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RELATIONSHIPS BETWEEN BIOECOLOGY AND HYDROLOGY AMONG TONLE SAP FISH SPECIES

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EXECUTIVE SUMMARY

Creation of a database of all Tonle Sap fish species

- This reports details how several sources of information and databases have been merged together to create a database of all Tonle Sap species and of all bioecological information documented about these species.

- The Tonle Sap species database results from the integration of four main sources of information: i) from scientific publications, summarized in FishBase; ii) from publications and fishers' knowledge as compiled in the MRC Mekong Fish Database; iii) from biological studies undertaken at IFReDI; and iv) from traditional knowledge gathered during the course of the Built Structures project.

- The information available in the Tonle Sap species database covers five fields: i) *species identification* (Species name in Latin, family; author; name in Khmer; name in Khmer (roman); name in English; ii) *biology* (max. total length; max. standard length; length at maturity; food; iii) response to hydrological changes (discharge as migration trigger; water level as migration trigger); iv) *reproduction* (spawning location, date of spawning; reproductive guild; fecundity; nursing location; possible breeding in reservoirs); and v) ecology (Tonle Sap distribution; field notes; migration type; feeding place; status; habitat; resilience; ecological guild.

- Two hundred and ninety-six species are recorded in the Tonle Sap. This is more than double than recorded so far in scientific publications. In terms of fish biodiversity, this makes the Tonle Sap the third richest lake in the world, after lakes Malawi and Tanganyika, and much before Lake Victoria.

- The 296 Tonle Sap species belong to 44 families, the dominant ones being Cyprinids (108 species), Silurids (20 species), Bagrids and Cobitids (17 species) and Pangasids (14 species).

- Thus the Tonle Sap sub-basin, that covers 10.7% of the Mekong Basin, comprises 32% of the Mekong fish species and 48% of the Mekong fish families. This qualifies the Tonle Sap system as an exceptional biodiversity hotspot by global standards, and calls for special attention from national and international institutions.

Response of Tonle Sap species to hydrological changes

- This analysis has been undertaken to better appraise the possible consequences of flow modifications due to built structures on the migration of species targeted by the fishery.

- Among the Tonle Sap species, three species are known to have their migration triggered by a discharge variation and twenty-three species have their migration triggered by a water level variation. In that field there is a large information gap about the other species, i.e. 91% of the Tonle Sap fish community.

- However among the species whose migration is triggered by a variation of water level, three taxa (*Cyclocheilichthys spp., Paralaubuca typus* and *Pangasius spp*.) contribute 13% to overall catches in Cambodia. This means that each year at least 38,000 and 56,000 tons of fish depend on species whose migration is triggered by hydrological cues altered by built structures. If *Henicorhinchus spp.* (Trey riel) is included, then the figure goes up to 38% of the catch, i.e. between 110 and 164,000 tons.

Ecological guilds

- It is usually considered that floodplain fishes belong to two ecological groups of fishes ("guilds"): either black fish, that spend the dry season in floodplain ponds, or white fish, that undertake long distance migrations at the end of the rainy season. Our results show that it is necessary to consider a third group of fish, named "grey fish", whose behavior is neither black nor white. These grey fish spend for instance the dry season in the Tonle Sap tributaries or in the main lake.

- According to current knowledge, 8% of Tonle Sap species belong the "Grey fish" guild. Detailed analyses show that differences between guilds are mainly behavioural, and that there is no significant difference between these guilds in terms of average length of fish. There is also no significant difference between the average trophic level of guilds.

- Last, a resilience analysis focussing on the ability of species to adjust to heavy exploitation has highlighted the species whose resilience is low, and that should be subject to specific monitoring.

I INTRODUCTION

This aim of this study is to clarify the relationship between the bioecology of Tonle Sap fish species and hydrology.
Information is available from:
- scientific publications, summarized in FishBase maintained by the WorldFish Center (Froese and Pauly 2000, and www.fishbase.org).
- published and expert information, summarized in the Mekong Fish Database produced by the Mekong River Commission (MFD 2003);
- expert information available with IFReDI and its biologists;
- traditional knowledge gathered during the course of the Built Structures project.
This approach has already been used in Baran *et al.* (2005) and Baran (in press).

We aim to combine these different sources of information to create a repository of the best available information on Tonle Sap fish species, with a focus on black, grey and white fish species. This repository will then be analysed to provide information relevant to the BayFish model of the Tonle Sap fish resource.

II MATERIAL AND METHODS

II.1 INFORMATION EXTRACTED FROM FISHBASE

The web-based version of FishBase (www.fishbase.org) is used for up-to-date information. In 2005 a specific module has been created by the FishBase team to generate a matrix of all species of a given system, and a number of life-history parameters for these species. A fraction of the quantitative information available in this matrix is summarised in Table I.

Table I: Life history variables detailed for in the species ecology matrix

Variable	Abbreviation; (unit)	Meaning	Measured or calculated
Maximum length	Lmax; (cm)	Maximum length ever reported for the species in question,	Measured
Life span	tmax; (year)	Approximate maximum age that fish of a given population would reach	Calculated (estimated from Linf., K and to.)
Age at first maturity	tm; (year)	Average age at which fish of a given population mature for the first time	Calculated (estimated from Linf., K and to.)
Length at maturity	Lm; (cm)	Average length at which fish of a given population mature for the first time	Calculated (estimated from Linf.)
Length for max. yield	Lopt; (cm)	Length class with the highest biomass in an unfished population	Calculated (estimated from Linf.)
Trophic level		Rank of a species in a food web, calculated from food items, weighted by the contribution of the various food items to the diet.	Calculated

The option used in this study is thus the “Information by ecosystem” (Tonle Sap ecosystem), with the sub-option “Species ecology matrix” (Figure 1).

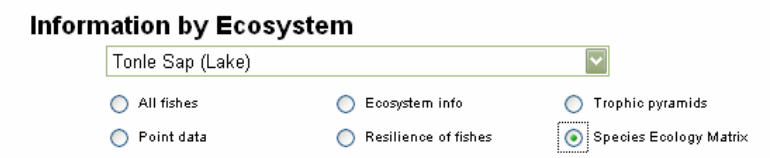

Figure 1: View of the FishBase option producing the matrix of life history parameters for Tonle Sap fish species

This option provides, all the life history parameters of each species recorded in the Tonle Sap, as shown below (Figure 2).

Address http://fishbase.org/report/KeyFactsMatrixList.cfm?backstep=-2 Go Links

More info

Life History Data For Fishes in Ecosystem Tonle Sap

Note: Values below are either median values from the database or estimates from empirical equations, usually depending on L infinity and other parameters. ' respective species and read the 'Estimation of Life-History Key Facts' chapter for more information.

Back n=193

Scientific Name	Status	Family	Max. length (Lmax) cm	L infinity (Linf) cm	K /year	to _year_	Natural mortality (M)/year	Life span (approx.) year	Generation time year	Age at first maturity (tm) year	L maturity (Lm) cm	L max. yield (Lopt) cm	Length-weight cm	Nit Pr
Acantopsis dialuzona	native	Cobitidae	25.0 SL	26.3	0.21	(-0.83)		13.5	3.7	3.5	15.7	16.1	26.3	30
Akysis filifer	native	Akysidae	5.0 SL	5.4	0.00	(0.00)		4.4	0.0	0.0	3.8	3.1	5.4	
Amblyrhynchichthys micracanthus	native	Cyprinidae	19.7	20.8	0.00	(0.00)		4.4	0.0	0.0	12.8	12.6	20.8	31

Figure 2: View of the FishBase "species ecology" matrix for the Tonle Sap

Options "All species" and "Resilience of fishes" were also used to supplement data compilation (Figure 3).

