FISH RESOURCE AND HYDROBIOLOGICAL MODELLING APPROACHES IN THE MEKONG BASIN

by

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Photo on front cover:
A Dai (bagnet) catch of ca. 500 kg. taken in 30 minutes during the peak of fish migrations in January 1996 in the Tonle Sap River, Cambodia. *Photo N. van Zalinge.*

ABSTRACT

This document summarises the outputs of a modelling approach of the relationships between hydrology and fisheries production in the Mekong River Basin. Environment (floodplains, wetlands and their vegetation) has also been taken into account as a constitutive part of the system.

Variables likely to influence fish catches in the Mekong River floodplain system have been identified as follows:
- hydrology : water level, duration of the flood, timing of the flood, continuity of flooding
- environment: total area of floodplains, area of each type of flooded vegetation, dry season refuges
- ecology: fish migrations

This study was constrained by the paucity of usable data, and also by the short period of time in common between available data sets (three years): the monitoring of the Cambodian fisheries started in 1995, and the hydrological model cannot be run after 1998 due to the absence of rainfall data after this year. For the analysis of the relationships between hydrology, floodplains and fish catches, we focussed on the Cambodian "dai" (bagnet) fishery for which the most complete and reliable data set was available. Hydrological data used were those provided by the MRC or alternatively those generated by the IWMI model.

Analysis of the dai fishery data showed a strong correlation between catches and water level the same year. The corresponding model is *Catches = 19580 . Ln (October water height) - 32025* with $r^2 = 0.85$. Analysis of the catches showed the dominance of two taxa (*Henicorhynchus sp.* and *Paralaubuca typus*) which make up to 49% of total catches. *Henicorhynchus sp.* closely reacts to the hydrology (the size of these fishes being correlated to the maximum water level reached the same year), but even the total catch of other species exhibits a significant correlation with the water level in the same year (but not with former years).

The total production of the Tonle Sap system, based on available statistics and including subsistence as well as rice field fisheries, amounts 230,000 tons a year. The productivity is also very high: 230 kg per hectare of floodplains. However comparisons with former estimates, when done on a standardised basis, show that the production per fishing inhabitant is much lower than 60 years ago. This can be considered as a warning signal of high exploitation rate. The analysis of catches in 1940, 1965, 1976 and nowadays also substantiate the conclusion that total catches in the Tonle Sap system were related to the water level of the Mekong River.

The annual yields of the dai fishery in Cambodia are apparently correlated with the surface of floodplains, as far as three years of data allow any correlation. Evidence from previous works in planktonology on the huge production of this floodplain supports this conclusion. A detailed analysis of the dai fishery and surfaces of different land covers shows a positive relationship between the fish catch and the extent of flooded forest, as well as that of low vegetation. The ecological importance of the flooded forest to fish is discussed.

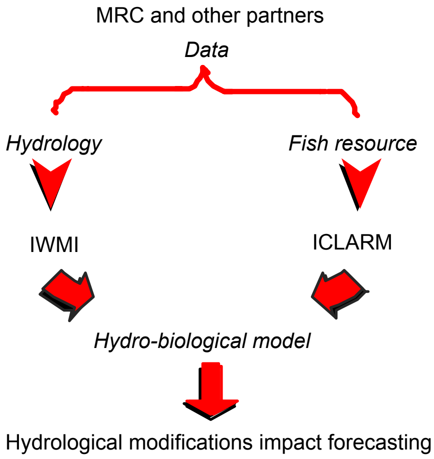
Around the Tonle Sap Great Lake, the water level - flooded surface relationship is not linear, implying that water level reduction (by management) would not linearly affect the surface of floodplain. The effect of flood duration on the growth of fish is also substantiated from the existing literature, as well as the effects of timing and continuity of the flood. However available data do not allow quantitative assessment of these latter issues.

Amongst other ecological factors, migrations are of critical importance in the Mekong basin. Although this qualitative factor is not easily integrable into quantitative modelling, available data demonstrate that the density of fish migration (more than 30 tons per hour in the Tonle Sap River) make fish ways an unrealistic mitigation measure against the negative effects of dams. Available studies also suggest that the presence of refuges in the dry season (ponds in floodplains, pools in streams) is a contributary factor allowing the sustainability of the production.

PREAMBLE

The following document reviews the work done on the fish resource in the Mekong River Basin within the frame of a project involving ICLARM, the Mekong River Commission and the International Water Management Institute. This project entitled " Modelling the management of water flows to optimise aquatic resource production in the Mekong Basin" was funded by the CGIAR Technical Advisory Committee, for the year 2000.

The core of biological data sets has been provided by the MRC/DoF/DANIDA project "Management of the Freshwater Capture Fisheries Project in Cambodia", the Global Association for People and the Environment (GAPE) in Southern Laos, and the MRC/LARReC/DANIDA project "Assessment of Mekong fisheries - fish migrations and spawning and impact of water management (basinwide)". Other sources of information are acknowledged further in this document.
Hydrological modelling has been done by IWMI using the SLURP model (Kite 2000 a, b, c, d), and model output files on surfaces flooded and flooded vegetation covers have been used as input files in the following analyses.



According to the terms of reference of the project, we focus here on "an evaluation, using the physical data derived from modelling and knowledge of fish habitat and species, of the potential aquatic resource yield of the wetlands of these countries and the consequences for this resource of altered flow rates and flooding regimes."

ACKNOWLEDGEMENTS

Several persons have contributed to this work, and it is a pleasure to acknowledge their inputs.
We are grateful to M. Nao Thouk (Department of Fisheries, Cambodia) whose suggestions have resulted in the implementation of this project.
Multiple helpful comments, improvements and fruitful ideas were due to MM. Jorgen Jensen and Jens Sorslev (MRC), Geoff Kite (IWMI), Peter Gardiner, Stewart Grant, Magnus Torell and Mark Prein (ICLARM), Terry Warren, Tyson Roberts, and Nguyen Van Hao (RIA II, Vietnam).
Additional data and information used in this document has been kindly provided by MM. Anders Poulsen, Theo Visser, Nguyen Van Trong, Sophiny Prang (MRC), Nguyen Thanh Tung (RIA II, Vietnam), Pierre Dubeau, and Hans Guttman (AIT, Thailand).
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Inside photos E. Baran

SUMMARY

Seine fishing on the Tonle Sap Great Lake (Cambodia)

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List of acronyms

AIT: Asian Institute of Technology (Bangkok, Thailand)
AMF: Assessment of Mekong Fisheries project (MRC Vientiane, Laos)
CCF: Management of the Cambodian Freshwater Capture Fisheries project (MRC Phnom Penh, Cambodia)
GAPE: Global Association for People and the Environment (Victoria, Canada and Pakse, Laos)
GRAC: GIS and Remote sensing Application Center (Phnom Penh, Cambodia)
ICLARM: the World Fish Center (Penang, Malaysia)
IWMI: International Water Management Institute (Colombo, Sri Lanka)
MRC: Mekong River Commission (Phnom Penh, Cambodia)
RIA II : Research Institute for Aquaculture n° II (Ho Chi Minh City, Vietnam)

GENERAL BACKGROUND

Box 1: Population and fish resources in the Mekong Basin

The Mekong River is the 10th longest in the world (4400 km), and the 14th in discharge. Its huge flows (varying from 1 to 30 fold within a single year), combined to a low altitudinal gradient in the Lower Basin, create large surfaces of wetlands in the rainy season. These wetlands, whose total surface equals that of Ireland, allow a fish production and a diversity considered among the most important in the world.

Social issues

• The lower Mekong River Basin houses a human population of about 55 million.

• The population growth rate reaches 2.5% per year. This demographic pattern implies a huge pressure on natural resources in the coming years.

• Proteins of aquatic origin make up 80% of the diet of Cambodian populations.

Fish production

• Eighty per cent of fish consumed in the basin are from open water capture fisheries.

• With an annual production of 300,000 – 400,000 tons Cambodia’s freshwater capture fisheries ranked fourth among the world’s top in 1996. No reliable figures are available for Laos and Vietnam.

• The average fish yield in the Tonle Sap floodplain and lake area (Cambodia) amounts to 230 kg/ha.

These statistics, based on field scientific surveys, are much higher than the officially reported ones, the latter being considered as underestimates and insufficient for appropriate management and policy analysis.

Ecological specificities

• A large majority of the freshwater fish populations in the Lower Mekong basin migrate seasonally into flooded areas -particularly flooded forest- to spawn and grow from July to September (rainy season). Fish migrating longitudinally in the river constitute 63% of the total catch in the Tonle Sap area. Population abundances are therefore closely tied to the annual flooding and are strongly influenced by its pattern. This pattern is very particular in the Great Lake, with a flow reversal (from the lake to the Mekong River in the dry season, and conversely in the rainy season).

• The whole Mekong River Basin is home to an estimated 1,200 species of fishes, making it one of the three highest fish biodiversity areas in the world with the Amazon and the Congo Rivers. There is a high rate of endemic species.

Threats

• More than 30 major dams have been built across the Mekong and its tributaries in the last 35 years, in addition to 20,000 small reservoirs, particularly in Thailand.

• Eleven dams are planned on the mainstream, including across major migration channels.

• Downstream and cumulative effects of these dams have never been assessed.

• In Cambodia, 33% of the flooded forest has been cleared between 1973 and 1993.

INTRODUCTION

The estimated capture fisheries production in the Lower Mekong Basin ranges between 800,000 and 950,000 tons annually, the production of Cambodia ranging between 36 and 45% of this overall (Van Zalinge *et al.* 2000). This is a conservative estimate, the total production basinwide probably reaching more than one million tons a year (Jensen 2000). This production of freshwater wild fish - one of the most important in the world if not the most important - depends on the natural environment, and particularly on floodplains. Yearly moderate floods are considered a boon in the Lower Mekong as they bring with them the migratory fish and allow them to grow by feeding in floodplains.

The considerable extent of these floodplains (83,700 km^2 in the Lower Mekong according to Scott 1989 and Lacoursiere *et al.* 1998) is due to the very high outflow of the Mekong in the monsoon season (mean maximal discharge basinwide = 67,000 m^3s^{-1}, after Welcomme 1985), combined with the very low altitude in Cambodia and Vietnam (the surface of the Tonle Sap Great Lake stands between 10 and 1 meters only above sea level).

In rivers with extensive floodplains such as the Mekong, the catch is directly correlated with water discharge and floodplain area (Welcomme 1995), and complex fish migrations transfer this production throughout the basin.

Floodplains are favourable to fishes for three major reasons (Welcomme 1985, Junk *et al.* 1997):

- as a food source, due to release of nutrients, primary production and settlement of a detritus-based food chain;
- they provide shelter to juveniles against predation, thanks to the shallowness and the intricate flooded vegetation;
- the food chain initiated by the vegetal production is very diversified (see section 2-2) and provides numerous niches for multiple strategies, species, sizes, stages and life cycle strategies.

Furthermore the abundance and the diversity of floodplain fishes is usually related to the nature of the flooded vegetation, a forested land offering more resources than a grass land, both of them being able to sustain a higher production than barren land (Fig. 1):

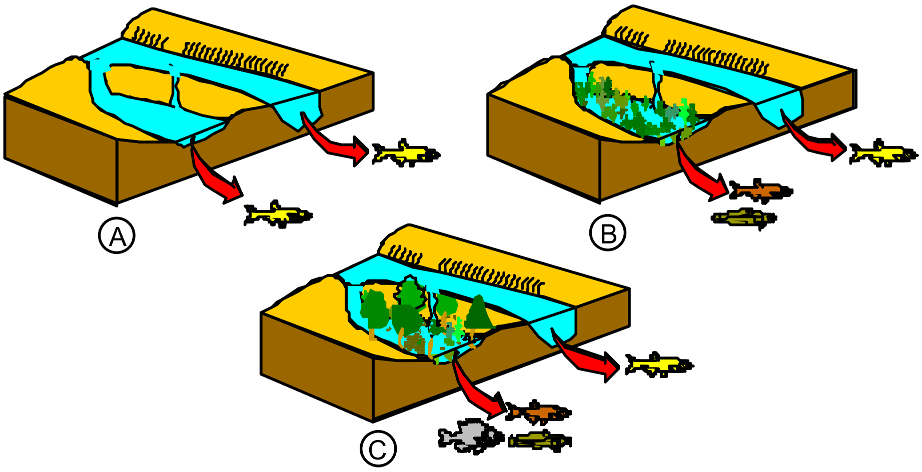


Figure 1: Different types of floodplains and their fish production
A: Flooding of barren land; limited and undiversified fish production
B: Flooding of a grass land; more abundant and diversified fish production
C: Flooding of a forest; abundant and diversified fish production.

Thus the fishery-environment interactions in floodplain fisheries are such that building a model of the fish yield, and of the consequences of altered flow rates, requires data on fisheries, on hydrology, but also on the environment (Van Zalinge & Touch Seang Tana 1996, Coates 2000, Baran & Coates 2000, Fig. 2).

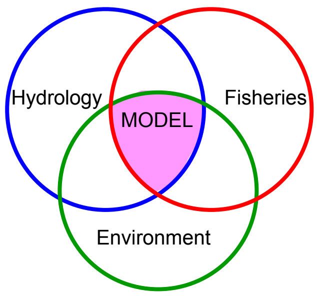


Figure 2: Hydrology, fisheries, environment and fish resource modelling

In the first part of this document we address the relationship between hydrology, area of floodplains and fisheries production. We address in the second part the other ecological aspects required in a more advanced modelling process.

In 1997, the MRC produced a "State of the environment report" for the Greater Mekong sub-region. In this report, current conditions of environmental resources are ranked on a three-degree scale. In Table I below this information is synthesised, and environmental resources are ordinated according to the degree of concern about them:

Table I: Degree of concern about environmental resources in the Greater Mekong sub-region (MRC 1997)

	Overall condition	Scale	Magnitude
Surface freshwater resources	1,50	1,36	1,43
Forests	1,29	1,29	1,50
Terrestrial biota	1,14	1,14	1,14
Biodiversity	1,07	1,21	1,14
Wetlands	1,00	1,00	1,00
Parks and reserves	1,00	1,14	0,86
Nutrition and health	0,86	1,00	1,00
Soils	0,93	0,93	0,86
Food production	0,86	1,07	0,79
Drinking water quality	0,93	0,86	0,93
Air quality	0,93	0,86	0,86
Lake and riverine fisheries	0,86	0,79	0,79
Groundwater resources	0,79	0,79	0,79
Coastline integrity	0,64	0,64	0,71
Nearshore fisheries	0,50	0,50	0,57
Marine water quality	0,43	0,36	0,50
Offshore fisheries	0,29	0,29	0,29

Table calculated after the summary given p. 5 of the MRC report. Qualitative three-degree scales (e.g. poor, fair, good) have been converted into numbers (e.g. 1, 2, 3) and averaged. The resulting overall scale (from 0.29 to 1.5) has been divided in 3 equal parts of different colours.

This table shows that scientifically underpinned information for management purposes in the fields of freshwater resources, wetlands, biodiversity, food production, lake and riverine fisheries is highly valuable. It is the aim of this work to provide a contribution in these fields, the initial focus on fish production having been broadened due to the ecological interactions between a biological resource and its environment.

DATA GATHERED

To establish this project with new partners and to seek out sources of relevant data amongst the range of holders, several trips were made to the region. These missions are listed below:

1) Inception meeting (20-27 / 1 / 2000)
Presentation of the project to all partners; preliminary contacts and works in Phnom Penh.

2) Mission from 19/ 3 to 7/4/00 in Cambodia, Laos and Thailand
Cambodia:
• MRC Secretariat: hydrological and climatic data sets; bibliography
• MRC Management of the Cambodian Freshwater Capture Fisheries project (*CCF*): Mobile gears data set
• GIS and RS Application Center (*GRAC*): Tonle Sap GIS data on land cover and Digital Elevation Model
Laos:
MRC Assessment of Mekong Fisheries project (*AMF*): bibliography
GAPE (*I. Baird*): Southern Laos fisheries monitoring data set
Thailand:
MRC Assessment of Mekong Fisheries project (*AMF*): Mekong mainstream migrations data set.
T. Warren: reports and species life-history traits data set.

3) Mission from 17/4 to 22/4/00 in Bangkok
Asian Institute of Technology (*H. Guttman*): Contacts and literature gathering

4) Mission from 29/5 to 5/6 in Phnom Penh
MRC Management of the Cambodian Freshwater Capture Fisheries project (*CCF*): Dai fishery data set; two years of length frequency data for some species; bibliography

5) Mission from 11 to 16/9/00 in Phnom Penh
Presentation at the MRC "Workshop on hydrologic and environmental modelling in the Mekong Basin"; works at the MFCFP; work at the CCF.

6) Mission from 29 to 31/10/00 in Saigon
Presentation of works and discussions at R.I.A. n° II; collection of bibliographic data.

