Figure 61: Two different types of spillway designs. Photos: Matt Kondolf and Itaipu Binacional

3.3 AVOIDANCE AND MITIGATION MEASURES DURING DAM CONSTRUCTION

We here review the options available for mitigation in terms of fish passage facilities alongside other management measures such as vegetation clearing in the reservoir and filling schedules. All these measures can together contribute to minimizing impacts of dams on fish resources.

3.3.1 VEGETATION CLEARING

Clearing vegetation before reservoir filling is a way to reduce, if not mitigate, the impacts of dams on fish resources. There are conflicting views regarding the need to remove vegetation, as decaying vegetation not cleared prior to filling can decrease water quality (Trussart *et al.* 2002), but may also provide nutrients, habitat, and protection for fish (Ploskey 1985, Bernacsek 2000, Agostinho *et al.* 2007). In addition, vegetation left in place can help to prevent bank erosion.

The differing effects of uncleared vegetation may be attributed to the type of vegetation in question; so-called 'soft' vegetation (such as bark, leaves, and shrubs) decays quickly in the first years and often leads to putrid, low-quality water conditions. 'Hard' vegetation such as tree trunks and roots decays more slowly and also provides substrate and shelter for fish. An extensive literature review (Baran *et al.*, in press) led to the conclusion that the best practice is partial vegetation removal from the reservoir area prior to filling. Cleared areas should be used for navigation and fishing activities, leaving the uncleared areas for fish habitat and shelter (Bernacsek, 2000). It is important that not just logs be removed for wood trade, leaving behind brush and leaves, as this can negate the positive effects of vegetation clearing (Agostinho *et al.* 2007). Controlled burning may also be of help, particularly when it reduces 'soft' matter and leaves the 'hard' vegetative matter in place. Thus the partial clearing of vegetation from the reservoir area, aimed at creating both navigation routes and fish habitat, is recommended as a standard practice aimed at reducing impacts on fish resources in the reservoir and downstream.

Figure 62: Partial vegetation clearing in a reservoir to create a network of navigation channels, remove soft vegetation and keep habitats for fish. Photo: E. Baran.

3.3.2 FILLING SCHEDULE

Some large reservoirs can take years to fill, and dam operators sometimes completely block the river or leave only a minimal outflow in order to reach faster the full production potential. In either case this is insufficient for sustaining the downstream ecosystem. In order to minimize downstream impacts, filling should take place during the rainy season, when water levels are higher and the system is less sensitive to changes (Lohani *et al.*, 1997). Downstream flow releases during impoundment should mimic seasonal flow patterns, in order to maintain ecosystem integrity. The recommended practice is to mimic seasonal flow patterns in releases during filling, and to **not reduce downstream flow by more than 10%,** as officially recommended by the ADB (Lohani *et al.* 1997). The management of downstream flows during filling must be closely monitored and conform to rainfall patterns.

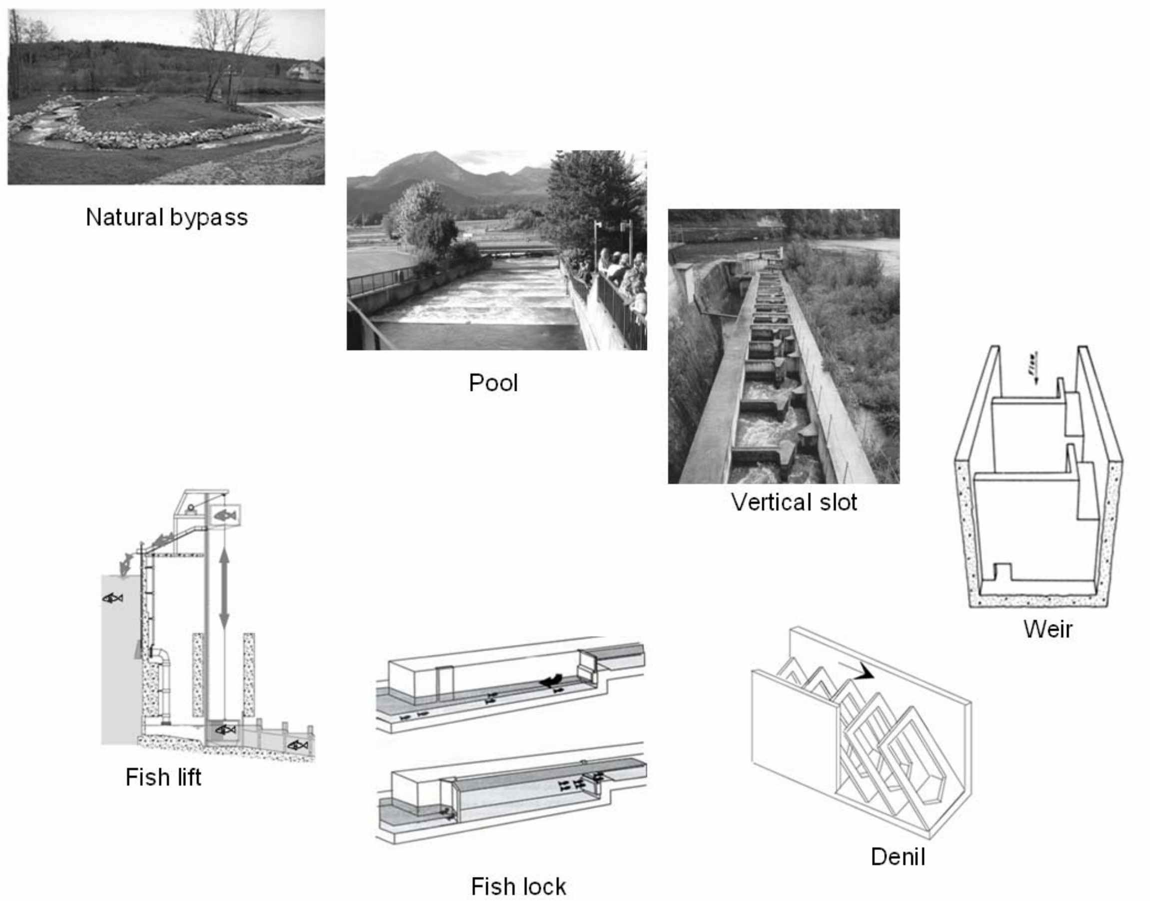
Figure 63: Releasing enough water downstream during the construction phase avoids destruction of aquatic resources. Downstream segment of the river dried up during the construction phase; Nam Lik 1-2 project, Nam Lik River, Lao PDR. Photo: E. Baran.

3.3.3 FISH PASSES

One of the major impacts of dams on fisheries is the blocking of fish migrations. Fish passes have been proposed as a means to mitigate this impact to varying extent. Information and experience about fish passes is extensively reviewed in BFPP (2002) and FAO/DVWK (2002) and more recently in Baran *et al.* (in press).

There are seven types of fish passes[38] that can help mitigate the barrage effect of the dam on fish migrations. The characteristics and limitations of these fish passes are outlined below, in relation to the 11 Mekong mainstream dams (and keeping in mind that the average height of these dams ranges between 8m -Don Sahong- and 76m -Pak Beng-, the average height of the mainstream dams being 43 meters).

Figure 64: The seven main types of fish passes.



[38] Classifications vary slightly depending on authors, sometimes "pool" and "weir" types are lumped as one single type, "Denil" is classified under "baffle" type, "natural by-pass" is called "rock ramp", etc.

3.3.3.1 NATURAL BYPASS CHANNELS

These passes are made by excavating a shallow channel in one of the river banks. The channel created bypasses the dam by linking the river downstream (tailwater) to the reservoir upstream (headwater). The channel is roughened with stone-blocks and alluvial material to mimic a real stream. This type is of fish pass common in France and in the Netherlands, and is suitable mainly for obstructions installed on rivers with a very low gradient, and for obstructions where the upstream water level remains virtually constant. Like other types of fish pass, water depths, current, flow patterns and turbulence levels must be adapted to river and target species. Natural bypasses 1 m deep, with a 2.8% slope and a minimum discharge of 0.6 $m^3.s^{-1}$ are suitable for small species of cyprinids. Santos *et al.* (2005) found natural bypasses to be effective in Portugal, but results have been mixed in other European rivers (Aarestrup *et al*. 2003, Schmutz *et al.* 1998). In the Mekong, these passes are possible only for low gradients, and one of these passes is considered for the Don Sahong dam, where the local environment makes it a possible option.

Figure 65: Natural bypass channel created on the Siikajoki River (Finland) to overcome a 4m high dam. Photo G. Marmulla.

3.3.3.2 POOL FISH PASSES

This type of fish pass uses a series of pools, which in gradual steps lead from the river at the foot of the obstruction to the river above. This division thus reduces the height for fish to clear at each step to a passable level, drops of 15 to 40 cm. These passes are designed based on hydraulic model studies and field experience (Larinier 2007), and may be the best solution when several migratory species are involved, and they would be most efficient for relatively low dams.

Figure 66: Pool fish pass of the Grand Coulee dam (USA). Photo Erin A. Barnes.

3.3.3.3 VERTICAL SLOT FISH PASSES

These passes are rectangular channels with a sloping or stepped floor and a series of baffles with vertical slots in each baffle. A vertical slot fish pass allows fish to swim upstream at their preferred depth without leaping over any obstacle. This type of pass can accommodate large upstream and downstream water level variations, and is particularly adaptable to low dams. In Australia, recent fish passes of the vertical slot type replaced early fish ladders of the pool and weir type, and have been much more successful, allowing large numbers of migrating broodstock and juveniles to access upstream habitats (Harris and Mallen-Cooper,1993, Mallen-Cooper 1994, Bernacsek 2000). However, while these passes have also been used successfully for low dams in France and Canada, there is no evidence that they would be effective for dams higher than 30 meters, and as such, these passes are best suited for dams lower than those currently planned in the Mekong.

Figure 67: Vertical slot fish pass on the Gardon River (France). Photo M. Larinier.

3.3.3.4 WEIR TYPE FISH PASSES

In this type of passes, notches and orifices in the weir are commonly used to modulate flow and provide different kinds of passages to fishes. These passes do not require an auxiliary flow in the downstream section or a control device regulating the flow upstream. Such passes are common on the North America Atlantic Coast, in the Columbia Basin and in Scotland. They can accommodate several species, in particular salmon and trout species, but are small in size and are definitely not appropriate for the size of migrations in the LMB.

Figure 68: Weir fish pass on the Spree River (Germany). Photo FAO/DVWK.

