INFLUENCE OF SEDIMENT LOAD ON MEKONG FLOODPLAIN AND COASTAL FISHERIES
State of knowledge and research options

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Project
"A Climate Resilient Mekong: Maintaining the Flows that Nourish Life"
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1 INTRODUCTION

The current study is the fourth in a series of five aimed at assessing the impact on fish resources of predicted changes in sediment load due to dam operation in the Mekong Basin.

After a review of the interactions between sediments and fish in tropical rivers and in the Mekong (report 1), a review of the impacts of flushing on fishes and the best flushing practices to minimize these impacts (report 2) and an identification of features of high fish productivity in the Mekong basin (report 3), the current study focuses on the consequences of sediment load reduction on Mekong floodplain and coastal fishery resources. The last study of the series will focus on the impact of predicted changes in sediment loads due to specific dam operation on fish resources in 5 main zones of the Mekong Basin. The five steps of the overall study are summarized in the figure bellow:

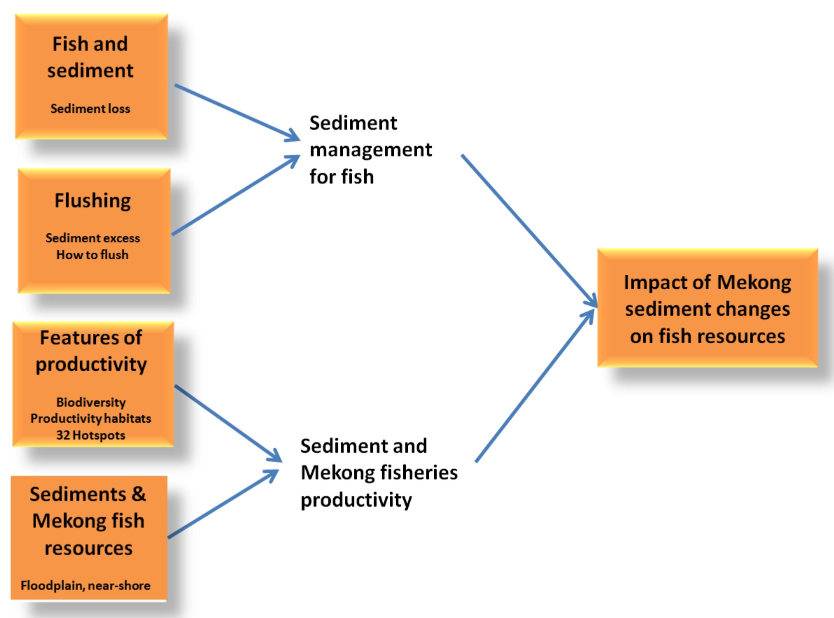

Figure 1:Steps in the assessment of the impact on Mekong fish resources of predicted changes in sediment load due to dam operation. Squares correspond to reports

The Tonle Sap floodplain is used as a case study of Mekong floodplains since this is the most documented floodplain in the Lower Mekong Basin (LMB). In the first section of the present report the conceptual framework of a model of the Tonle Sap fish productivity is used as a proxy for all Mekong floodplains (i.e. Tonle Sap and floodplains southeast of Phnom Penh and in Vietnam). In the second section of the report we review the state of knowledge about the influence of Mekong sediment loads on coastal fisheries. Since the literature available for the Mekong is very limited, the review is extended to other near shore tropical fisheries under the influence of large rivers.

2 INFLUENCE OF SEDIMENT LOADS ON FLOODPLAIN FISHERIES

The Mekong floodplains cover up to 3.9 million hectares, from Kratie in Cambodia to the delta. Each year the Mekong inundates approximately 1.2-1.8 million hectares, the flood lasting between 6 months and a few weeks (at the fringe of the floodplain), the water depth ranging between 5m and a few centimeters (again at the fringe of the inundation zone; Carling 2009).The upper limit of floodplains is Kratie in Cambodia (TKK and SEA START 2009) and their maximal extent – 38,900 km^2- was assessed during the year 2000 record flood.

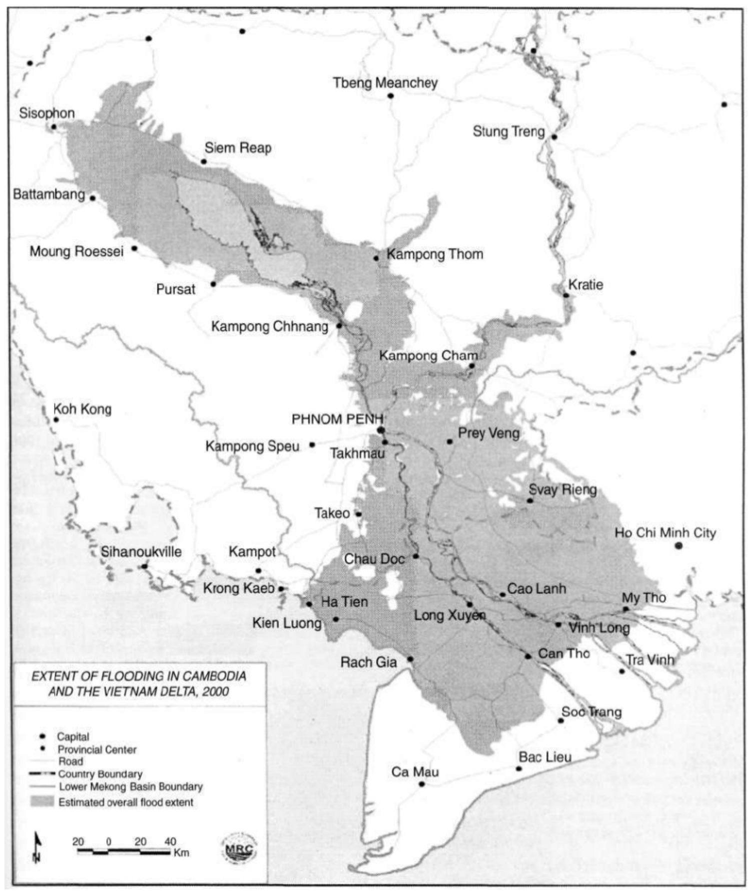

Figure 2: Extent of the 2000 floods showing the limits of the Mekong floodplains. Source: Carling 2009

With more than one million tonnes of fish yielded each year, floodplains are the heart of the Mekong fisheries. Out of the 2.1 million tonnes of freshwater fish produced each year in the Mekong Basin, floodplains contribute 1.2 to 1.5 million tonnes (Barlow *et al.* 2008) and are therefore home of the most productive fisheries in the world (UNEP 2010).

Mekong fisheries in general and floodplains fisheries in particular are largely influenced by nutrient inputs from the river sediment load. It appears from our literature review on the interactions between fish and sediments (Baran and Guerin 2012) that sediment loads and attached nutrients contribute substantially to fish production. This was already pointed out by Koponen *et al.* (2010a) for the Tonle Sap: "*a remarkable part of the nutrients retained in the Great Lake ends up to the fish biomass. This also indicates that a major part of primary production of the Great Lake is channeled to the fish production".*

The dependency of Mekong fisheries upon sediment loads is not documented. The only study that has explicitly addressed the role of Mekong sediments vis-à-vis fishery productivity is the SYKE/EIA Productivity modelling study of the Detailed Modelling Support project for the MRC (Koponen et al. 2010a), whose conclusions are detailed further in this review. Within the Mekong system, the Tonle Sap Lake stands as an exception since it has been much more studied than other floodplains (Campbell *et al.* 2009). In particular, a model describing the multiple drivers of the Tonle Sap floodplains fish production was developed (Baran and Jantunen 2005, Baran *et al.* 2007, Jantunen 2007) and a series of simulations of the influence of sediment upon the Tonle Sap lake fish production were produced (Sarkkula and Koponen 2010).