Data/information collected are summarised in Fig. 3 below:

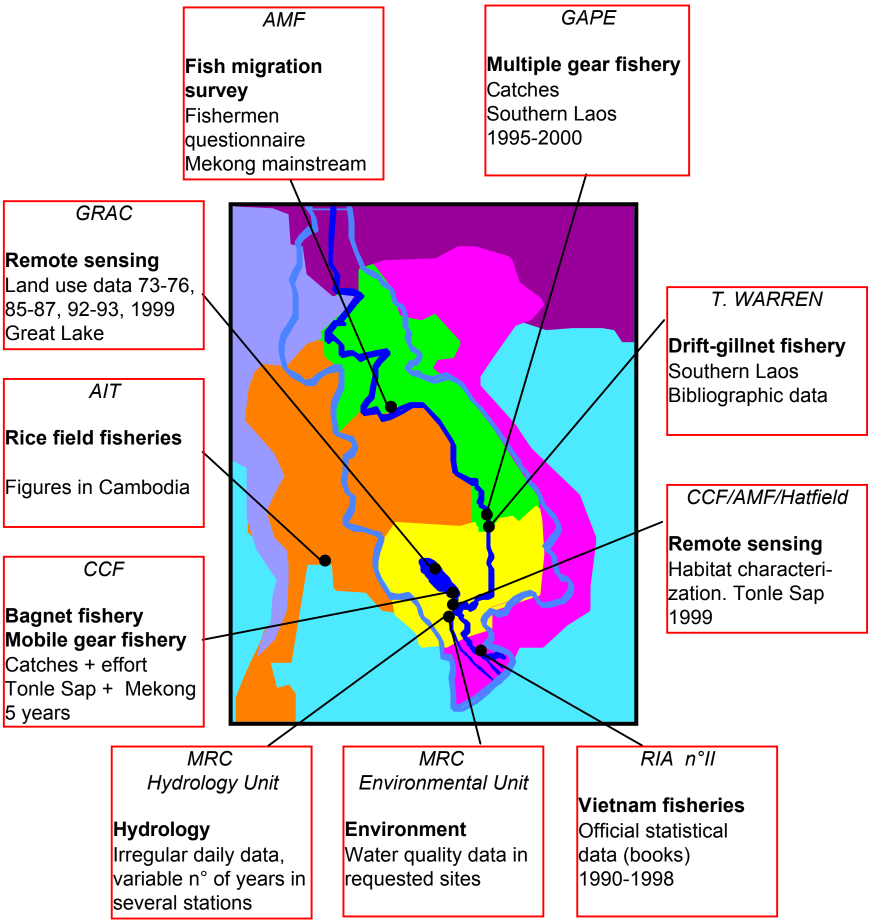


Figure 3: Data gathered in the course of this project

ASSESSMENT OF DATA GATHERED

Following the Project terms of reference, we focussed on fishery production data, and therefore on the only long-term production monitoring program in the region, that of the Management of the Freshwater Capture Fisheries of Cambodia project conducted by the MRC.

1) CCF PROJECT CATCH DATA SETS

The project set out to monitor three fisheries in Cambodia:
- dai fishery (2 provinces monitored on a monthly basis since the end of 1994, considered as the most reliable monitoring)
- mobile gears fisheries (more than 40 small gears monitored on a monthly basis in 8 to 12 provinces since 1995)
- lot fishery (139 lots monitored per month or season, in 8 provinces from 1995 to 1998).

In the first two cases data are recorded in the field according to a stratified sampling protocol, then computerised as raw data under the Artfish software (Stamatopoulos 1994, 1995), which provides an assessment of catches per stratum and globally.

Dai fishery

A first analysis was performed in June 2000, based on data provided by CCF (30/5/00), following a manual compilation of annual statistical figures produced by the Project (Diep Loeung *et al.* 1998, Van Zalinge & Nao Thuok 1999). However, it appeared that when recalculated from available raw data, catch figures differed significantly from those based on the CCF compilation. The difference (of about 25%) is due to a recent re-assessment of 1995-2000 data based on the 1996 census of dais, but the original raw data have not been modified.

This led to a second analysis based on basic raw data files generated by the Artfish software. Despite complications due to software structure which works on 493 different unit files, a unique data file was built. Analyses of these raw data pointed out data problems (Baran *et al.* 2001), which have led to a third and final analysis.

The third analysis was done on a core of raw data (Artfish data files whenever available), supplemented by manual compilation of former figures for January 1998, October 1996 and the whole 1999-2000 season.
Several taxonomic problems have been ignored in this analysis, to allow the development of a coherent, basic set of production figures. Despite these impediments, the dai fishery monitoring provided the core of the production-hydrology relationships analysis detailed below.

These detailed analyses are available in a separate report dedicated to this topic (Baran *et al.* 2001).

Box 2: The dai fishery

A "dai" (word of Vietnamese origin) is a bag net mounted on a scaffolding of trunks and set in a stream. It operates as an immobile trawl and targets moving fishes, particularly migrating ones. Dais are often set by rows of 3-4 units.

In Cambodia 63 dais operate and are concentrated in the Tonle Sap River. They target fishes migrating back from the Great Lake to the Mekong River at the end of the rainy season. The fishing season is limited in time (usually from October to March, with a marked peak in January) but the fish are so dense during the migration that the 63 Cambodian dais harvest 1600 tons per day during the 10 days peak period (i.e. 250 kg per 15 mn per dai, day and night, Ngor Pen Bun 2000). The dai fishery harvests 14,000-16,000 tons a year, which represents 4-5% of the total fish catches in Cambodia (Van Zalinge *et al.* 2000).

Mobile gear fishery

This fishery is an aggregate of numerous sorts of mobile gears, including gillnets, seines, arrow-shaped traps, river trawls and traps. It is an open-access fishery (all year long) and is considered as medium-scale. Due to practical limitations, 40 gears are regularly monitored, on a monthly basis in several provinces.
However the project staff is of the opinion that the collected data are covering the mobile fisheries only to an uncertain extent. Therefore the mobile gear data set has not been analysed.

Lot fishery
Due to the non-transparent character of the management in the floodplain lots (CNMC/Nedeco 1998 b, Ly Vuthy *et al.* 2000, Degen & Nao Thuok 2000) data collection is very difficult. In particular the data on total catches cannot be considered as reliable and therefore no analysis has been done. To date the most detailed biological analysis of lot fisheries (based on these data) is that of Puy Lim *et al.* (1999).

Hydrological data
Hydrological data have been requested independently of IWMI's modelling effort, for matching hydrological and patterns of fish catches.
Water heights in Kampong Chhnang (zone of the Dai fishery) were provided by the MRC Hydrology Unit on 2/6/00. The MFCFC Project questions these data, arguing that they are not reliable due to the change in the position of measuring gauges between 1957 and 1994 (Mekong Secretariat 1993, Lieng *et al.* 1995). Furthermore many years are missing (e.g. the 89-93 period). Alternative hydrological data have been provided by the project (which include the 89-93 period), but two supposedly identical files differ for 1982, 1998 and 1999. However the difference between these data sets and the MRC data is very small.
We have also been provided with the Kampong Chhnang alternative hydrological data set entitled "Hydrological observation book" corresponding to the new gauge height, but measurements cover only the October 99 - February 2000 period.

In absence of evidence and of MRC data for 98-99, it was decided to base the following catch-hydrological level relationships on the second Project hydrology data set.

2) TAXONOMY

Taxonomy is obviously a major problem when dealing with the Mekong river fish resource, not only because of the diversity of species, but also because of lack of coherence between the different taxonomists specialising in this fauna. This problem has already been noted by Warren *et al*. (1998), detailed by CNMC/Nedeco (1998 b) and in Baran *et al.* (2001). For instance, according to Roberts & Baird (1995), Roberts (1997) and Baird *et al.* (2000), one of the most important species migrating in Southern Laos from Cambodia is *Cirrhinus lobatus* Smith 1945. This species is not recorded in Rainboth (1996) and is absent from published species lists in Cambodia, even under its (invalid) synonym *Henicorhynchus lobatus*.

According to Chavalit Vidthayanon (personal communication, Dec. 2000) there are 2 species of the cyprinid "Riel" occurring in the Dai catches. The most common one is "Riel" or *Cyrrhinus ("Henicorhynchus") lobatus,* less common is "Riel Tob" or *H. siamensis*. The two species have not been separated so far in the sampling work.

3) IWMI MODEL COMPUTED DATA

This works aimed at matching fisheries data and hydrological data. As no comprehensive hydrological model of the whole Mekong, including the Tonle Sap sub-system, had been built since 1965 (Kreuze 1998, Al-Soufi 2000, Ringler 2000), such a model was developed within the course of this project by IWMI (Kite 2000 c, d), based on the SLURP model (Kite & Droogers 1999, Kite 2000 a, b).
This basin model simulates the hydrological cycle from precipitation to runoff at a daily timestep. It divides a basin into sub-basins using topography from a digital elevation map. The sub-basins are further divided into

areas of different land covers using data from a digital land cover classification. Each land cover class has a distinct set of parameters. The hydrological model simulates the vertical water balance, transforming the daily precipitation into evapotranspiration, water retention and runoff separately for each land cover within each sub-basin. The outputs of each vertical water balance include evaporation, transpiration, runoff, groundwater flow and changes in canopy storage, snowpack, soil moisture and ground water. It potentially includes the effects of reservoirs, regulators and water extractions.

This hydrological model encompassing the Tonle Sap River reversing flow has resulted in a daily estimate of the Mekong discharge (from China to the upper non-tidal delta) and of the Tonle Sap River discharge. For the purpose of fishery-environment relationships modelling, it has been supplemented by the integration of a Digital Elevation Model and a GIS-referenced map of land cover of the Tonle Sap Great Lake zone, resulting in an assessment of the surface of each land cover flooded each year in this zone.

This modelling started with the year 1994, due to the absence of production monitoring in Cambodia before this date. It stopped in December 1998 due to the absence of available data in 1999 (Kite 2000 c).

4) SPATIAL DISTRIBUTION OF AVAILABLE DATA SETS

Figure 4 below summarises quantitative data sets available along the Mekong River that have been used in this work.

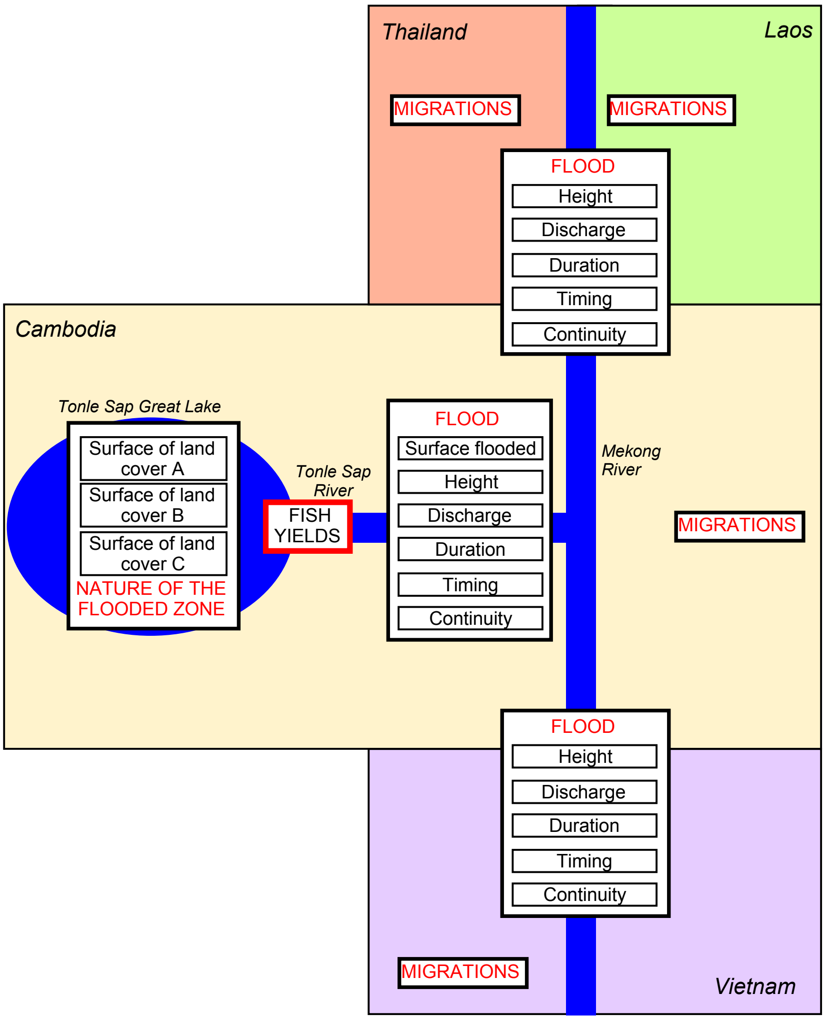


Figure 4: Distribution of hydrobiological data sets in the Mekong Region

5) COMMON TEMPORAL SEQUENCES

The project anticipated relying on available data. However on review of the previous sources (see previous) the period in common between Cambodian fish production monitoring statistics and the IWMI hydrological model data and output is for three years only (Fig. 5).

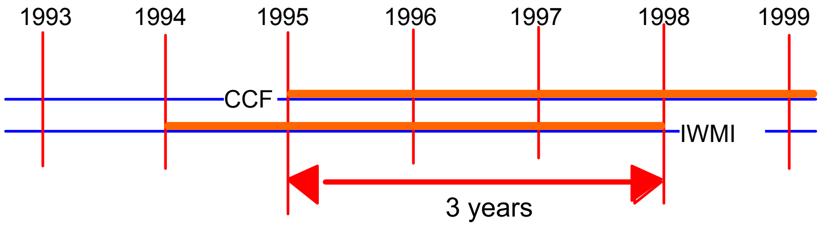


Figure 5: Common temporal sequence among major data sets gathered

It is therefore impossible to statistically test any relationship between hydrological and production figures. This also seriously hampers the demonstration the significance of any trend or conclusion drawn from these very limited data.

Gill net fishing in Vietnam

RESULTS

1) MODELLING THE IMPACT OF HYDROLOGY ON FISH PRODUCTION

1-1) FISH CATCHES AND FLOOD LEVEL

Several studies world-wide have shown a correlation between the *total catch* (in tons) and the river flooding the same year (Welcomme 1985); the relationship is:

$$C_y = a.(L_y) + b$$

C = total catch (tons) L = water level (m)
y = year a & b =coefficients

Note: the total catch results both from fish availability and from fishing effort, so whenever possible it is preferable to focus on the Catch Per Unit Effort (Bayley 1988, Moreau & De Silva 1991). The effort is usually the number of fishing gears and number of days/hours of fishing, but in the case of complex multi-gears tropical fisheries, integrating the fishing population as a rough indicator of the fishing effort is a preliminary step in year-to-year or site-to-site analyses of trends (see section 2-1-2).

1-1-1) Case of the Cambodian "dai" fishery

The relationship between fish production and floods has been known for a long time, and Lagler (1976) for instance plotted a "hypothetical relationship between magnitude of river discharge and fish stock". We analyse this relationship below, based on available MRC hydrological and fish production data.

In the case of the dai fishery analyses, "annual" refers to the annual fishing season, i.e. from October to March (the peak being in January as shown in Fig. 6).
Hydrological data have been referenced accordingly.

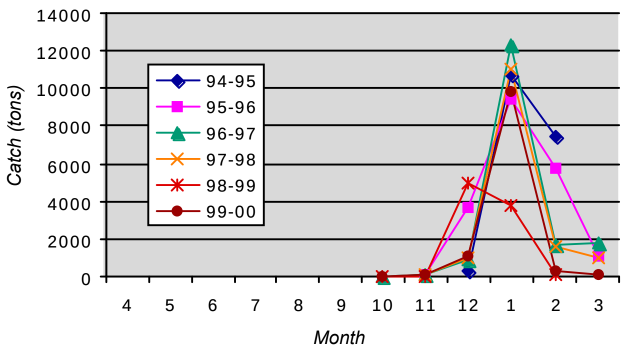


Figure 6: Monthly distribution of dai catches

Correlation between total catch and hydrology

In Cambodia the annual flood peak occurs in October (Fig. 7), and it was decided to compare the annual dai catch (mostly localised in the Kampong Chhnang zone) with the average October water level in the K. Chhnang zone (Deap Loeung 1999).