3.3.3.5 DENIL TYPE FISH PASSES

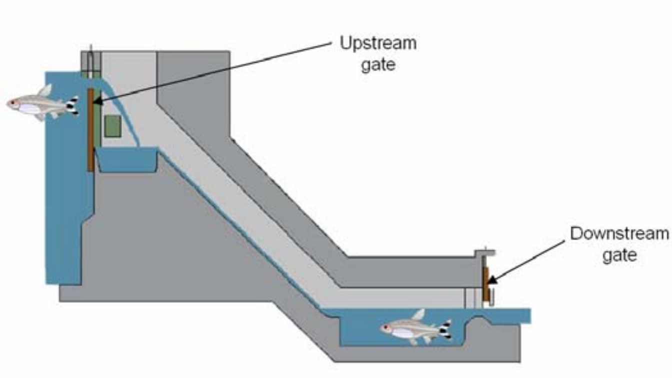
These channels contain symmetrical, closely spaced baffles on the sidewall and the floor; these baffles create turbulence and energy dissipation to control flow velocity. The passes are designed specifically so that the swimming speed of the target species to be accommodated is not exceeded within the fishway. Denil fish passes can tolerate only moderate variations in upstream water level. While relatively easy and cheap to build, these are best suited for smaller rivers. Appropriate for larger fish, this type of pass has mainly been used on the East Coat of North America, in Alaska and throughout Western Europe (Clay 1995). At a maximum height and slope of 30 m and 20%, respectively, these passes would be restricted to small tributaries in the Lower Mekong Basins.

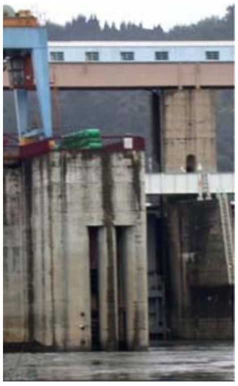
Figure 69: Denil fish pass (Trout Creek, USA). Photo Michigan DNRE.

3.3.3.6 FISH LOCKS

These locks are analogous to boat locks. When fishes are attracted into the lock, the downstream sluice gates are closed, the lock is filled in, and the upstream door is opened. The largest fish locks (30 m high) can be used for dams 10-60 m high, which is in the range required for LMB dams. However, a significant drawback is the low capacity of fish locks: they fill and empty slowly, so a limited number of fish can be transported per hour. Furthermore, the entire efficacy of a fish lock is based upon the ability to attract fishes into the lock at the outset. Given the diversity of migrating species in the LMB, it would be difficult to optimize the locks for multiple species.

Figure 70: Principle of a fish lock and view of the downstream gate of the Belver Dam (Portugal). Photo J. Bochechas.





3.3.3.7 FISH LIFTS

These passes are literally lifts, elevating fish in water from the tailwaters below the dam to the headwaters above the dam, where fish are released. Fish are trapped downstream in tanks on rails, and the tank is lifted by a cable up to the top of the dam, before fish are released in the reservoir. This device is used in Canada, USA, France, and Russia. Fish lifts have also been installed at dams in Brazil to enable the upstream migrations of tropical fish (Pompeu and Martinez 2005), but results have been disappointing (Oldani *et al*. 2007). These lifts can be used for high dams, over 8 m, which is appropriate for dams planned in the LMB. However, two aspects of fish lifts prohibit them from being of much use in the LMB: their capacity and size requirements. The lifts can only transport very small numbers of fish (10 to 50 individuals each time), and are only suited for transporting relatively large fish species. Furthermore, these lifts, while cheap to construct, have high operation costs. In Brazil, one of the few tropical countries having experience with fish lifts, the efficiency of the Santa Clara fish lift reached an average of 7% for all migratory species (Pompeu and Martinez 2007). Because of the sheer volume and diversity of Mekong fishes, fish lifts would be completely inappropriate.

Figure 71: Fish lifts of the Golfech Dam (France) and Paradise Dam (Australia) for upstream migrations, and waterslide for downstream migrations (Poutès, France). Note the small size of these facilities. Photos: F. Travade, S. Lamond and EDF.

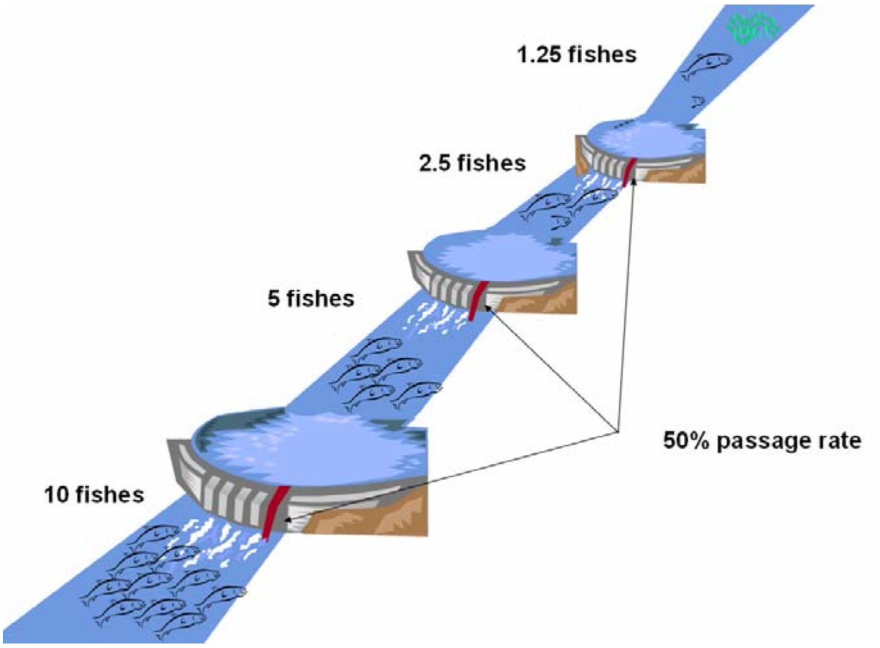
3.3.4 APPLICABILITY AND EFFICIENCY OF THE DIFFERENT FISH PASS SYSTEMS

Following extensive description and analysis of the different fish pass models, an overview is proposed by FAO/DVWK (2002; see following pages).

Whatever the fish pass model considered, an additional element must also be taken into account: the cumulative impact of dams. For example, should the passage efficiency of a given facility reach 50%, meaning that 50% of the fish in the river can get though the fish pass (which is considered a good performance), then only half of the initial stock would be able to continue migration after the first dam. Each additional dam would thus reduce further the size of the migrant population, to the extent that only 12.5% of the stock would remain after only the third dam. In the case of the Mekong, under the assumption of similarly efficient fish passes at each dam, only about a tenth of the Tonle Sap fish undertaking a migration upstream would be able to keep migrating towards their breeding grounds past the Latsua or Lower Sesan 2 dams.

Ultimately, it should be noted that the presence of an "efficient" fish pass is not a sufficient condition to ensure mitigation, since migrating fish also need to find appropriate conditions in the environment above the passage (e.g. access to spawning grounds and nursery areas).

Figure 72: Reduction of fish stocks in case of successive fish ladders.

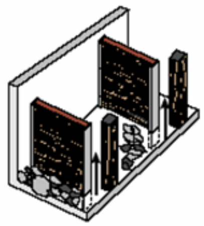
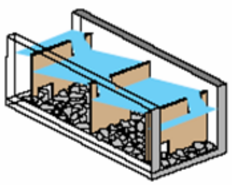
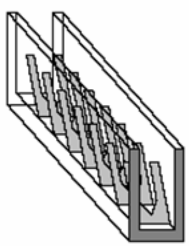


A review of fish passes in La Plata River Basin -a watershed almost four times bigger than the LMB and characterized by more than 450 dams- concluded that "existing fish passage technology in the Lower Basin is inadequate" (Oldani *et al.* 2007).

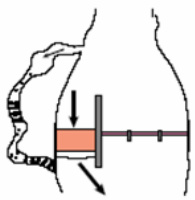
More generally, a global review of fish passages in South America[39] concluded that "management policies related to minimizing reservoir impacts were historically related to stocking (construction of hatcheries), fishery control (enforcement) and fish translocation (fish passages), usually constrained by law. Unfortunately, most of these actions failed, mainly because they were based on poor technical and scientific information and had unclear purposes. […] It was expected that efficient fish passages would lead to the maintenance of fish populations above reservoirs, without damaging downstream populations. However, this does not appear to be a simple task, as seen so far."

[39] Neotropical Ichthyology 2007, vol.5 no.2 Online: www.scielo.br/ni

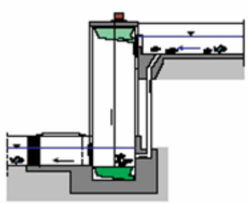
Technical structures

Type	Sketch	Principle	Dimensions* and discharge	Range of application	Advantages and disadvantages	Effectiveness
Slot passes		Slot passes are generally concrete channels with cross-walls of concrete or wood and with one or two vertical slots that extend over the whole height between the cross-wall and the lateral bounds.	Pool dimensions: l_b > 1.90 m; b > 1.20 m; h > 0.5 m; Slot width: s > 0.17 m. Discharge can be from Q = 140 l/s up to several cubic metres per second.	Used for small and medium heads, suitable for variable impounding heads. Can be used for small streams and large rivers. The minimum tailwater depth must be h > 0.5 m.	Relatively high discharges can be sent through, thus good attraction currents can form. More reliable than conventional pool passes because of the lower risk of clogging of the slots.	They are currently the best type of technical fish pass, being suitable for all species of fish and are passable for invertebrates if a continuous bottom substrate is built in.
Pool passes		Are generally concrete channels with cross-walls of wood or concrete which are fitted with submerged orifices and top notches on alternate sides.	Pool dimensions depend on the river zone; l_b > 1.4 m; b > 1.0 m; h > 0.6 m. Submerged orifices: b_S/h_S > 25 · 25 cm Discharge Q = 80 to 500 l/s.	Used for small and medium heads, at melioration dams and at hydroelectric power stations.	Only relatively low discharges allowed; there is great risk of clogging with debris.	Suitable for all species of fish if the dimensions of the pools and orifices are chosen as a function of the fish size that can be expected to occur. There might not be sufficient attraction current at low discharges.
Denil passes		Wooden or concrete channel with sectioned baffles (usually of wood) that are U-shaped, and are set at an angle of 45° against the flow direction.	Channels: b = 0.6 to 0.9 m; h > 0.5 m; < 1:5; Q > 250 l/s. Channel lengths can be 6 to 8 metres; resting pools are required for heights > 1.5 to 2 m.	Suitable for small heads, particularly for retrofitting of old milldams when there is not much space.	Relatively high discharges; should not be used for variable headwater levels; not sensitive to varying tailwater levels; need little space; cheap; good formation of attraction current.	According to present knowledge, less suitable for weak swimmers or small fish. Selective. Benthic fauna cannot pass.

Close-to-nature types of structures

Type	Sketch	Principle	Dimensions* and discharge	Range of application	Advantages and disadvantages	Effectiveness
Bypass channels (sect. 4.2)		Offer an alternative route round a dam with a natural-looking stream bypassing the impoundment.	b > 1.2 m; h > 0.20 m; < 1:20. The bypass should extend up to the upstream limit of the backwater. Discharge must be at least q = 100 l/s m.	Suitable for all barriers and heads if there is sufficient space, particularly useful for retrofitting existing installations. They are not suitable when impounding heads vary; in the latter case, inlet constructions for water regulation might be necessary.	Their financial cost is low, their demand for space high! Deep cuts into the surrounding terrain may be necessary or combination with other technical structures. Bridges or underpasses are often required.	They are passable for all aquatic fauna, provide living space for rheophilic species, are the only fish pass that can bypass the whole area of the dam and the impoundment, blend well into the landscape.