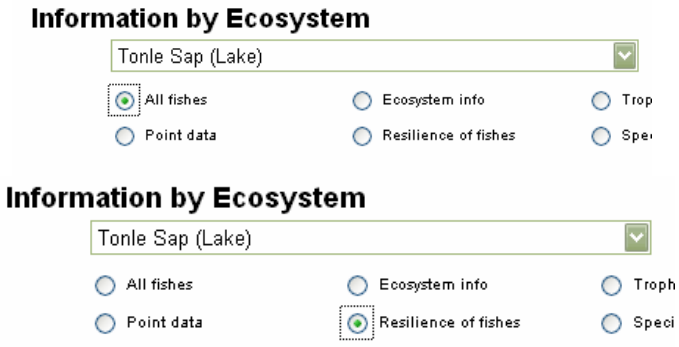

Figure 3: View of the FishBase options for Tonle Sap specific additional information

II.2 INFORMATION EXTRACTED FROM THE MEKONG FISH DATABASE

This information in MFD is of different nature than that of Fish Base, as in includes much more ecological information gathered through field surveys and questionnaires on traditional ecological knowledge. This database includes in particular the knowledge gathered by Chan Sokheng *et al.* (1999), Poulsen (2000, 2003), Poulsen and Valbo-Jorgensen (2000), AMFC (2001), Valbo-Jorgensen and Poulsen (2001) Bao *et al.* (2001), Poulsen *et al.* (2002).

The species found specifically in the Tonle Sap Basin are identified in MFD in an "Occurrence" table, than can be related to the detailed "Location" table and to a "Species Data" table. The tables

of the database have been combined to summarize in one table all the information scattered in different tables. For each species of the life history matrix, information on migration was automatically extracted, in MS Access mode, from the Mekong Fish Database. For species listed in FishBase but not present in the MDF, all possible synonyms were searched from a synonyms correspondence table, and the relevant information was then extracted from the synonym species.

II.3 INFORMATION FROM IFREDI

Over the years, the Cambodian Inland Fisheries Research and Development Institute and its biologists previously involved in MRC fisheries monitoring projects have accumulated a significant body of knowledge. This knowledge is partly reflected in the MRC documents on spawning and migrations in the Mekong Basin, but is also still scattered in several local publications such as So *et al.* (1999, 2005), So and Haing (2006) or So (2005). The corresponding list of species is given in Annex A.

II.4 INFORMATION FROM THE BUILT STRUCTURE PROJECT

Last the Built Structures project undertook a sampling of traditional ecological knowledge around the Tonle Sap Lake. This project is based on the interviews of 24 experienced senior fishers in 6 sites round the lake. The methodology is based on the recommendations of IIRR (1996) and Cambpbell and Salagrama (1999) supplemented by Ticheler *et al.* (1998). Experience relative to gathering traditional knowledge of Mekong fishers was integrated thanks to Baird and Overton (2001), Baird (2003) and Dubois (2005). Questionnaires to fishers are detailed in Annex 1.
The questions focussed on 30 species identified by their Khmer name, and for these species, on spawning habitat; spawning location; feeding habitat; nursing habitat and ecology type (black white or grey type).
Equivalences between Khmer fish names and Latin fish names were drawn from Baran (2003) and Baran and Chheng (2003). These two documents tackle the issue of several Latin names for one Khmer name, and provide a list of scientific species for each Khmer fish name. Last, the latest valid Latin names of fish followed the list of Baran and Garilao (2003) based on FishBase.

II.5 MERGER OF DATABASES

II.5.1 FishBase matrix

The FishBase matrix of life history parameters was used as a basis. The original variables of this matrix, including information from “Resilience” and “All Species” supplementary matrices, are as follows:

Table II: Main variables of the FishBase species ecology matrix

Latin name	Author	Family	English name	Max. total length (cm)	Max. standard length (cm)	Life span (years)	Length at maturity (cm)
	Length for max. yield (cm)	Length-weight (cm)	Main food	Trophic level	Status	Habitat	Resilience

One hundred and ninety three species are listed as Tonle Sap species in FishBase. This matrix is converted into an Excel table for further analysis.

II.5.2 MRC database

The ecological information used mostly originates from the MRC Mekong Fish Database. In fact the file used was created for the analyses of migrations and migration triggers in the Mekong Basin (Baran, *in press*). This files combines to the FishBase life history matrix of all Mekong species all the ecological information available in MFD. This information is as follows:

Table III: Main variables extracted from the Mekong Fish Database

Species	Migrating?	Migration info	Migration type	Spawning info	Breeds in reservoirs?	Note	Mekong distribution	Feeding info
	Yes	text	Longitudinal	text	Yes	text	text	text
	No	#N/A	Lateral	#N/A	No	#N/A	#N/A	#N/A
	#N/A		Both					
			#N/A					C

In the resulting table, for readability, it has been concentrated into one single column "Ecological information" compiling all the others listed above.

II.5.3 IFReDI Tonle Sap species list

The list of species met in the Tonle Sap, provided in Annex 1, mainly bears two variables: *Scientific name* and *Khmer name.* Several species were removed from this list, with the following arguments:

Table IV: Species removed from the IFReDI list

Latin name	Family	Tonle Sap distribution
Arius caelatus	Ariidae	Probably not (Vietnam only)
Batrachocephalus mino	Ariidae	Marine and estuarine only (tidal zone)
Butis gymnopomus	Eleotridae	No information at all in MFD, Indonesian species not in Cambodia according to FishBase
Clarias canius	Clariidae	Unknown from MFD and from FishBase
Cynoglossus punticeps	Cynoglossidae	Common in the freshwater tidal zone of the Mekong Delta, but not yet reported from Cambodia (Ref. 12693).
Hemipimelodus bicolor	Ariidae	Only in the delta
Lobocheilos davisi	Cyprinidae	No evidence at all
Lobocheilos quadrilineatus	Cyprinidae	Unlikely (Laos only)
Mystus cavasius	Bagridae	5 occurrences only in Cambodia, none is TS related

This information was added to the previous compilation of matrices.

II.5.4 Built Structures questionnaires

The database integrating the information gathered through the questionnaires of the Built Structures project included questions about the following variables:

Table V: Main variables of the Built Structures – Species ecology database

Species	Spawning location	Feeding habitat	Nursing habitat
In Khmer	Floodplain lake / rice field	Floodplain	Floodplain
	Major river / river	Never caught	Never caught
	Stream / Inlet		
	TS permanent lake		
	Never caught		

The questions asked focussed on 38 taxa selected because they are either i) dominant and important fish species for livelihoods; ii) important fish species for aquaculture development; iii) little known from an ecology viewpoint, or iv) potentially vulnerable.