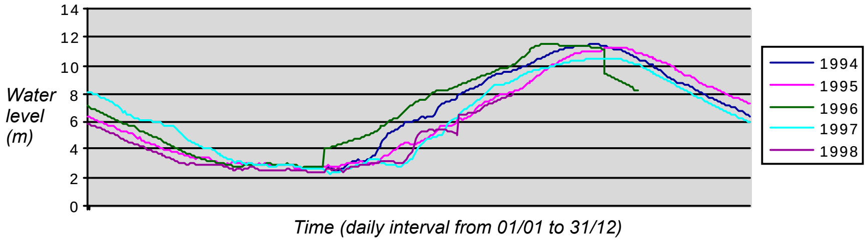


Figure 7: Water level variations in Kampong Chhnang (MRC data)

Plotting catches versus flood level shows that the annual dai catches for October in the Tonle Sap river closely follow the average October water lever in the same river (Fig. 8):

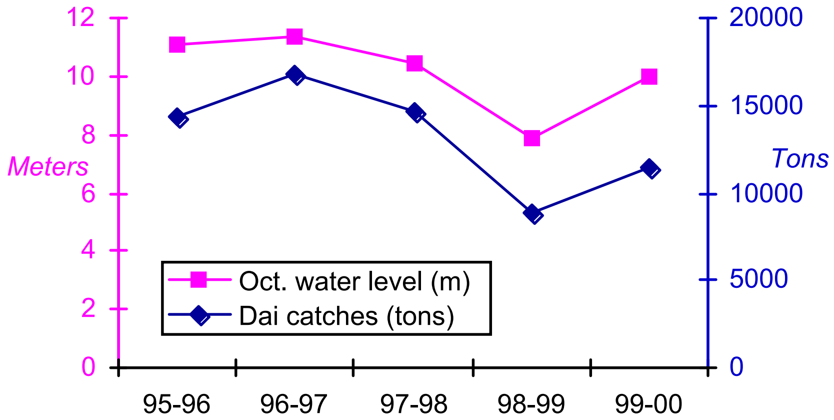


Figure 8: Comparison between average October water levels in K. Chhnang (Project data) and seasonal Dai catches (our analysis)

Preliminary work on this relationship (Baran *et al.* 2001) showed that the most appropriate fit was not a linear but a logarithmic relationship, as biological responses to environmental variations are not linear, but asymptotic. The logarithmic curve better illustrates such responses.
Figure 9 below details the relationship between yearly Dai catches and water level:

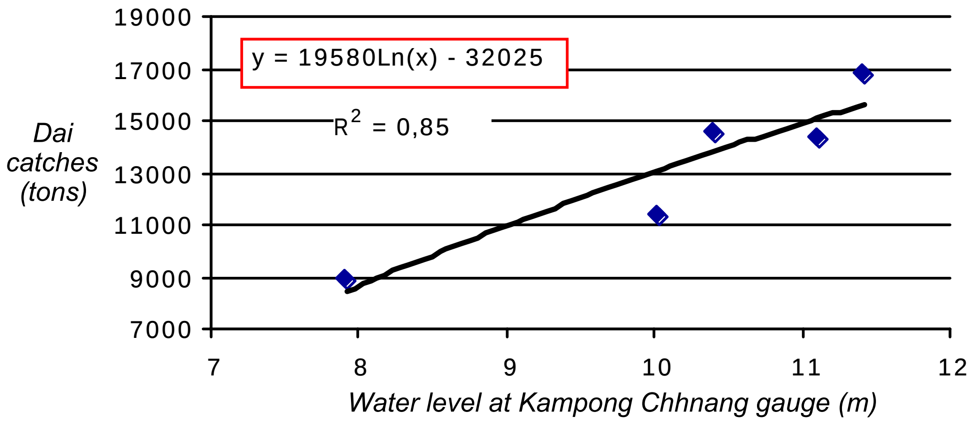


Figure 9: Annual dai catches in Cambodia vs. average October water level

In that case, the equation is:

Catches = [19580 . Ln (average October water height) - 32025]	
Catches in tons	Kampong Chhnang average October height in meters

Nil catches correspond to:
Ln(x) = 32025/19580 = 1.636 => x = Exp(1.636) = 5,1 m

It must be stressed that the accuracy of this model is dependant upon that of the data and therefore of the representativeness of sampling. Given the data set used (see section "Assessment of data gathered") it is not possible to calculate confidence intervals for the outputs of this model. One can note that the yearly dai catch is considered to range between 14,000 and 16,000 tons (Van Zalinge *et al.* 2000). A similar error range of 15% at least should be applied to any output of the model.
The equation for the upper range of catch values is: y = 22517Ln(x) - 36829 (R^2 = 0,85)
and for the lower range of catch values: y = 16643Ln(x) - 27221(R^2 = 0,85)

This model, when computed for lower water levels, predicts that the catch will be nil when the October water height does not exceed 5.1 m at the Kampong Chhnang gauge (Fig. 10):

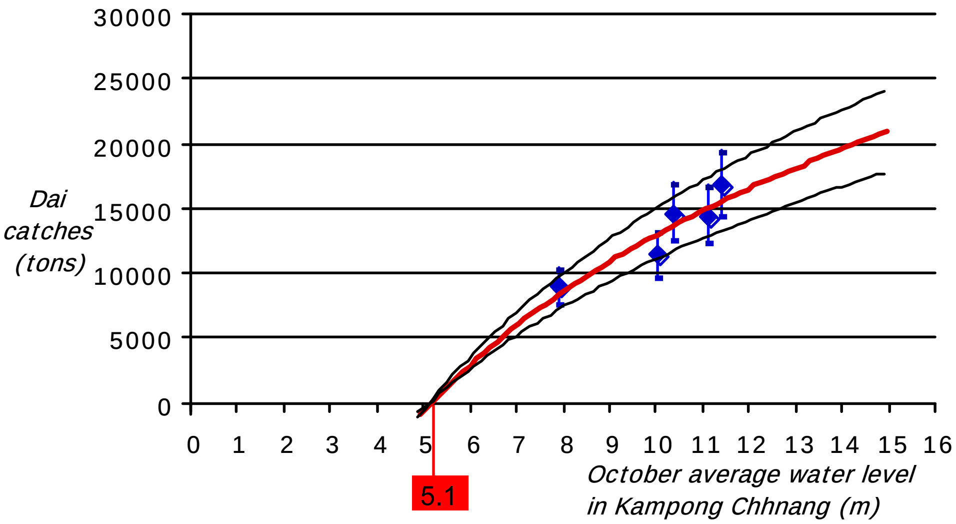


Figure 10: Annual dai catches in Cambodia vs. average October water level

This predicted nil catch would correspond to a reduction by 57% of the average October water height of these five last years (but only a reduction of 30 % of the low water level experienced two years ago, in 1998).

Here, although this is in principle out of the scope of the hydrology- total production relationship, we must mention that detailed analysis focusing on species composition (Baran *et al.* 2001) have shown that the majority of the catch (55.4%) consists of two taxa only (Fig. 11): *Henicorhynchus sp.* and *Paralaubuca typus*.

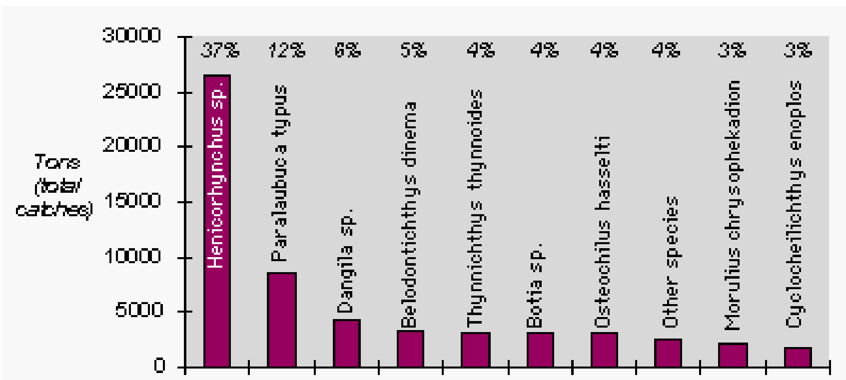


Figure 11: Species composition of dai catches between 1995 and 2000

It is to be noted that the close relationship between the total catch and the hydrology is due to *Henicorhynchus sp*, as the other species do not follow the same temporal pattern and exhibit no correlation with the water level (Fig. 12):

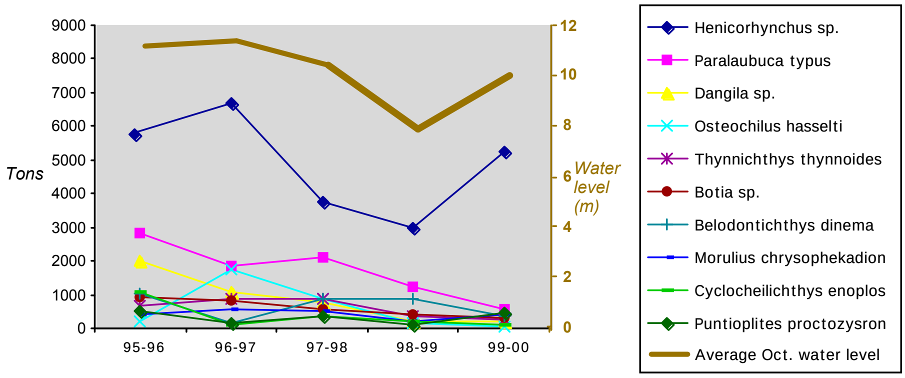


Figure 12: Yearly catch trends for the 10 most abundant taxa

The logarithmic equations linking catches with or without *Henicorhynchus sp.* and water heights are given in Fig. 13:

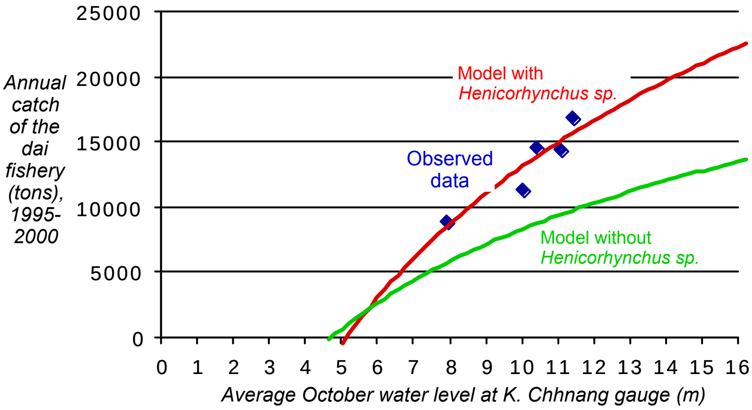


***Figure 13: Dai catches vs. average October water level, with or without* Henicorhynchus sp.**

This visually confirms the importance of *Henicorhynchus sp.* in the accuracy of the model.
However it is to be noted that whether *Henicorhynchus sp.* is taken into account or not the critical threshold remains very similar in both models.
The small number of data does not permit the calculation of confidence intervals for these predictions (they can only be calculated under the assumption that the data are normally distributed, which cannot be tested here).

Correlations between the hydrology and the total catch 1 to n years before

Several works (e.g. Welcomme *et al.* 1989, Laë 1992) have pointed out the relationship between catches and the hydrology n years before. This can be summarised by the following equation:

$$C_y = a.(L_{y-n}) + b$$

C = total catch (tons) — L = water level (m)
y, y-n = years — a & b =coefficients

Or alternatively by the following equation (Welcomme *et al.* 1989):

$$C_y = a + b\ (p_1 I_{y-1} + p_2 I_{y-2} + p_z I_{y-n})$$

C = catch in a year (tons) — I: index of flood intensity
y, y-n = years — a & b =coefficients
p: relative importance of a particular year's flood

In the case of Project data, the short time-series does not allow the proper calculation of this inter-annual relationship by removing the auto-correlations between years;
We however give in Box 3 the result of a linear forward stepwise regression on
$Catch_Y = f^n (L_Y; L_{Y-1}, L_{Y-2}, L_{Y-3})$:

Note: this calculation is made on total catch data except *Henicorhynchus sp*., to avoid a bias due to this dominant taxon whose response masks that of other species.

Box 3: regression between catch and yearly water levels

```
DEPENDENT VARIABLE    CATCH (without Henicorhynchus sp.)
PREDICTIVE VARIABLES: 1 CONSTANT; 2 LY; 3 LY-1, 4 LY-2, 5 LY-3
MINIMUM TOLERANCE FOR ENTRY INTO MODEL =  0.020000
[…]
STEP #    4 R= 0.777 RSQUARE=  0.604
VARIABLE            COEFFICIENT    STD ERROR  STD COEF TOLERANCE    F    'P'
IN:
1 CONSTANT
  2 LY                1594.238      745.224     0.777  .1E+01    4.576   0.122
OUT:                   PART. CORR
  3 LY-1                 0.839         .            . 0.93760    4.757   0.161
  4 LY-2                -0.387         .            . 0.77780    0.353   0.613
  5 LY-3                -0.394         .            . 0.49608    0.368   0.606

THE SUBSET MODEL INCLUDES THE FOLLOWING PREDICTORS:
* CONSTANT
* LY (water level the same year)

DEP VAR:   CATCH      N:        5  MULTIPLE R: 0.777  SQUARED MULTIPLE R: 0.604
ADJUSTED SQUARED MULTIPLE R: 0.472    STANDARD ERROR OF ESTIMATE:     2055.242

VARIABLE      COEFFICIENT    STD ERROR     STD COEF TOLERANCE     T    P(2 TAIL)
CONSTANT        -7150.237    7630.024        0.000       .      -0.937     0.418
LY               1594.238     745.224        0.777     1.000     2.139     0.122
```

From the computation in Box 3 it can be concluded that the only significant linear correlation is between catches and the water level of the same year. There is a slight and insignificant correlation between the catch and the water level one year before, and no correlation with previous years.

Given that we are not within the theoretical limits of this linear statistical approach, we prefer plotting the catch as a function of the water level one or two years before (Fig. 14).

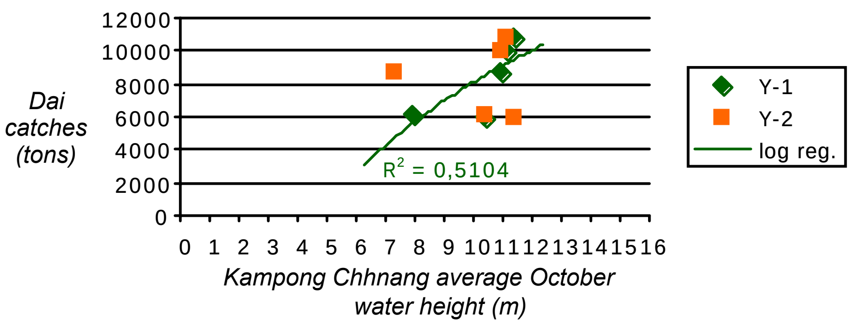


Figure 14: Dai catches (without* Henicorhynchus sp.*) versus water level 1 year (Y-1) or 2 years before (Y-2)

The slight (but non significant) relationship between the catch and the water level one year before is also observed in this log relationship.

Furthermore available data on the size and weight of *Henicorhynchus sp.*, although limited (Tab. III), tend to confirm the relationship between flood levels and fish production:

Table II: Body measurements of **Henicorhynchus sp.** *and relationship with water level*

Season (dai fishery)	*Henicorhynchus sp.* average weight	*Individuals sampled*	*Henicorhynchus sp.* average length	*Individuals sampled*	Average K. Chhnang October water level (m)
95-96	15,3	*13640*	11	*894*	11,1
96-97					11,4
97-98					10,4
98-99	8,4	*44720*	9,1	*5330*	7,9
99-00	12,3	*80010*	11,3	*6511*	10,0

In Fig. 15, the average weight and size of this taxon are plotted for each available year, as well as the corresponding average October water level in the Tonle Sap River (Kampong Chhnang gauge).

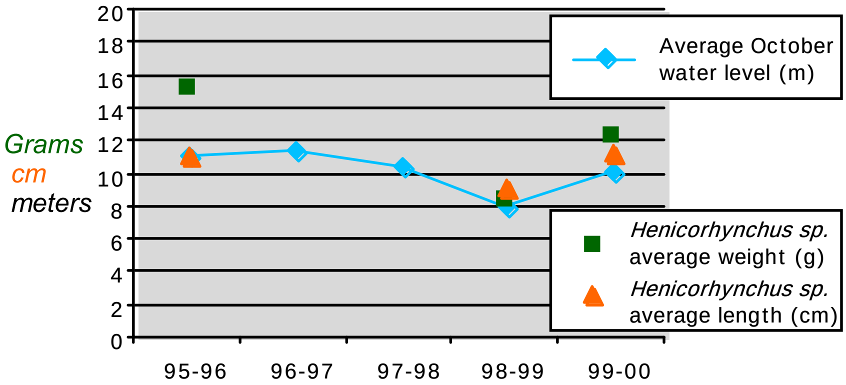


Figure 15: Water levels, fish size and fish length (*Henicorhynchus sp.*)

Water level - body measurements relationships are displayed below (Fig. 16). Although the number of points does not allow a statistically validated conclusion, a linear relationship is apparent.

This relationship is between growth and water level, not duration (although higher water levels and longer duration are linked). Unfortunately we could not process MRC daily flow measurements for 1999-2000 (data not yet available), and outputs of the IWMI model do not go beyond 12/1998. Once again, hydrological data shortage is an impediment to more refined analyses.