Special constructions

Type	Sketch	Principle	Dimensions* and discharge	Range of application	Advantages and disadvantages	Effectiveness
Fish locks		A pit-shaped chamber with controllable closures at headwater and tailwater openings. The attraction current is formed by controlling the sluice gate openings or by sending water through a bypass.	Their dimensions can vary, with minimum chamber width and water depth being similar to those in a pool pass. Water quantity requirements depend on chamber size, cycle intervals for lock operation and required intensity of attraction current.	Used for high heads, and where space or available water discharge is limited.	Planning and construction is often technically demanding. Require high efforts in maintenance and operating, high construction and service costs, low water consumption. Useful where very large fish (e.g. sturgeon) are to be taken into consideration.	According to present knowledge, suitable for salmonids and fish with weak swimming capacities. Less suitable for bottom-living and small fish.
Fish lifts		Lifting device with transport trough and mechanical drive to hoist fish from tailwater to headwater; connection to headwater through a channel; water sent through a bypass creates attraction current.	Dimensions variable, volume of transport trough about 2 to 4 m^3. Continuous flow through a bypass needed to create attraction current.	Used for same situations as fish locks, but often the only type of pass that can be built for heights greater than 10 metres, e.g. at high dams.	Need little space. Planning and construction is often technically demanding. Require high efforts in maintenance and operating, high construction and service costs.	According to present knowledge, suitable for salmonids and fish with weak swimming capacities. Less suitable for bottom-living and small fish. Not suitable for macrozoobenthic fauna or for downstream migration of fish.

3.3.5 FISH PASS APPLICABILITY IN THE MEKONG

Halls and Kshatriya (2009) have recently modeled the cumulative barrier and passage effects of mainstream hydropower dams on migratory fish populations in the Lower Mekong Basin, while distinguishing downstream and upstream migrations, for different fish guilds and size classes. Their conclusions are summarized below.

Downstream migrations: adults of the small species (<25cm) are predicted to experience a 2% – 15% mortality rate per dam crossed during their return migrations from upstream spawning habitat. This mortality can decline further if a large fraction of individuals could be safely by-passed via spillways, by-pass channels or sediment sluices. This assumption actually depends entirely on the design of the dam considered and on its operation mode.

Upstream migrations: the minimum upstream passage success to sustain wild populations depends for each species on i) the number of dams to be passed; ii) the exploitation rate (i.e. additional fishing mortality); iii) the reproductive potential of the species, and iv) the proportion of downstream migrating adults avoiding dam turbines through fish passes. For *small species*, the study predicts that fish ladders or other types of fish passes would need to pass at least 60 - 87% of adults migrating upstream in the case of a single dam, and 80 - 95% of these upstream migrating adults in the case of two or more dams if viable exploited populations are to be maintained. For *large species*, the study concludes that the impact of mainstream dams on migrations would be dramatic even if near perfect engineering solutions could be developed to re-direct 75% of downstream migrating adults and allow 90-100% of upstream migrations.

In the case of a single dam, exploited populations of large species such big pangasiids or barbs would remain viable only if 80% upstream passage and 75% downstream passage success rates are achieved. No large species are predicted to persist if three dams or more have to be crossed.

According to the literature review done, **the rates of upstream passage success necessary to sustain even the small species have not been achieved anywhere in the world**.

Mitigation: Halls and Kshatriya (2009) predict that populations of larger species are more likely to respond positively if mitigation efforts focus on redirecting downstream migrating adults away from turbines by a by-pass system. On the contrary redirecting small fishes and juveniles away from turbines seems to have little impact. The literature review done by these authors shows that estimates of downstream passage success (survival) range from 0% to 100%, average upper and lower estimates ranging from approximately 40% to 70% (mainly for juvenile stages). A major issue explaining the relative success of fish pass technology in Northern countries is highlighted:

> *Only after some 30 years of research and development at a cost of more than US$7,000 million, attempts to mitigate dam impacts on Pacific salmon populations in the Columbia River basin have been relatively successful compared to those in tropical systems. An important reason for this success might be that adult Pacific salmons die shortly after spawning and therefore are not subject to the strong size-dependent downstream passage mortality effects. In river systems such as the Mekong, adults of medium and large size species reproduce more than once during their lifetime and may therefore experience, because of dams, cumulative mortality rates too important to sustain viable populations.*

We review below the potential of fish passes as mitigation measures against the impact of dams on fish resources in the context of the Mekong, this system being characterized by an exceptional intensity and diversity of migrations detailed in the Fisheries Baseline section of this SEA.

Table 64: Summary of the 7 main types of fish passes, and of their prospective utility on the Mekong.

Fish pass type	Planned for	Major limitations/requirements and caveats	Number of species able to pass	Applicability on the Mekong mainstream
Pool pass		- Best for relatively low dams	Many	Possible only on low dams in tributaries
Vertical slot pass	Lat Sua Xayaburi	- Best for lower dams but may be applicable to mainstream dams	Many	Possible although the height of these dams (27 and 32m) is close to or beyond the efficiency limit of these passes
Weir type pass		- Best for low dams <10m	Several	Inapplicable (too small or too flat)
Denil type pass		- Small dams (<30 m height, <20% slope) - Large fish species	Several	Very unlikely to accommodate the intensity of fish migrations in December-January for downstream dams, and impossible for very high upstream dams
Natural bypass channel	Don Sahong	- Relatively unchanged upstream water level - Depth and gradient must be tailored for species	Potentially many	Don Sahong is the only case possible
Fish lock	Sambor (?)	- Low capacity - Must be able to attract fish into lock	Very few	Possible although very unlikely to accommodate the intensity of fish migrations in December-January in downstream dams
Fish lift		- Very low capacity - Large fish species	Few	Inapplicable (unable to accommodate the intensity of fish migrations)

So far, only 3 of the 11 mainstream dams (i.e. Latsua, Xayaburi, and Don Sahong projects) explicitly include fish passes at this stage; several other mainstream dams have no plans for fish passes or have not provided any details regarding passes possibly planned.

Table 65: Mainstream dams and fish passes planned in project documents[40]

	Dam height (m)	Fish pass
Pak Beng	76	No mention
Louang Prabang	68	No mention
Xayaburi	32	2 fish ladders, opening 3m x 10m
Pak Lay	35	Mentioned but no details
Sanakham	38	Mentioned but no details
Pakchom	55	Mentioned but no details
Ban Koum	53	Mentioned but no details
Latsua	27	800m x 10m x 3m; 4 fish entrances 10m wide
Don Sahong	10.6	Excavated by-pass channel
Thakho diversion	No dam (diversion)	Not required
Stung Treng	22	No mention
Sambor	56	3,398 m long; no details

As a conclusion, although some of these fish passes are realistic mitigation options for the medium-height dams in tributaries where migrations are not intensive, none of these fish passes can accommodate the size and intensity of fish migrations in the Mekong mainstream. Unfortunately **fish passes, whatever their type, are not a realistic measure to mitigate the impact of mainstream dams on mainstream fish migrations**.

These conclusions are echoed by the group of 17 international experts in fisheries and fish passes brought together by the MRC in September 2008 (Dugan 2008). These experts concluded that:

- existing mitigation technology cannot handle the scale of fish migration on the Mekong mainstream;
- if dams are built upstream and on tributaries, specific mitigation measures should be designed from the start and integrated into dam engineering and operation;
- in considering the design of mitigation measures existing off-the-shelf designs cannot be used, but the basic concepts used in developing these can be drawn upon.

These experts also recognized that the ability to provide the partial mitigation measures seen in North America and Europe has been dependent on substantive site-specific research and development over several decades, and that similar investments will be needed in the Mekong.

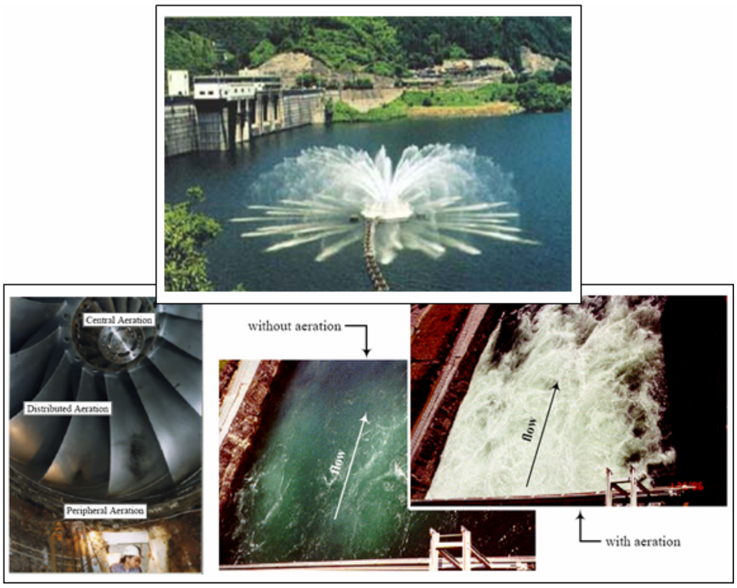
3.4 MITIGATION MEASURES AFTER DAM CONSTRUCTION

3.4.1 RESERVOIR AERATORS

De-oxygenation is a potential problem both in reservoirs and downstream of the dams, and aerators are a possible measure to address this problem. Increased aeration improves environmental conditions for fish, as it leads to growth of food sources and precipitation of contaminants (e.g. hydrogen sulphate, iron, and manganese). Downstream reoxygenation has been used with positive results (Trussart *et al*. 2002), as has aeration of small reservoirs (IEA 2000). However, forced aeration can become expensive in larger reservoirs (IEA 2000), and as such the use of auto-venting turbines would be preferential for improving discharge water aeration (March *et al*. 1992; March and Fisher 1999). Ideally, auto-venting turbines and reservoir aerators would be used in combination to improve the overall water quality, both in reservoirs and downstream.

[40] see SEA Inception report, volume II

Figure 73: Reservoir aerator (above), auto-venting turbine (below) and subsequent improvement of tailwater aeration. Source: Hopping *et al.* 1997.



3.4.2 MITIGATION OF DOWNSTREAM EFFECTS

In a manner analogous to the timing of flows during reservoir filling (discussed previously), it may be possible to mitigate some of the downstream impacts of dam operation through the maintenance of environmental flows.