The corresponding list of taxa, identified by their Khmer name, is as follows:
Ampil tum, Andat chhkae, Angkot prak, Bandol ampov, Chhlang, Chunlungh moan, Chunteas phluk, Dong khteng, Ka-ek, Kamphleav, Kanhchos bai, Kanhchras thom, Kantrorng preng, Kaock, Kasan, Kes, Khlang hay, Kromorm, Krum, Phtoung, Reus Chek,

The problem is that in this case, the specific information is recorded on the field under its Khmer name, and there are often several species corresponding to one Khmer name. So two documents were used to establish the equivalence between Khmer names and Latin names. Baran (2003) in particular, based on FishBase 2004, gives for each Latin names the number of occurrences of a given translation; this allows an assessment of the reliability of the translation.
We propose below a list of equivalences between Khmer names and Latin names (Annex B).

II.5.5 Merging the databases

FishBase and the MFB have in common Latin species names; the IFReDI compilation of species includes Latin species names and Khmer fish names, and the database of ecological knowledge gathered during the Built Structures project is based on Khmer names. Ultimately these databases are merged (Figure 4).

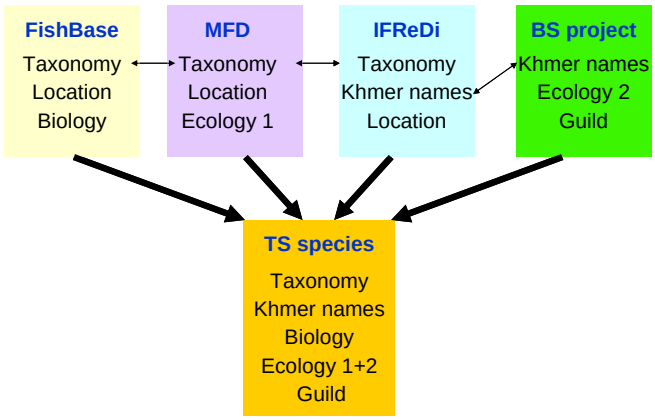

Figure 4: View of the FishBase options for Tonle Sap specific additional information

In view of quantitative analyses, some variables initially expressed qualitatively (e.g.; migration pattern) have been coded. Codes are as follows (Table VI):

Table VI: Coding used in the Tonle Sap species database

MIGRATION	Code
Caught in dry season	1
Caught in dry then rainy season	2
No migration pattern	3
Caught in rainy season	4
Unknown	5

MIGRATION TYPE	Code
Longitudinal and lateral migrations	1
Only longitudinal migrations	2

DISCHARGE VARIATION AS MIGRATION TRIGGER	Code
Yes	1
Unknown	2

WATER LEVEL VARIATION AS MIGRATION TRIGGER	Code
Yes	1
Unknown	2

STATUS	Code
native	1
Introduced	2
Misidentification	3
Questionable	4

RESILIENCE	Code
Very low	1
Low	2
Medium	3
High	4

HABITAT	Code
Benthopelagic	1
Demersal	2
Pelagic	3

RESERVOIR BREEDING	Code
Yes	1
Unknown	2
No	3

III RESULTS

III.1 CONTENTS OF THE TONLE SAP FISH SPECIES DATABASE

The information compiled in the database of Tonle Sap species can be classified as follows:

Identification

Species name in Latin, Family; Author; Name in Khmer; Name in Khmer (roman); Name in English:

Biology

Max. total length; Max. standard length; Length at maturity; Food:

Ecology vs. Hydrology

Discharge as migration trigger; Water level as migration trigger

Reproduction

Spawning location (floodplain lakes / rice fields; rivers; streams; / inlets; TS permanent lake); Date of spawning (based on % of respondents); Reproductive guild; Fecundity; Nursing location; Possible breeding in reservoirs

Ecology

Tonle Sap distribution; All MFD ecological information; Migration type; Feeding place; Status; Habitat; Resilience; Guild (black, grey or white fish)

It is the first time that all the information available about Tonle Sap species is concentrated into a single place.

III.2 PRELIMINARY ANALYSES

The table created is very rich as it covers all the species of the Tonle Sap, and all the information known about these species. It allows all kinds of quantitative analyses. We propose below some exploratory analyses about global trends revealed by this table.

III.2.1 Species and families

The results of this comprehensive review show that two hundred and ninety-six species are recorded in the Tonle Sap. These 296 species represent 2.5 times the number of species identified in 1999 by Puy Lim *et al.* (1999; 120 species) and twice more than twice the 149 species mentioned by Campbell *et al.* (2006). This is also significantly more than the 95 Tonle Sap species whose ecology has been detailed in Chan *et al.* (2001)

When compared to the other major lakes worldwide (figures from FishBase 2004), the Tonle Sap appears to be the third richest lake of the world in terms of fish biodiversity (Table VII and Figure 5). This exceptional feature has never been highlighted before.

Table VII: Comparison of Tonle Sap fish biodiversity with that of other lakes worldwide

Lake	Number of species	Note
Malawi	433	Southeast Africa. Over 2 million years old
Tanganyika	309	East central Africa. About 20 million years old.
Tonle Sap	296	Southeast Asia. About 6000 years old. Combination of freshwater and estuarine fish faunas
Victoria	222	East central Africa. About 4 million years old. World's second largest freshwater lake
Chilka	210	India.Largest tropical lake in Asia
Lake chad/ Chari River	170	Central Africa
Turkana	60	East Africa
Rukwa Basin	54	East Africa
Taal	53	Philippines
Kainji	45	Northern Nigeria. It is part of the Niger river
Liambezi	43	Southwest Africa/ Namibia
Baikal	42	Siberia and north of Mongolia. Largest, deepest and oldest freshwater lake, about 25-30 million years old.
Kariba	41	Southern Africa.

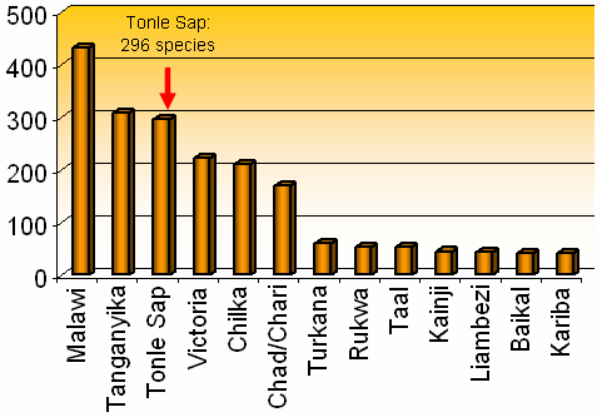

Figure 5: Place of the Tonle Sap fish biodiversity among other lakes worldwide

Forty-four fish families are present in the Tonle Sap. The family represented by most species is that of Cyprinidae (minnows or carps), with 108 species. It is followed by Siluridae (catfishes, 20 species), Bagridae (catfishes, 17 species), Cobitidae (loaches, 17 species) and Pangasidae (catfishes, 14 species).