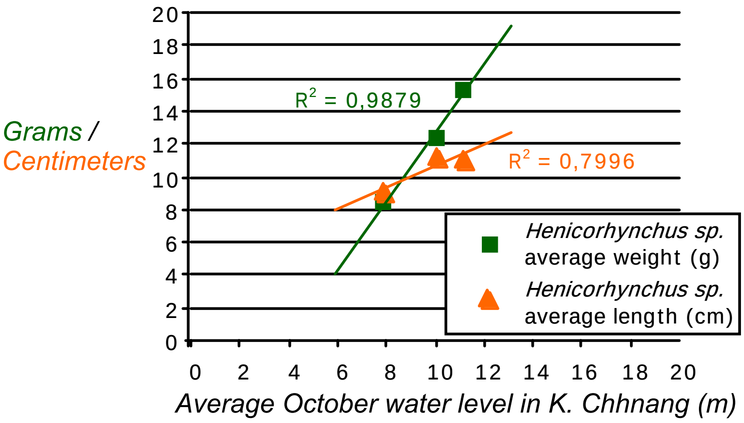


Figure 16: Relationships between size and weight of Henicorhynchus sp. and water level

1-1-2) Flood level: relationships with fish catches and surface flooded

a) Flood level and fish catches

It is clear from all former studies of riverine fisheries that the existence of a seasonal hydrological regime is crucial in sustaining fish productivity. Moses (1987) for instance showed that the catches in the Nigerian Cross River were strongly related to the high water flood regime at the beginning of each season. Similarly Bailey (1988) proved that young Amazonian fish experienced enhanced growth during maximum floods.
This relationship between fish production and hydrology in the same year is typical of juvenile productive systems based on short- life span species. This is partly due to the natural water fluctuations which prevent the system from reaching a steady state, and keep it in a permanent, very productive, juvenile state (Junk 1982). However this can also be partly due to the intensive fishing which has lowered the size of catches (Chevey & Le Poulain 1940, Van Zalinge & Nao Thuok 1999) and favours short life span, quickly growing species such as *Henicorhynchus sp*.

Here we focussed on maximum water levels; it must be noted that minimum water levels are also to be considered as they also affect natural survival rate and fishing mortality (MRAG 1994); Vidy (1983) for instance has shown a clear inverse correlation between the amount of water remaining in the dry season and the catch the same year, due to increased vulnerability of fish. In the case of the Mekong, this problem has been reported by Hill & Hill (1994), who also warn about a higher vulnerability of fish to fishing.

Another factor possibly biasing the hydrology-production relationship at basin level is that of extremely efficient fisheries blocking several Mekong tributaries and targeting ascending juvenile fish (e.g. mosquito net fishery blocking the Sangke River in Battambang -Troeung Rot 2000-, illegal bagnet fisheries in Kampong Cham and Kandal (Ngor Peng Bun 1999). However, it is not known how such fisheries impact the whole fish production.

Finally, catch models have also been made independently from river discharge, utilising river drainage area instead. According to these models, the expected catch for the whole Mekong is given in Table II:

Table III: Theoretical fish catches in the Mekong Basin, after its drainage or wetlands area

Model (C: tons, A: km^2)	**Remarks**	**Authors**	**Corresponding catch if applied to the Mekong river (tons)**[1]
$C = 0.03\ A^{0.97}$	"excluding catches from exceptionally large flooded areas"	Welcomme 1985	15,866
$C = 0.046\ A^{0.901}$	From Latin American rivers	Payne *et al.* 1993	9,528
$C = 7{,}99\ A^{0.99}$	12 Asian rivers whose production reaches 80±16kg/ha. Refers to wetland surface[2].	Halls & Payne 1994	597,097

b) Flood level and surface flooded

In natural systems and at a large scale, the surface of floodplains can be grossly correlated to river water height; however this relationship is not strictly linear as two kinds of thresholds can be identified: flooding

[1] Mekong drainage area = 795 000 km^2 (Welcomme 1985)
[2] Surface of Mekong related wetlands (Scott 1989, Lacoursiere *et al.* 1998)
Laos: 9 700 km^2 (edges of the river, along 1700 km)
Cambodia: Mekong edges = 20 000 km^2 ; Tonle Sap = 15 000 km^2 ; total = 35 000 km^2 (19% of the country)
Vietnam: 39 000 km^2 (larger than Belgium)
Grand total: 83 700 km^2 (the surface of Ireland)

threshold (the water height at which the river flows out of its bed) and elevation thresholds (due to the presence of hills) (Fig. 17):

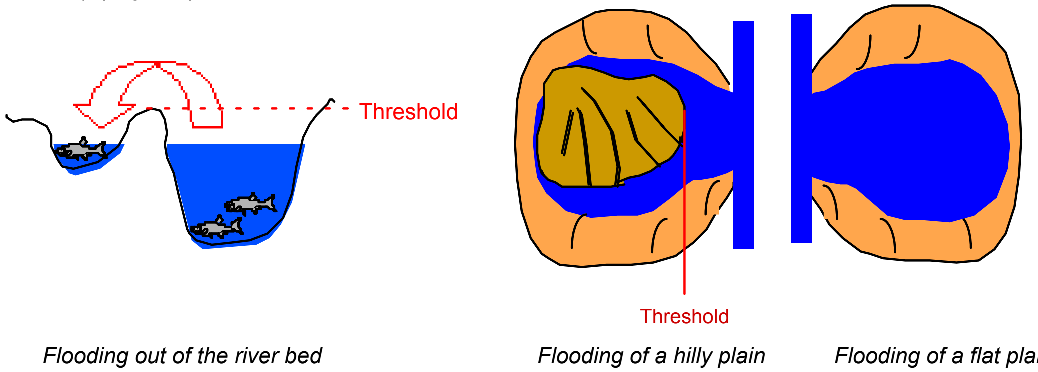


Figure 17: Two types of flooding thresholds

In the case of the Tonle Sap floodplain, if we select the period of flood progression (April-October, see Fig. 18) and plot the relationship between observed water levels and related surfaces of floodplain computed by the IWMI model, the resulting graph (Fig. 19) shows that the relationship is far from being constant:

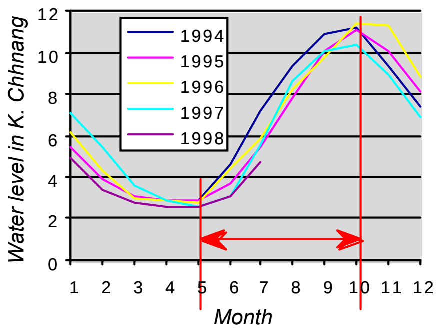


Figure 18: Average monthly water level measured in K. Chhnang

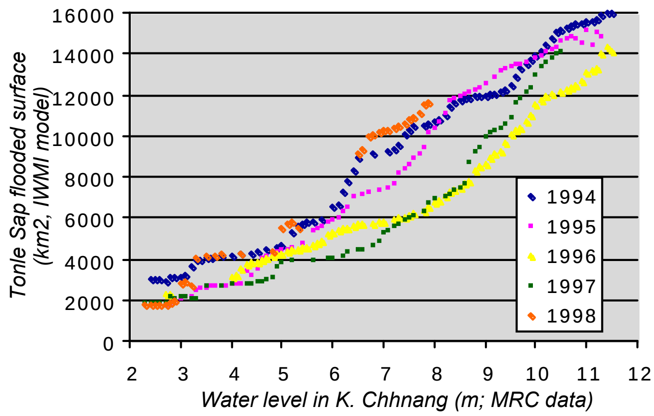


Figure 19: Computed flooded surface vs. observed water level in K. Chhnang during the flooding period

As the flooded surface is computed according to the rainfall pattern, by using a constant terrain model and independently from the measured water level, this result questions either the reliability of the rainfall data or that of the water height measured in Kampong Chhnang.

If the *computed* water level is used instead of the measured one, the relationship is now constant from year to year; however it is not totally linear but exhibits thresholds (Fig. 20).

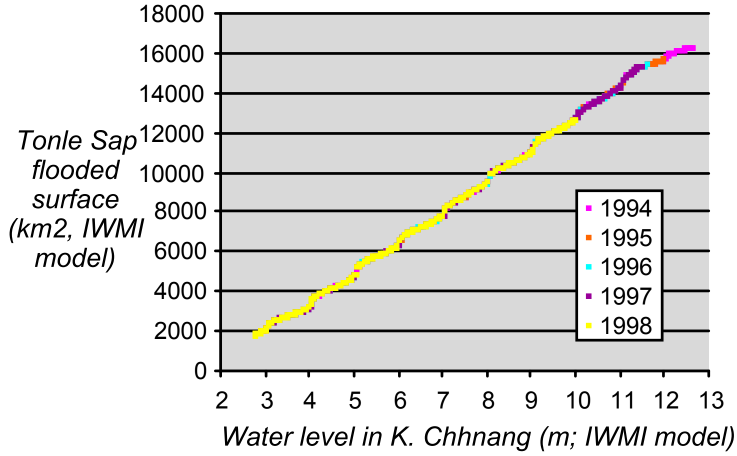


Figure 20: Computed flooded surface versus computed water level in K. Chhnang (flooding period)

The variability of the relationship between flow and flooded area is demonstrated if we plot the increased surface of floodplain when shifting from one water level to the next (Fig. 21):

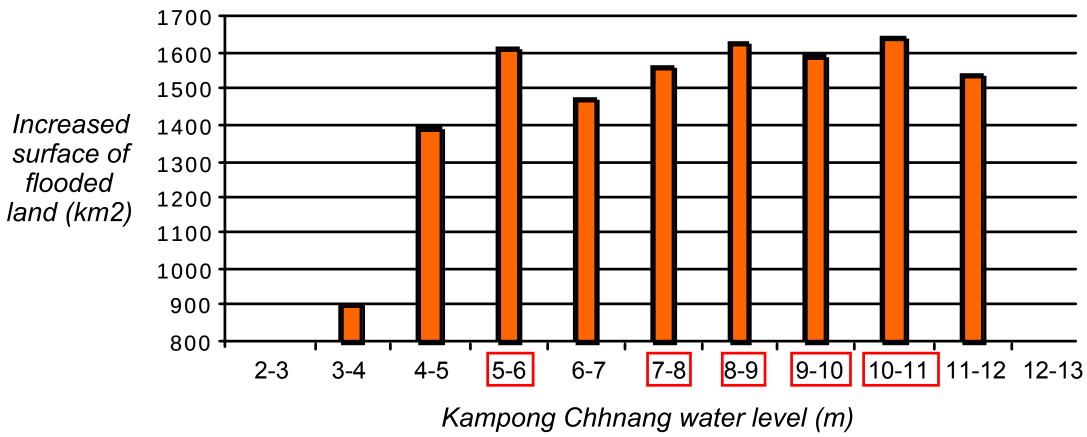


Figure 21: Surface of land flooded for each one-meter increase of the water level (Tonle Sap floodplain and K. Chhnang gauge)

The figure confirms that the extension of the flooded surface is not constant for each elevation of one meter of water. Thus a water management scenario in which the water level is reduced from 7 to 6 meters would have a relatively lower impact on the surface of floodplains than one in which the water level is reduced from 6 to 5 meters or from 8 to 7 meters.

An additional impact of water heights is the filling up -or not- of ponds that act as refuges during the dry season. Terrain configuration might create critical thresholds under which ponds will not be replenished.

In comparison with these estimates, the present total catch estimate for the Mekong amounts to 1 million-1,2 million tons (Jensen 1996, 1999). It can be noted that in South America the figure is probably biased by an exploitation rate much lower than in Asia (Junk 1982). For the whole of Africa, Welcomme estimated the total theoretical catch in 1976 to be 530,000 tons a year; but given the population and fishing effort increases since, the figure should probably be much higher today. However, the range given by these models is too large to allow further detailed comparisons.

Arrow-shaped trap along the river bank (Vietnam)

1-2) WATER REGIME AND FISH PRODUCTION

Junk *et al.* (1989) have noted that the ecological benefit of the flood comes from the alternation of emersions and immersions, and that the resulting recycling of nutrients allows a global production higher than in stable aquatic or terrestrial ecosystems. The frequency of this alternation determines the efficiency of the recycling (Roux & Copp 1993), and a deep alteration of this alternation will result in a global loss of productivity, and therefore a loss of fish production. Thus the instability at a certain scale is the key to fish production stability at a higher scale.

Improvements of the above production models therefore require consideration of the extent, duration, timing and consistency of flooding (Resource Development Associates 1972, Baran & Coates 2000). More refined - and useful- production models should also integrate the nature of land cover (habitat) subject to flooding (vegetation cover) and the availability of dry season refuges for fish (Coates 2000).

In the sections below, we detail aspects to be taken into account for a fuller modelling of the fish resource. These aspects are sometimes only addressed in a conceptual way as available data do not always allow quantitative evaluation. This is to be regarded as a perspective for future research works.

1-2-1) Duration

It is usually considered that a longer period of flood allows a longer growth of fishes, and therefore a higher yield (Fig. 22)

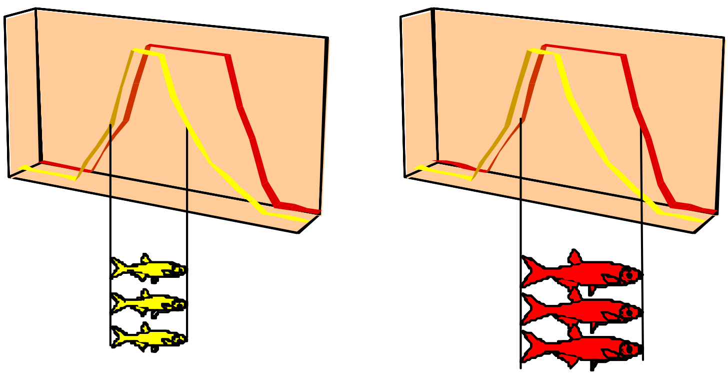


Figure 22: Flood duration and fish growth

In the Danube River, Stankovic and Jankovic (1971) have shown, following analysis of a 38 year long time-series, that there was a strong correlation between the yearly fish production and the duration of the flood (from 500 tons for 20 days to 1500 tons for 200 days). However the process being linked to organic matter decay and nutrient release, the relationship is asymptotic (stabilised after a certain optimum has been reached).

D'Aubenton (1963, 1965) has addressed the issue of artificially extended flooding period by water retention in the Tonle Sap, and set a hypothetical equivalence between a 1.5 m reduction of the water level and a 2 month increased duration of the flood maximum. Although this equivalence is not underpinned by quantitative data, he has also pointed out the fact that such a water retention would have a qualitative impact on the fish community, with the proportion of carnivores probably increased in the dry season.

Generally speaking, diverse combinations of surface and duration can have very different biological consequences: the impact of a 5-days flood over 100 square kilometres is different from that of a 100-days flood over 5 square kilometres (500 km^2-days in both cases). Therefore the simple product of surface by duration is not precise enough for fish production assessment purposes. Duration (referring to flooded days above) can thus be quantified by the number of days during which water spreads out of the river bed. The effect of the combination of duration and surface on production can be modelled by multiple regression:

$$\textbf{Production} = f^n \textbf{(Duration, Area)}$$

In the case of the IWMI model, as flooded area is calculated on a daily basis, annual flooded area and flood are integrated in the annual average of daily flooded surfaces:

$$\textbf{(Surface flooded)}_{year} = \sum \textbf{(surface flooded)}_{day} / \textbf{number of flooded days}$$

1-2-2) Timing

The fact that many species release eggs just before or during the flood which results in their spreading into floodplains is widely acknowledged (Bailey & Li 1992, Roux & Copp 1993). In the Mekong too, it seems that adults are triggered to spawn by rising waters or alternatively by turbidity or first rains (Poulsen 2000 a, b), then juveniles drift to the Tonle Sap system where they grow (Fig. 23; see also section 2-3 on migrations). This is the case for Pangasiidae whose breeding migrations at Khone Falls start with rapid changes in discharge levels at the beginning of the rainy season (Baird *et al.* 2000 b). This behaviour is typical of most tropical freshwater fish species (Lowe-McConnell 1987). After release, eggs and/or fry drift downstream to their nursing areas if the hydrology permits.
Timing can therefore have an impact on the total production, depending on whether spawning, the hydrological regime and the time allowed for growth are matched optimally or not; this notion relates to that of the optimal environmental window for recruitment in marine fisheries (Cury & Roy 1989).

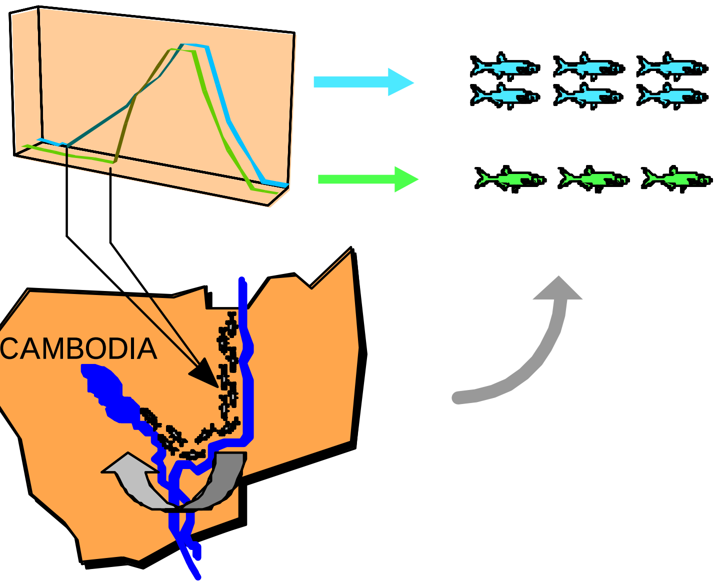


Figure 23: Flood timing and offspring migration

When sufficient time series data allow calculation of correlations to be calculated, timing is expected to be a key parameter to be taken into account. In that case, the timing of flooding can be expressed by the number of the week at which the flood starts.
Example: if the flood starts during the 2^{nd} week of May (19^{th} week of the year), timing factor = 19
In that case, a "starting point" must be defined, and this would be the yearly minimal water level averaged over a period of x years.