Generally, estimates of water required to maintain a fair condition of freshwater ecosystems range from 20 to 50% of the mean annual flow quantity in a river basin (Smakhtin *et al.* 2004). It is important to note this is a global estimate, and does not account for any local geographic, seasonal, or ecological specificities. Furthermore, changes in water flow volume are not the only factors in ecological impacts; even when the dam does not, in principle, involve significant water retention (i.e. the theoretical case of run-of-the-river projects), the timing and dynamics of natural flows can be significantly modified, and this does have an ecological impact. Therefore minimizing or mitigating impacts of mainstream dams on fish resources calls for comprehensive case-by-case analyses of environmental flows required. Environmental flow studies are extremely complex and could not be reviewed or summarized here. However the magnitude of stakes definitely calls for environmental flow studies in the Lower Mekong Basin, and the cost of such studies would be modest by comparison with the budget of the projects themselves (between USD 1,787 million for Sanakham and USD 7,394 million for Sambor[41]) and the socio-economic and environmental implication of these projects.

3.5 CONCLUSION

Many mitigation measures are only possible or effective when considered from the earliest dam planning stages, such as dam location and design. However this also implies that dam planning is not done from a sole hydro-electric power generation viewpoint. Given the remarkable abundance of LMB fisheries resources and the importance of fisheries in the economic and food supply of the region, the fisheries perspective should form an integral part of dam planning and operation.

While there are promising measures that can help conserve some portion of fisheries on tributaries and for small scale dams, it is clear that existing mitigation techniques will not address the dramatic impacts of mainstream Mekong dams on fish resources.

[41] the cost of the Don Sahong project, the smallest of the 11 mainstream projects, is not known

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ANNEXES

5 ANNEXES

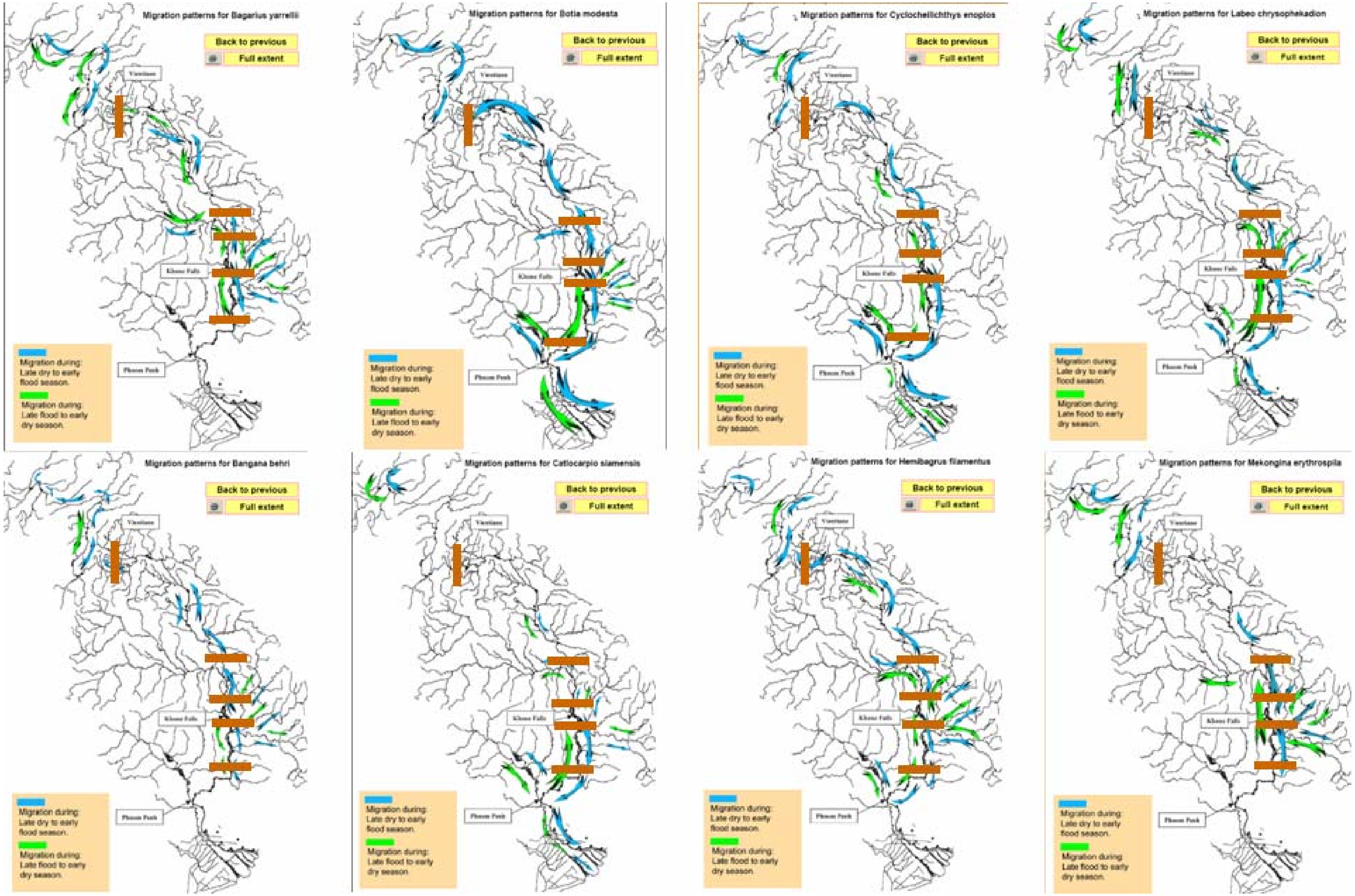
5.1 ANNEX 1: DAM PROJECTS IN THE BDP2 SCENARIOS AND CORRESPONDING CHARACTERISTICS

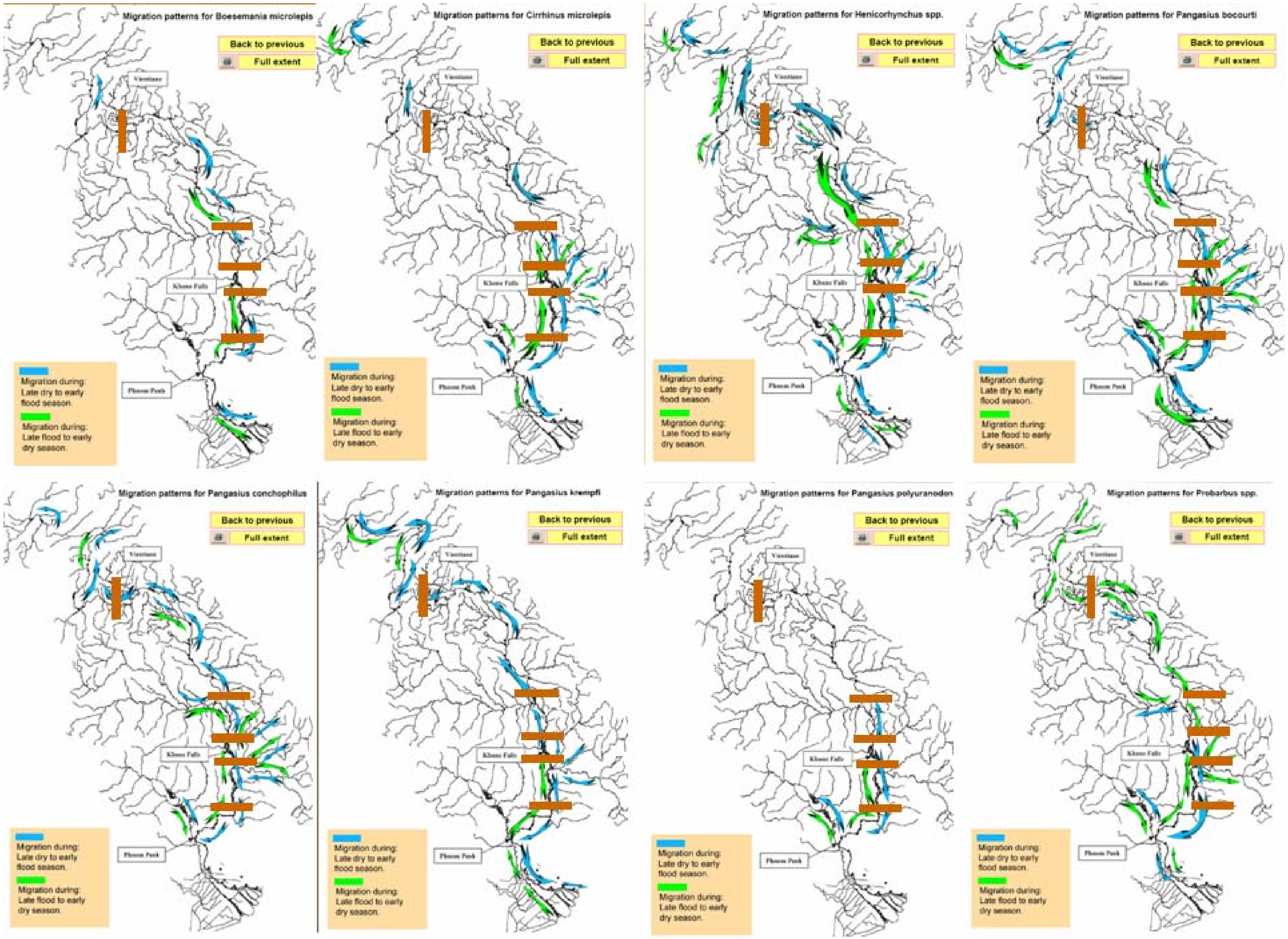
Project name	Basin	River	Cluster zone	Year	Watershed area	2000		2015		2030							
						S1. Baseline	Area S1	S2. Definite future	Area S2	S3. No MS dams	Area S3	S4. 6 MS dams in upper LMB MS	Area S4	S5. No Cam MS dams	Area S5	S6. All 11 MS dams	Area S6
Dochashan	Mainstream	Mainstream	China	2003				1	-	1	-	1	-	1	-	1	-
Ganlanba	Mainstream	Mainstream	China														
Gongouqiao	Mainstream	Mainstream	China					1	-	1	-	1	-	1	-	1	-
Jinghong	Mainstream	Mainstream	China	2008				1	-	1	-	1	-	1	-	1	-
Manwan	Mainstream	Mainstream	China	1996		1	-	1	-	1	-	1	-	1	-	1	-
Mengsong	Mainstream	Mainstream	China														
Nuozhadu	Mainstream	Mainstream	China	2014				1	-	1	-	1	-	1	-	1	-
Xiaowan	Mainstream	Mainstream	China	2013				1	-	1	-	1	-	1	-	1	-
Nam Beng	Nam Beng	Nam Beng	Ups.	2014	1,908					1	1,908	1		1		1	
Nam Dong	Nam Dong	Nam Dong	Ups.	1970	4	1	4	1	4	1	4	1	-	1	-	1	-
Nam Ko	Nam Ko	Nam Ko	Ups.	1996	223	1	223	1	223	1	223	1	-	1	-	1	-
Nam Long	Nam Ma	Nam Ma	Ups.	2013	156					1	156	1	-	1	-	1	-
Nam Ngay	Nam Ngay	Nam Ngay	Ups.	2002	315			1	315	1	315	1	-	1	-	1	-
Nam Ou 1	Nam Ou	Nam Ou	Ups.	2013	25,979					1	25,979	1	-	1	-	1	-
Nam Ou 2	Nam Ou	Nam Ou	Ups.	2014	22,568					1	-	1	-	1	-	1	-
Nam Ou 3	Nam Ou	Nam Ou	Ups.	2013	19,774					1	-	1	-	1	-	1	-
Nam Ou 4	Nam Ou	Nam Ou	Ups.	2014	11,799					1	-	1	-	1	-	1	-
Nam Ou 5	Nam Ou	Nam Ou	Ups.	2013	10,371					1	-	1	-	1	-	1	-
Nam Ou 6	Nam Ou	Nam Ou	Ups.	2014	5,527					1	-	1	-	1	-	1	-
Nam Ou 7	Nam Ou	Nam Ou	Ups.	2015	3,477					1	-	1	-	1	-	1	-
Nam Nga	Nam Ou	Nam Ou	Ups.	2017	2,477					1	-	1	-	1	-	1	-
Nam Pha	Nam Pha	Nam Pha	Ups.	2016	2,837					1	2,837	1	-	1	-	1	-
Nam suang 1	Nam Suang	Nam Suang	Ups.	2016	5,755					1	5,755	1	-	1	-	1	-
Nam Suang 2	Nam Suang	Nam Suang	Ups.	2016	5,195					1	-	1	-	1	-	1	-
Nam Tha 1	Nam Tha	Nam Tha	Ups.	2013	8,990					1	8,990	1	-	1	-	1	-
Pakbeng	Mainstream	Mainstream	Ups.	2016	218,000							1	-	1	-	1	-
Luangprabang	Mainstream	Mainstream	Ups.	2016	230,000							1	-	1	-	1	-
Xayabuly	Mainstream	Mainstream	Ups.	2016	272,000							1	-	1	-	1	-
Paklay	Mainstream	Mainstream	Ups.	2016	283,000							1	-	1	-	1	-
Sanakham	Mainstream	Mainstream	Ups.	2016	292,000							1	-	1	-	1	-
Pakchom	Mainstream	Mainstream	Ups.	2017	295,500							1	295,500	1	-	1	-
Sirindhorn	Lam Dom Noi	Lam Dom Noi	Middle	1971	2,097	1	2,097	1	2,097	1	2,097	1	2,097	1	-	1	-
Lam Ta Khong P.S.	Lam Ta kong	Lam Ta kong	Middle	2001	1,430			1	1,430	1	1,430	1	1,430	1	-	1	-
Pak Mun	Mun	Mun	Middle	1994	117,000	1	117,000	1	117,000	1	117,000	1	117,000	1	-	1	-
Nam Kong 1	Nam kong	Nam kong	Middle	2014	1,250					1	1,250	1	1,250	1	-	1	-
Nam Lik 1	Nam Lik	Nam Lik	Middle	2014	5,050					1	5,050	1	5,050	1	-	1	-
Nam Lik 2	Nam Lik	Nam Lik	Middle	2010	1,993			1	1,993	1	-	1	-	1	-	1	-
Nam Ngiep-regulating dam	Nam Ngiep	Nam Ngiep	Middle	2015	3,750					1	3,750	1	3,750	1	-	1	-
NamNgiep 1	Nam Ngiep	Nam Ngiep	Middle	2015	3,700					1	-	1	-	1	-	1	-
Nam Ngum 1	Nam Ngum	Nam Ngum	Middle	1971	8,460	1	8,460	1	8,460	1	8,460	1	8,460	1	-	1	-