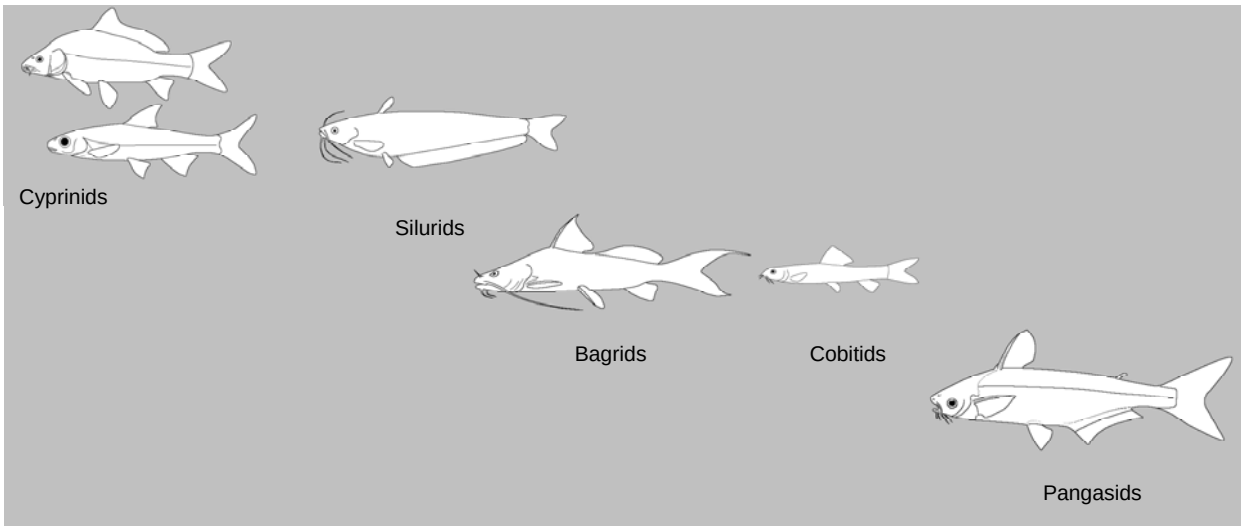

Figure 6: The dominant fish families (in number of species) of the Tonle Sap Great Lake

These 5 dominant families are supplemented by 39 others including from 1 to 10 species: Akysidae, Ambassidae, Anabantidae, Anguillidae, Ariidae, Balitoridae, Belonidae, Callionymidae, Carcharhinidae, Centropomidae, Channidae, Clariidae, Clupeidae, Coiidae, Cynoglossidae, Dasyatidae, Datnioididae, Eleotridae, Engraulidae, Gobiidae, Gyrinocheilidae, Hemiramphidae, Mastacembelidae, Megalopidae, Nandidae, Notopteridae, Ophichthidae, Osphronemidae, Plotosidae, Poecilidae, Polynemidae, Schilbeidae, Sciaenidae, Sisoridae, Soleidae, Synbranchidae, Syngnathidae, Tetraodontidae, and Toxotidae (Figure 7).

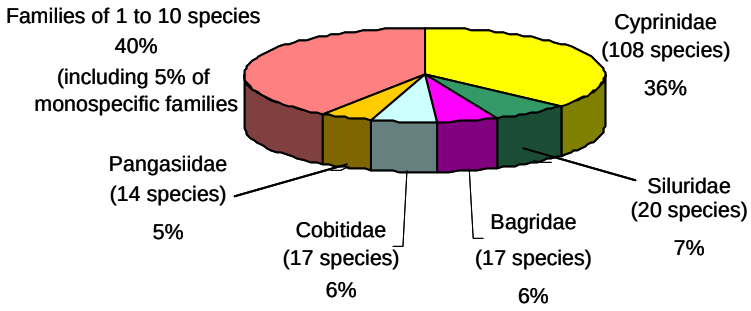

Figure 7: Repartition of Tonle Sap species between 37 families

Thus the Tonle Sap basin that covers, with 85,000 km^2, 10.7% of the Mekong Basin comprises 296 or 32% of the 924 Mekong species recorded in MFD[1]. The families present in the Tonle Sap sub-basin represent 48% of the 91 families present in the Mekong Basin. This confirms the exceptional richness of the Tonle Sap by global standards, and its status of biodiversity hotspot that requires special attention from national and international institutions.

[1] (this is a conservative percentage since FishBase only records 768 Mekong species)

III.2.2 Response to hydrology

III.2.2.1 Number of species whose migration is triggered by hydrological changes

The analysis below aims at identifying species whose migrations are triggered by hydrological changes. The objective is to better appraise the possible consequences of flow modifications (mainly due to damming or built structures in general) on the migrations of the species that contribute to the catch of Cambodian fisheries. This issue has been identified by the Technical Advisory Board of the Mekong River Commission as being an important factor likely to play a major role in the sustainability of the Mekong fishery resources (Baran 2007).

The database records two types of response to hydrological changes: migrations triggered by a variation in discharge, and migrations triggered by a variation in water level.
A preliminary analysis shows that:

- three species are known to have their migration triggered by a discharge variation: *Hemisilurus mekongensis*[2] (Kromorm in Khmer), *Pangasius macronema* (Pra chveat) and *Cyprinus carpio* (Karp samanh)
- twenty-three species have their migration triggered by a water level variation: *Barbonymus gonionotus (*Chhpin prak in Khmer)*, Botia modesta* (Kanhchrouk krohorm), *Chitala blanci* (Kray), *Cyclocheilichthys enoplos* (Chhkaok), *Hemibagrus filamentus* (Tanel), *Hemisilurus mekongensis* (Kromorm), *Labeo chrysophekadion* (Ka-ek), *Lycothrissa crocodiles* (Chhmar krapeu)*, Macrochirichthys macrochirus* (Dong khteng)*, Micronema bleekeri* (Kes krohorm)*, Osphronemus exodon* (Trocheak domrei), *Pangasius conchophilus* (Pra kae), *Pangasius hypophthalmus* (Pra thom), *Pangasius krempfi (Bong lao), Pangasius kunyit (Pra kchao), Pangasius larnaudii* (Pra po), *Pangasius polyuranodon* (Pra chveat), *Pangasius sanitwongsei* (Pra po pruy), *Parachela oxygastroides* (Chunteas phluk), *Paralaubuca typus* (Sleuk russey), *Pristolepis fasciata* (Kantrob), *Tenualosa thibaudeaui* (Kbork) and *Wallago leerii* (Stuok).
- there is no information about 270 species (Figure 8)

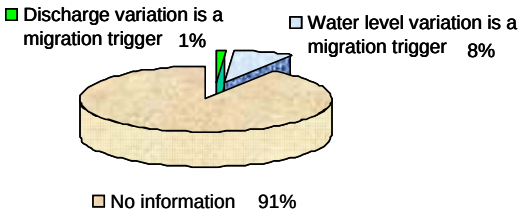

Figure 8: Response of Tonle Sap species to hydrological changes

As detailed by Baran (2007), some other species can be added to this list: *Pangasius bocourti* (Chhuon, 2000), *Puntoplites falcifer* and the southern population of *Pangasius sanitwongsei* (Poulsen *et al.,*2004). “Trey riel” (*Henicorhynchus spp.* and *Cirrhinus spp.)* is apparently receptive to flood recession as well as to lunar stage, but this is an unclear case as: i) the taxonomy of the genus *Henicorhynchus* is confused (in particular with *Cirrhinus*); ii) the number of species in this genus is not fixed; and iii) the identification of most species of the genus is almost impossible in the field.

The main information resulting from the above analysis is that there is a huge knowledge gap and that the response of fish to hydrological changes is not documented for ninety percent of the Tonle

[2] *Hemisilurus mekongensis* is also recorded among species whose migration is triggered by a water level variation

Sap species. Conversely Baran (2007) highlights that 90% of Mekong fish species *for which migration cues are documented* respond to a variation in water level or in discharge. Data analysed basinwide show (not specifically on the Tonle Sap) show that among documented species, catfishes, with 15 species, are by far the group most sensitive to hydrological migration triggers. This group contributes to dominant species in catches.