The systematic approach to the drivers of fish production in the Tonle Sap floodplains offers a model for the Mekong floodplains in general. Since the Tonle Sap floodplains cover up to 16,000 km^2 and thus represent more than 40% of the Mekong floodplains, the latter being a relatively homogenous ecosystem, we propose to use the conceptual framework of the BayFish – Tonle Sap fish production model as a proxy for the overall Mekong floodplains fish production. The BayFish model completed in 2007 did not include a specific component about sediments, but it listed and ordered multiple other drivers of fish production, and thus offers an entry point and a systematic approach to build upon. This can provide a preliminary step in the perspective of a more detailed research aimed at parametrizing in detail the model following the ongoing sediment load assessments.

After a brief review of the state of knowledge of the influence of sediment loads on the Tonle Sap fisheries and an introduction to the BayFish-Tonle Sap model as it was developed in 2005-2007, the last section of this chapter will present possible changes and updates to the initial model, as well as an integration of the "Sediment" variable in the conceptual model.

2.1 Tonle Sap sediments and nutrients

In the Tonle Sap, sediment-related nutrients consist mainly of nitrogen (N) and phosphorus (P), the two nutrients most important to ecosystem productivity. In their study, Koponen *et al.* (2010a) assumed that the system is not nitrogen-limited (considering inputs from plant nitrogen fixation and seasonal decaying of plant material) but underline that there is a need for a better assessment of the nutrient cycle, in particular in the dry season (limited nitrogen inputs in the dry season? inputs from agriculture fertilizers?).

The Tonle Sap Lake retains 4.3 to 5.7 million tonnes of suspended solids each year, and receives 21,500 tonnes of bioavailable phosphorus annually. It is estimated that of its received sediment input, the Great Lake *retains* 4.3 (Eloheimo *et al.* 2002) to 5.7 (Inkala *et al.* 2008) million tonnes of suspended solids each year. Assuming a value of 130 mg of bioavailable phosphorus per kilo of sediment, Sarkkula *et al.* (2010) estimate that the Great Lake receives 21,500 tonnes of bioavailable phosphorus each year. Of this input a certain amount is removed through export, in particular through the production of migratory fishes that grow and absorb nutrients in the lake but migrate and die outside of the lake (Koponen *et al.* 2010b). This export being discounted, Koponen *et al.* (2010a) estimate that ultimately 8,500 tonnes of *dissolved inorganic nitrogen*, 1,350 tonnes of total *dissolved phosphorus* and 850 tonnes of *phosphate* PO_4^-P are retained by the lake each year. The authors underline that these figures are probably underestimates and that sediment accumulation could be facilitated by the vegetation cover and thus be higher in the flooded areas than in the open parts of the Great Lake.

A significant portion of the nutrients retained in the Great Lake ends up to the fish biomass. Assuming that fish biomass is comprised of 0.5% of phosphorus and 2.5% of nitrogen (source not given), and that the lakes produces 230,000 tons of fish annually (Baran et al. 2001), Koponen *et al.* (2010a) estimate that the nutrients removed through the fish biomass amounts to 1,150 tons of phosphorus and 5,750 tons of nitrogen each year.

Sediment trapping by dams is expected to reduce bioavailable phosphorus input to the Cambodian floodplains and Delta by 10,000 to 18,000 tonnes each year. This assessment is based on the assumption of a 50% - 80% downstream sediment loss caused by hydropower development and a total amount of bioavailable phosphorus of 21,500 tonnes (Sarkkula and Koponen 2010).

2.2 Tonle Sap fish resources and sediments

The catch of the Dai fishery in Cambodia is correlated to the sediment inflow. Koponen *et al.* (2010a) have plotted the catch of the dai fishery in the Tonle sap River as a function of the sediment inflow during a decade (1999-2009; Figure 3), which shows a positive correlation (r^2=0.68) between these two variables, as detailed in Figure 4.

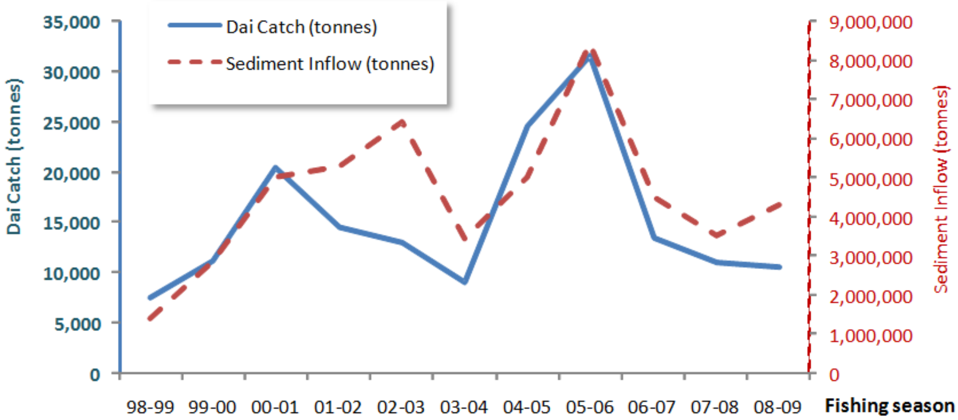

Figure 3: Dai fishery catch and sediment inflow in the Tonle Sap. Source: redrawn from Koponen et al. 2010a

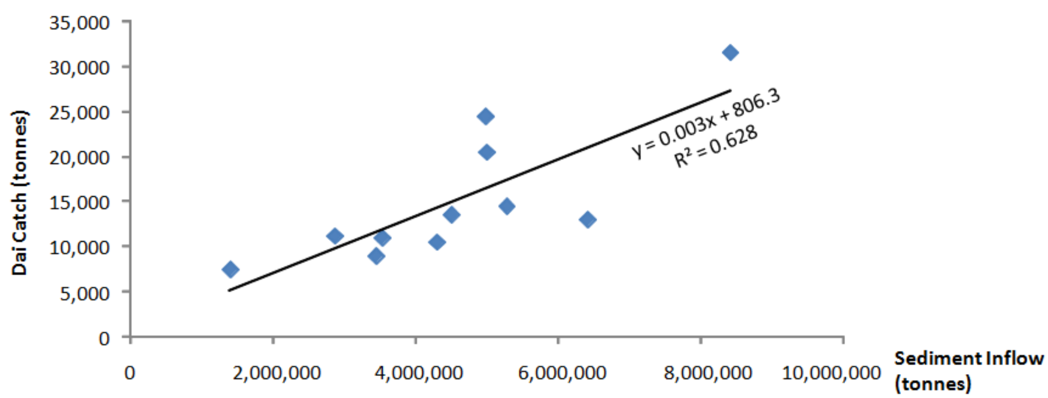

Figure 4: Dai fishery catch as a function of sediment inflow in the Tonle Sap.