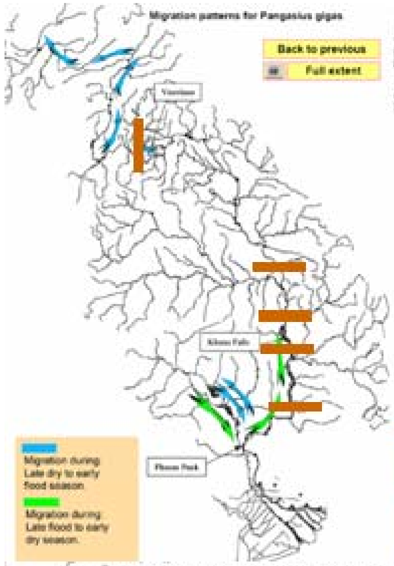
Project name	Basin	River	Cluster zone	Year	Watershed area	2000		2015		2030							
						S1. Baseline	Area S1	S2. Definite future	Area S2	S3. No MS dams	Area S3	S4. 6 MS dams in upper LMB MS	Area S4	S5. No Cam MS dams	Area S5	S6. All 11 MS dams	Area S6
Nam Ngum 2	Nam Ngum	Nam Ngum	Middle	2010	5,640			1	-	1	-	1		1	-	1	-
Nam Ngum 3	Nam Ngum	Nam Ngum	Middle	2014	3,888					1	-	1	-	1	-	1	-
Nam Ngum 5	Nam Ngum	Nam Ngum	Middle	2011	483			1	-	1	-	1	-	1	-	1	-
Nam Leuk	Nam Ngum	Nam Leuk	Middle	2000	274	1	-	1	-	1	-	1	-	1	-	1	-
Nam Mang 3	Nam Ngum	Nam Mang	Middle	2004	82			1	-	1	-	1	-	1	-	1	-
Chulabhorn	Nam Phrom	Nam Phrom	Middle	1972	545	1	545	1	545	1	545	1	545	1	-	1	-
Huai Kum	Nam Phrom	Nam Phrom	Middle	1982	282	1	-	1	-	1	-	1	-	1	-	1	-
Ubol Ratana	Nam Pong	Nam Pong	Middle	1966	12,104	1	12,104	1	12,104	1	12,104	1	12,104	1	-	1	-
Nam Pung	Nam Pung	Nam Pung	Middle	1965	296	1	296	1	296	1	296	1	296	1	-	1	-
Nam San 3	Nam San	Nam San	Middle	2014	155					1	155	1	155	1	-	1	-
Nam Theun1	Nam Theun	Nam Theun	Middle	2014	14,070					1	14,070	1	14,070	1	-	1	-
Theun-Hinboun expansion	Nam Theun	Nam Theun	Middle	2012	8,937			1	8,937	1	-	1	-	1	-	1	-
Theun-Hinboun	Nam Theun	Nam Theun, Hinboun	Middle	1998	8,927	1	8,927	1	-	1	-	1	-	1	-	1	-
Theun-Hinboun exp. (NG8)	Nam Theun	Nam Theun	Middle	2012	2,942			1	-	1	-	1	-	1	-	1	-
Xekaman-Sanxay (Xekaman2)	Xe Kaman	Xe Kaman	Middle	2011	3,740			1	3,740	1	3,740	1	3,740	1	-	1	-
Xekaman 1	Xe Kaman	Xe Kaman	Middle	2011	3,580			1	-	1	-	1	-	1	-	1	-
Nam Theun 2	Xebangfai	Nam Theun, Xe Bangfai	Middle	2009	4,013			1	4,013	1	4,013	1	4,013	1	-	1	-
Xelabam	Xedon	Xedon	Middle	1969	6,360	1	6,360	1	6,360	1	6,360	1	6,360	1	-	1	-
Houayho	Xekong	Houayho	Middle	1999	192	1	192	1	-	1	-	1	-	1	-	1	-
Xe Katam	Xenamnoy	Xenamnoy	Middle	2013	263					1	263	1	263	1	-	1	-
Xepian-Xenamnoy	Xepian/Xenamnoy	Xepian/Xenamnoy	Middle	2013	820					1	820	1	820	1	-	1	-
Ban Kum	Mainstream	Mainstream	Middle	2017	418,400									1	-	1	-
Latsua	Mainstream	Mainstream	Middle	2018	550,000									1	-	1	-
Don sahong	Mainstream	Mainstream	Middle	2013	553,000									1	553,000	1	-
O Chum 2	O Chum	O Chum	Downs.	1992	45			1	45	1	45	1	45	1	45	1	-
Lower Se San2 / Sre Pok 2	Se San	Se San	Downs.	2016	49,200					1	49,200	1	49,200	1	49,200	1	-
Se San 4A	Se San	Se San	Downs.	2008	9,368			1	9,368	1	-	1	-	1	-	1	-
Se San 4	Se San	Se San	Downs.	2009	9,326			1	-	1	-	1	-	1	-	1	-
Se San 3A	Se San	Se San	Downs.	2007	8,084			1	-	1	-	1	-	1	-	1	-
Se San 3	Se San	Se San	Downs.	2006	7,788			1	-	1	-	1	-	1	-	1	-
Yali	Se San	Se San	Downs.	2001	7,455	1	7,455	1	-	1	-	1	-	1	-	1	-
Plei Krong	Se San	Kroong Po Ko	Downs.	2008	3,216			1	-	1	-	1	-	1	-	1	-
Upper Kontum	Se San	Dak Bla/Dak Nghe	Downs.	2011	350					1	-	1	-	1	-	1	-
Sre Pok 4	Sre Pok	Sre Pok	Downs.	2009	9,568			1	9,568	1	9,568	1	9,568	1	9,568	1	-
Sre Pok 4A	Sre Pok	Sre Pok	Downs.	2009	9,568			1	-	1	-	1	-	1	-	1	-
Sre Pok 3	Sre Pok	Sre Pok	Downs.	2009	9,410			1	-	1	-	1	-	1	-	1	-
Dray Hlinh 2	Sre Pok	Sre Pok	Downs.	2007	8,880			1	-	1	-	1	-	1	-	1	-
Dray Hlinh 1	Sre Pok	Sre Pok	Downs.	1990	8,880			1	-	1	-	1	-	1	-	1	-
Buon Kuop	Sre Pok	Sre Pok	Downs.	2009	7,980			1	-	1	-	1	-	1	-	1	-
Buon Tua Srah	Sre Pok	Krong Kno	Downs.	2009	2,930			1	-	1	-	1	-	1	-	1	-