Conclusion

From a fish production perspective, three essential dimensions should be considered in flooding: height, duration and timing (Fig. 24).

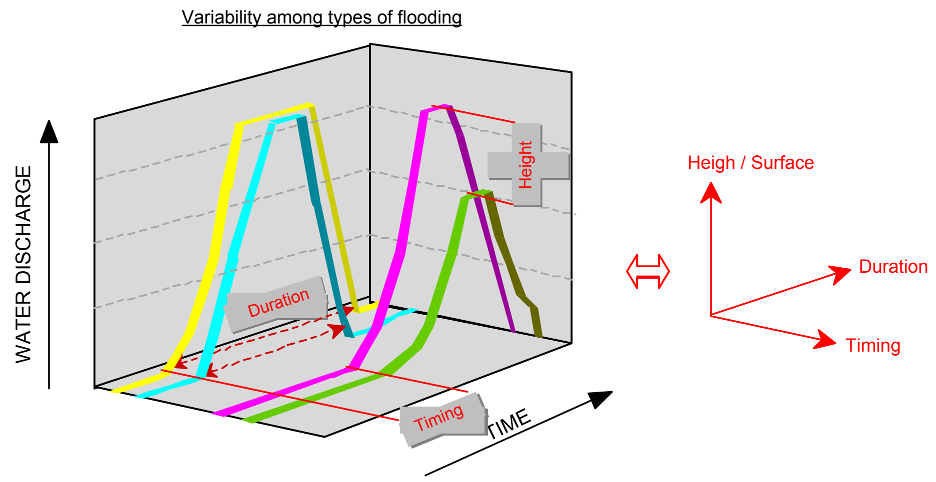


Figure 24: The three major dimensions of a flood

However, this implies a single system of reference, although there are various types of floodplains and flooding patterns in relation to land shape and elevation. A lower level floodplain can be flooded for a long time whereas higher areas may (naturally) experience several floods in one season as height fluctuates around the peak flood. Thus the necessary reference system allowing quantification of flood characteristics might not be common to the whole basin, but to a more homogenous unit, such as the Mekong Plain physiographic region or land type (MRCS 1992, Hill 1995).

Last, natural variations between years is a supplementary issue. It is likely indeed that the system is naturally complex with many species, each of which can optimise its production only in certain years, and other species taking advantage in other years with different hydrological characteristics (Welcomme 1995). Therefore “smoothing” the flood curve by water management (extending duration, lowering maximum and removing natural rapid peaks and troughs within a season) will probably favour certain species at the expense of others - i.e. possibly maintaining gross production but reducing biodiversity.

1-2-3) Continuity of flooding

The importance of small drought periods in the beginning of the rainy season (Fig. 25) has been pointed out (I. Baird, pers. comm.) as they can result in massive mortality of eggs stuck to suddenly exposed vegetation, or of fish larvae, fragile fry and amphibians blocked in limited ponds.

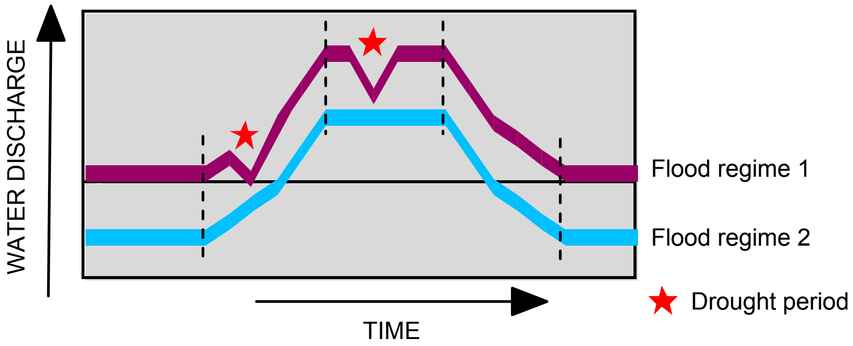


Figure 25: Continuity of flooding

Quantifying the importance of this factor requires a notion of continuity index for the flood. We propose to use as an index the sum of recession periods in the floo*ding* period (e.g. number of days during which the water level decreases between April and October in the Tonle Sap), weighted by the water level loss during these days.

$$CI = \sum \left[\textit{(duration of recession periods in the flooding period)} \times \left|\textit{Water level variation for each recession period}\right| \right]$$

However this issue is made more complex by the migration patterns; for instance the fishery in Southern Laos is highly influenced by migrations coming from Cambodia; production in Southern Laos should then be related to Consistency index in Cambodia, not in Southern Laos.

1-2-4) Conceptual considerations

Below are some hypotheses of interest for the understanding of factors influencing the total fish production and the management of the fishery. However the data they require for being tested are not currently gathered, and the hypotheses are to be considered as possible conceptual developments.

Phases of a flood

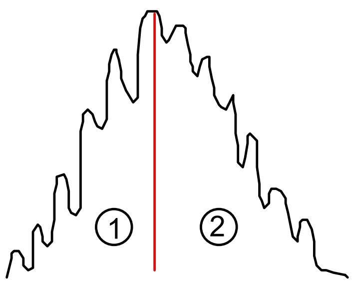


Figure 26: The two phases of a flood

The progression phase of the flood (Fig. 26) is more productive than its regression phase, because of release of nutrients by the soil and deposition of silt coming from upstream at the beginning of flooding. This results in a bloom of planktonic communities and aquatic vegetation, particularly algae, but also in a temporarily increased availability of terrestrial insects. Most fish species span at the beginning of the flood, when there is a higher availability of planktonic organisms. This was already noted by Blanc in 1957: "It is

likely that there is a quick enrichment of waters at the beginning of the flood, but that this enrichment does not last during all the flood".
After this hypothesis has been validated along the Mekong by some productivity studies, this aspect might be integrated into water management scenarios as influencing the fish production. As a matter of fact most fish spawn at the beginning of the flood and thus have a higher dependency, as juveniles, on the planktonic organisms at the commencement of the flood.

Irregularity of a flooding process

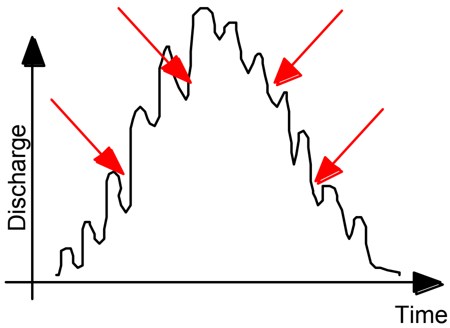


Figure 27: Jaggedness of a flood

The irregular increase and decrease of water level during the flood (influence of rains, Fig. 27) creates an environmental diversification and therefore make more niches available for fish and all aquatic species. This also implies a diversification of gears. A reduction of this natural short-term variability could lead to
- a reduction of the biodiversity (loss of niches and of corresponding species)
- a reduction of the fishing gear diversity, which implies:
    * a loss of resilience (higher dependence on a lower number of fishing methods)
    * socio-economic concerns (women, children and non-professional fishers losing access to accessory catches)

> Last, the presence of -even short- peaks in water height could be important in terms of opening migration routes. If this hypothesis were verified, this would imply that water management should allow the flow level to reach certain values, even for a few days only (this is an issue of particular importance at Khone Falls).

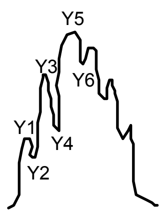
Measuring jaggedness in flooding.

The unit differences between short-term peaks in flooding can be represented by:

$$d = Y_{min} – Y_{max}$$

where the Y's represent progressive local minima and maxima during flooding. The biological effect of flooding is better represented by the square of the Y's, the terms being squared to approximate the relationship between flooding (m) and area (m^2)

$$D = Y_{min}^2 – Y_{max}^2$$



Therefore a measure of jaggedness of the progression of flooding might be the average of the squared differences between highs and lows

$$J = \sum(Y_t^2 - Y_{t-1}^2)/n$$

Where n is the number of measured differences. This statistic, however, is suitable for only periods of flooding when the trend is in one direction (from April to October in the case of the Tonle Sap).

Braided streams around the Tonle Sap Great Lake.
The red circles and lines point out the density of gears.

2) MODELLING THE IMPACT OF ECOLOGICAL FACTORS ON FISH PRODUCTION

2-1) FISH CATCHES AND AREA OF FLOODPLAINS

The relationship between catches and area of floodplains has been widely documented (see Welcomme 1985, Welcomme *et al*. 1989, Welcomme 1995). The general relationship is usually stated as:

$$\mathbf{C = a \cdot A + b} \quad \textit{or} \quad \mathbf{C = a \cdot A^{b}}$$

C = catch (tons) A = surface of floodplains
y, y-n = years a & b =coefficients

In the Tonle Sap, we have shown that the bulk of the catch is related to the flood the same year. However it might be good to check the relationship between the catch and the surface of floodplain 1 to n years before. In that case, the relationship is:

$$\mathbf{C_y = a \cdot A_{y-1} + bA_{y-2} + \ldots + xA_{y-n}}$$

C = total catch (tons) A = surface of floodplains
y, y-n = years a, b, c =coefficients

and the significance of each term of the sum must be tested.

2-1-1) Case of the Cambodian "dai" fishery

The IWMI model allows the calculation of flooded surfaces every day, including per land cover type (for the Tonle Sap area). The model has been run and produced these figures from 01/01/1994 to 31/12/1998, but not later due to unavailability of rainfall data.
The surface of the lake itself is given by the following relationship (Kite 2000 c):
$A = 0{,}0243.H^2 + 1{,}1721.H + 1{,}4498$ where A = lake area (1000 km^2)
and H= water level in Kampong Luong (m)
This corresponds, for the four years of modelling, to an average minimal surface of the lake of 2896 km^2 .

Given the beginning and end of computed hydrological data (01/01 ➔ 31/12), and that of the dai fishery seasons (1/9 ➔ 30/3), two hydrological years are lost for comparison with the dai catches. Three hydro-biological seasons remain: 95-96, 96-97 and 97-98 (table). This paucity of data does not allow any statistical testing.

Table IV: Tonle Sap area water surfaces

Season	Average flooded area (A; km^2)	Average permanent lake surface (B; km^2)	Average surface available to fish (A+B; km^2)
95-96	7,598	2,893	10,491
96-97	7,615	2,846	10,461
97-98	7,152	2,849	10,001

Figure 28 below shows the trend for the three years in common:

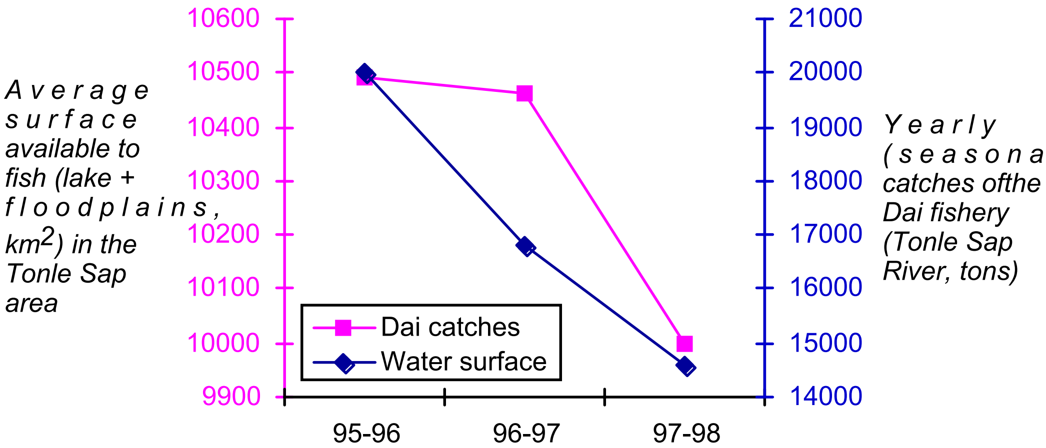


Figure 28: Relationship between dai catches and flooded surface (I)

Although it is strongly recommended by statistics standards not to compute such short data series, we have plotted the relationship between catches and water surfaces during these three seasons, and calculated the log relationship (Fig. 29); apparently there is a fairly good relationship, which need to be confirmed by further data.

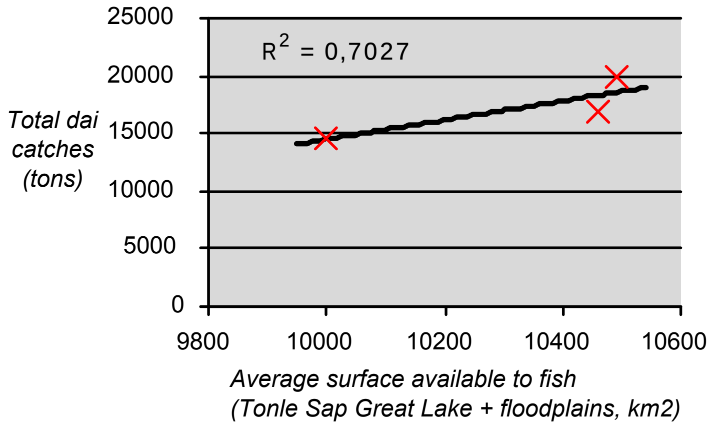


Figure 29: Relationship between dai catches and flooded surface (II)

The detailed study of relationships between dai fishery catches and surface of each type of land cover is made in section 2-2.

2-1-2) Production, productivity and historical trends in the Tonle Sap system

The only production figures basinwide have been made by Lagler (1976), who gives:
- 95,000 tons/year and for the upstream Basin fishery zone (above Kratie; reservoirs excluded)
- 236,000 tons for the downstream lowland and delta freshwater zone (from Kratie to Can Tho and Vinh Long, including the Tonle Sap system)[3]
- 156,000 tons in the brackish water and coastal zone
- 13,000 tons for reservoir fisheries

In absence of new data allowing to detect recent trends basinwide, we focussed below on the Tonle Sap system, for which more information is available.

[3] page iv but alternatively 200,000 - 250,000 tons p. 108 and 195,000 - 245,000 tons p. 281

2-1-2-1) Total production and production per hectare for the Tonle Sap area

For the calculation of the production and productivity of the Tonle Sap area (Great Lake + River) we compiled all published and available results, which are listed in Annex A. Table V summarises the resulting figures:

Table V: Recent fish production of the Tonle Sap Great Lake and River (tons)

Year	Dai	Mobile	Lots	Subsistence	Ricefields	TOTAL
1994 or 94-95			75,000			
1995 or 95-96	14,400	62,800	"	71,500	12,900	237,000
1996 or 96-97	16,800	"	"	"	"	239,000
1997 or 97-98	14,600	"	"	"	"	237,000
1998 or 98-99	8,900	"	"	"	"	231,000
1999 or 99-00	11,400	"	"	"	"	234,000

From these statistics we can consider that the total fish production of the Tonle Sap Great Lake and River amounts 230,000 tons a year, with an unknown annual variability.

The combination of Tables IV and V gives the productivity of the Tonle Sap zone (Tab. VI):

Table VI: Productivity of the Tonle Sap zone, for the 1995-1997 period

Year	Catch (kg)	Average water area available to fish (ha)	Productivity (kg/ha)
1995	237,000,000	1,049,100	226
1996	239,000,000	1,046,100	228
1997	237,000,000	1,000,100	237

From these statistics we can consider that the fish productivity of the Tonle Sap Great Lake area (calculated taking the yearly average flooded surface -including the lake itself- as a reference) amounts 230 $kg.ha^{-1}.year^{-1}$.

It is to be noted that the productivity figure highly depends on the option chosen for the calculation of the floodplain surface: dry season lake surface, maximum flooded zone or average flooded area.
This is outlined in Van Zalinge & Touch Seang Tana (1996) who gave two productivity figures for a maximum production amounted to 111,000 tons:

- dry season lake surface: 275,000 ha => about 400 $kg.ha^{-1}$
- average between dry and wet season lake surface: 750,000 ha => about 150 $kg.ha^{-1}$

This latter calculation was also used by CNMC/Nedeco (1998 b).

Productivity figures are detailed in CNMC/Nedeco (1998 a) and used in the 1999 MRCS brochure:

135000 tons and average lake area of 775,000 ha => 174 $kg.ha^{-1}$
135000 tons and average floodplain area of 525,000 ha => 257 $kg.ha^{-1}$
these two values being averaged to produce a final estimate of 215 $kg.ha^{-1}$

One can note that this latter calculation is not relevant, as the average lake area is calculated by using its maximum extent, but the maximum extent is mostly constituted of floodplains, which therefore intervene twice in the final averaging.
The Tonle Sap area fish production range (i.e. 120,000-150,000 tons/year), given without details in these documents, is not in agreement with our assessment above, the latter being almost 1.8 times higher and based on the statistics detailed in Annex A.