The correlation between fish biomass and sediment inflow implies that sustaining the Tonle Sap fish productivity requires a sustained sediment input from the Mekong. According to Koponen *et al.* (2010a), the fisheries production ultimately depends on, and is limited by, the primary production of the ecosystem and the flood pulse processes. The period during which bottom sediments can release nutrients, although not well known, is not very long. Experience from dam reservoirs shows that in absence of sufficient nutrient input from the watershed, the production collapses after a few years (Koponen *et al.* 2010a).

In the Tonle Sap a 36% decline in total fish biomass is expected if the Mekong sediment input is reduced by 80%. Sarkkula and Koponen (2010), summarizing the different components and findings of their modelling approach, estimate that if sediment retention reaches 80%, then the impact on fish biomass production will ultimately be a 36% reduction compared to year 2004.

This model refers to the biomass, not the catch, and is based on available food only. It does not take into account other fish production drivers such as recruitment or survival. The findings of this model reflect the work of Halls *et al.* (2010) who performed statistical analyses on available fisheries and environmental data and concluded i) that the best single predictor of fish biomass in the Tonle Sap was the rate of sedimentation explaining 95 % of the variation in fish biomass available for exploitation, and ii) that the latter could decline by up to 20% - 30%.

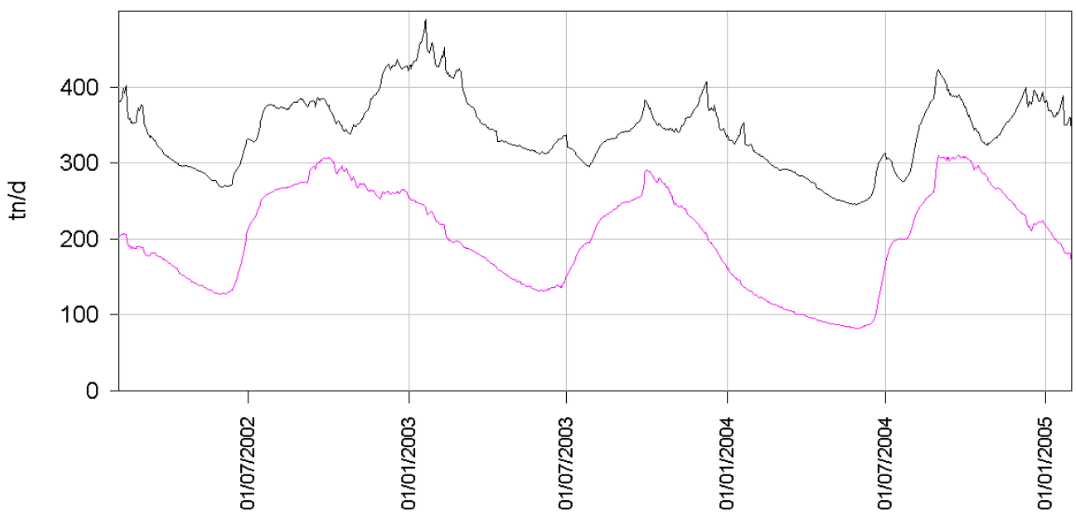

Figure 5: Modelled impact of a 80% reduction of sediment load on Tonle Sap fish biomass. Black line: before reduction; pink line: after reduction. Source: Koponen *et al.* 2010b.

Overall, the main impacts of sediment trapping on fish resources are to be expected in the floodplains of the delta and at sea, since only a very small fraction of Mekong sediment load (roughly 5 million tonnes out of 165 million, i.e. 3% annually; Sarkkula *et al.* 2010) goes into Tonle Sap. The impact of sediment reduction on coastal fisheries is reviewed in Section 3.

The results of the MRC Detailed Modelling Support Project are focussed on sediments and do not reflect a number of other factors that also influence the fish production. Halls *et al.* (2010) note that sedimentation rates are inextricably linked to the extent and duration of flows (i.e. flood index), and that data available do not allow distinguishing the relative importance of each factor (Figure 6). Koponen *et al.* (2010a) also point out that "*nutrient inputs from fertilizers should be included in the model".* Indeed, Tonle Sap is generally not nitrogen limited, except during the dry season when the shallow and turbid dry season lake seems to be nitrogen limited (Koponen *et al.* 2010a). Furthermore these authors i) note that it is not clear to what extent the organic matter used for the secondary and fishery production is exogenous or endogenous ("*Unpublished data collected by the Mekong River Commission on organic matter concentrations in inflowing water suggest that the vast majority of the primary organic matter in the Tonle Sap is produced locally"*), and ii) do not specifically review, unlike in the BayFish model, the other drivers or inhibitors of the fishery production.

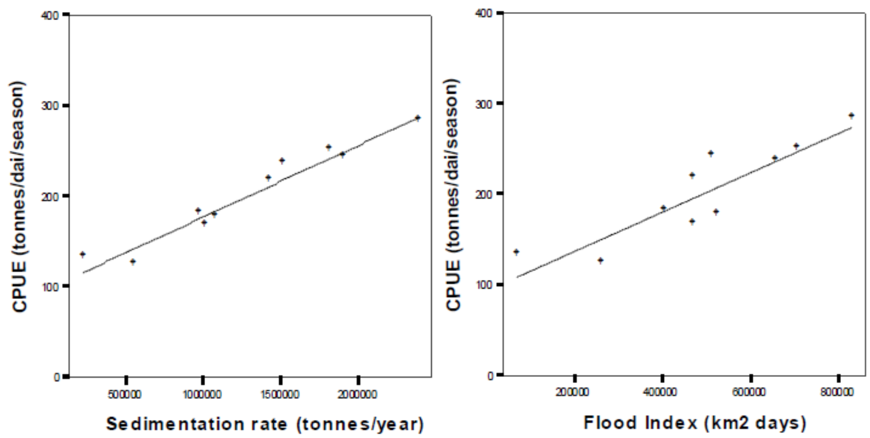

Figure 6: Fish biomass index plotted as a linear function of (left) rate of sedimentation and (right) the flood index (right). Source: Halls *et al.* 2010

The Tonle Sap fisheries depend upon a complex combination of inter-related variables that cannot be considered one by one. Despite their importance, nutrients are not the single driver of Mekong floodplains fish productivity. As initially highlighted by Baran and Coates (2000) or Baran and Cain (2001), fish production in the Mekong in the Mekong in general and in the Tonle Sap in particular depends on a number of factors including habitat, flooding characteristics, migrations, connectivity, and fisheries (Kurien *et al.* 2006).

In a complex system of multiple drivers, the impact of sediment reduction on floodplain fish production cannot be assessed through linear correlations and bivariate statistics alone, and we recommend as an alternative a multifactor model, which would allow assessing the relative weight of nutrients in relation to other drivers such as flooding patterns, floodplain habitats, connectivity or fishing pressure. The BayFish-Tonle Sap model of fish production constitutes a starting point for such approach, although it does not include sediments at this point.

The fact that floodplain fish production is driven by multiple factors led to the development, in 2005, of a multifactor model of the Tonle Sap fish production. The purpose of the BayFish model was to determine the impact of water and land use options on fish production and to assist with planning and decision-making. Data available were not enough to allow a proper quantification of all factors considered important, but this was overcome by the use of a Bayesian approach allowing a combination of available data with complementary expert knowledge (Baran *et al.* 2003). Using quantitative or qualitative information about fish and hydrological and environmental variables as inputs, the model can generate the probability of a certain fish production. The structure of the BayFish – Tonle Sap model is detailed in Baran and Jantunen (2005). The model was further developed and strengthened over years until 2007 (Baran *et al.* 2007, Jantunen 2007). However the BayFish – Tonle Sap model did not initially include a Sediments component, since it is only a few years ago that sediment issues became part of the research agenda in the Mekong (Lu and Siew 2005, Kummu *et al.* 2005, Kummu and

Varis 2007), and the sediment- fish relationship was never addressed before the work of the MRC Detailed Modelling Support Project in 2009-2010. In the following sections we show how Sediments could be integrated to the BayFish model.

