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# FLOODS, FLOODPLAINS AND FISH PRODUCTION IN THE MEKONG BASIN: PRESENT AND PAST TRENDS

E. Baran[1], N. van Zalinge[2], Ngor Peng Bun[2]

*1: ICLARM, PO box 500 GPO, Penang, Malaysia*
*2: MRC Management of the Freshwater Capture Fisheries of Cambodia Project, Department of Fisheries, 186, Norodom Boulevard. P.O.Box 582, Phnom Penh, Cambodia*

Abstract
This paper deals with relationships between hydrology, wetlands and fisheries production in the Mekong River Basin.
A five-year monitoring of the bag net ("*dai*") fishery in the Tonle Sap River (Cambodia) showed a strong correlation between catches and water level in the same year. One taxon making up to 37% of total catches explains most of the relationships between catches and water level.
The current overall catch in the Tonle Sap system amounts 230,000 tons a year. When compared with historical surveys, this catch is twice as much as the catch 60 years ago. However when population increase is taken into account, the catch per fisherman has drastically declined. This can be considered as a warning signal of high exploitation rate. There is also a positive relationship between historical catches and water level in the Mekong River.
Several hydrological, environmental and ecological variables are likely to influence fish catches in the Mekong River floodplain. Hydrological variables are water level, duration, timing and regularity of the flood. Environmental variables are the total area of floodplain, the area of each type of flooded vegetation, and the presence or absence of dry season refuges. Among ecological variables, fish migration is by far the most important.
The importance of fish catches in the economy and the food security of the region requires a very careful approach to water management in the Mekong Basin.

## Introduction

The Mekong River, with a length of 4400 km, is the $10^{th}$ longest river in the world and its average annual discharge of 475 million $m^3$ ranks it fourteenth in the world (Welcomme 1985). However this river is the third (after the Amazon and the Brahmaputra) in terms of maximal outflows. These rainy season flows, combined with a very low slope in the Lower Basin, create wetlands whose total surface equals that of Ireland.

This exceptional extent of wetlands favours the abundance and diversity of fish. The total number of species has been estimated at 1200 (Rainboth 1996) and the total fish production in the Lower Mekong basin is over one million tonnes (Jensen 1996, 2000).

Out of a total population of 155 million in the four Lower Mekong Basin countries, 55 million people live directly within the watershed area, and three of the four Lower Mekong Basin countries (Cambodia, Laos, Vietnam) are ranked amongst the poorest in the world (UNDP Human Development Index 1998).

In Cambodia, fish constitute up to 65-75 per cent of the total protein diet (Guttman 1999). The fish consumption of the Cambodians (75 kg per capita per year according to Ahmed *et al.* 1998) is almost three times the fish consumption level of developed countries. When crop production fails, fish becomes an essential food and also helps to buffer the loss of income. For the poor of the Mekong Basin countries, fish and aquatic produce are critical to daily sustenance.

Fishing may be adversely influenced by the rapid development planned in the Mekong River watershed if these developments threaten the sustainability of the fish resources and wetlands. The Mekong fish resource is also threatened by a very high exploitation rate, acknowledged in Cambodia as well as in Vietnam. What are the effects of this exploitation, and does it threaten the future of the resource?

In this article we address these issues, based on fisheries data available in the region. We detail current relationships between catches and flood level and then compare these recent statistics with assessments made in the 1940s and 1970s. We finally list the major environmental parameters influencing the fish catch in the region. This overview leads to an identification of research needs to ensure sustainable management of the fish resource in the Lower Mekong River Basin.

## Data analysed

The data presented in the first part of this paper are those of the Mekong River Commission Project on Management of the Cambodian Freshwater Capture Fisheries (CCF), which has been monitoring fisheries in Cambodia since 1994.

The most comprehensive and reliable monitoring is that of the *Dai* fishery. A *Dai* is a fixed trawl or bag net mounted on scaffolding of trunks and set in a stream (Lieng *et al*. 1995). It targets fishes migrating from the Tonle Sap Great Lake to the Mekong River at the end of the rainy season. In Cambodia the *Dai* fishery is concentrated in the Tonle Sap River where 63 nets operated in 2000. The catch of the *Dai* fishery is 14,000-16,000 tons a year, that is 4-5% of the total fish catches in Cambodia (Van Zalinge *et al.* 2000). The analyses summarized here have been detailed in Baran *et al.* (2000 & *in press*).