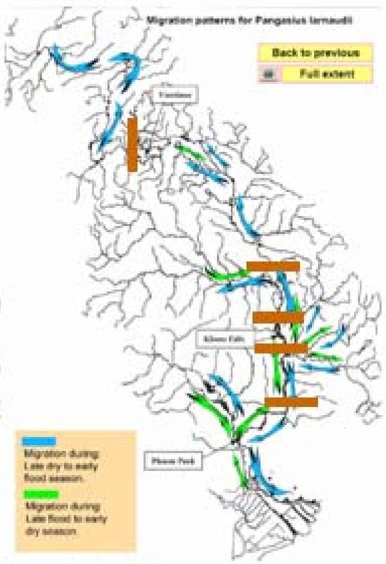
Project name	Basin	River	Cluster zone	Year	Watershed area	2000		2015		2030							
						S1. Baseline	Area S1	S2. Definite future	Area S2	S3. No MS dams	Area S3	S4. 6 MS dams in upper LMB MS	Area S4	S5. No Cam MS dams	Area S5	S6. All 11 MS dams	Area S6
Duc Xuyen	Sre Pok	Krong Kno	Downs.		1,100					1	-	1	-	1	-	1	-
Xeset 1	Xe Set	Xe Set	Downs.	1994	485	1	485	1	485	1	485	1	485	1	485	1	-
Xeset 2	Xe Set	Xe Set	Downs.	2009	392			1	-	1	-	1	-	1	-	1	-
Xe Kong 3d	Xekong	Xekong	Downs.	2012	9,700					1	9,700	1	9,700	1	9,700	1	-
Xe Kong 3up	Xekong	Xekong	Downs.	2012	5,882					1	-	1	-	1	-	1	-
Xekong 4	Xekong	Xekong	Downs.	2014	5,400					1	-	1	-	1	-	1	-
Xe Kong 5	Xekong	Xekong	Downs.	2016	2,615					1	-	1	-	1	-	1	-
Xekaman 3	Xekong	Houayho	Downs.	2009	712			1	712	1	-	1	-	1	-	1	-
Stung Treng	Mainstream	Mekong	Downs.	NA	635,000											1	-
Sambor	Mainstream	Mekong	Downs.	2020	646,000											1	646,000
		Nb of dams / km2 obstructed for migrations				*16*	164148	*47*	187695	*77*	296568	*83*	545901	*86*	621998	*88*	646000
LMB area (km2)		% of LMB obstructed for migrations				20.6		23.6		37.3		68.7		78.2		81.3	
795,000		Km2 obstructed specifically by LMB mainstream dams				0		0		0		S4 - S3 =	249333	S5 - S3 =	325430	S6 - S3 =	349432
		% of LMB obstructed specifically by mainstream dams				0		0		0		31		41		44	

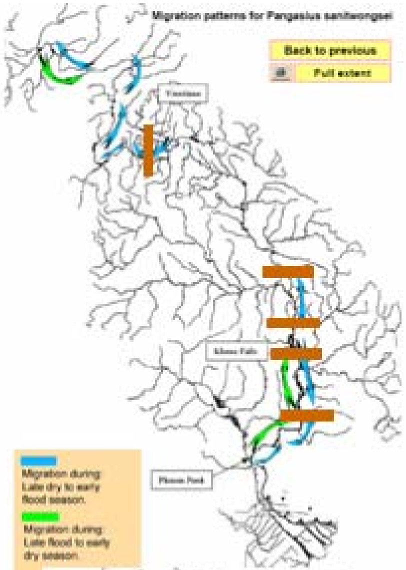
5.2 ANNEX 2: MIGRATION PATTERNS OF 23 MIGRATORY FISH SPECIES

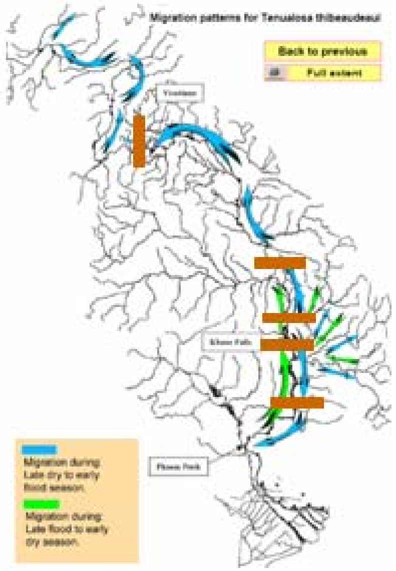


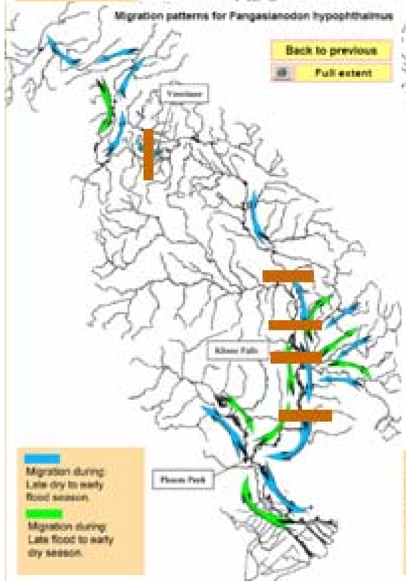

Migration patterns for Boesemania microlepis
Migration patterns for Cirrhinus microlepis
Migration patterns for Henicorhynchus spp.
Migration patterns for Pangasius bocourti
Migration patterns for Pangasius conchophilus
Migration patterns for Pangasius krempfi
Migration patterns for Pangasius polyuranodon
Migration patterns for Probarbus spp.
Back to previous
Full extent
Vientiane
Khone Falls
Phnom Penh
Migration during: Late dry to early flood season.
Migration during: Late flood to early dry season.

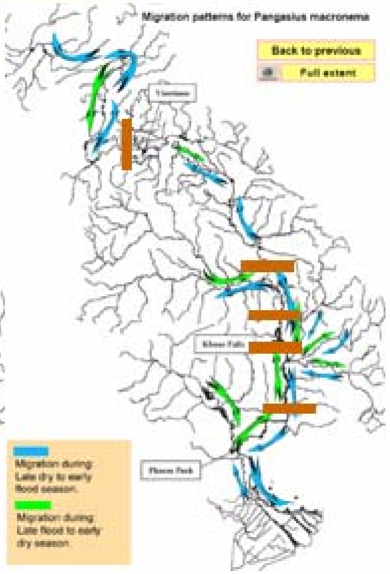

Migration patterns for Pangasius gigas
Back to previous
Full extent
Migration during Late dry to early flood season
Migration during Late flood to early dry season

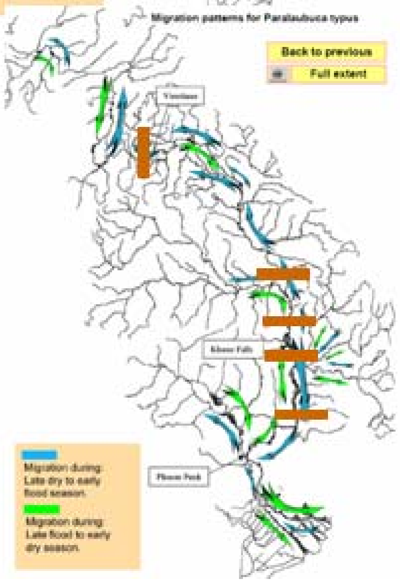

Migration patterns for Pangasius larnaudii
Back to previous
Full extent
Migration during: Late dry to early flood season.
Migration during: Late flood to early dry season


Migration patterns for Pangasius sanitwongsei
Back to previous
Full extent
Migration during: Late dry to early flood season.
Migration during: Late flood to early dry season.


Migration patterns for Tenualosa thibaudeaui
Back to previous
Full extent
Migration during Late dry to early flood season
Migration during: Late flood to early dry season.


Migration patterns for Pangasianodon hypophthalmus
Back to previous
Full extent
Migration during Late dry to early flood season
Migration during Late flood to early dry season.

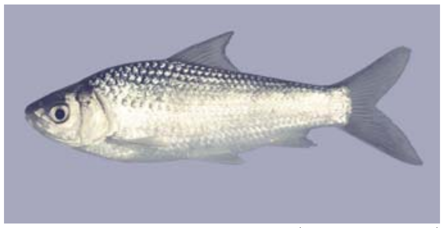

Migration patterns for Pangasius macronema
Back to previous
Full extent
Migration during Late dry to early flood season.
Migration during: Late flood to early dry season.


Migration patterns for Paralaubuca typus
Back to previous
Full extent
Migration during: Late dry to early flood season.
Migration during: Late flood to early dry season.

5.3 ANNEX 3: ECOLOGICAL INFORMATION ON TWO SPECIES DOMINANT IN MEKONG CATCHES

This information is extracted from the recent report
Baran E., So N. Information on migrant fish species dominant in Mekong fisheries. WorldFish Center and IFReDI, Phnom Penh, Cambodia. 62 pp.
prepared in February 2010 for the project *"Scenario-based assessment of the potential effects of alternative dam construction schemes on freshwater fish diversity in the Lower Mekong Basin" funded by the* Mitsui &. Co., Ltd. Environment Fund.

Henicorhynchus siamensis (Chavalit Vidthayanon)



Henicorhynchus siamensis (Rainboth, W)

Species	% of total catch	Cumulative % of total catch	Cumulative % among guilds at risk
Henicorhynchus siamensis	8.09	8.1	21

IDENTIFICATION:
- Family: Cyprinidae
- Species name: Henicorhynchus siamensis
- Remark: Formerly Cirrihinus siamensis

BIOLOGY:
- Max. standard length (cm): 20
- Length at maturity (cm): 12.9
- Status: Native

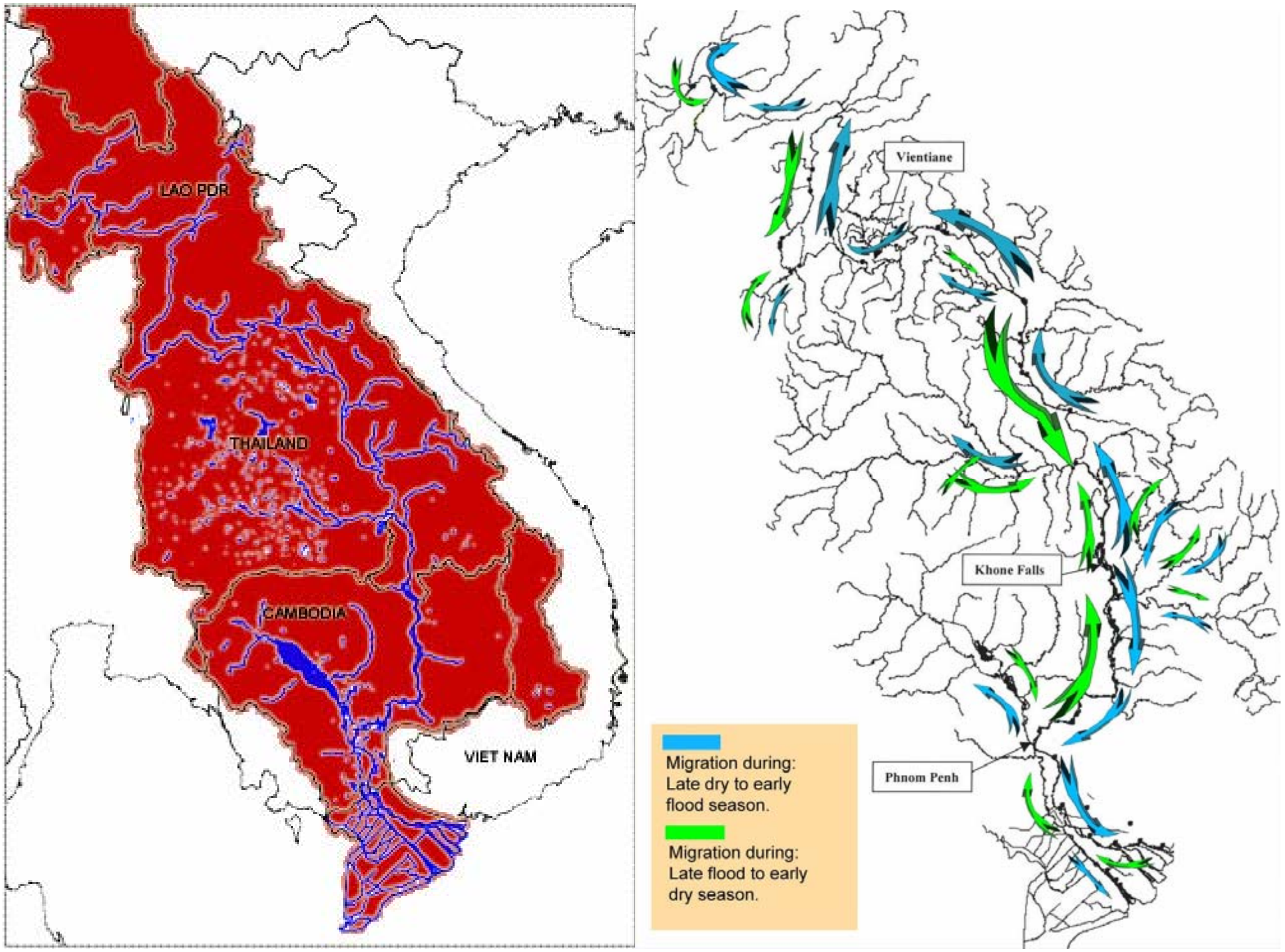
REPRODUCTION:
Spawning: Mature eggs are reported from April to July with a strong peak during May-June (Poulsen and Valbo-Jørgensen, 2000, Singanouvong et al. 1996). Spawns in the rainy season (Baird et al., 1999).
- Breeds in reservoirs: not known to prosper in impoundments (Rainboth, 1996).