2.3 The "BayFish-Tonle Sap" fish production model

The BayFish-Tonle Sap model considers that fish production results from four major drivers: hydrology, habitat, migrations and fisheries. The first three variables (hydrology, habitat, migrations) drive the fish stock, while the fisheries sector exploiting the fish stock drives the fish production.

Fish Catch = Fish Stock + Fishing effort

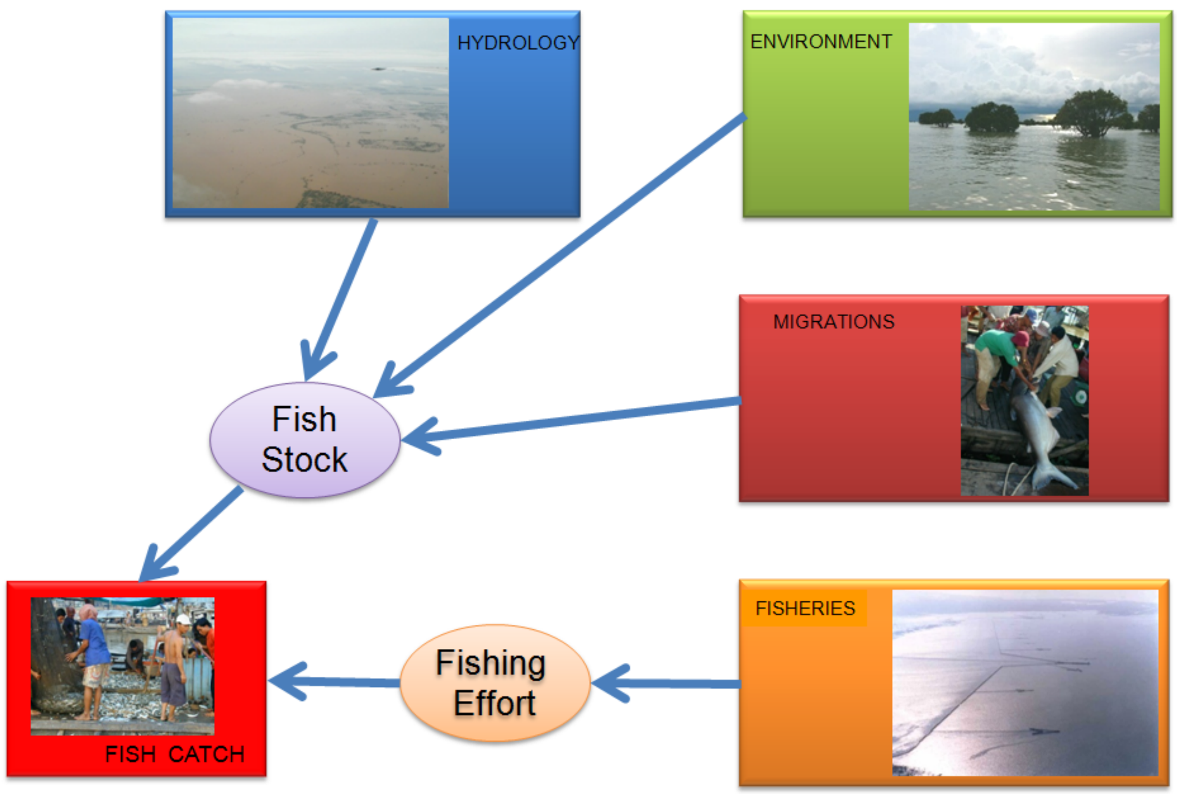

Figure 7: Main drivers of the Tonle Sap fish production in the original BayFish model

<u>*Fish Stock*</u> (i.e. fish biomass in water) is a function of hydrological, environmental and migration parameters:

Fish Stock = Hydrology + Environment + Migration

The *Hydrology component* describes the quality of a hydrological year from a fish perspective (e.g.: long and high floods are known to result in higher fish abundance). Similarly the *Environment component* describes the habitat quality from a fish perspective (e.g. flooded vegetation plays a positive role vis-à-vis fish production). *Migration* is also an essential component of the fish production in floodplains that get dry half of the year, and in the Tonle Sap River where the migration intensity can reach 30 tonnes of fish per hour during the migration peak (Baran *et al.* 2001).

The *Fisheries component* covers 3 scales of exploitation. The 2007 version of the BayFish-Tonle Sap model reflects the official classification of fisheries at that time: large-scale fisheries (fishing lot operations, barrages fishing and bag-net fishing), medium-scale fisheries (motorized commercial fishing); and small-scale or subsistence fishing (simple small gears). This classification requires updating since the large-scale fisheries have been abolished in March 2012.

2.3.1 Model components and variables

Each group of drivers (hydrology, floodplain environment, migrations and fishing) includes significant variables, as detailed in Figure 8.

Hydrology: the quality of flooding for fish reflects a combination of *Water level*, *Flood duration* and *Flood timing. Water level* reflects the maximum Tonle Sap flood level in a given year. The *Tonle Sap flood level* results from a combination of *Tonle Sap runoff* (water originating from rainfall over the Tonle Sap watershed), of *Mekong inflow* (water coming from the Mekong River via the Tonle Sap River) and of *Overland flow* (overland Mekong water, in particular between Kompong Cham and Phnom Pen, not measured at Prek Kdam). Water level is also affected by the flood beginning since earlier floods are generally correlated with higher floods.
Flood timing is in fact the flood beginning, defined as “the date of spill-over from the river to the floodplain”. This definition was extracted from the available hydrological data and stakeholder consultations.
Flood duration is defined as the time span between the flood beginning and the end of flooding, i.e. the date of flow reversal in the Tonle Sap River at Prek Kdam.
These variables combine into *Flood for fish*

Hydrology = Water level + Flood duration + Flood Timing = Flood for fish

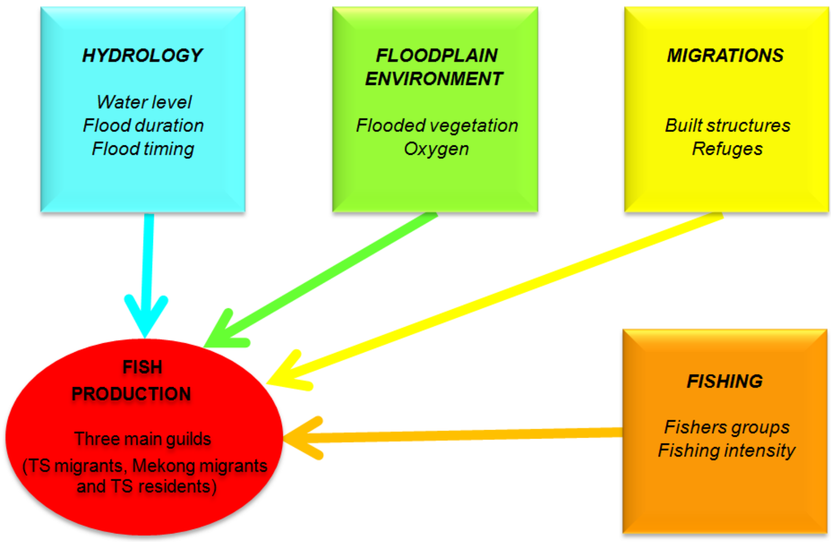

Figure 8: Significant variables for each driver of the fish production in the BayFish model.