III.2.2.2 Biomass of species whose migration is triggered by hydrological changes

In addition to that taxonomic approach, a fishery-centered approach requires an analysis of biomasses at stake. Baran and Chheng reviewed in 2003 the dominant species in Cambodian fisheries. According to their list, three taxa listed above are among whose migration is triggered by a variation of water level. These species are *Cyclocheilichthys spp.* (Sraka kdam in Khmer)*, Paralaubuca typus* (Sleuk russey), and *Pangasius spp*. (Trey pra) and they contribute significantly to Cambodian fish catches (by 8.3%, 2.8% and 1.9% respectively).
This means that overall, without mentioning "Trey riel" that makes up to 25.2% of the total catch but whose sensitiveness to discharge is unclear, at least 13% of the fish catch in Cambodia, i.e. between 38,000 and 56,000 tons of fish a year, are made of species sensitive to hydrological variations likely to be altered by built structures. If "Trey riel" is added, this amount goes up to 38% of the catch, i.e. between 110,000 and 164,000 tons. Along the same lines, Baran *et al.* (2005) showed that in Southern Laos, 96% of the total biomass caught is made of species highly sensitive to discharge variations.
These results highlight the potential dramatic effect of built structures that would significantly alter the hydrology and flood dynamics in the lake.

III.2.3 Ecological guilds

Floodplain fish are usually characterised as "black fish" or "grey fish" (Welcomme 1985), and this also applies to the Mekong system. Van Zalinge et al. define these ecological groups (also called "guilds") as follows:
"**Black fish** species undertake relatively short migrations between the flooded areas in the rainy season and permanent water bodies in or close to the floodplain in the dry season. They are adapted to withstand adverse environmental conditions (e.g. low dissolved oxygen) often prevailing on the floodplains. During the wet season the fish go back to the floodplains for feeding and spawning.
"**White fish** species carry out considerably longer migrations. At the beginning of the dry season most species move from the floodplains via the tributaries to the Mekong main stream. Their migrations may extend to several hundred kilometres. In the main stream they use the deeper parts of the river as refuges for the rest of the dry season. At the onset of the rains spawning takes place near these areas before the adult fish move back again for feeding to the floodplains again for feeding. In Cambodia the fish larvae drift downstream with the river current to the floodplains."

In fact floodplain specialists have long acknowledged the need to detail this binary classification in order to better reflect the reality. Thus Régier *et al.* (1989) proposed a third group, of "**grey fish**", made of species that do not clearly belong to white nor to black ecological guilds. This need is confirmed by Welcomme (2001) and So *et al.* (2006) describe grey fish as "species that leave flooded areas and return to rivers or other main water bodies (i.e. dry-season refuge) at the end of wet season. They perform short distance spawning migration (i.e. river/main water-floodplain) and spawn on floodplain in rainy season. They spend a part of their lives on floodplain and another part in rivers/tributaries/streams or other main water bodies. They also have a certain tolerance regarding water quality (e.g. DO = 4 - 5 mg/l?), meaning that water conditions acceptable for grey

fish are between those acceptable to white and black fish". In the Mekong Basin, Poulsen *et al.* (2002) have already acknowledged the existence of a group of grey fish, but so far this has never been put into practice, and the Mekong Fish Database for instance does not mention any grey fish. Lévêque and Paugy (1999) detail the specificities of this third group as follows (Table VIII):

Table VIII: Characteristics of Grey fish

	Grey fish
Oxygenation	Gills and adaptations to hypoxia
Tolerance to hypoxia	Low to medium oxygen rates
Type of muscular fibres	Red or white
Migrations	Short range longitudinal migrations, lateral migrations
Body shape	Body compressed laterally, spiny, usually with strong scales
Color	Dark, usually ornamented and colored
Reproduction guild	Nest builders and guarders, lay eggs on the substrate, phytophiles
Dry season habitat	Tributaries or edges of the main stream
Wet season habitat	Floodplain

Following these authors, during project field trips and questionnaires fishers were asked to detail the ecology of a list of fish, and these fish were ultimately classified categorized as belonging to the white, black or grey guild. These results are part of the matrix of Tonle Sap species, and a brief analysis shows that out of 296 species, 55 are classified as white fish, 18 are classified as Black fish, and 24 are characterized as Grey fish[3]. The results of questionnaires are contradictory with the literature for 10 species, whose guild remain undetermined, together with 189 other species (Figure 9).

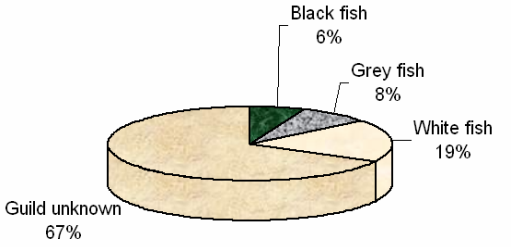

Figure 9: Distribution of Tonle Sap species between 3 ecological guilds

III.2.3.1 Ecological guilds and size of fishes

The database of Tonle Sap species allows detailing the size of fish for each ecological guild. The graph below, that combines total length and ecological guild (Figure 10) shows that there is no significant difference between guilds in terms of average length of fish. However White fishes includes species such as *Pangasionodon gigas* (Reach in Khmer), *Pangasius sanitwongsei* (Pra po pruy), *Catlocarpio siamensis* (Kolreang) or *Wallago attu* (Sanday) that can become giants reaching 366 cm.

[3] The latter grey fish species are:
Arius maculatus (Trey Kaock in Khmer), *Arius sona* (Kaock), *Arius stormii* (Kaock), *Arius thalassinus* (Kaock), *Arius truncatus* (Kaock), *Barbonymus gonionotus* (Chhpin prak), *Belodontichthys dinema* (Khlang hay), *Chitala blanci* (Kray), *Coilia lindmani* (Chunlungh moan), *Hemibagrus wyckii* (Chhlang khmao), *Hemisilurus mekongensis* (Kromorm), *Hyporamphus limbatus* (Phtoung), *Kryptopterus bicirrhis* (Kes prak), *Kryptopterus cheveyi* (Kamphleav stung), *Kryptopterus cryptopterus* (Kamphleav khlanh), *Micronema bleekeri* (Kes krohorm), *Mystus albolineatus* (Kanhchos bai), *Parachela maculicauda* (Chunteas phluk), *Parachela oxygastroides* (Chunteas phluk), *Parachela siamensis* (Chunteas phluk), *Parachela williamminae* (Chunteas phluk), *Parambassis apogonoides* (Kanhchras thom), *Parambassis wolffii* (Kantrorng preng), and *Xenentodon cancila* (Phtoung),

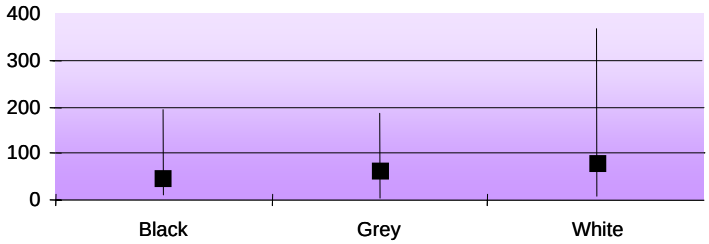

Figure 10: Fish length variability within each ecological guild
(mean, min. and max. total length in centimetres)

III.2.3.2 Ecological guilds and trophic level

The trophic level of a species is its position in the food chain, determined by the number of energy-transfer steps to that level, in other words by the nature of its diet: phytoplankton represents trophic level 1, zooplankton that eats phytoplankton represents trophic level 2, the trophic level of fish that eat zooplankton is 3, that of carnivores eating zooplanktivore fishes is 4, and top predators eating carnivores reach level 5. In practice, since fish diet almost always combines several sources of food from different levels, the trophic level of a given species can be a decimal (Pauly and Christensen 1999).
FishBase gives the trophic level of fishes whose diet has been studied. An analysis also integrating ecological guilds shows that there is no significant difference between the average trophic level of guilds (Figure 11) , although white fish have a slightly lower trophic level corresponding probably to the greater abundance of planktivores in that dominant family.