Hydrological data are those provided by the Hydrology Unit of the Mekong River Commission, supplemented by gauge measures in the Tonle Sap River (Kampong Chhnang, zone of the *dai* fishery).

In the second part of this paper, we make use of historical data and information. The Mekong River was the subject of several detailed studies during colonial times and before the Khmer Rouge period. We have used the two most extensive reviews available, that of Chevey & Le Poulain (1940) on the Tonle Sap fisheries, and Lagler (1976) on the Mekong fish resources.

## Relationship between fish catches and flooding

### *Relationship between total catch and water level*

The positive relationship between fish production and water level 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 give below the actual relationship over five years between the total annual catch of the *dai* fishery and the water level in the Tonle Sap River during October, the month of the flood peak (Figure 1).

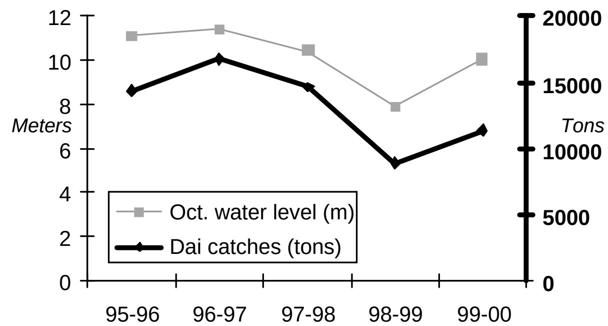


***Figure 1: Comparison between yearly* dai *fishery catches and average water level in October in the Tonle Sap River (Kampong Chhnang gauge).***

This figure shows that the annual *Dai* catches in the Tonle Sap River closely match the water level during the annual flood and thus also match the extent of the flood.
Based on these data, the relationship between annual *Dai* catches and water level is modelled in Figure 2.

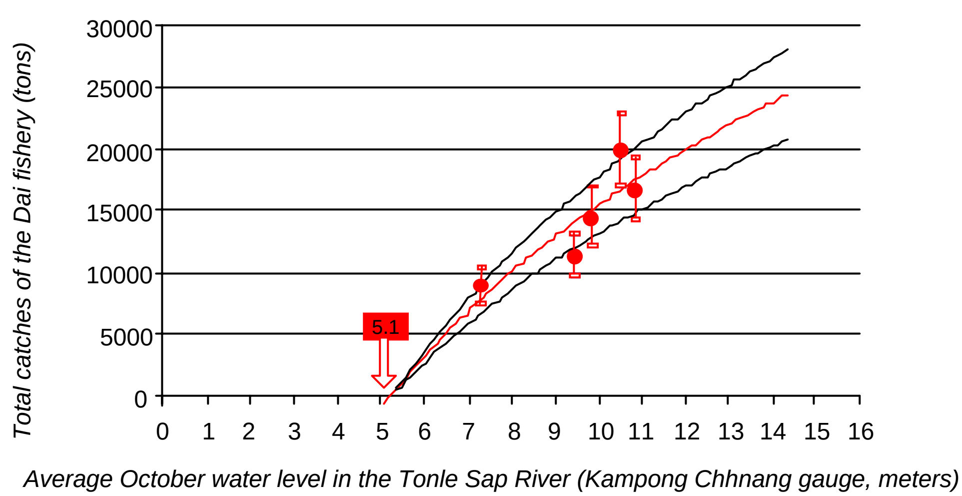


***Figure 2: Relationship between annual dai catches and average water level in October in the Tonle Sap River (logarithmic regression)***

The model equation is:

**Catches = [19580. Ln (average October water height) - 32025]**

*Catches in tons* *Average October water height in meters at the K. Chhnang gauge* **r=0.92**

Given the data set used it was not possible to calculate confidence intervals for the outputs of this model. However the yearly dai catch is considered to range between 14,000 and 16,000 tons (Van Zalinge *et al.* 2000), so a similar error range of ±7% has been applied here (black curves in Figure 2)

This model predicts that the catch will be nil if the October average water level does not exceed 5.1 m in the Tonle Sap River. This predicted nil catch would occur at a level 57% below the average water height of the last five years, or 30 % below the low water level of 1998.