Floodplain environment: this component is made of two sub-variables: *Dissolved oxygen concentration* and *Flooded vegetation type*. Each of these variables is considered from the viewpoint of three ecological fish guilds: floodplain residents (black fish), Tonle Sap migrants (grey fish) and Mekong migrants (white fish). A lot of other variables were mentioned and discussed during the stakeholder consultations, but these two variables are the only ones whose role vis-à-vis fish production could be substantiated and clearly defined. Vegetation in particular provides feed and protection from predators for juvenile fishes, but also plays a negative role by reducing dissolved oxygen concentrations through decomposition of organic material at the beginning of the flood.

Floodplain Environment = Flooded Vegetation + Oxygen concentration

Migration: migrations are considered for the three fish guilds detailed above. Migrations of resident fish (black fishes) are understood as the possibility for fish to migrate within the floodplain and to have access to refuges in the dry season. This variable is thus driven by two factors: the availability of *Floodplain refuges* and the presence or not of *Built structures* (dykes, embankments, roads, etc) that reduce access to floodplain habitats and increase fish catchability and mortality. Migrations of Mekong migrants (white fish) and Migrations of Tonle Sap migrants (grey fish) depend upon the same factors, although there is more emphasis on longitudinal migrations and larval drift between the Mekong or Tonle Sap tributaries and the Lake.

Migrations = Built Structures + Refuges

Fishing results from the combination of two sub variables:
Fishers groups, a sub-variable taking into account the three official scales of fishing, but also the ethnicity of fishers, the fishing activity -methods, efficiency and fishing mortality- depending largely upon the ethnic group considered.
Fishing intensity results from the gear size and the gear efficiency among the different fishing groups.

Fishing = Fishers Groups + Fishing Intensity

Fish production is split into three components (resident fish, Tonle Sap migrants and Mekong migrants) subject, in different ways, to the above drivers.

Fish Production = Floodplain residents + Tonle Sap migrants + Mekong migrants

2.3.2 Model network

A network of connection describing interrelations between the components of the system and detailing the variables of each component was built, based on literature reviews and contributions from local experts and stakeholders. These interrelationships are summarised in Figure 9 below.

2.3.3 Model parameterization

Once the model framework was built, a second round of stakeholder consultations, in conjunction with an assessment and analysis of available data, led to the definition of the relevant states for each variable. Some of these variables (e.g. water level) could be characterized quantitatively and precisely thanks to time series, while others had to be qualified in vague terms, such as *"Abundant"* or *"Scarce"*, since no data were available for these factors although stakeholders considered them important vis-à-vis fish production. This illustrates the compilation of "best available knowledge" made possible in a Bayesian model, as opposed to an algorithmic model based exclusively on data and numbers.

Flooding for fishes is purposely qualified as *"Good"* or *"Bad"*, which synthetically describes the quality of a hydrological year from a fishery perspective. All variables seen as essential to fish by stakeholders are taken into account. Flooding for fishes results from three variables:
Flood beginning: the flood is considered "early" when it starts *"Before mid-July"*, "normal" when it starts from *"Mid-July to mid-August"*, and "late" when it begins *"After mid-August".*
Flood duration*:* *"Less than 6 weeks"* (short flood), *"Around 8 weeks"* (6 to 11 weeks, normal flood) and *"More than 11 weeks"* (long flood).
Flood level: *"Low"* or *"High"*, depending whether the water level of a given year is *"Above"* or *"Below"* the average of multiple rainy seasons.

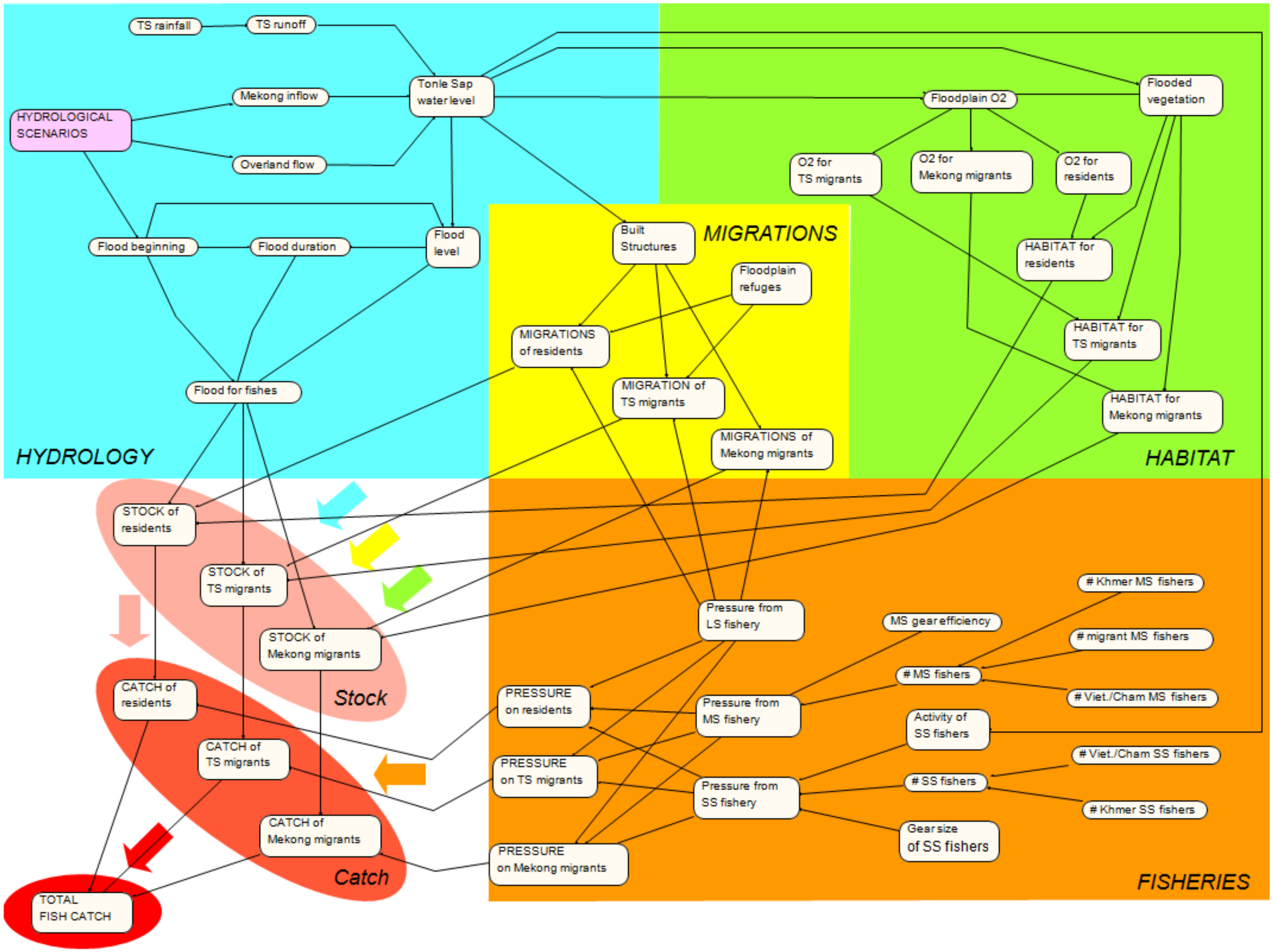

Figure 9: Network of interrelations in the BayFish - Tonle Sap model

Floodplain environment is *"Good"* or *"Bad"* from the perspective of Floodplain residents, Tonle Sap migrants or Mekong migrants.
Floodplain Dissolved Oxygen:"Above 4 mg/l" (value acceptable to almost all fishes), *"Between 2 and 4 mg/l"* (values acceptable by resident black fishes and most grey fish but too low for migrant white fishes) and *"Below 2 mg/l"* (values too low for any fish species). This rough classification was confirmed by a consultation of local aquaculturists.
Flooded vegetation: surface area of *"Grass"*, *"Shrub"* and of *"Forest"*, based on GIS data