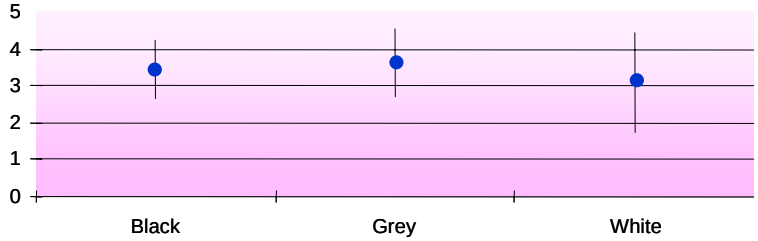

Figure 11: Average trophic level of each ecological guild
(bars indicate the 95% confidence range)

III.2.3.3 Ecological guilds and species resilience

Resilience is the capacity of a system to tolerate impacts without irreversible change in its outputs or structure. In species or populations, this term is often understood as the capacity to withstand exploitation. FishBase calculates the resilience of each species based on several parameters including growth coefficient K, age at first maturity t_m and maximum age t_{max} (Musick 1999, Froese and Pauly 1999). When applied to the three guilds of Tonle Sap species, the analysis shows (Figure 12) that the guild with the highest proportion of resilient species is that of black fish; and that the group of white fish is the only one including species considered of “very low” resilience. The least resilient species (i.e. the most likely to be subject to drastic reduction in catches or collapsing) are *Cyclocheilichthys enoplos* (Chhkaok in Khmer), *Labeo chrysophekadion* (Ka-ek), *L. dyocheilus* (Pava mouk mouy) and *Probarbus jullieni* (Tra sork krohom). It is to be noted that Baird (2006) has already described the extinction threats that this species, classified as “endangered” on the IUCN red list, is subject to. Among black fish, it seems that *Channa micropeltes* (Chhdau) is the species least likely to resist intensive exploitation. These species should be given priority in

biological studies so that their level of exposure is better assessed, and specific protection measures can be considered if necessary.

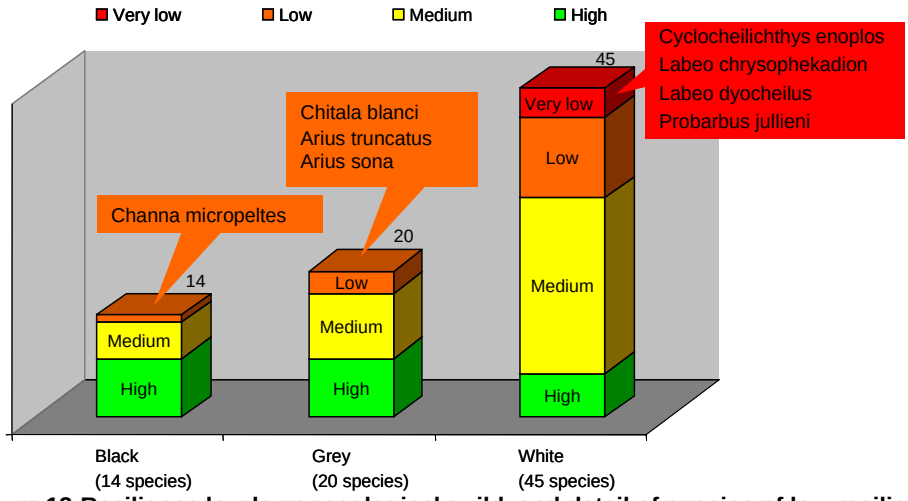

Figure 12:Resilience levels per ecological guild, and detail of species of low resilience

IV CONCLUSIONS

The exploitation of the database of Tonle Sap fish species has just been superficially initiated in that report. A number of additional analyses will follow; they should allow creating a typology of Tonle Sap species and general rules about the response of these various species groups to environmental modifications. Chief among them are the hydrological modifications (changes in water volume and discharge) as well as change in hydrodynamics (flood timing, flood duration, etc) both driven by built structures.

The major conclusion from the preliminary analyses of this report are that three Tonle Sap fish taxa have their migration triggered by changes in water level[4]. This means that the development of built structures, such as dams, that would significantly modify the dynamics of water and the timing of the flood might disrupt the migrations of these taxa. This timing issue can have an impact on the total production, depending on whether migration, spawning, the hydrological regime and the time allowed for growth are matched optimally or not (notion of environmental window for recruitment, Cury and Roy 1989).

Since these three taxa alone contribute between 38,000 and 56,000 tons to fishery yield each year, the issue is significant. Beyond financial value, a comprehensive risk analysis should encompass the livelihood value of these fish, and their role in the diet and food security of rural populations.

Last, it should be noted that not only three taxa are at stake. The extent of our knowledge gap is such (the sensitiveness to hydrodynamics in unknown for 90% of Tonle Sap species) that it is likely that several other species significant to fisheries are sensitive to hydrological modifications induced by infrastructures and likely to collapse in case of excessive perturbations.

[4] In Khone Falls for instance *Cyclocheilichthys enoplos* is caught between 1,500 and 20,000 $m^3.s^{-1}$, with a sharp peak around 3,000 $m^3.s^{-1}$, and *Paralaubuca typus* displays a sharp and intense peak around 2,000 $m^3.s^{-1}$

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ANNEX A: IFREDI LIST OF TONLE SAP FISH SPECIES

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Khmer name	Latin name	Khmer name
Ampil tum	Puntius orphoides	
Andaeng ngang	*Clarias nieuhofi*	ត្រីអណ្តែងងាំង
Andaeng reung	Clarias batrachus	ត្រីអណ្តែងរឹង
Andaeng toun	Clarias macrocephalus	ត្រីអណ្តែងទន់
Andaeng toun	*Clarias meladerma*	ត្រីអណ្តែងទន់
Andat chhkae	*Achiroides leucorhynchos*	ត្រីអណ្តាតឆ្កែ
Andat chhkae	Brachirus harmandi	ត្រីអណ្តាតឆ្កែ
Andat chhkae	Brachirus orientalis	ត្រីអណ្តាតឆ្កែ
Andat chhkae	*Cynoglossus feldmanni*	ត្រីអណ្តាតឆ្កែ
Andat chhkae	Cynoglossus microlepis	ត្រីអណ្តាតឆ្កែ
Angkot prak	*Puntius brevis*	ត្រីសង្កត់ប្រាក់
Antong	Monopterus albus	ត្រីអន្ទង់
Arch kok	Labiobarbus siamensis	ត្រីអាចម៏កុក
Bandol ampov	Clupeichthys aesarnensis	ត្រីបណ្តូលអំពៅ
Bandol ampov	*Clupeichthys goniognathus*	ត្រីបណ្តូលអំពៅ
Bandol ampov	*Clupeoides borneensis*	ត្រីបណ្តូលអំពៅ
Bandol ampov	*Corica laciniata*	ត្រីបណ្តូលអំពៅ
Bangkouy/Dorng Darv	Luciosoma bleekeri	ត្រីបង្គួយ រឺ ដងដាវ
Changva	*Rasbora dusonensis*	ត្រីចង្វា
Changva	*Rasbora hobelmani*	ត្រីចង្វា
Changva	*Rasbora myersi*	ត្រីចង្វា
Changva	*Rasbora pauciperforata*	ត្រីចង្វា