No information on breeding in reservoirs
- Spawns in rivers (%respondents): 100
- Nurses in floodplain (%respondents): 100

ECOLOGY:
- Habitat: Benthopelagic. Often found in great abundance at midwater to bottoms depths in large and small rivers.

Distribution: occurs from the Mekong Delta all the way along the Mekong mainstream to Chiang Khong (Poulsen and Valbo-Jørgensen, 2000); also recorded from the Xe Bangfai Basin (Roberts, 1997).
Migration: From Xayaboury to Chiang Khong, the fish migrates upstream from March to July, first the juveniles, later followed by the adults. At Khone Falls medium sized fish migrate downstream, while large individuals migrate upstream during the wet season. These migrations are for reproductive purposes, and during the migration the fish feeds very little relying on fat deposits around the viscera (Singanouvong et al., 1996). From the Khone Falls the fish migrate downstream from May to July, towards the large floodplains located north and south of Phnom Penh and all the way to the Mekong Delta. Here, the fish migrate out of the Mekong into canals and flooded areas during August-September (Poulsen and Valbo-Jørgensen, 2000). When the water recedes it enters the Tonle Sap from the flooded areas along the river and the Great Lake (Lieng et al. 1995, Poulsen and Valbo-Jørgensen 2000, Rainboth 1996), when in the Tonle Sap, they migrate down to the Mekong (Lieng et al. 1995) and from October to February continue their journey upstream the Mekong, at least until they reach the Khone Falls (Lieng et al. 1995, Poulsen and Valbo-Jørgensen 2000).
- Discharge as migration trigger: Discharge variation is a migration trigger (So Nam, pers. comm., 2007)
- Water level as migration trigger: no information

GUILD: White (So Nam, pers. comm., 2007)



Records, distribution (in red) and migrations of *Henicorhynchus siamensis*

Pangasius conchophilus (IFReDI collection)

Pangasius conchophilus (Rainboth, W.)

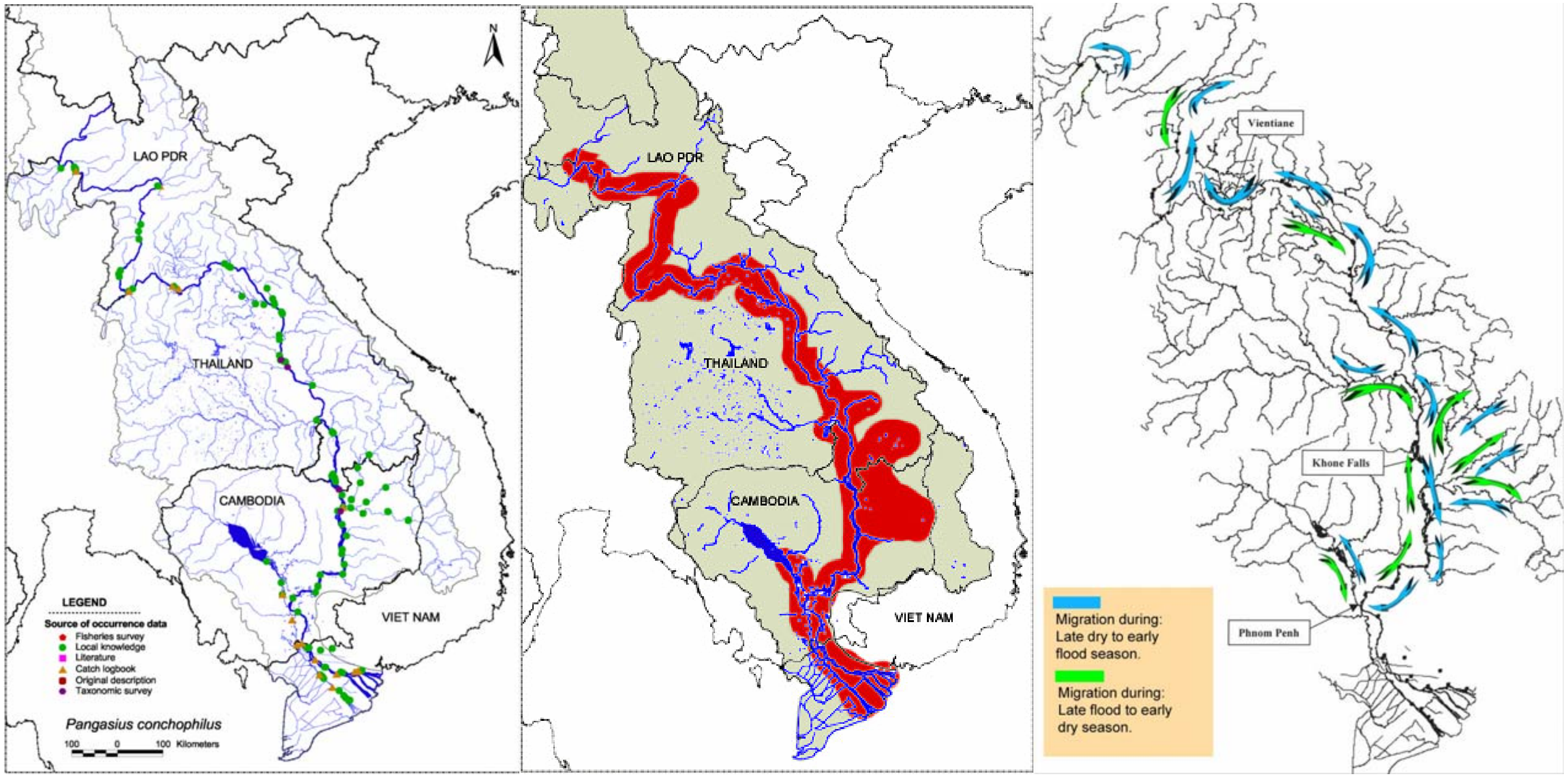
Species	% of total catch	Cumulative % of total catch	Cumulative % among guilds at risk
Pangasius conchophilus	2.07	17.1	44

IDENTIFICATION:
- Family: Pangasiidae
- Species name: Pangasius conchophilus

BIOLOGY:
- Max. standard length (cm): 120
- Length at maturity (cm): 62.9
- Status: Native

REPRODUCTION:
Spawning: Based on eggs reports from March to August with a strong peak in May-July (Poulsen and Valbo-Jørgensen, 2000) and the presence of females in spawning condition in March, June and August (Baird and Phylavanh, 1999); and juveniles of 6 to 7cm by late June (Rainboth, 1996); it seems likely that the species spawn at various times of the year (Baird and Phylavanh, 1999) although it probably mainly reproduces early in the flood season (Rainboth, 1996, Poulsen and Valbo-Jørgensen, 2000) the spawning period may extend to October (Singanouvong et al., 1996). An important spawning ground appears to be in the Mekong mainstream somewhere between Kompong Cham and Khone Falls (Poulsen and Valbo-Jørgensen, 2000); and in rapids and riffles of the Mun river (Schouten et al. 2000).- Breeds in reservoirs: No information on breeding in reservoirs

ECOLOGY:
Distribution: The distribution range is from the Mekong Delta all the way along the Mekong to Chiang Saen. In the Mekong Delta in Viet Nam, mainly juveniles less than 30cm are reported (Poulsen and Valbo-Jørgensen, 2000). There seem to be one population below Khone Falls and one (to several) above the Falls (Poulsen and Valbo-Jørgensen, 2000). Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang (Nguyen et al., 2002).
Migration: it is migratory and mainly moves at night. It is a very important species in the fishery and is caught with nets, traps, and hooks (MFD 2003). It migrates upstream from just upstream Khone Falls to Chiang Saen when the Mekong River rises quickly with the beginning of the monsoon season around May (Baird and Phylavanh, 1999, Singanouvong et al., 1996, Rainboth, 1996, Poulsen and Valbo-Jørgensen, 2000), it mainly moves in large schools at night (Baird and Phylavanh, 1999); and the migration continues until August; However this migration of 40 - 90cm sexually mature fish seem to be preceded by a migration of 10 to 40cm sub-adults in the period March to May (Poulsen and Valbo-Jørgensen, 2000). It migrates up the Mun river to spawn in the rainy season (Schouten et al. 2000). - - Discharge as migration trigger: no information
- Water level as migration trigger: Water level variation is a migration trigger
GUILD: A white fish species (Bardach, 1959)