Migration: The migration status of each group of fishes (Tonle Sap residents, Tonle Sap migrants and Mekong migrants) was qualified of *"Free"* or *"Blocked"*.
Built structures: states are "*Blocked*" or "*Open*" and the value of each state was determined thanks to a GIS-based assessment of the number and length of built structures in the Tonle Sap (Lauri 2007).
Floodplain refuges are defined as "*Perennial*" (an actual dry season refuge for fish) or "*Temporary*" (non-refuge because dry in the dry season), and the respective value for each state was based on GIS mapping in the dry season.

Fishing variable: as all stakeholders agreed that the fishing pressure was unlikely to decrease in the coming years because of population growth, fishing intensity was defined as "*Increasing*" or "*Stable*", even though no quantitative assessment of this fishing pressure was currently available nor in progress.

Fish production: in absence of any quantitative stock assessment, the stock of resident fish, stock of Tonle Sap migrants and the stock of Mekong migrants are simply defined as "*Abundant*" and "*Scarce*". **The absence, in the Mekong, of any stock assessment and of any undertaking to assess the fish stock is to be underlined, since this is a major impediment to a proper quantification of the relationship between sediment reduction and fish production.**

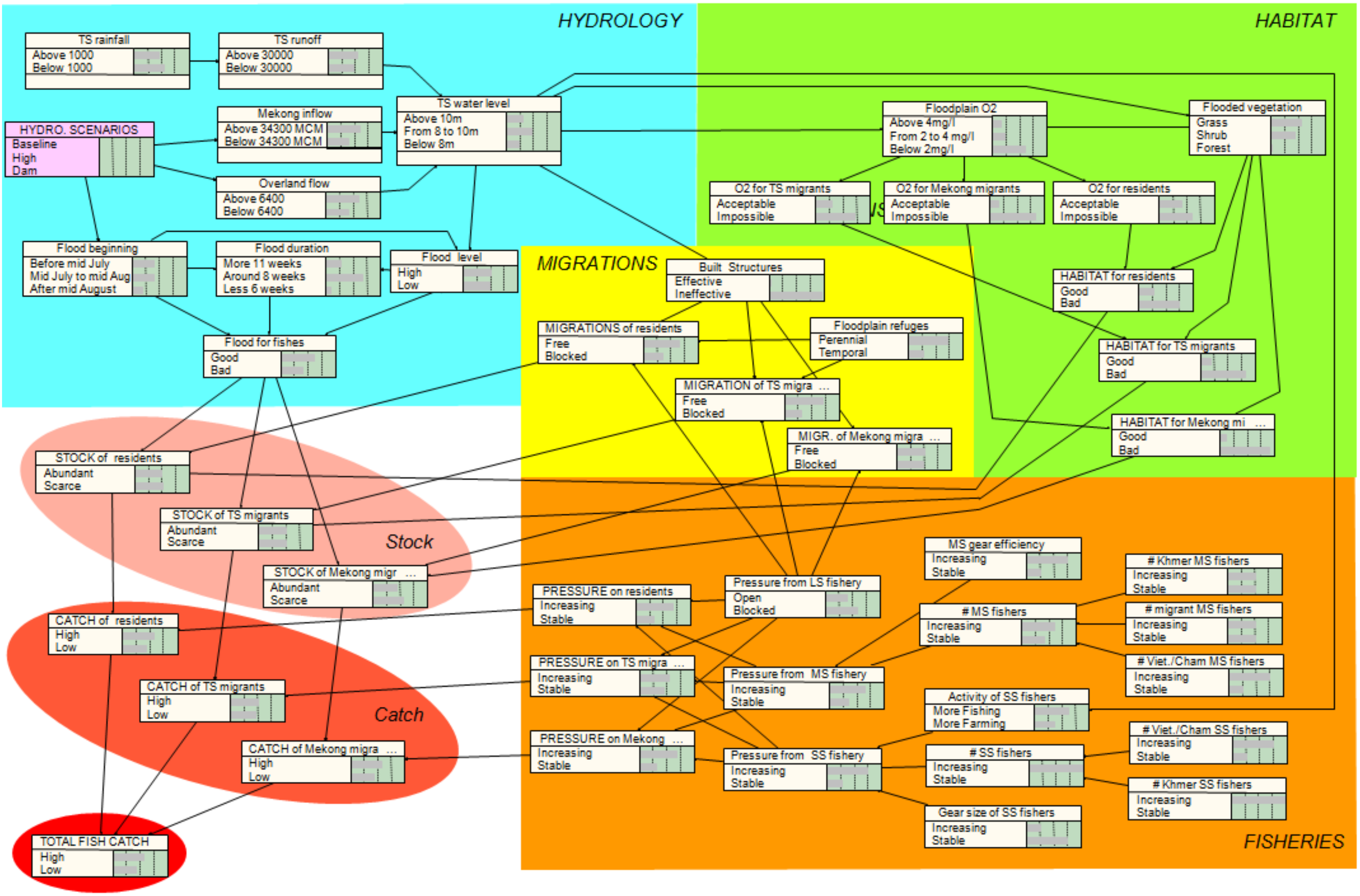

Figure 10: Variables of the BayFish - Tonle Sap model and their states

2.4 Updating theBayFish-Tonle Sap fish production model

In 2005-2007, when the BayFish model was developed, the role of sediment loads vis-à-vis fish production in the Mekong basin was suspected but completely undocumented. Thus sediment loads were not included as one of the drivers of fish production in the model. Nevertheless, the BayFish model probably stands as the most elaborate tool to date describing the respective and relative weights of the multiple drivers of Mekong floodplains fish resources.

Once updated to take into account recent changes in fishing practices (e.g. fishing lots closure), progress in knowledge about the different variables previously considered (e.g. influence of dissolved oxygen considered less important) and adapted to take into account the role of sediment loads, the resulting model will be able to provide a better perspective about the relative role played by sediments on floodplains fish resources. We review below the updates needed and the corresponding data required.

2.4.1 Variables to be removed

In the original model, *Habitat for fish* was dependent upon two variables: *Floodplain Dissolved Oxygen* and *Flooded Vegetation*, both functions of *Tonle Sap Water Level*.