Changva chnot	*Rasbora daniconius*	ត្រីចង្វាឆ្នូត
Changva chnot	*Rasbora paviei*	ត្រីចង្វាឆ្នូត
Changva chunchuk	*Crossocheilus reticulatus*	ត្រីចង្វាជញ្ជក់
Changva moul	*Rasbora tornieri*	ត្រីចង្វាមូល
Changva phleang	*Esomus longimanus*	ត្រីចង្វាស្លៀង
Changva ronoung	*Lobocheilos melanotaenia*	ត្រីចង្វារនោង
Cheik tum	Bagrichthys macracanthus	ត្រីចេកទុំ
Cheik tum	*Bagrichthys obscurus*	ត្រីចេកទុំ
Chhdau	Channa micropeltes	ត្រីឆ្តោ
Chhkaok	Cyclocheilichthys enoplos	ត្រីឆ្កោក
Chhkaok phleung	Cyclocheilichthys furcatus	ត្រីឆ្កោកភ្លើង
Chhkaok pukmotbai	*Cyclocheilichthys heteronema*	ត្រីឆ្កោកពុកមាត់បី
Chhkok Kda / Kampoul Bai	Cosmochilus harmandi	ត្រីកំពូលបាយ
Chhlang	*Hemibagrus spilopterus*	ត្រីឆ្នាំង
Chhlang khmao	Hemibagrus wyckii	
Chhma	*Setipinna melanochir*	ត្រីឆ្នា
Chhmar krapeu	Lycothrissa crocodilus	ត្រីឆ្នាក្រពើ
Chhpin	Hypsibarbus lagleri	ត្រីឆ្ពិន
Chhpin	Hypsibarbus pierrei	ត្រីឆ្ពិន
Chhpin krohorm	Hypsibarbus wetmorei	ឆ្ពិនក្រហម
Chkaok tytuy	Albulichthys albuloides	ត្រីឆ្កោកទីទុយ
Chlounh	Macrognathus siamensis	ត្រីឆ្ពូញ
Chpin prak	Barbonymus gonionotus	ត្រីឆ្ពិនប្រាក់
Chra kaeng	Puntioplites falcifer	ត្រីច្រកែង

Chra kaeng	Puntioplites proctozysron	ត្រីច្រកែង
Chunlungh moan	*Coilia lindmani*	ត្រីជន្លូញមាន់
Chunlungh moan	*Coilia macrognathos*	ត្រីជន្លូញមាន់
Chunteas phluk	*Parachela maculicauda*	ត្រីជន្ទាសភ្លុក
Chunteas phluk	*Parachela oxygastroides*	ត្រីជន្ទាសភ្លុក
Chunteas phluk	*Parachela siamensis*	ត្រីជន្ទាសភ្លុក
Chunteas phluk	*Parachela williamminae*	ត្រីជន្ទាសភ្លុក
Domrei	Oxyeleotris marmorata	ត្រីដំរី
Dong khteng	Macrochirichthys macrochirus	ត្រីដងខ្ទេង
Ka-ek	*Labeo chrysophekadion*	ត្រីក្អែក
Kahe krohorm	Barbonymus altus	ត្រីកាហែក្រហម
Kahe lueung	Barbonymus schwanenfeldii	ត្រីកាហែល្បើង
Kambot chramos	Amblyrhynchichthys truncatus	ត្រីកំបុតច្រមុះ
Kamphleanh phluk	*Trichogaster microlepis*	ត្រីកំភ្លាញភ្លុក
Kamphleanh srae	Trichogaster trichopterus	ត្រីកំភ្លាញសម្រែ
Kamphleav	*Kryptopterus schilbeides*	ត្រីកំភ្លៀវ
Kamphleav khlanh	Kryptopterus cryptopterus	ត្រីកំភ្លៀវខ្លាញ់
Kamphleav stung	*Kryptopterus cheveyi*	ត្រីកំភ្លៀវស្ទឹង
Kanhchak slar / Khla	Toxotes microlepis	ត្រីកញ្ជ្រោក់ស្លា
Kanhchak slar/Khla	*Toxotes chatareus*	ត្រីកញ្ជ្រោក់ស្លា
Kanhchos	*Mystus wolffi*	ត្រីកញ្ឆេះ
Kanhchos bai	*Mystus albolineutus*	ត្រីកញ្ឆេះបាយ
Kanhchos chnot	*Mystus multiradiatus*	ត្រីកញ្ឆេះឆ្នូត
Kanhchos chnot	Mystus mysticetus	ត្រីកញ្ឆេះឆ្នូត

Kanhchoun chey	Channa lucius	ត្រីកញ្ឆុនជ័យ
Kanhchras thom	*Parambassis apogonoides*	ត្រីកញ្ឆោស់ធំ
Kanhchrouk	*Botia beauforti*	ត្រីកញ្ជ្រោក
Kanhchrouk	*Botia morleti*	ត្រីកញ្ជ្រោក
Kanhchrouk chnot	Botia helodes	ត្រីកញ្ជ្រោកឆ្នូត
Kanhchrouk krohorm	Botia modesta	ត្រីកញ្ជ្រោកក្រហម
Kanhchrouk leung	*Botia lecontei*	ត្រីកញ្ជ្រោកលឿង
Kantho	Trichogaster pectoralis	ត្រីកន្ធរ
Kantrob	Pristolepis fasciata	ត្រីកន្ត្រៀប
Kantrorng preng	Parambassis wolffii	ត្រីកន្ត្រងប្រេង
Kantuy krohorm	*Discherodontus schroederi*	ត្រីកន្ទុយក្រហម
Kaock	Arius maculatus	ត្រីក្អុក
Kaock	*Arius sona*	ត្រីក្អុក
Kaock	*Arius stormi*	ត្រីក្អុក
Kaock	Arius thalassinus	
Kaock	*Arius truncatus*	ត្រីក្អុក
Kaork	*Hemipimelodus borneensis*	ត្រីក្អុក
Karb sor	Hypophthalmichthys molitrix	ត្រីកាបស
Karp samanh	*Cyprinus carpio*	ត្រីកាបសមញ្ញ
Kasan	Channa gachua	ត្រីក្សាន
Kbork	Tenualosa thibaudeaui	ត្រីក្បក
Keat srang	*Balantiocheilos melanopterus*	ត្រីគ្បៀតស្រង
Kes krohorm	*Micronema bleekeri*	ត្រីកេសក្រហម
Kes prak	*Kryptopterus bicirrhis*	ត្រីកេសប្រាក់