### *Relationship between specific catches and water level*

A more detailed analysis focused on species composition of *Dai* catches has been done (Baran *et al.* 2000). This analysis shows that the majority of the catch (37%) consists of only one taxon, that of the Cyprinid *Henicorhynchus sp.* (Figure 3).

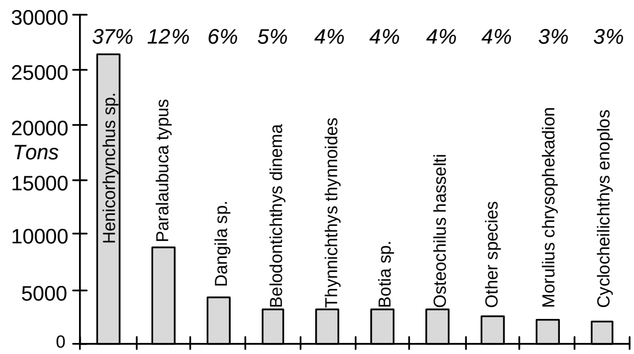


***Figure 3: Species composition of* Dai *catches between 1995 and 2000***

The strong correlation between the total catch and the water level is mostly due to the dominance of *Henicorhynchus sp*. whose abundance is highly correlated to the flood level (Figure 4). This taxon comprises fast-growing Cyprinids believed to reach sexual maturity within only a year. The other nine most abundant species do not individually exhibit significant correlations with water level, and the global correlation of the size of the catch with water level seems to be determined by *Henicorhynchus sp.*

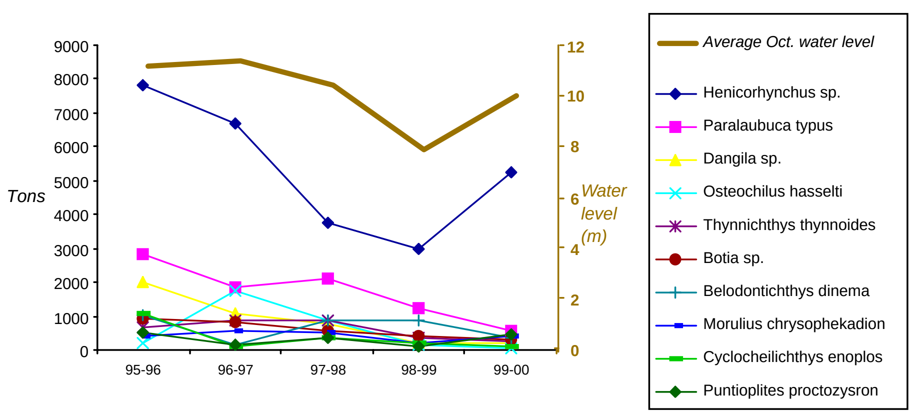


***Figure 4: Water level and yearly catches for the 10 most abundant taxa caught by the* Dai *fishery***

We examine below the relationship between the total catch in year n and the water level n years before. Given the limited time-series, an accurate calculation removing the auto-correlations between years is not possible. We performed instead a linear forward stepwise regression between total catch and the water level in the three previous years: $Catch_Y = f^n (L_Y; L_{Y-1}, L_{Y-2}, L_{Y-3})$

When the total catch includes *Henicorhynchus sp.*, there is only a significant linear correlation between the total catch in year n and the water level in the same year.
Similarly when the total catch does not include *Henicorhynchus sp.* (removal of the bias due to this dominant species), the linear correlation between the remainder of the catch and the water level is significant for the same year only. There is a slight and non-significant correlation between the catch and the water level one year before, and no correlation with previous years.

Such correlation between fish production in year *n* and water level in year *n* is typical of juvenile and productive systems based on short life-span species. This can be partly explained by high water-level fluctuations that 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 explained by the intensive fishing that favours short life span and fast growing species such as *Henicorhynchus sp*. Indeed, species like the Giant Mekong Catfish (*Pangasianodon gigas*) and Giant Barb (*Catlocarpio siamensis*), who mature after several years, are extremely rare nowadays.

## Present and past trends

#### *Production and historical trends in the Tonle Sap system*

Until recently, the only basin-wide production figures were those of Lagler (1976), who calculated that total fish production of the Lower Mekong River was 500,000 tons in 1975 (from Laos to Vietnam, including reservoir fisheries). In the absence of other data allowing comparison of trends basin wide, we focussed on the Tonle Sap system, for which more information is available.
Table 1 below summarises the information on fish production in the Tonle Sap system:

***Table 1: Fish production in the Tonle Sap Great Lake and River between 1907-1997 (tons)***

| **Reference**<br><br>**Year** | **Pellegrin (1907)** | **Chevey, Le Poulain (1940)** | **Fily, d'Aubenton (1965)** | **Lagler (1976)** | **DoF statistics** | **Van Zalinge & Touch Seang Tana (1996)** (Average of the given range) | **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** | | | | | 53,150 | | 239,000 |
| **1997** | | | | | | | 237,000 |

Two major factors must be considered when comparing the historic and recent statistics: i) subsistence and rice-field fisheries are only taken into account in recent statistics; ii) there has been rapid population growth in the last fifty years and the total fishing effort resulting in the compared catches has varied over the years.

*Population and fishing pressure*
In 1995-1996 a MRC survey of the fishing-dependant communes around the Tonle Sap Great Lake (Ahmed *et al.* 1998) found that they comprised 1.2 million out of a total of 10.7 million, which represents 11.2% of the Cambodian population. If we assume this ratio to be constant over time and use historical censuses for Cambodia, then catch statistics can be related to (fishing dependant) population around the Tonle Sap Great Lake over years.

*Subsistence and rice field fisheries*

Nowadays the Great Lake subsistence capture fisheries are estimated to be 71,500 tons (i.e. 59.6 kg/fishing commune inhabitant/year) and rice field fisheries to be at 12,900 tons (i.e. 10.8 kg/fishing commune inhabitant/year) for the 1.2 million inhabitants of the area. We used the above values to assess the past catches of these specific fisheries (which are not taken into account in the older studies), assuming that catch rates and rice cultivation methods have remained the same.

Once the overall previous catches have been determined according to the size of the fishing communities the fish catches per individual can be calculated and compared on a standardised basis (Table 2).

***Table 2: Catch per fishing inhabitant over time in the Tonle Sap zone***

| **Period** | **Great Lake fish production as historically recorded (tonnes)** | **Population in Cambodia (million hab.)** | **Fishing community (Tonle Sap area, million.)** | **Catches of subsistence fisheries (tonnes)** | **Catches of rice field fisheries (tonnes)** | **Overall catches (tonnes)** | **Fish catch/ fishing commune inhabitant (kg/person /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 | 1.2 | 71,500 | 12,900 | 230,000 | 192 |

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

The assumption that the proportion of the Cambodian population living and fishing around the lake has been constant over the years can be disputed. However as population pressure was less in the past than it is now, it is probable that more land was available for rice cultivation and that people were relatively richer, so that fewer people fished and lived by the lake. In support of this it can be seen today that many refugees have taken up fishing because of a shortage of land and because only a small investment is needed to become a fisher. If this were the case, then the above trends would be more marked.

Figure 5, drawn from these figures, shows the trends of production and catch per individual for the Tonle Sap Great Lake area from the 1940s to 2000s. It appears that even though production has increased over the years and has almost doubled since the 1940s, the catch per individual is almost half that in the 1940s. This is a classical symptom of a fishery under heavy exploitation (Welcomme 1995) and therefore monitoring of the fishery is vital. Applied research for management strategies that can be actually implemented here should be promoted.

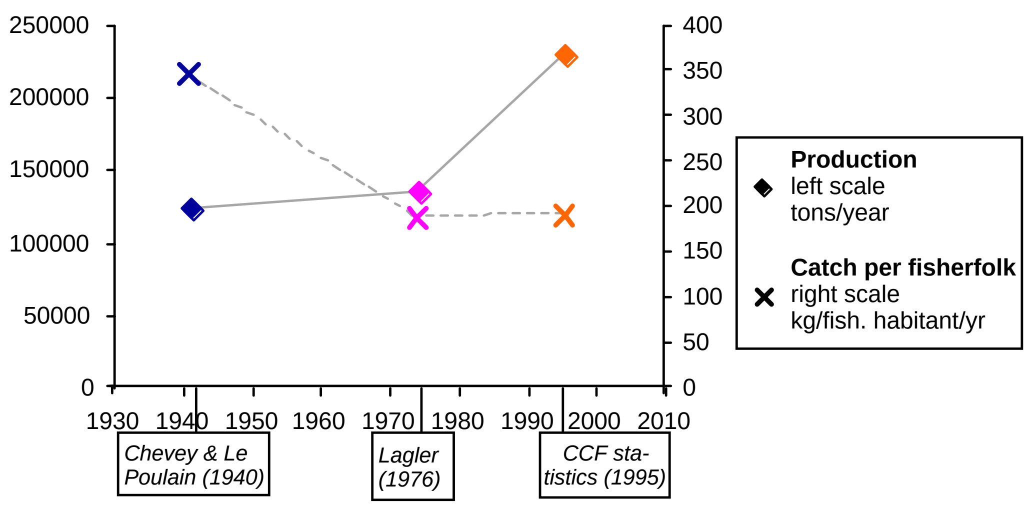


***Figure 5: Production and productivity of the Tonle Sap area over time (standardised basis)***

It can be concluded from comparing historical surveys with those of the current CCF project that the catch per fishing effort has decreased in the last six decades. This finding is also consistent with reports of fishers around the Tonle Sap (Ahmed *et al.* 1998) as well as along the Mekong (Roberts 1993, Hill 1995). The increase in fishing effort has clearly come from the small-scale fisheries, which have expanded with the increasing population. Effort of the large-scale (limited access) fisheries has declined gradually, but strongly since 1919, as the area occupied by the fishing lots is presently only about one third of what it was then.

Additional trends can be noted by integrating surveys from 1965 (Fily & d'Aubenton) and 1976 (Lagler) and comparing the catch figures with water levels over more than 70 years. Figure 6 illustrates the long-term trends in the water level and production estimates for the Tonle Sap system (the 146,000 tons in 1995 correspond to the total estimated catch minus subsistence and rice-field fisheries, which are not included in the other surveys). Although the four data points are insufficient for any correlation there is a good relationship between the total catch and the water level. Available data on the number of *dais* also show that the exploitation in the past used to be at least as intensive as at present.

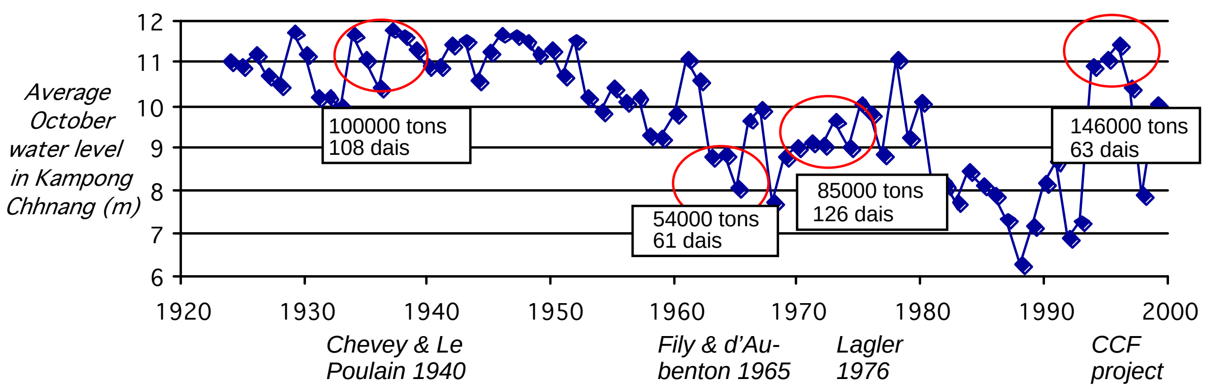


***Figure 6: Tonle Sap long-term hydrological changes and catch estimates***

Production figures here do not distinguish between species, size or quality of the catches, however the large migratory species have significantly declined in comparison to the small migratory and non-migratory species (Van Zalinge *et al*. 2000). The current high production figures for the Tonle Sap area can be attributed to the reduction of the age and size of fish (Junk 1982, Welcomme 1995, Laë 1995) and the high exploitation of the fish resource (Van Zalinge & Nao Thuok 1999).
Last, these production estimates should not be compared to those of other freshwater natural lakes (which are much lower, see Randall *et al.* 1995) nor be related to classical lake functioning and limnological approaches. This is because the Great Lake functions much more as a floodplain than as a lake and the biological approach relevant to lakes is not appropriate when dealing with floodplains (Bailey 1980).

## Factors influencing fish production

We present below a summary of the parameters influencing fish production in the Mekong Basin. This is a conceptual overview based on a review of the literature on major floodplains of the world, but in the case of the Mekong River the relationships between most of these parameters and the fish production or species are being demonstrated (Baran *et al. in press*).

*Water level*
The correlation between the *total catch* (in tons) and the river discharge the same year has been extensively documented (Welcomme 1985). It has also been shown more specifically that catches could be strongly related to the high-water flood regime at the beginning of each season (Moses 1987, Cross River in Nigeria), and that fish grow more quickly when flood levels are highest (Bailey 1988, Amazonia).

*Duration of the flood*
A longer period of flood provides a longer growth period for fishes, and therefore a higher yield. This strong correlation between the annual fish production and the duration of the flood has been clearly demonstrated by Stankovic & Jankovic (1971, Danube River) based on a 38-year time-series. However, as the process is linked to organic matter decay and nutrient release, the relationship seems to be asymptotic, a plateau being reached after a certain duration.

*Timing of the flood*
Most tropical species release eggs just before or during the flood, which results in their spreading into floodplains (Lowe-McConnell 1987, Bailey & Li 1992). In the Mekong River, rising waters trigger spawning in adults of many species such as Pangasiids (Poulsen 2000, Poulsen *et al.* 2000, Baird *et al.* 2000) and juveniles drift towards the Tonle Sap system where they grow. Timing of the flood and duration of the flood season during which the juveniles can grow are therefore two parameters that will influence the total production.

*Regularity of flooding*
After early rainfalls and river level rise have prompted migration and spawning, small drought periods can cause massive mortality of eggs, fish larvae and fry as well as amphibians. Sticky fish eggs can become suddenly exposed on vegetation, while larvae and juveniles can be marooned as the water recedes and small ponds dry up. This factor has scarcely been mentioned in the literature, but sometimes happens in the Tonle Sap region where it can result in massive mortality.

*Characteristics of the flooded zone*
For fishes, floodplains are favourable as a feeding zone (release of nutrients, primary production and detritus-based food chain), and because they provide shelter to juveniles against predation (shallow water, flooded vegetation) (Welcomme 1985, Junk *et al.* 1997). The diversity of food resources and habitats allows multiple strategies, species, sizes, stages and life cycle strategies.
Flooded forest offering more resources than flooded grassland, and the latter being richer than barren land, the diversity and abundance of species in a floodplain is usually related to the diversity of habitats (Figure 7).

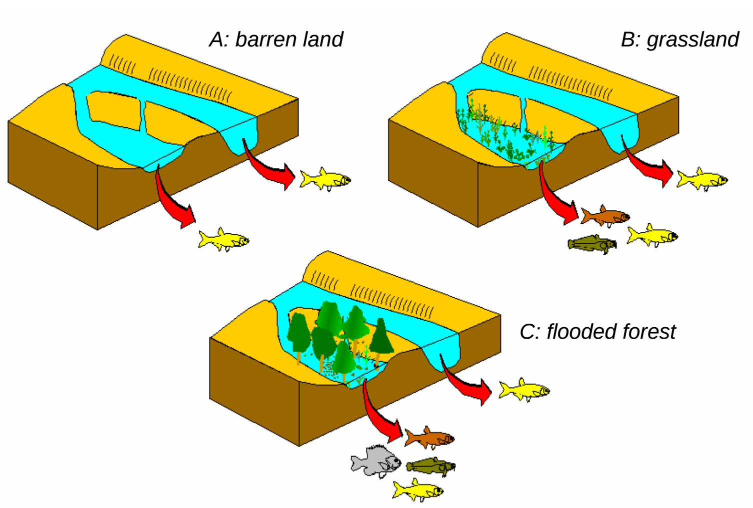


***Figure 7: Different types of floodplains and their fish production***
*A: Flooding of barren land; limited and undiversified fish production*
*B: Flooding of a grassland; more abundant and diversified fish production*
*C: Flooding of a forest; abundant and diversified fish production.*

*Migration routes*
The importance of migratory behavior among Mekong River fishes, acknowledged for long (Sao-Leang & Dom-Saveun 1955, Shiraishi 1970, Roberts & Warren 1994, Roberts & Baird 1995 among others) has recently been confirmed and detailed (Srun and Ngor 2000, Baird *et al*. 2000, Poulsen *et al*. 2000). Such complex fish migrations have a major ecological role as they transfer production throughout the basin (Welcomme 1995). Longitudinal migrants contribute 63% to the catch of the major Tonle Sap fisheries (Van Zalinge *et al*. 2000). Fish concentrate during brief migration peaks, and the impediment to migrations during these periods has been poorly assessed, although it is likely to be dramatic. Ngor Pen Bun (2000) and Baran *et al.* (in press) have shown that 90% of the *Dai* fishery harvest was caught in ten days each month of the fishing season; when the catch rate reaches up to 34 tons of fish per hour.

*Dry season refuges*
Depressions and ponds in floodplains serve as refuges for fish at the beginning of the dry season, particularly for the group of "black fish" (Pellegrin 1907, Welcomme 1985). The total area of ponds available to fish as refuges and the intensity of fishing in these ponds are two parameters likely to influence the recolonization rate and therefore the catch the following season.
Deep pools in the mainstream of the Mekong River are also known as refuges, particularly for catfishes during the dry season (Blanc 1959, Nguyen Xuan Tan and Nguyen Van Hao 1991, Roberts & Baird 1995).

## Conclusions

Although studies suffer from a lack of historical data and long time-series, fish production can be closely related to the flood levels in the same year in the Mekong River and particularly in the Tonle Sap system. This is particularly true for dominant species such as *Henicorhynchus sp*. with a short life span, but might not be the case for species with longer life span.
Comparison of current statistics with historical studies shows that the total production has increased over the years, as a result of an increased fishing effort (population pressure), but that the catch per person has notably decreased.
A summary of factors influencing the total catch is given below (Figure 8).

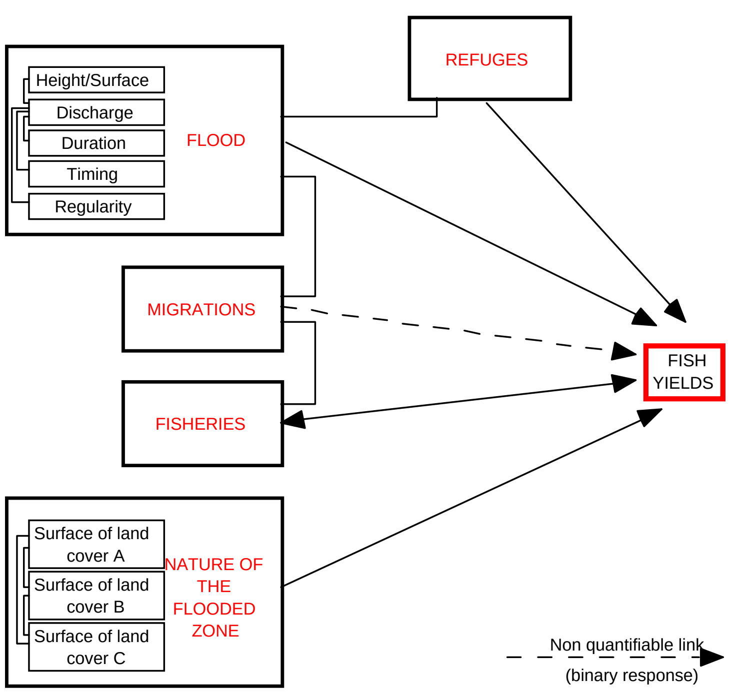


***Figure 8: Factors influencing total fish production in the Mekong system***

Most of these relationships have been identified as ecologically important, and are underpinned by published observations and field observation; however almost none of them have been formally quantified. Quantification of these relationships and forecasting of the behaviour of this complex system represents a major challenge for resource managers in the coming years. The diverse nature of interacting factors (hydrology, environment, fisheries technology, sociological pressures, etc) will require the integration of different disciplines in a multidisciplinary approach.

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