Dissolved Oxygen is indisputably one of the most important parameters for fish survival. Nevertheless its role in the case of the Tonle Sap should be reconsidered. Anoxia or hypoxia (i.e. dissolved oxygen levels incompatible with the presence of fish) due to the decomposition of vegetal matter occur in inundated areas during the flooding (Koponen *et al.* 2003), but this is a natural phenomenon. It takes place in newly flooded habitats where fishes have not already settled, it does not result in fish habitat reduction nor in fish mortality, it does not last more than 4 to 6 weeks in a year and overall this natural phenomenon has never prevented the lake from being extremely productive. Thus oxygen should not be considered as a driver of fish production and *Dissolved Oxygen* variable is to be deleted in the updated model.

Fisheries: in the original model, the description of the Cambodian fishery sector was based on the official classification of the Ministry of Agriculture, Forestry and Fisheries, which at that time included large scale fishing, medium-scale fishing and small-scale or subsistence fishing. *Considering the recent decision of the government to abolish the large scale fisheries and to ban middle scale fishing, there is no reason to keep these variables in the updated model.*

2.4.2 Adding a Sediment variable in the model

As detailed in the first section of this report, a reduction in sediment loads and associated nutrients would have a negative impact on fish production via a reduced primary production. It could also have an indirect but important impact on floodplain fish production via a river bed incision leading to a reduction of the flood spill-over effect (equivalent to a reduction of water level) and a subsequent loss of flooded area. This phenomenon already occurred in the Ganges and Rhine rivers where the river bed was incised by several meters, resulting in the channelization of the river and the loss of the original floodplains. *A multivariate model of the fish resource should therefore include a Sediment component.*

In the updated model, the floodplain fish production would therefore depend on 5 main groups of drivers: hydrology, sediment, habitat, migrations and fisheries. The four first groups drive the fish stock, while fisheries convert fish stock into fish production (Figure 11).

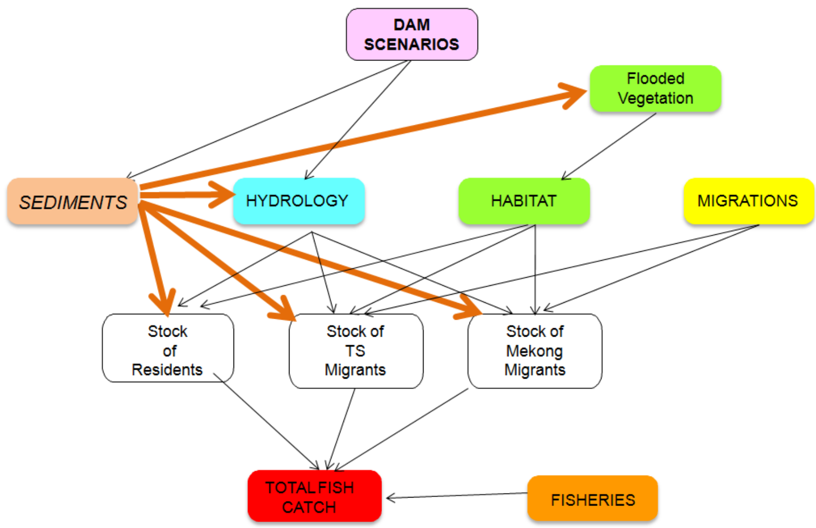

Figure 11: Sediment variable connections with other variables in an updated model of the floodplain fish production

Updating the BayFish Tonle Sap fish production model would allows a better understanding of the *relative* role of sediments vis-à-vis fish production when compared to other drivers such as flooding patterns or migrations. However this would require the parameterization of the sediment component. Indeed, several descriptors of the *Sediment* component remain to be quantified or at least qualified:

- range of sediment load variations depending on damming and flushing scenarios;
- response of the each fish guild to a given change in the sediment content (primary productivity being eluded here – a very complex environmental black box whose details have never been tackled by scientists so far);
- impact of sediment load changes on the vegetation of the floodplain;
- impact of sediment loss on river bed incision and subsequent loss of floodplain area (i.e. indirect impact of sediment on the floodplain Water level variable);

Furthermore, the integration of a new variable and its parameterization have consequences on the relative weight of the other variables, which should also be re-parameterized.

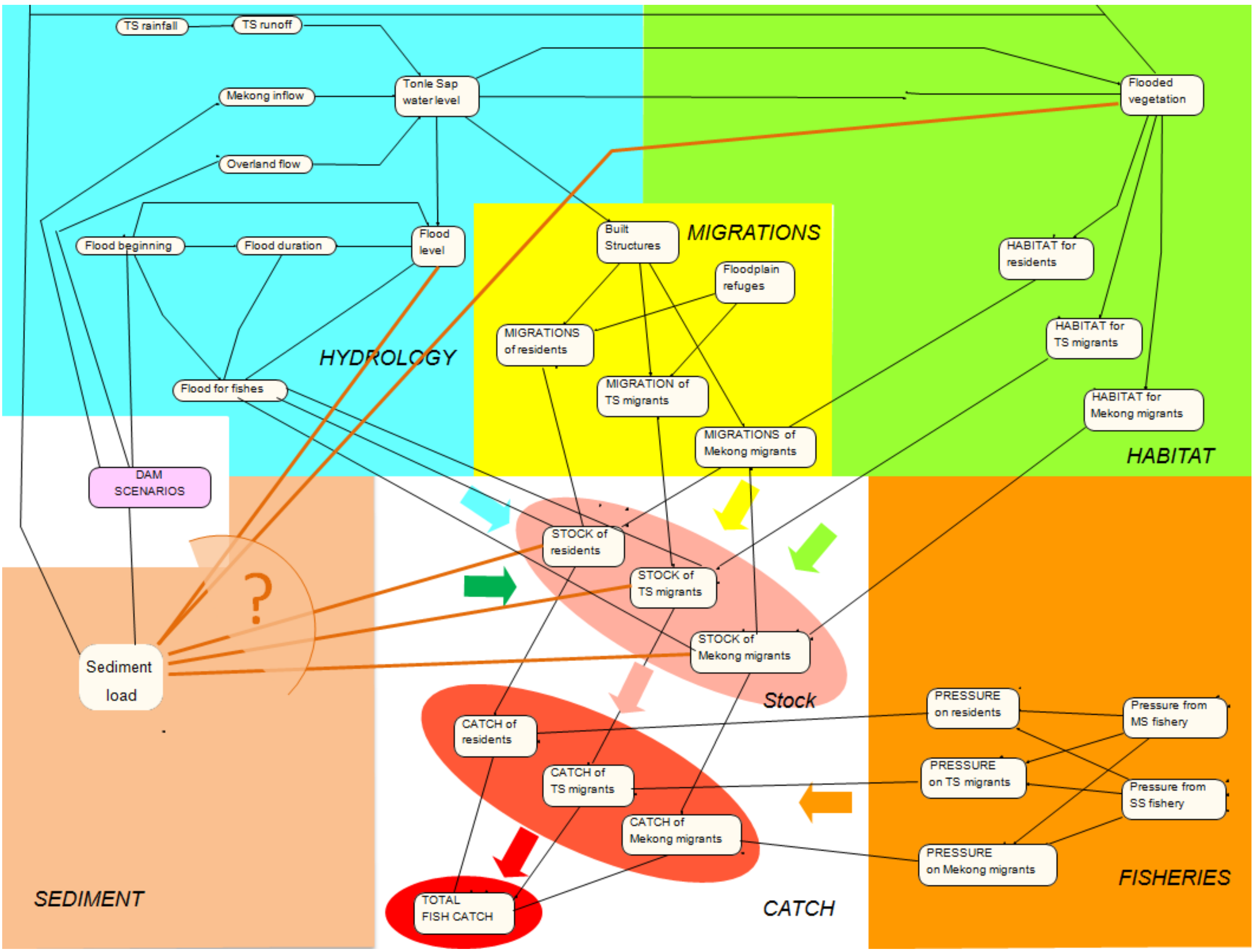

Figure 12: Integration of a *Sediments* component into the BayFish-Tonle Sap fish production model and highlight of the connections that require additional information and data.