Records, distribution (in red) and migrations of *Pangasius conchophilus*

5.4 ANNEX 4: DOMINANT SPECIES IN MEKONG CATCHES AND THEIR MIGRATION PATTERNS

Species	Migrates up to Sambor	Migrates through KF	Migrates up to Vientiane	Migrates upstream of Vientiane	Migrates to 3S	Migrates to Mun	% of total catch
Cynoglossus microlepis	Yes	?	?	?	?	?	1.32
Lycothrissa crocodilus	Yes	?	?	?	?	?	0.03
Amblyrhynchichthys truncatus	Yes	Yes	?	?	?	?	0.17
Bagarius suchus	Yes	Yes	?	?	?	?	0.3
Botia helodes	Yes	Yes	?	?	?	?	0.7
Brachirus harmandi	Yes	Yes	?	?	?	?	0.06
Cirrhinus prosemion	Yes	Yes	?	?	?	?	0.03
Cosmocheilus harmandi	Yes	Yes	?	?	?	?	2.87
Kryptopterus bicirrhis	Yes	Yes	?	?	?	?	0.01
Labiobarbus siamensis	Yes	Yes	?	?	?	?	0.35
Osteochilus waandersi	Yes	Yes	?	?	?	?	0.01
Cyclocheilichthys furcatus	Yes	Yes	?	?	?	Yes	0.25
Hypsibarbus lagleri	Yes	Yes	?	?	Yes	?	0.38
Hypsibarbus wetmorei	Yes	Yes	?	?	Yes	?	0.27
Pangasius polyuranodon	Yes	Yes	No	No	No	No	0.6
Catlocarpio siamensis	Yes	Yes	Yes	No	Yes	Yes	-
Pangasius pleurotaenia	Yes	Yes	Yes	Yes	?	?	0.1
Pangasianodon gigas	Yes	Yes	Yes	Yes	?	Yes	0.01
Boesemania microlepis	Yes	Yes	Yes	Yes	No	No	-
Cyclocheilichthys enoplos	Yes	Yes	Yes	Yes	No	No	1.11
Pangasius sanitwongsei	Yes	Yes	Yes	Yes	No	No	-
Anguilla marmorata	Yes	Yes	Yes	Yes	Yes	?	0
Cirrhinus molitorella	Yes	Yes	Yes	Yes	Yes	?	0
Luciosoma bleekeri	Yes	Yes	Yes	Yes	Yes	?	1.05
Probarbus jullieni	Yes	Yes	Yes	Yes	Yes	?	0.27
Probarbus labeamajor	Yes	Yes	Yes	Yes	Yes	?	0.1
Bangana behri	Yes	Yes	Yes	Yes	Yes	No	0.24
Pangasianodon hypophthalmus	Yes	Yes	Yes	Yes	Yes	No	0.37
Pangasius bocourti	Yes	Yes	Yes	Yes	Yes	No	0.33
Pangasius krempfi	Yes	Yes	Yes	Yes	Yes	No	0.49
Tenualosa thibeaudeaui	Yes	Yes	Yes	Yes	Yes	No	0.03
Yasuhikotakia modesta	Yes	Yes	Yes	Yes	Yes	Yes	0.37
Cirrhinus microlepis	Yes	Yes	Yes	Yes	Yes	Yes	0.41
Hemibagrus filamentus	Yes	Yes	Yes	Yes	Yes	Yes	-
Bagarius yarrelli	Yes	Yes	Yes	Yes	Yes	Yes	-
Henicorhynchus lobatus	Yes	Yes	Yes	Yes	Yes	Yes	4.07
Henicorhynchus siamensis	Yes	Yes	Yes	Yes	Yes	Yes	8.09
Labeo chrysophekadion	Yes	Yes	Yes	Yes	Yes	Yes	-
Mekongina erythrospila	Yes	Yes	Yes	Yes	Yes	Yes	0.33
Pangasius conchophilus	Yes	Yes	Yes	Yes	Yes	Yes	2.07
Pangasius larnaudii	Yes	Yes	Yes	Yes	Yes	Yes	0.57
Pangasius macronema	Yes	Yes	Yes	Yes	Yes	Yes	0.8
Paralaubuca typus	Yes	Yes	Yes	Yes	Yes	Yes	1.65
					26	*Total =*	*29.81*

5.5 ANNEX 5: MAINSTREAM FISH SPECIES HIGHLY VULNERABLE TO DAM DEVELOPMENT

Vulnerable guilds of Mekong migratory fish at risk of mainstream dam development

Migratory guild	Potential range of habitat utilized	Typical characteristics*	Likely impact of mainstream dams on migrations.
Migratory main channel spawner guild	Floodplains to running river upstream	• Spawn in the mainstream, in tributaries and around floodplains • Adults and drifting larvae return to floodplains to feed. • May migrate to deep pools in the mainstream during the dry season. • Sensitive to damming	Very high
Migratory main channel refuge seeker guild	Floodplains to slow river downstream	• Spawn in floodplains • Migrations between floodplains and mainstream deep pools in the dry season. • Sensitive to damming	Very high
Semi-anadromous guild	Estuary and lower slow river downstream	• Enters fresh/brackish waters to breed. • Enters freshwaters as larvae and juveniles (bligate or opportunistic) • Impacted by river mouth dams that stop migration into the river.	High (for dams located in river mouths or lower potamon)
Catadromous guild	Marine to running river upstream	• Reproduction, early feeding and growth at sea. • Juvenile or sub-adult migration to freshwater habitats • Vulnerable to overexploitation and tend to disappear when river is dammed preventing longitudinal upstream migration. • May respond favorably to fish passage facilities.	Very high

Source: adapted from Halls and Kshatriya 2009

List of species belonging to vulnerable guilds and their contribution to catches

Family	Species	Guild	Total weight	Cumulative weight (kg)	Cumulative %	% of total catch	Cumulative %
Cyprinidae	Henicorhynchus siamensis	3	9838	9838	21	8.09	8.1
Cyprinidae	Henicorhynchus lobatus	3	4946	14784	32	4.07	12.2
Cyprinidae	Cosmochilus harmandi	3	3489	18273	39	2.87	15
Pangasiidae	Pangasius conchophilus	2	2516	20789	44	2.07	17.1
Cyprinidae	Paralaubuca typus	3	2013	22801	49	1.65	18.8
Gyrinocheilidae	Gyrinocheilus pennocki	2	1976	24778	53	1.63	20.4
Pangasiidae	Helicophagus waandersii	2	1925	26703	57	1.58	22
Palaeomonidae	Macrobrachium sp.	9	1854	28557	61	1.52	23.5
Cyprinidae	Hypsibarbus malcolmi	2	1798	30354	65	1.48	25
Cynoglossidae	Cynoglossus microlepis	2	1606	31960	68	1.32	26.3
Cyprinidae	Cyclocheilichthys enoplos	3	1346	33306	71	1.11	27.4
Cyprinidae	Luciosoma bleekeri	3	1281	34587	74	1.05	28.4
Pangasiidae	Pangasius kunyit	2	1149	35736	76	0.94	29.4
Pangasiidae	Pangasius macronema	2	977	36713	78	0.8	30.2
Cobitidae	Botia helodes	3	849	37562	80	0.7	30.9
Cyprinidae	Puntioplites proctozysron	3	780	38342	82	0.64	31.5
Pangasiidae	Pangasius polyuranodon	2	725	39068	83	0.6	32.1
Pangasiidae	Pangasius larnaudii	2	697	39765	85	0.57	32.7
Pangasiidae	Pangasius krempfi	2	596	40361	86	0.49	33.2
Cyprinidae	Cirrhinus microlepis	3	503	40864	87	0.41	33.6
Cyprinidae	Hypsibarbus lagleri	2	460	41323	88	0.38	34
Pangasiidae	Pangasianodon hypophthalmus	2	451	41774	89	0.37	34.4
Cobitidae	Botia modesta	3	449	42223	90	0.37	34.7
Cyprinidae	Labiobarbus siamensis	3	421	42643	91	0.35	35.1
Cyprinidae	Mekongina erythrospila	2	401	43045	92	0.33	35.4
Pangasiidae	Pangasius bocourti	2	399	43443	93	0.33	35.7
Sisoridae	Bagarius suchus	2	369	43812	94	0.3	36
Cyprinidae	Probarbus jullieni	2	330	44143	94	0.27	36.3
Cyprinidae	Hypsibarbus wetmorei	2	329	44471	95	0.27	36.6
Cyprinidae	Cyclocheilichthys furcatus	2	309	44781	96	0.25	36.8
Schilbeidae	Clupisoma sinensis	2	298	45078	96	0.24	37.1
Cyprinidae	Bangana behri	2	286	45365	97	0.24	37.3
Cyprinidae	Amblyrhynchichthys truncatus	3	213	45577	97	0.17	37.5
Cyprinidae	Bangana sp.	2	194	45771	98	0.16	37.6
Pangasiidae	Pangasius micronemus	2	139	45911	98	0.11	37.8
Cyprinidae	Probarbus labeamajor	2	121	46032	98	0.1	37.9
Dasyatidae	Dasyatis laosensis	2	116	46149	99	0.1	37.9
Pangasiidae	Pangasius pleurotaenia	2	116	46265	99	0.1	38
Cobitidae	Botia sp. cf. lecontei	2	99	46364	99	0.08	38.1
Soleidae	Brachirus harmandi	2	68	46432	99	0.06	38.2
Pangasiidae	Pangasius pangasius	2	58	46491	99	0.05	38.2
Cyprinidae	Garra fasciacauda	2	56	46547	99	0.05	38.3
Pangasiidae	Pangasius siamensis	2	51	46598	100	0.04	38.3
Clupeidae	Tenualosa thibaudeaui	8	41	46639	100	0.03	38.4
Engraulidae	Lycothrissa crocodilus	8	35	46674	100	0.03	38.4
Cyprinidae	Cirrhinus prosemion	3	31	46705	100	0.03	38.4
Pangasiidae	Pangasius spp.	2	23	46728	100	0.02	38.4
Siluridae	Kryptopterus bicirrhis	2	15	46743	100	0.01	38.4
Pangasiidae	Pangasianodon gigas	2	13	46756	100	0.01	38.4
Cyprinidae	Osteochilus waandersii	2	10	46766	100	0.01	38.5
Megalopidae	Megalops cyprinoides	9	9	46775	100	0.01	38.5
Cyprinidae	Puntioplites bulu	2	8	46782	100	0.01	38.5
Cobitidae	Botia sp. Cf. beauforti	2	6	46789	100	0.01	38.5
Clupeidae	Tenualosa toli	8	4	46793	100	0	38.5
Anguillidae	Anguilla marmorata	9	2	46796	100	0	38.5
Cyprinidae	Cirrhinus molitorella	3	2	46798	100	0	38.5
Cyprinidae	Puntioplites waandersi	2	1	46799	100	0	38.5
Cyprinidae	Aaptosyax grypus	2	0	46800	100	0	38.5
	Total catch of 58 species (kg)			*46800*			
	Overall catch of 233 species (kg)			*121607*			

Source: Halls and Kshatriya 2009, Annex 1.


MAINSTREAM
PROJECTS
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IMPACTS
WATER
LOSS
VIETNAM
LIVELIHOODS
CHANNEL
SYSTEMS
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CAMBODIA
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INCLUDING
INCREASE
FIGURE
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CHANGES
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SIGNIFICANT
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MEASURES
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PRODUCTIVITY
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PRODUCTION
DECISION
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LAOS
IMPACT
SECTOR
AFFECTED
BASIN
TRIBUTARY
HIGH
RESERVOIR
TRANSPORT
STRATEGIC
FLOW
LIKELY
POTENTIAL
ZONE
MRC
IRRIGATION
REDUCED
CONSTRUCTION
CAPACITY
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