These productivity values exceed most known figures (Tab. VII), even in Asia where floodplain fisheries amount about 100 $kg.ha^{-1}.year^{-1}$ (Hoggarth *et al.,* 1999 a)

Table VII: Fish productivity of various Asian floodplain fisheries

Location	**Fish productivity** ($kg.ha^{-1}.year^{-1}$)	**Source**
Bangladesh floodplain fisheries	67-123	MRAG 1999
Indonesian floodplain fisheries	38-129	MRAG 1999
Thailand floodplain fisheries	25-52	MRAG 1999
Bangladesh	104-130	Hoggarth *et al.* 1999 c

2-1-2-2) Historical trends

Table VIII below summarises the available information regarding the fish production of the Tonle Sap system:

Table VIII: Fish production of the Tonle Sap Great Lake and River (historical overview)

Year	**Pellegrin (1907)**	**Chevey, Le Poulain (1939)** [1]	**Fily, d'Aubenton (1965)**	**Lagler (1976)** [2]	**DoF statistics** [3]	**Van Zalinge & Touch Seang Tana (1996)** [4]	**CCF statistics (including subsistence and rice field fisheries)**
1907	15,000						
1940		100,000					
1964			54,000				
1974				75,000			
1981 - 1993					42,355 - 61,000		
1994					51,050		
1995					58,,774	115,000	237,000
1996					53150		239,000
1997							237,000

[1] pp.14 and 16: "Fisheries yields in Cambodia can amount to 130,000 tons (50,000 t. sold as fresh fish, and 80,000 t. for dried fish)"; "the Great Lake provides annually about 100,000 tons of fish" -*Figures often misquoted as 50,000 tons.* In Chevey & Le Poulain (1940) the total yields of Cambodian fisheries amounted 120,000 tons (on the basis of 50,000 tons of fresh fish, but the estimate for fresh fish production varies between 50,000 and 80,000 tons within the same book).

[2] Calculated from p. 112 and p. 284. Woodsworth (1995), quoting Lagler (1976), gives the 50,000 - 80,000 range.

[3] 6 Great Lake provinces + Kandal + Phnom Penh, as quoted in Nao Thouk & Ly Sina 1998

[4] Average of the given range: 106,000-124,000 tons

Note: Pantulu (1986) also quotes a survey from the Government of India (1962) which amounts the production of the Great Lake to 101700 tons for the 1956-1961 period.

Two major biases must be overcome when comparing past and recent statistics:

1) subsistence and rice field fisheries are taken into account in recent statistics only;

2) the population has dramatically increased over these fifty past years, and the total fishing effort resulting in the compared catches has also varied over years (see § 1-1)

Population and fishing pressure evolution

In 1995-1996 a MRC survey provided indications on the fishing population around the Tonle Sap Great Lake (Ahmed *et al.* 1998). The population living in fishing-dependent communes around the lake amounted 1.2 million habitants, and reached 10.7 million habitants in the whole of Cambodia (see Annex A); thus 1.2 / 10.7 = 11.2% of the total national population inhabited in the Tonle Sap area fishing communes.

If we assume that this ratio was constant in time and use population statistics from the past, we can then relate the total Tonle Sap fish catch to the fishing population in past estimates (Table VIII).

Integration of subsistence and rice field fisheries

For a population of 1.2 million people in fishing communes around the Great Lake Great Lake, subsistence capture fisheries are estimated nowadays to be 71,500 tons, i.e. 59,6 kg/fishing commune inhabitant/year, and rice field fisheries amount 12,900 tons, i.e. 10.8 kg/fishing commune inhabitant/year.

These values can be used to assess *a posteriori* the past catches of these fisheries (assuming that consumption rates and rice cultivation methods have remained stable).

Once determined the overall catches in past references and the corresponding fishing population, the fish catches per fishing commune inhabitant can be calculated, and now compared on a standardised basis (Table IX).

Table IX: Catch per fishing inhabitant over time in the Tonle Sap zone

Period	**Great Lake fish production as historically amounted (tons)**	**Population in Cambodia (million hab.)**	**Fishing population (million hab.)**	**Catches of subsistence fisheries (tons)**	**Catches of rice field fisheries (tons)**	**Overall catches (tons)**	**Fish catch/ fishing commune inhabitant (kg/fish. hab /year)**
1940's	100,000[a]	3.2 [c]	0.36	21,500	3,900	125,000	347
1975's	85,000 [b]	6.3 [d]	0.71	42,300	7,700	135,000	190
1995's		10.7 [e]	1.2	71,500	12,900	230,000	192

a: Chevey & Le Poulain 1940 b: Lagler 1976 c: Blanc 1959
d: MRCS 1992 e: see Annex A

Although surprisingly high nowadays, the fish productivity of the Tonle Sap area, when compared on a standardised basis taking the population increase into account, is much lower than 60 years ago.

Our demographic assumption about a constant proportion of habitants around the lake might not be entirely correct: it is likely that proportionally less people lived by the lake and were engaged in fishing, as population pressure was less, more land was available for rice cultivation and people were richer. Recently, many refugees have taken up fishing as land is occupied and only a small investment is needed to start fishing. This remark strengthens the above conclusion.

Figure 30 below details the historical trends of production and catch per fisherfolk for the Tonle Sap Great Lake area. Although, once again, the number of points is low, the results are coherent and show that the Tonle Sap production has increased over years and is almost double of what it was in the forties. However the catch per inhabitant has drastically decreased, and is almost half of what it used to be in the forties. This warning indicator, classical symptom of a fishery under heavy exploitation (Welcomme 1995), shows that the sustained monitoring of the fishery is of critical importance, and should promote applied research for management strategies which can be implemented on the field.

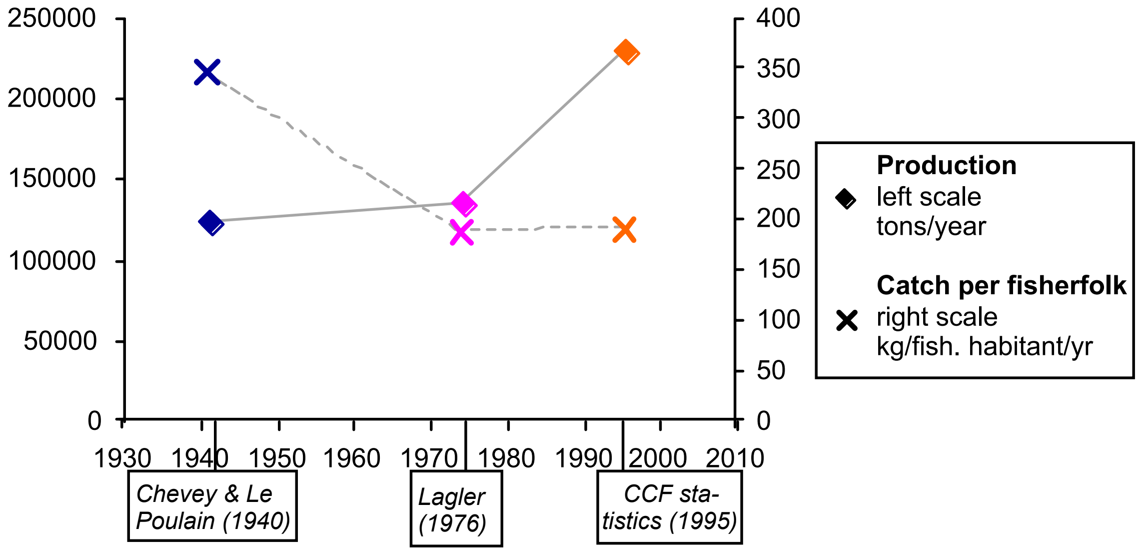


Figure 30: Production and productivity of the Tonle Sap area over time (standardised basis)

Discussion

If we compare the two most detailed surveys, those of the Chevey & Le Poulain (1940) and of the CCF project nowadays, we can conclude that the catch per fishing effort has decreased in the last decades. This is consistent with fishermen's sayings around the Tonle Sap (Ahmed *et al.* 1998) as well as along the Mekong (Roberts 1993, Hill 1995). If we integrate surveys made in 1965 (Fily & d'Aubenton) and 1976 (Lagler) and compare the catch figures with hydrological trends in the Mekong River, interesting features can be noted.

Figure 31 below illustrates the long-term trend in the Mekong flow (from the Dai fishery data analysis report) and production estimates for the Tonle Sap (the 146,000 tons in the 1995's correspond to the total estimated catch minus subsistence and rice field fisheries, not included in the other surveys).
Four points are not enough for any correlation, but there is a good agreement between the total catch and the water level. Available data on the number of dais also show that the lot exploitation used to be at least as intensive as it presently is (but the pressure in the open access sector was lower).

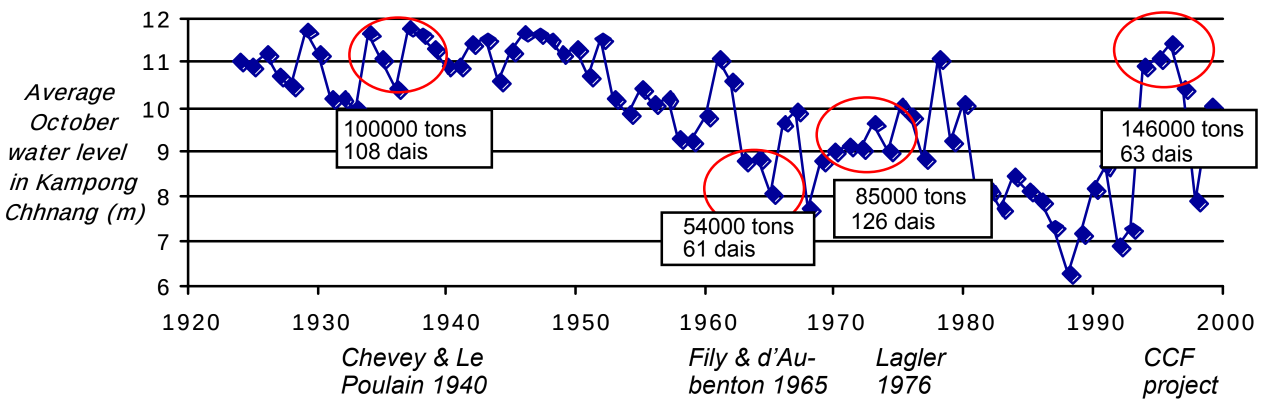


Figure 31: Tonle Sap long term hydrological changes and catch estimates

The currently very high production values for the Tonle Sap area might reflect the high exploitation rate of the fish resource, and its increased productivity due to the reduction of age and size of fishes (Junk 1982, Welcomme 1995, Laë 1995). As early as 1933 Chevey noted that the production of the Great Lake corresponded to a yield of nearly ten tons per square kilometre (wet season extent), "which is nearly ten times that of the North Atlantic fishing zone".

It must be noted that we deal here with the whole production, without consideration of species, size or quality of catches. As Welcomme (1995) points out, "concerns of over-exploitation or optimum yields have to be referred to the community as a whole, not to one or two larger reference species" because "fish communities in rivers cannot be fished at any degree of intensity without the loss of the larger elements of the community", which is apparently already the case for the Tonle Sap fishery (Van Zalinge *et al.,* 2000). Here the larger migratory species have declined significantly contrary to the small migratory and the non-migratory species. The Tonle Sap fishing lot catch still consists for 38% of piscivores (such as *Channa spp.,* i.e. snakeheads), which are one trophic level up the food chain from detriti/herbi-vores.

In any case, the productivity estimates should not be compared to those of other freshwater natural lakes (which are much lower, see Randall *et al.* 1995). Nor are they related to classical lake functioning and limnological approaches (e.g. Downing *et al.* 1990) because the Great Lake functions much more as a floodplain than as a lake, and the biological approach relevant for lakes has proven its limits when dealing with floodplains (Bailey 1980).

Seine yield on the Tonle Sap Great Lake :plenty of (small) fish

2-2) FISH CATCHES AND FLOODED VEGETATION

The type of flooded zone is important for the life and growth of fish. Thus a grassland provides less habitat diversity than a flooded forest, and structural complexity of habitat is known to reduce predatory efficiency and thus juveniles survival rate (Fraser & Cerri 1982, Crowder & Cooper 1982, Savino & Stein 1989, Gotceitas & Colgan 1990).
Therefore the quality of the wetland should be taken into account. This refers to the assessment of surfaces of the different land covers such as in the MRC Land cover atlas (MRC 1994).
Given data availability in the Basin, such a study was, once again, only possible around the Tonle Sap Great Lake because of a lack of precise Digital Elevation Models for other regions.
The IWMI model provided estimates of surfaces flooded each day for different land covers. Here we compare dai catches with average annual surfaces flooded for each land cover. For the reasons stated above (see section 1-1), only three years in common between the IWMI model estimates and dai fishery results are common and can be matched.

Note: Land cover types have been pooled into three basic categories (Tab. X): low vegetation ("grassland"), intermediate vegetation ("shrub land") and high vegetation ("trees") following the description of categories in MRC 1994:

Table X: Land cover types around the Tonle Sap Great Lake

Original land cover classification	Remarks	Category used for modelling
Deciduous forest	mostly Dipterocaps	High vegetation
Coniferous forest		
Mixed forest		
Orchard		
Plant	rubber plantations	
Marsh		Low vegetation
Paddy		
Grassland		
Swidden	land burnt for cultivation	
Crop	vegetables, maize,,…	
Shrubs		Medium vegetation
Barren land		Barren land

Field data and outputs of the model give:

Table XI: Catches and flooded surfaces per land cover type

	Average flooded surfaces per land cover type (km2)				Dai catches (tons)
Season	**Trees**	**Shrubs**	**Low vegetation**	**Barren land**	
95-96	2587	1371	3382	257	14400
96-97	2668	1177	3504	266	16800
97-98	2458	1193	3260	240	14600

The above table is plotted below (Fig. 32).

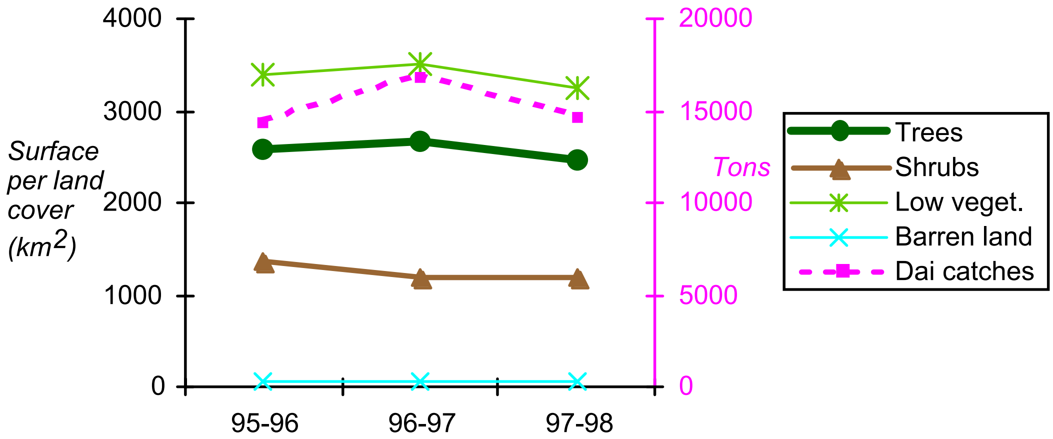


Figure 32: Relationship between Dai catches and flooded vegetation in the Tonle Sap area

According to these very limited data, there is a positive relationship between the yearly dai fishery catches and:
- the yearly extent of flooded forest
- the yearly flooded surface of low vegetation (paddy fields, marshes, wetland)

in the Tonle Sap area.

However the correlation between dai catches and the yearly flooded surface of trees or low vegetation, although positive, is not strong (r^2 = 0.68 and 0.55 respectively), and with these few data its significance cannot be tested. There is no apparent relationship between yearly dai catches and flooded surface covered with shrubs.

Discussion

It must be stressed that these correlations, based on three points for each class, are not statistically robust; from this point of view, their significance can easily be disputed. However the scientific evidence of these relationships between forest, wetlands and fish production is also strongly underpinned by biological and ecological research. Some underexploited studies in particular shed light on the functioning of the Tonle Sap system.

The reasons for the extremely high productivity of the Great Lake have been explained, in a vivid style, by Chevey in 1934:
at the beginning of the flood a young fish is surrounded by "a vegetal and even forest soup in which grow a microscopic and extremely abundant fauna and flora (protozoa, small crustacea, tiny algae, etc…). If an enemy threatens, it immediately finds a secure shelter in the inextricable surrounding brushwood.[…] When its increased size forces it to modify its diet, it can find in abundance a kind of green purée made of billions of microscopic algae which is a first choice food item for it. Thanks to this item, it will grow approximately twice faster than other fishes born outside the Lake".
These statements about the biology of fish and the lake are scientifically underpinned.
Dry seasons being identified by dark circles in fish scales, Chevey (1930) showed by this means that fish from the lake had a growth rate twice that of those from the river (demonstration on *Labeo chrysophekadion, Hampala macrolepidota, Leptobarbus hoevenii* and *Cyclocheilichthys enoplos*).
In 1932, Chevey showed that there were two populations of *Barbus balleroïdes* in the Great Lake in October; one population consistently stayed in the deep lake and fed on bottom microgasteropods only, while the other population lived in the floodplain and fed on algae and wood fragments only. Scale reading showed that at a similar size, the second population was half the age of that population in the central lake, implying rate approximately twice as fast in the flood plain.
Blache (1950), who made a plankton survey in the Tonle Sap system and in the Mekong around Phnom Penh in December-January, confirms the exceptional density of the "animal and vegetal soup" in these waters. It is essentially due to Myxophicaea and is typical of eutrophic lakes. These Myxophicae clusters are

a dominant source of food for species such as *Pangasius micronemus*. Blache also noted an extremely dense development of *Spirogyra sp.* around the submerged vegetation. Globally the plankton community in the Tonle Sap river is similar to that of the floodplain it drains; this contrasts with the Mekong community whose species richness is lower and characteristic of large rivers.