Khchoeung	*Macrognathus maculatus*	ត្រីខ្ជឹង
Khchoeung	Mastacembelus armatus	
Khchoeung	*Mastacembelus favus*	ត្រីខ្ជឹង
Khchoeung pkhar	*Mastacembelus erythrotaenia*	ត្រីខ្ជឹងផ្កា
Khla	*Datnioides pulcher*	ត្រីខ្លា
Khla	Datnioides undecimradiatus	ត្រីខ្លា
Khlang hay	*Belodonthichthys dinema*	ត្រីក្តាំងហាយ
Khman	*Glossogobius aureus*	ត្រីក្ងាន
Khman	Hampala dispar	ត្រីខ្មាន់
Khman	Hampala macrolepidota	ត្រីខ្មាន់
Khnorng veng	Labiobarbus lineatus	ត្រីខ្នងវែង
Khya	Hemibagrus wyckioides	
Kranh	Anabas testudineus	ត្រីក្រាញ់
Kray	Chitala blanci	ត្រីក្រាយ
Kray	Chitala lopis	
Kray	Chitala ornata	ត្រីក្រាយ
Kreum	*Trichopsis schaleri*	ត្រីក្រឹម
Kreum	*Trichopsis vittata*	ត្រីក្រឹម
Kromorm	Hemisilurus mekongensis	ត្រីក្រម៉ំម
Kros	Osteochilus hasseltii	ត្រីក្រុស
Kros	Osteochilus lini	ត្រីក្រុស
Kros	Osteochilus microcephalus	ត្រីក្រុស
Kros chhnout	Osteochilus waandersii	ត្រីក្រុស
Kros phnom	*Poropuntius deauratus*	ត្រីក្រុសភ្នំ

Krum	Osteochilus melanopleurus	ត្រីក្រុំ
Kuch chreov	*Puntioplites bulu*	ត្រីគុចជ្រៀ/កញ្ជ្រៀ
Kul chek	*Epalzeorhynchos frenatum*	ត្រីគល់ចេក
Kulreang	Catlocarpio siamensis	ត្រីគល់រាំង
Linh	Thynnichthys thynnoides	ត្រីលិញ
Lolouk sor	Osteochilus schlegeli	ត្រីលលកស
Pase ee	Mekongina erythrospila	
Pava mouk mouy	Labeo dyocheilus	
Phkar ko	Cirrhinus jullieni	
Phkar ko	*Cirrhinus molitorella*	ត្រីផ្គាគ
Phtoung	Hyporhamphus limbatus	ត្រីផ្ទោង
Phtoung	Xenentodon cancila	ត្រីផ្ទោង
Pra chveat	Pangasius macronema	ត្រីឈ្វេត
Pra chveat	Pangasius polyuranodon	ត្រីឈ្វេត
Pra kae	Pangasius conchophilus	ត្រីកែ
Pra kandorl	Helicophagus waandersii	ត្រីប្រាកណ្តុរ
Pra khchao	Pangasius bocourti	ត្រីប្រាខ្ចៅ
Pra po	Pangasius larnaudii	ត្រីពោ
Pra po pruy	Pangasius sanitwongsei	ត្រីពោព្រួយ
Pra thom	Pangasianodon hypophthalmus	ត្រីប្រាធំ
Prama	Boesemania microlepis	ត្រីប្រម៉ា
Proloung / Chroloeung	Leptobarbus hoevenii	ត្រីព្រលួង/ច្រឡឹង
Pruol / Krolang	Cirrhinus microlepis	ត្រី ព្រួល/ក្រឡង់

Reach	Pangasianodon gigas	ត្រីរាជ
Riel anhkam	*Henicorhynchus cryptopogon*	ត្រីរៀលអង្កាម
Riel thmor	Cirrhinus cirrhosus	
Riel top	Henicorhynchus siamensis	ត្រីរៀលតុប
Ros / Phtuk	Channa striata	ត្រីរ៉ស់
Sanday	Wallago attu	ត្រីសណ្តាយ
Slat	Notopterus notopterus	ត្រីស្លាត
Sleuk russey	*Paralaubuca harmandi*	ត្រីស្លឹកឫស្សី
Sleuk russey	*Paralaubuca riveroi*	ត្រីស្លឹកឫស្សី
Sleuk russey	Paralaubuca typus	ត្រីស្លឹកឫស្សី
Sraka kdam	*Cyclocheilichthys apogon*	ត្រីស្រកាក្តាម
Sraka kdam	*Cyclocheilichthys amatus*	ត្រីស្រកាក្តាម
Sraka kdam	*Cyclocheilichthys lagleri*	ត្រីស្រកាក្តាម
Sraka kdam	Cyclocheilichthys repasson	ត្រីស្រកាក្តាម
Stuok	Wallago leerii	ត្រីស្តុក់
Ta aon	Ompok bimaculatus	ត្រីតាអោន
Ta aon	*Ompok hypophthalmus*	ត្រីតាអោន
Tanel	*Hemibagrus filamentus*	ត្រីតានេល
Tra sork krohom	Probarbus jullieni	ត្រីត្រសក់
Tra sork sor	Probarbus labeamajor	ត្រីត្រសក់ស
Trocheak domrei	Osphronemus exodon	ត្រីត្រចៀកដំរី

ANNEX B: QUESTIONNAIRES ON TRADITIONAL ECOLOGICAL KNOWLEDGE

Fisheries Ecology Survey Form

COMPLETE 1 FORM FOR EACH INTERVIEW

Section A. - DETAILS OF THE INTERVIEW

		Respondents	Gender/Age
Date			
Location			
Structure type			
Village name			
Commune			
District		Who identified them?	
Province			

Section B. - MAPPING THE CURRENT SITUATION

Guidelines:

We get the respondents to draw a map of the area as it is now (use large piece of paper).
Important aspects to include are:
1. types of habitat (e.g. canals, paddy fields, ponds, rivers, streams, swamps etc.) that might be important for fish and/or fishing. Highlight which ones are new or have changed. Location name
2. Distances, estimated areas and depths and seasonality of the resource (mark these on map)
3. Any rules that are in place regarding access to and use of resources. Mark these with the letter private or protected areas on the map.
4. Gear and main gear types in each fishing location.

Now **go to section C.**

Section D - LOCAL MIGRATIONS AND SPAWNING

D1. Use the local map and transparencies to show the location and timing of migrations and where the fisher perceives the source of young fish to be (e.g. local, tributary or Mekong).

Species	**Where the young fish come from**
Pra Thom	
Prual	
Riel	
Chhpin	
Ta Oan	
Kanh Chos	
Kanthou	
Kray Srae	
Proloong	

D2. Have there been any changes in migrations and movements because of the built structure? If yes, which species and why do they think this has happened?

Section E. - NEW INFORMATION ON FISH ECOLOGY

H1. Ask fishers for which species they have knowledge of spawning, nursing, feeding and migrations within the basin. For those fish that they have knowledge, complete the following table. For the ecology type (black/white/grey) you will need to identify this yourself.

Species name	**Type of Spawning habitat**	**Name of Spawning location**	**Type of Feeding habitat**	**Type of nursing habitat**	**Ecology type**
Andet Chhkae					
Kanhchos Bay					
Kanchras Thom					
Bandoul Ampov					
Reus Chek					
Kasan					
Phtoung					
Chlaing					
Ka Ek					
Angkot Prak					
Dorng Khteng					
Chunteas Phluk					
Ampil Tum					
Stuk					
Kra Morm					
Ka Uk					
Krum					
Chunluanh Moan					
Kantrang Preing					
Kampleav					
Khlaing Hay					
Kes					

Form completed by: