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# TONLE SAP PULSING SYSTEM AND FISHERIES PRODUCTIVITY

**Sarkkula, J.[1], Baran, E.[2], Chheng, P.[3], Keskinen, M.[4], Koponen, J.[5], and Kummu, M.[4]**

[1] Finnish Environment Institute (SYKE), Mechelininkatu 34a, 00260 Helsinki, Finland - juha.sarkkula@environment.fi
[2] World Fish Center, IFReDI, PO box 582, Phnom Penh, Cambodia – e.baran@cgiar.org
[3] Inland Fisheries Research and Development Institute (IFReDI), Cambodia – chhengp@yahoo.com
[4] Laboratory of Water Resources, Helsinki University of Technology, P.O. Box 5200, FIN-02015 HUT, Finland - marko.keskinen@hut.fi & matti.kummu@iki.fi
[5] EIA Ltd., Tekniikantie 21B, 02150 Espoo, Finland – koponen@eia.fi

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## 1. INTRODUCTION

Cambodian inland fisheries have a remarkably high importance as a source of food and animal protein for the country's population. Cambodian inland fisheries amounted to 360 000 tons in 2002 according to the Department of Fisheries, contributing up to 16% of the GDP. The Tonle Sap Lake and its floodplain play a central part in fisheries productivity, not only for Cambodia but for the other parts of Lower Mekong Basin as well. Mekong Basin developments, major hydropower dams and reservoirs in particular, pose a risk for the sustainability of the Lower Mekong Basin fisheries by changing the hydrological and sediment transport patterns.

For increase the understanding of the mechanisms and controlling factors of the fisheries productivity in the Tonle Sap system, a number of studies and modelling works are being implemented, in cooperative manner. Among them, the WUP-FIN Project (2003) has carried out a measurement programme and developed a numerical 3D hydrodynamic and water quality model of the system and established links between water parameters, environmental indicators and fisheries impacts (TA for the Mekong River Commission). BARAN et al. (2004) have elaborated a Bayesian probabilities network based model and fisheries stakeholder analysis to identify relationships between river hydrology, floodplain habitats and fish production (TA for the Asian Development Bank). This paper aims at demonstrating the progress of these projects and identifying ways to quantify the role of various factors contributing or limiting fish production in the Tonle Sap system.

## 2. TONLE SAP LAKE

The Tonle Sap Lake and its floodplains in Cambodia contain the largest continuous areas of natural wetlands habitats remaining in the Mekong system, while being the largest permanent freshwater body in Southeast Asia. The lake has an extraordinary hydrological system: in the wet season, the Tonle Sap River changes its direction and flows to the Tonle Sap Lake because of the flooding of the Mekong River in June-September (Figure 1). The lake functions as a natural flood water reservoir for the Mekong system and supports the Mekong delta by the stored flood waters in the dry season. The area of the lake varies between dry and wet seasons from 2500 $km^2$ up to about 15,000 $km^2$, while the depth of the lake increases from less than one meter up to 7–9 m (WUP-FIN 2003). The Tonle Sap ecosystem is believed to be one of the most productive inland waters and one of the most fish-abundant lakes in the world (BONHEUR 2001).

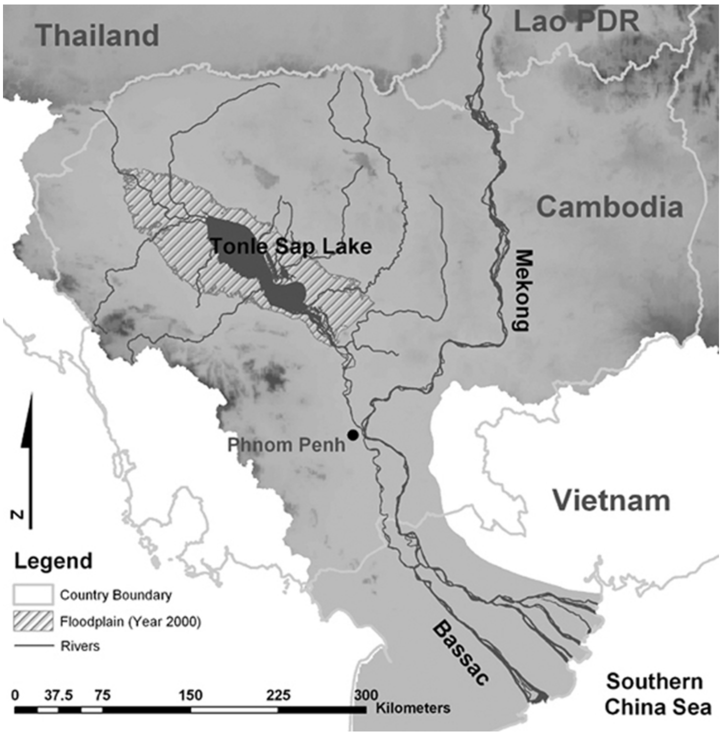


*Figure 1 Lower Mekong Basin with Tonle Sap Lake.*

## 3. PHYSICAL-CHEMICAL CONDITIONS

The weather in the lake area is dominated by the monsoon. During the wet season in May – October winds are predominantly from south-west and during the dry season in November – April from north-east. Wind velocities are typically low, on the average 2 – 3 m/s, except during short storms. The low wind velocities combined with the sheltering effect of vegetation make the inundated forest quite calm environment. Calm physical conditions facilitate net sedimentation and decrease aeration. Average yearly precipitation varies from 1300 mm in the south to 1500 mm in the northern part of the area. Lake water temperature varies between 28 and 33 °C.

### 3.1. Dissolved oxygen

The waters of the lake proper are well oxygenated because of the wind and wave induced mixing. During the flood, the inundated areas are to a large extent anoxic, dividing the fish into two distinct groups: the black fish adapted to nearly anoxic flood plain conditions and white fish staying in the lake and its nearby flooded forests and scrublands.

### 3.2. Total suspended solids and Nutrients

The highest concentrations of nutrients and TSS were generally reached in the lake in April-June, during the lowest water level. The high values of TSS indicate that at the beginning of the wet season the pelagic primary production of the Tonle Sap Lake is more likely to be light than nutrient limited. When the concentration of TSS stated to decrease due to sedimentation in late July improving the light availability for phytoplankton, the concentration of PO4-P rapidly dropped close to the detection limit of conventional laboratory analysis. While PO4-P was consumed close to zero, the availability of DIN (NO23-N and NH4-N) stayed good. This indicates that when light conditions are adequate for primary production, the first limiting nutrient is more likely to be phosphorus than nitrogen (WUP-FIN 2001).

The average total suspended sediment flux into the Tonle Sap Lake is 7-9 million tons/year (MT/year) while the outflow flux is only 1.6 MT/year (SARKKULA et. al. 2003). Total suspended solids (TSS) showed clear difference between the floodplain and the open lake. The mean value for forest (23 mg·dm$^{-3}$) was only one third of the value for the open lake (77 mg·dm$^{-3}$). The densely vegetated habitats clear effectively the inflowing waters by sedimentation. This is shown by the 3D model accordingly. During the high water period typical values for the open lake and flood forest were 5-100 and 1-10 mg·dm$^{-3}$ (Figure 2), respectively.

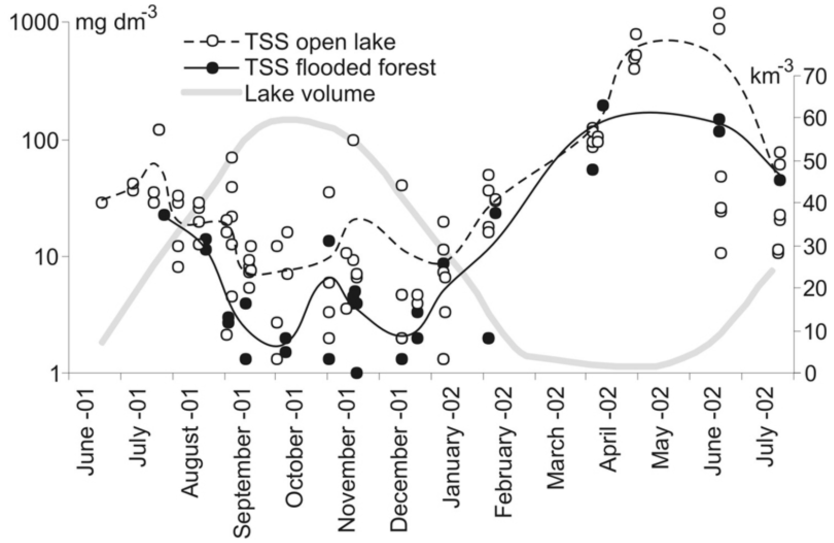


*Figure 2 Total suspended solids (TSS) in open lake and flooded forest.*

### 3.3. Chlorophyll and plankton

The chlorophyll-a concentrations varied between 0.3-14.0 with average of 4.5 µg/l without any clear temporal pattern. The values are relatively low indicating that development of phytoplankton blooms may be controlled in the Tonle Sap Lake by effective grazing. Both the chlorophyll-a (CHL-A) and the phytoplankton biomass peaked during the low water period in April 2002 (Figure 3) amounting to ca. 60 $mg{\cdot}dm^{-3}$ of CHL-A and 2.5 $mg{\cdot}C{\cdot}dm^{-3}$ (SARKKULA et. al. 2003). Although the peak values appeared in the low water lake, almost all the annual biological production takes place in the flood season due to the immense volume of the flood waters.

The traditional concept of eutrophication does not fit well to the Tonle Sap Lake. The naturally high primary production is effectively channelled to the food web ending up to the remarkably high fish production. Massive algal blooms are not reported to be typical for the lake. In the present situation, slight increases in the nutrient loading would probably only increase the fish production without negative side effects.

The sediment transported by the floods into the lake basin is likely to make up an important phosphorus source for flood lake ecosystems. The sediment bound phosphorus is assumed to become available for phytoplankton via higher plants growing in the transition zone between the aquatic and terrestrial ecosystems. The nutrients bound into higher plants during the terrestrial phase are released to water by the decomposition of plant material during the rising-water period (FURCH & JUNK 1997).

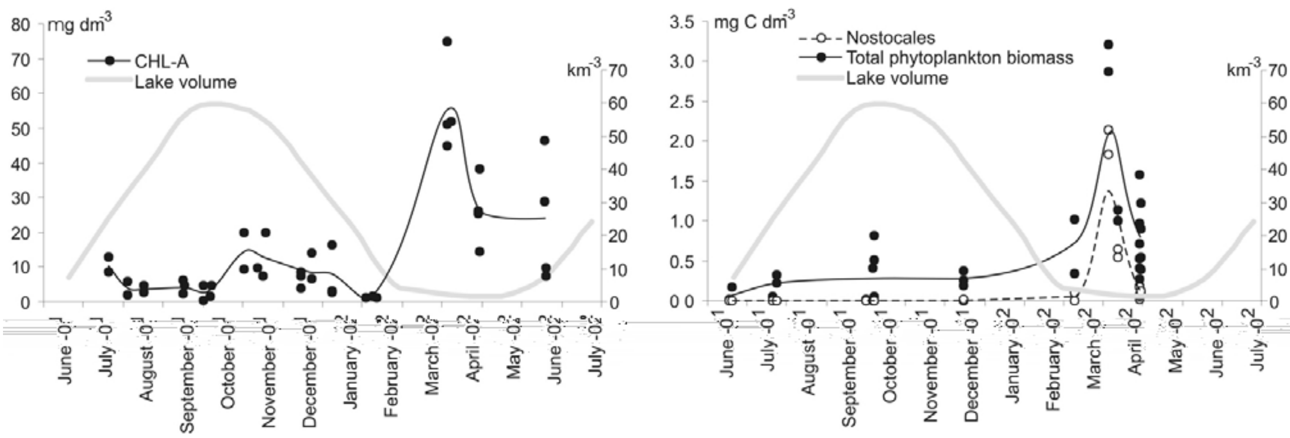


*Figure 3 Chlorophyll-a (CHL-A) [left], and Nostocales and total phytoplankton biomass in Tonle Sap Lake [right].*

# 4. FLOOD PULSE CONCEPT AND FISHERIES PRODUCTIVITY

## 4.1. Flood pulse

In the last two decades, the flood pulse concept has been widely accepted as the key factor for highly productive floodplains. Thorough studies made in the Amazon Basin (JUNK 1997) obviously offer a lot of useful information on pulsing system processes for the other basins with similar behaviour, like the Mekong Basin.

Junk and his colleagues state that the river and its floodplain must be considered as an indivisible unit because of their common water and sediment budget. The areas oscillating between the terrestrial and the aquatic state are defined as the Aquatic/Terrestrial Transition Zone (ATTZ). In this Zone, floodplain plants and animals use the available nutrients during their active growth phase and transfer some of them into the less active phase, thus fuelling an internal nutrient and energy cycle within the floodplain (JUNK 1997). This exchange of energy and nutrients between the two phases by different groups of organisms is the principal reason for high productivity of most floodplain systems.

## 4.2. Fisheries productivity

Observations on the bag net (Dai) fishery for migrating fish in the Tonle Sap River indicate that year-to-year variations in maximum Mekong river flood levels and related Tonle Sap floodplain inundation strongly affect the yield of this fishery, which is dominated by short-lived species (VAN ZALINGE et al. 2003). This study concerned the effect of the variations in the height of the flood on the fish yield and on the average size of some major species. The higher the flood is, the bigger the catch. Moreover, it was hypothesized by the authors that sediments carried by the Mekong waters to the Tonle Sap Lake bring in the essential nutrients that feed into the lake's food webs. The higher the flood the more sediments and nutrients is brought in. Transport with flood waters determines also, where upstream Mekong fish larvae and juveniles end up and start their growth. Effective transport leads to improved survival and growth of fish and hence to improved fishery yields.

## 4.3. Model for Tonle Sap fish resource

In 2003, World Fish and IFReDI (Cambodian Fisheries Research Institute) undertook modeling of the Tonle Sap fish production, using Bayesian network approach (BayFish –Tonle Sap model, BARAN et al. 2004). The objectives of the study are to identify relationships between river hydrology, floodplain habitats and fish production and to set up baseline for a decision support system helping in the management of the river and its floodplain. The objectives are very similar to the ones of the WUP-FIN project and, consequently, this has led to combine these partly different approaches to a collaborative effort. The Bayesian network consists of quantitative and qualitative variables linked by probabilistic interactions. The variables contain a number of hydrological and environmental driving variables, variables for fish environment and fisheries (rainfall, runoff, river flows, water level, flood properties, floodplain DO and vegetation, fish stocks, fishing activities etc.).

# 5. CONCLUSION

For helping in planning and deciding on sustainable fisheries management of the Tonle Sap system it is necessary to identify the factors driving and controlling its fisheries productivity. As a summary of the above considerations, the favourable conditions promoting high fisheries productivity in the Tonle Sap system could be listed as the following preconditions (BARAN & COATES 2000; BARAN et al. 2004; VAN ZALINGE et al. 2003; and SARKKULA et al. 2003):

- early flooding and long flood i.e. long growth period for the fish
- sufficient flow velocity in the Tonle Sap River for successful transport of larvae and juveniles to the lake and floodplain
- high flood level and large inundated habitat
- preservation of plant communities for effective nutrient and energy exchange in the floodplain
- maintaining high sediment and nutrient input to the lake with flood waters

There is a fairly limited amount of data available of the Tonle Sap system and the Mekong Basin in general, and the research works on its ecosystem and food web are still in an early stage. By cooperative efforts, it is possible to speed up this process, as well as bringing in knowledge of similar ecosystems with more advanced research results e.g. the ones from the Central Amazon Floodplain. This would surely contribute to designing the ecosystem research, monitoring, and developing analytical tools for Mekong Basin resources management.

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