Nguyen Xuan Tan & Nguyen Van Hao (1991) also led a 3 years-long survey in freshwater Cambodian waters. Regarding phytoplankton, they have identified 197 species; 139 species in the Mekong River, 72 in tributaries and 112 species in flooded areas. Twenty-two species were found only in flooded areas. The average density of phytoplankton is 118 cells.l^{-1} in the Mekong river, 230 cells.l^{-1} in the Tonle Sap River and varies between 132,000 and 1,121,000 individuals.l^{-1} in flooded areas (average: 418 individuals.l^{-1}, higher in the wet season).

They identified 46 species of zooplankton (38 in rivers, 46 in flooded areas), with an average density 3.6 times higher in the flood plain (52,605 individuals.m^{-3} instead 14,532 individuals.m^{-3}).

Their survey also showed that the density of zoobenthos in the rainy season reached an average 237 individuals.m^{-3} (66.4 g.m^{-2}) in the floodplains, double that in the dry season.

One can note that this latter biomass only, if related to the total surface of floodplains (an average of 6,500 km^2 between 1995 and 1998 according to IWMI model), would represent a total zoobenthos biomass of 431 million tons!

It should be noted that not only production but also species diversity has been proven to be related to habitat heterogeneity (together with basin area and historical traits -Guégan *et al.* 1998).

And as Lagler noted in 1976, "ecosystems with a greater diversity of fish species and with more complex nutritional chains ultimately will be the more stable. Ecosystem stability means stability in the annual standing crop, and, therefore, catch. Thus ecosystem stability is important for economic stability, which is important for management in the industrially developing societies".

An important issue is that of the "useful" size of flooded forest. Two aspects are to be detailed: the theoretical relationship, and the chemical environment. From a theoretical point of view, the relationship between size of the flooded forest and fish production, if confirmed, is probably asymptotic, as most environment-biological production relationships. In that case, similar to the relationship between mangrove surface and coastal fish production (Baran 1999), there might be a threshold under which the production is prone to collapse. From a chemical perspective, d'Aubenton (1965) observed that the most productive part of the flooded forest seemed to be the narrow zone along the open water, because the wider ones -located higher and less inundated- experienced a chemical process in which the vegetation decay resulted in anoxic shallow immobile waters unsuitable for fish. These observations are confirmed by Nguyen Xuan Tan & Nguyen Van Hao (1991) and Lamberts & Tim Sarath (1997).

2-3) MIGRATIONS

Migrations of Mekong species have been mentioned in several studies, but described more precisely in Sao-Leang & Dom-Saveun (1955), Bardach (1959), Shiraishi (1970), Lagler (1976), Viravong *et al*. (1994), Roberts & Warren (1994), Roberts & Baird (1995), Singhanouvong *et al.* (1996 a & b), Warren *et al*. (1998), Chan Sokheng *et al*. (1999) and recently by Baird *et al*. (2000) and Srun Phallavan & Ngor Peng Bun (2000). The most comprehensive study of Mekong fish migrations to date is that of Poulsen *et al*. (2000), based on fishermen's traditional knowledge, which provides evidence of long-distance longitudinal migrations for 27 species among the commercially most important ones. All these studies confirm the critical importance of the migration events in the biological functioning of the fish resource. Longitudinal migrants contribute 63% of the total catch taken by these fisheries in the Tonle Sap area (Van Zalinge *et al*. 2000)

These studies focus on longitudinal migrations along the river; lateral migrations from the mainstream to floodplains are another critical issue. Nguyen Xuan Tan & Nguyen Van Hao (1991) even identify four types of migrations: breeding migration; passive catadromous migration of eggs and juveniles; feeding migration; and catadromous migration during water recession. Figure 33 shows simplified major migration patterns of the fish resource between the Tonle Sap Great Lake and the Mekong mainstream.

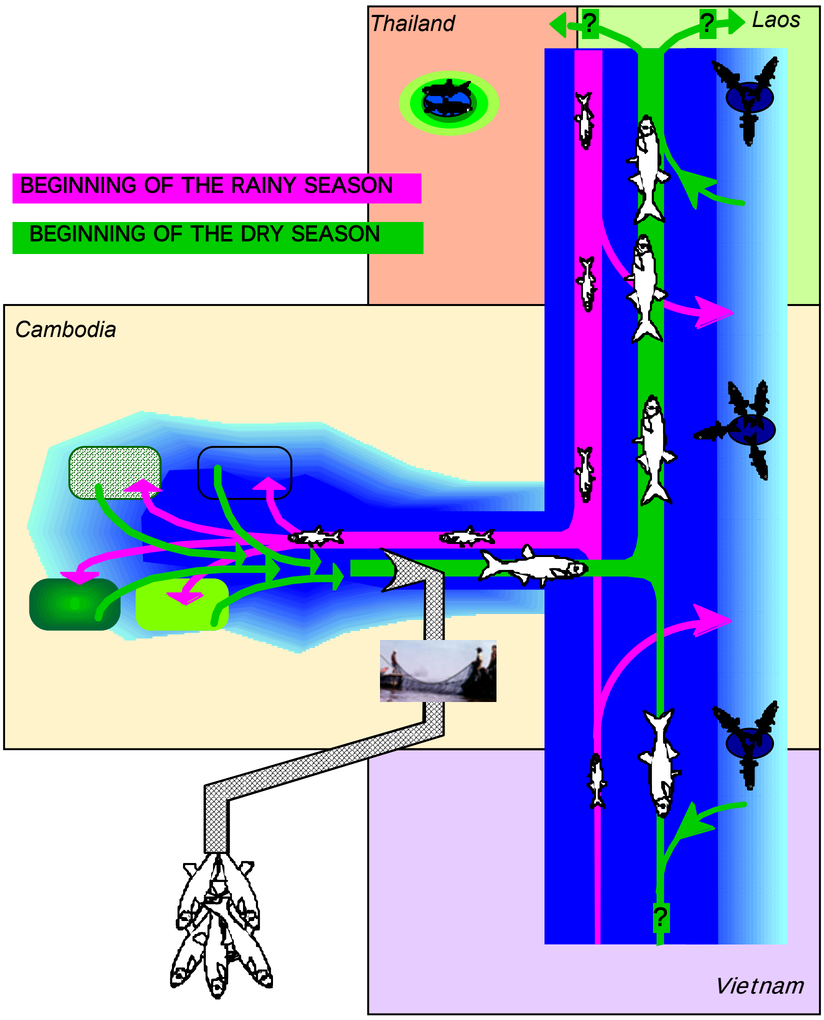


Figure 33: Summary of migration patterns in the Mekong River

Although they are qualitative by nature, and thus difficult to bring into a modelling approach, these migrations are an essential feature of the Mekong fish resource, and a critical part of the sustainability of this resource. A threat to these migration patterns is of course the building of dams. Hill & Hill (1994) provided an extensive review of the effects of damming on the environment and the fish resource, particularly on migrations. They point out that the nine "run-of-the-river" dams planned along the Mekong main stream are in fact 32m high on average (30-46 m).

Two major issues are to be addressed in view of an integrated management of the fish/water resource:

1) how to quantify the importance of migrations in the production mechanism?

2) how to quantify the impact of dams on migrations and fish production?

To date knowledge is empirically based on case studies, where the estimated loss of wild fish production is compared to the gain created by reservoir fisheries (e.g. Lagler 1976, Pantulu 1976, Bernacsek 1997).

An argument often stated by proponents of dams is the possible presence, as a mitigation measure, of fish ladders along these dams. However their design has almost never been considered in relation to tropical species behaviour and their results have been inconclusive so far (Pantulu 1970, Bernacsek 1984 and 1997, Roberts 1993, Jensen 1996, Bergkamp *et al.* 2000). We will not debate here the efficiency of these fish ladders (or fish elevators), but quantify a fact initially mentioned by Roberts (1995): the migration of major species is so concentrated in time and abundance that no existing fish ladder can cope with such a density in a limited lapse of time.

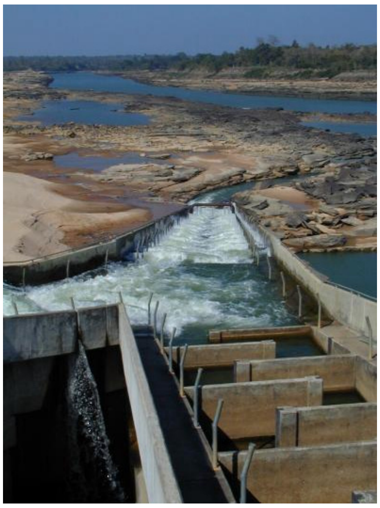
Table XII summarises the catch of the Cambodian dai fishery in January (peak period of the yearly catch, see figure 6). Catches are detailed for *Henicorhynchus spp*. These 3 species (*H. caudimaculatus*, *H. cryptopogon*, and *H. siamensis*), make up to 37% of the total yield and are strongly migratory species whose catches are concentrated almost entirely (90%) within the ten days preceding the full moon (Lieng *et al.* 1995, Ngor Pen Bun 2000).

Table XII: Abundance of fish during the migration peak

	Total catch (t) at peak migr.	Tons/hour during peak 10 days	% Henicorhynchus sp. in the catch	Tons of Henicorhynchus sp. /hour ten days before the full moon
Jan.96	9411	35.3	39	13.8
Jan.97	12263	46.0	40	18.4
Jan.98	10991	41.2	25	10.3
Jan.99	3803	14.3	33	4.7
Jan.00	9812	36.8	45	16.6

Therefore at the migration period, in the Tonle Sap River, an average of **34 tons of fish per hour** (i.e. about 3 million fish per hour) are caught by the dai fishery.

Although this figure only corresponds to a removal from the natural stock (which is replenished by inputs from other floodplains further along the Mekong mainstream), it gives an idea of the quantities involved in migrations periods, and of the irrelevance of fish ladders as a mitigation tool for dams.



The Pak Mun dam fish ladder (Thailand)

Another issue related to migrations is the complexification of basic parameters of fishery science such as total catch and CPUE. The example below, drawn from the Khong fishery (Southern Laos, I. Baird pers. comm.), based on the Probarbus fishery, points out the problem: the duration of the migration varies from year to year, the fishing effort and the total catch vary accordingly, but the standard CPUE can be constant.

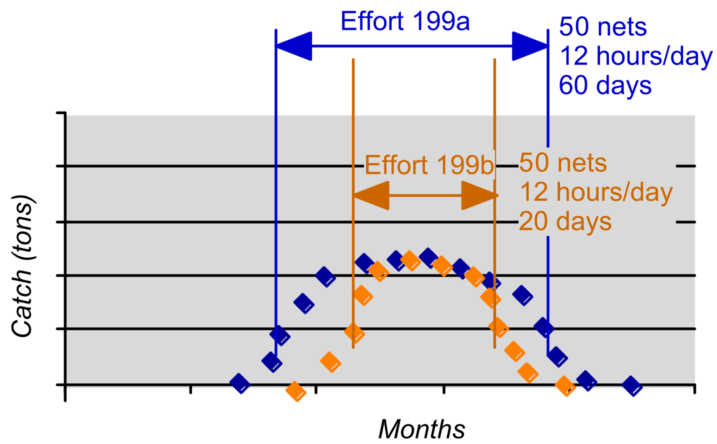


Figure 34: Catches, fishing effort and duration of migration (conceptual figure)

In such a case where the duration of migration varies from year to year depending on the hydrological regime, the analysis of total catches is biased by variable fishing effort, or conversely the analysis of CPUE does not reflect the varying total catch.

Year	Catch	Effort	CPUE
199a	15000 tons	50 nets, 12 h/day, 60 days	0.42 kg/h/net
199b	5000 tons	50 nets, 12 h/day, 20 days	0.42 kg/h/net

TOTAL CATCH ANALYSIS
Bias: variable effort
(12000 or 36000 hours-net)

CPUE ANALYSIS
Bias: variable total catch
(5000 or 15000 tons)

The assessment of the production must here result from a tri-dimensional approach (Fig. 36):

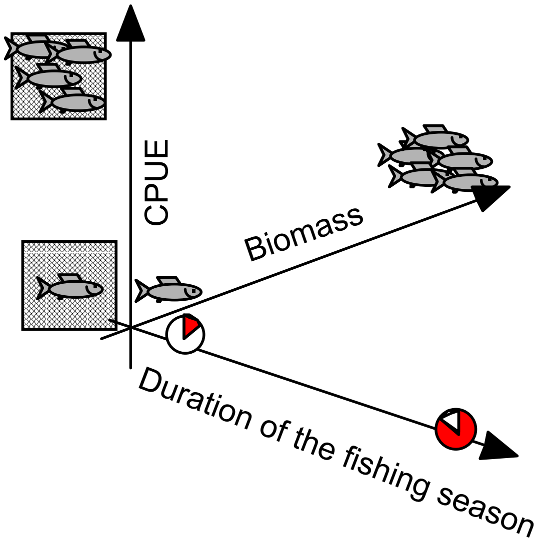


Figure 35: Parameters of importance in the monitoring of migrating species production

2-4) IMPORTANCE OF REFUGES

It is widely acknowledged that depressions serve as refuges for fish in the dry season act, particularly for "black fish", allowing them to recolonize flooded areas in the next season (Pellegrin 1907, Welcomme 1985; Fig. 34).

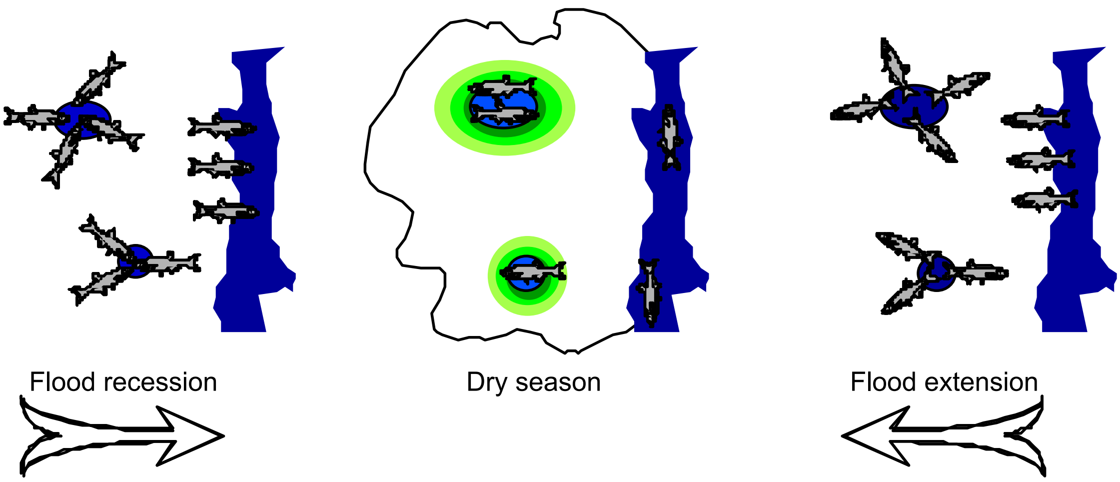


Figure 36: Fish and refuges

The term refuges however has a broader meaning, including not only small water bodies replenished by the flood every year but also deep river pools in the main rivers.

Refuges in floodplains
Their importance to fishes and their possible influence on a sustained (black) fish production (Lorenzen *et al*. 1998) should be better evaluated by a monitoring of existing irrigation reservoirs basinwide, as initiated by the Cambodian Department of Fisheries (1999), which lists 669 reservoirs. This assessment could be made easier by remote sensing, as demonstrated by the Hatfield work on the Tonle Sap floodplain (HCL 2000). Then the total surface of ponds available in the dry season could be integrated as a parameter in a multivariate approach. However the presence of ponds must be combined with their sustained accessibility to and presence of fishes (no extensive embankments such as in Bangladesh, see Hoggarth *et al.* 1999 c), nor pumping dry as often happens in Cambodia).

Refuges in the mainstream
The importance of deep pools in the Mekong River -particularly between Stung Treng and Kratie- has been acknowledged for many years (Blanc 1959, Nguyen Xuan Tan and Nguyen Van Hao 1991, Roberts & Baird 1995). However empirical evidence from preservation and management studies in Southern Laos (Baird *et al.* 1999) as well as in Cambodia (Chea Vannaren & Sien Kin 2000) would benefit from a more substantiated biological monitoring, and the current lack of data does not allow further development of this issue here.

Small-scale river trawler (Vietnam)

CONCLUSION

Summary of conclusions

Conceptualising a model for the management of the fish resource along the Mekong has led us to address the following issues and variables, identified as influencing catches:

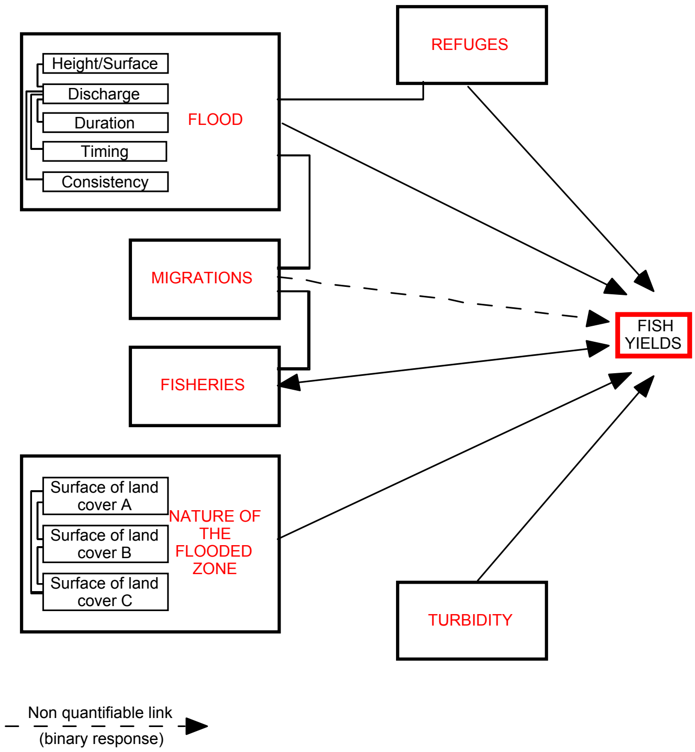


Figure 37: Variables involved in a fish production model

For practical reasons, the analyses had to focus on the Cambodian "dai" (bagnet) fishery for which the most complete and reliable data set was available. Hydrological data used originated from the MRC or were generated by the IWMI model (particularly estimates of flooded surfaces). However due to the beginning of fishery monitoring in 1995 and the absence of rainfall data after 1998, hydrological model outputs and catch statistics have only three years in common, which constrained the study of fish-flooded surfaces relationships.

Analysis of the dai fishery data showed a strong relationship between catches and water level the same year (n=5). The corresponding model is *Catches = 19580 . Ln (October water height) - 32025* with r^2 = 0.85. Two taxa are dominant in catches: *Henicorhynchus sp.* and *Paralaubuca typus* make up to 55% of total catches. *Henicorhynchus sp.* is responsible for this good relationship between catches and water level, but the total catch of other species also exhibits a significant correlation with the water level the same year (not with former years). Data also show that the size of *Henicorhynchus sp.* (short life span and fast-growing species) is closely related to the water level of the same year (and therefore to the extent of floodplains). The effect of flood duration on the growth of fish is also substantiated from the existing literature

The productivity of the lake is surprisingly high (230 kg/ha of floodplains), but nowadays statistics also include subsistence and rice field fisheries, whose yields are quite significant. Standardised comparisons with former asessments showed however that the production per fishing inhabitant had clearly decreased since 1940. This historical analysis of catches also substantiated the conclusion that total catches in the Tonle Sap system were related to the water level of the Mekong River.

In the section of this report which focusses on water regime, it is shown that the water level-flooded surface relationship is not linear, which implies that water level reduction (by management) would not linearly affect the surface of floodplain.

The yield of the Cambodian dai fishery is apparently correlated with the surface of the Tonle Sap Great Lake floodplains, as far as three years of data allow any correlation. Evidence from previous works in planktonology on the huge production of this floodplain supports this conclusion. A detailed analysis of the relationship between the fish production (globally or detailed for the dai catches) and surfaces of different land covers showed a positive relationship between the fish catch and the extent of flooded forest and of flooded grassland. The evidence of importance of the flooded forest to fish is discussed in this section.

Migrations are pointed out as being of critical importance in the Mekong basin; however this qualitative factor is not easily integrable to quantitative modelling. Available data demonstrate that the density of fish migration (more than 30 tons per hour in the Tonle Sap) make fish ways an unrealistic mitigation measure against the negative effects of dams. Available studies also suggest that the presence of refuges in the dry season (ponds in floodplains, pools in streams) is another factor allowing the sustainability of the production.

Broader perspective from other works

In a synthetic paper, Hoggarth *et al.* (1990 a) conclude from experience in tropical riverine fisheries management that:
- the impacts of floodplain modifications must be investigated and managed at both catchment and local levels
- quantity and quality of flood water must be maintained for high fish productivity
- diversity of floodplain habitats must be maintained for high fish biodiversity
- river channels must be maintained for fish migrations and access to spawning grounds

The Mekong River, still in a relatively unaltered state, provides an unique opportunity for managers to take into account the experience drawn from more than thirty years of hydrobiological research in the tropics. The sequence of events in the anthropisation of a river is well known now, as Welcomme (1995) summarises in a remarkable paper:
"River fish assemblages behave in a characteristic manner when placed under stress. Responses in sequences are: elimination of major migratory species, progressive elimination of the larger elements of the community; reduction in quality of catch; substitution of native species with introduced species; fluctuation in catch".
Recent trends in catches (Van Zalinge & Nao Thuok 1999) suggest that steps 2 and 3 have been reached in the Cambodian fishery; the elimination of major migratory species has not occurred yet, the Lower Mekong river mainstream being still free from damming due to its size.

Future directions

This work has outlined the paucity of data, which considerably limits standard statistical approaches. We have identified above eight measurable factors influencing the fish production: water height, flood duration, timing and consistency, surface of floodplain, surface of flooded vegetation and turbidity. The next step is to ordinate these factors according to their influence on the production. A multivariate approach, which has the lowest requirements among statistical methods in terms of amount of data, would require a minimal ratio of 3n years for n variables, i.e. here 24 years of monitoring. Given the development rate in the region, which is going to bring other anthropic variables into the equation long before the 24th year has been reached, this approach is not realistic, and expecting ordinated quantified results from scientists in this extremely complex field is not realistic either.
Alternative and creative approaches have therefore to be developed for management purposes. A possible one is the trend model (or multi-agent system, Ferber 1999); its principle is simple: each modification of an environmental parameter will have an impact on a fish group, and this is known from experts (whether they are scientists of professional fishermen). These individual impacts can thus be semi-quantified, as positive or negative, and strong or medium. The aim of the trend model is to make a quantitative and large-scale synthesis of these individual impacts.

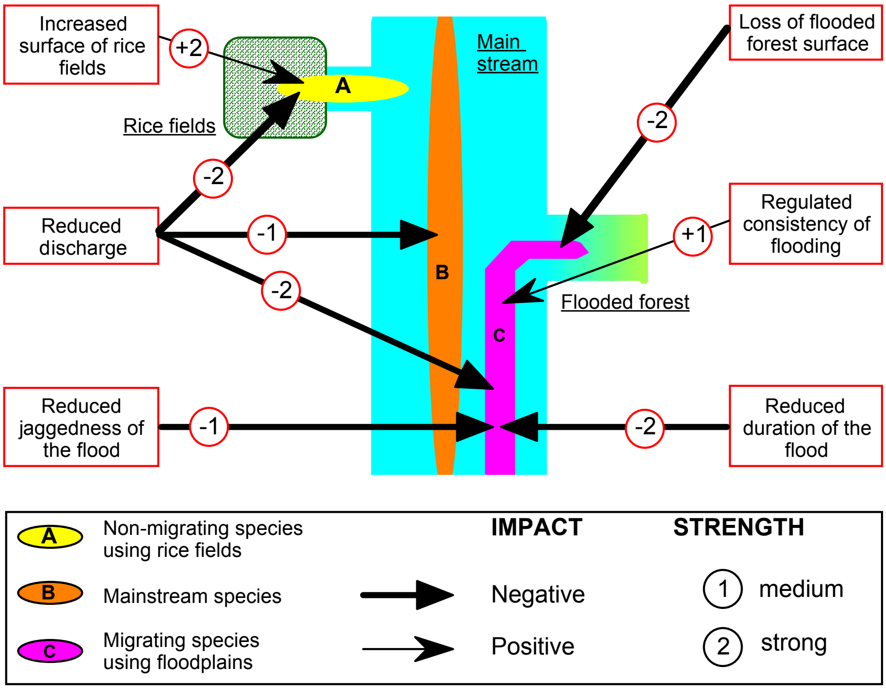


Figure 38: Example of semi-quantitative trend model

This approach, for which modelling tools already exist (Bousquet 1994, Bousquet *et al.* 1998), implies a preliminary work on groups of species having a similar response to a given environmental parameter (i.e. an ecological guild). This synthesis work at species level is possible and relies on tools such as ICLARM's FishBase or the MRC Mekong fish base.

Traditional fishing in the Khone Falls (Southern Laos)

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Cast net fishing in Southern Laos

ANNEX A

COMPILATION OF FISH CATCHES AND POPULATION STATISTICS FOR THE TONLE SAP GREAT LAKE AND RIVER AREA.

We have compiled here the different sources of detailed catch statistics for the Tonle Sap fisheries, and indicate in case of multiple sources which one was chosen, and why.

Dai fishery

Source: Lieng *et al.* 1995, van Zalinge & Touch Seang Tana 1996

Year	1994-1995
Dai fishery catches (tons)	18400*

* "Project estimates"

Source: Diep *et al* 1998 p. 6 and p. 63:

Year	1995-1996	1996-1997
Dai fishery catches (tons)	20000	16800

Source: Deap Loeung 1999, p. 143

Year	1995-1996	1996-1997	1997-1998	1998-1999
Dai fishery catches (tons)	14400	15500	14700	8900

Source: Baran *et al.* 2001

Year	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000
Dai fishery catches (tons)	20000	16800	14600	8900	11400

A recent re-assessment of the dai catches, based on a 1996 census (Ngor Pen Bun 2000), has resulted in a reevaluation of statistics, particularly for the 1995-1996 season. The correct catch for this season is considered to be 14400 tons. Therefore the dai fish catches estimates used in this report are next:

Year	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000
Dai fishery catches (tons)	14400	16800	14600	8900	11400

Mobile gears fishery

Source: Van Zalinge & Touch Seang Tana 1996

Year	1995
Mobile gears fishery (tons)	29997

Source: Diep *et al* 1998 p. 5:

Year	1994	1995	1996
Mobile gears fishery (tons)	31336	32243	24398

Source: Thor Sensereivorth *et al.* 1999 p. 42

Year	1997
Mobile gears fishery (tons)	23342

These statistics are considered incomplete, and data from household survey (Ahmed *et al.* 1998) are considered more reliable (van Zalinge *et al.* 2000 p. 39; this document § 3-1)

Alternative statistics for 1994-1995 are available in Ahmed *et al.* 1998 p. 63.:

	Middle-scale fishery (mobile gears)
Phnom Penh:	22600
K. Chhnang	7000
Siem reap	3000
Pursat	12000
Battambang	4500
K. Thom	13700
Total (without Kandal and Kampong Cham provinces)	62800

From the original source Kampong Cham province has been excluded (not directly related to the Great Lake system), as well as Kandal province which dominantly belongs to the Mekong sytem.

In absence of other reliable sources, these statistics gathered during years 1995-1996 have been used without modification for the following years.

Lot fishery

Source: Van Zalinge & Touch Seang Tana 1996

Year	1995
Lots	22119

Source: Diep *et al* 1998 p. 5

Year	1994-1995	1995-1996	1996-1997
Lots	24847	24201	25329

Source: Thor Sensereivorth et al. 1999 p. 42

Year	1997-1998
Lots	24794

Given the lack of transparency of the lot fishery (CNMC/Nedeco 1998 b, Ly Vuthy *et al.* 2000, Degen & Nao Thuok 2000) and the very high productivity of these lots (Chevey & Le Poulain 1940, Fily & D'aubenton 1965), an arbitrary but conservative value of three times the reported catch (i.e. 75,000 tons/year) has been used.

Subsistence fisheries (= family fisheries = small-scale fisheries)

Source: Van Zalinge & Touch Seang Tana 1996

Year	1995
Lots	17564 - 32912

Source: Ahmed *et al.* 1998 p 63:

	Small-scale fishery (subsistence) 1995-1996
Phnom Penh:	10600
K. Chhnang	26300
Siem reap	6500
Pursat	6400
Battambang	15500
K. Thom	6200
Total (without Kandal and Kampong Cham provinces)	71500

From the original source Kampong Cham province has been excluded (not directly related to the Great Lake system), as well as Kandal province which dominantly belongs to the Mekong sytem (the only districts along the Tonle Sap River are estimated to produce 2100 tons annually (Ahmed *et al.* 1998).

These figures are supplemented by an analysis of Long Keo (1999), who worked on the same data set and resulted in an estimate of 71,300 tons for the same provinces.

In absence of other reliable sources, these statistics gathered during years 1995-1996 (Ahmed *et al.*1998) have been used without modification for the other years.

Rice field fisheries

Location	Production	Source
Svay Rieng province	100-125 $kg.ha^{-1}.year^{-1}$	Gregory *et al.* 1996 Guttman 1999
Takeo province	38 $kg.caput^{-1}.year^{-1}$	APHEDA 1997
Kompong Thom province	201 kg/household (5 months period)	Numa Sham & Try Hong 1998

For the whole Cambodia, Gregory (1997) gives a productivity range of 25 - 100 $kg.ha^{-1}.year^{-1}$ and Guttman (1999) considers possible a rice field wild fish production of 50-100 $kg.ha^{-1}.year^{-1}$ in Southern Cambodia.
We used for statistics the value of 50 $kg.ha^{-1}$.

According to the Mekong River Commission Secretariat (1999 p.14) there are 258,000 hectares of rice fields in the Tonle Sap area (below the 10m elevation contour line).

This represents an annual production of 12,900 tons of ricefield wild fish for the Tonle Sap area.

Overall statistics

Global catches statistics for 5 Great Lake provinces (Siem Reap, Kampong Thom, Pursat, Kampong Chhnang, Battambang) + Phnom Penh + Kendal; tons.

Source: Department of Fisheries, 1997, quoted in Nao Thuok & Ly Sina 1998 p. 40

1981	1982	1983	1984	1985	1986	1987	1988	1989
44612	57240	48738	47806	46365	53745	52355	50004	42355

1990	1991	1992	1993	1994	1995	1996
53890	61000	56368	55200	51050	58774	53150

Global catches statistics for 5 Great Lake provinces only (Siem Reap, Kampong Thom, Pursat, Kampong Chhnang, Battambang). They slightly differ from the previous ones for the same provinces.

Source: CNMC/Nedeco 1998 b p. 33

1981	1982	1983	1984	1985	1986	1987	1988	1989
34019	40060	40101	35632	30239	31141	37375	32490	31800

1990	1991	1992	1993	1994	1995	1996
36050	41000	40408	39200	38280	39077	36700

Figure 17 of this report uses the statistics of the DoF.

Fish catches in the Tonle Sap-Great Lake area
Source: CNMC/Nedeco (1998 a p. 24) and MRCS (1999 p. 16)

Type of fishery	*Catch in tons*
Commercial fisheries (fishing lots and dais)	40000 - 60000
Commercial mobile fisheries (licensed)	30000 - 40000
Family mobile fisheries	50000
Total	120000 - 150000

Summary

The selection and collation of above statistics gives:

Recent fish production of the Tonle Sap Great Lake and River (tons)

Year	**Dai**	**Mobile**	**Lots**	**Subsistence**	**Ricefields**	**SUM**
1994 or 94-95			75,000			
1995 or 95-96	14,400	62,800	"	71,500	12,900	242200
1996 or 96-97	16,800	"	"	"	"	239000
1997 or 97-98	14,600	"	"	"	"	236800
1998 or 98-99	8,900	"	"	"	"	231100
1999 or 99-00	11,400	"	"	"	"	233600

HYDROLOGICAL DATA

CCF project data

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Average October level at the Kampong Chhnang gauge (m)	8,16	8,69	6,85	7,28	10,92	11,1	11,4	10,4	7,9	10,02

POPULATION AROUND THE TONLE SAP GREAT LAKE

Source: Ahmed *et al.* 1998 p. 84-85

	Population	Number of fishing communes	Total number of communes	Percentage of fishing communes	Population of fishing communes
With Kandal and Kampong Cham provinces	4,191,649	328	562	58%	2,431,000
Without Kandal and Kampong Cham provinces	2,310,749	161	307	52%	1,202,000

When dealing with the fishing population of the Tonle Sap area, we used the 1.2 million value.
This is in line with Nao Thuok & Sam Nuov (1996) and with the MRCS (1999 p. 8)

The total population of Cambodia amounted 11.6 million in 1999 (CIA World fact Book 1999) and 10.7 million in 1996 (Demographic Survey of Cambodia, 1996 NIS). We used this latter value, corresponding to the period of most detailed fisheries statistics.