3 INFLUENCE OF SEDIMENT LOADS ON COASTAL FISHERIES

We review in the following sections the state of knowledge on the influence of Mekong sediment loads on near shore fisheries. Since available literature is very limited to non-existent in the case of the Mekong, the review was extended to other near shore tropical fisheries under the influence of large river discharges. In order to give the clearer picture of relationship between sediments and fisheries in the complex coastal system, we also reviewed the different influential drivers.

3.1 General features of coastal zones

The near shore zone, located at the interface between fresh and sea water, is a complex ecosystem dependent upon combined riverine and marine influences. From a physico-chemical as well as a biological perspective, the near shore area is an ecotone[1] but it should also be considered as a true ecosystem characterized by its own specific environmental characteristics and fauna (Day and Yanez-Arancibia 1985, FAO 1995). This coastal system where the river nutrients meet the open ocean is usually characterized by very productive fisheries (Longhurst and Pauly 1987, Loneragan and Bunn 1999).

The productivity of coastal systems depends on the relative influence of the river discharge and the ocean currents, but never reaches stability. If the dynamics of freshwater and nutrients outflows conditions the hydrology, biogeochemistry and productivity of the coastal zone (Milliman and Mei-e 1995, Cozzi *et al.* 2012), fluctuation in the coastal zone is the norm and applies to salinity but also turbidity, nutrients concentration, temperature and biological communities (Day *et al.* 1989).

Coastal ecosystems and fisheries, like riverine ecosystems and fisheries, have been extensively studied but surprisingly very few studies have addressed the influence of rivers on coastal fisheries. In particular southern hemisphere estuaries and coastal zones have been largely neglected by scientists; in particular sediments processes in tropical coastal systems are poorly known (Blaber 2002). The extent to which fishes rely on terrestrial organic inputs is also a knowledge gap in tropical systems (Nagelkerken 2009).Thus a literature search using Mendeley (7,200,000 science papers indexed) and keywords "discharge"+"coast"+"fish" harvested 140 documents only, most references dealing with either pollution, mono-specific studies, estuarine fish, plankton or aquaculture but not with the impact of river outflows on coastal fish or fisheries.

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[1]An *ecotone* is defined a transition zone between two adjacent ecosystems.

3.2 General features of the Mekong coastal zone

The Mekong River contributes a large amount of sediments to the coastal zone in Vietnam. According to Sarkkula *et al.* (2010) and Bravard and Goichot (2012) the annual sediment load at Kratie represent 145-166 million tonnes of sediments per year. Ketelsen and Ward (in ICEM 2010) synthesized the work of Wolanski *et al.* (1996, 1998), Walling (2008, 2009), Wang *et al.* (2009) or Kummu *et al.* (2010) and concluded, after discounting sediment deposition in the Tonle Sap and in the delta, that about 100 million tonnes of sediments and 16,000 – 17,000 tonnes of attached nutrients reach each year the coastal zone at the mouth of the Mekong (Figure 13).
The Mekong dams are expected to result by 2030 in a 50% reduction in the arrival of sediments and nutrients to the coastal zone, a reduction aggravated by intensive sand extraction all along the Mekong River (43,2 millions tonnes in 2011, Bravard and Goichot 2012).

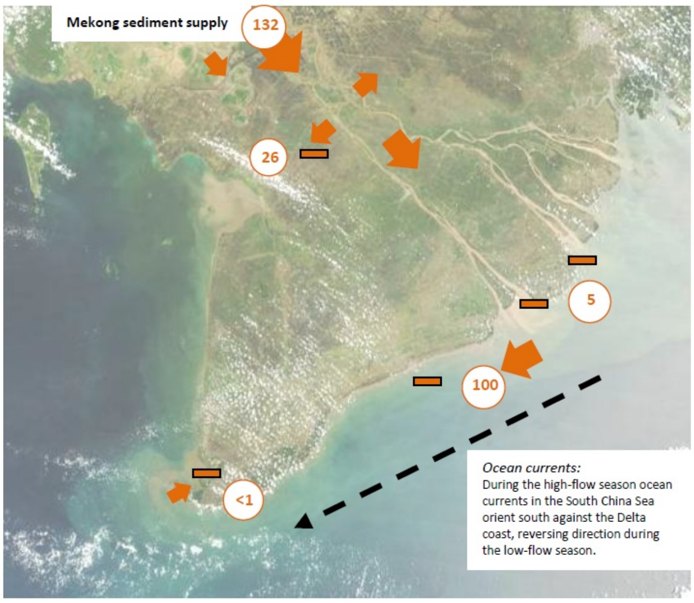

Figure 13: Mekong sediment supply in the delta (million tonnes in red circles). Source: ICEM 2010.

The Mekong outflow into the South China Sea support particularly productive coastal fisheries. The Mekong outflow, characterized by a plume of sediments and brackish water, extends far into the South China Sea and shifts seasonally between north and south, following dominant winds and currents (Xue *et al.* 2000, see Figure 14).

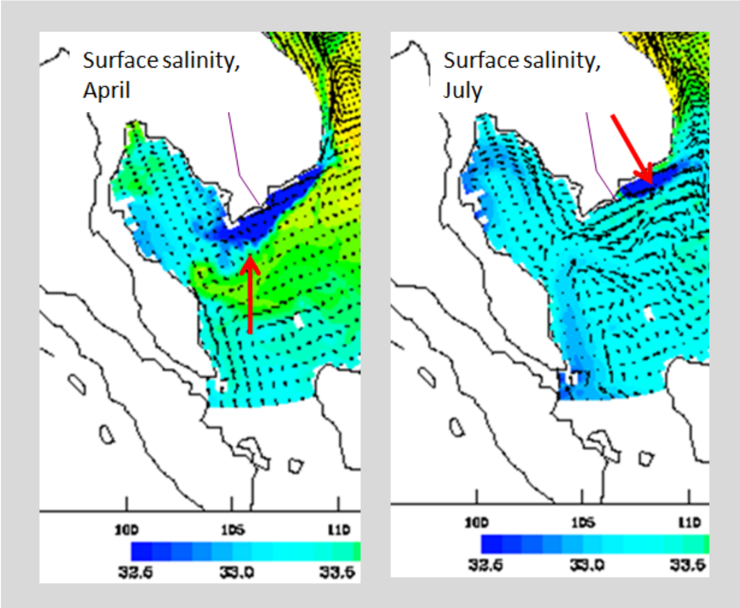

Figure 14: Mekong outflow traced by brackish water in the South China Seaintwo different seasons.
Source: Xue *et al.* 2000.

With more than half a million tonnes of fish harvested annually, southern Vietnam coastal fisheries are very significant. Near shore fisheries in southern Vietnam generate 500,000 – 726,000 tons of fish per year, employ almost 6,000 fishing boats, constitute a significant component of the Vietnamese delta economy and have grown by 80% in the last 15 years (ICEM 2010). Fish constitute eighty to ninety percent of coastal yields and are supplemented with 10 to 20% of valuable invertebrates such as penaeid shrimps, crabs, lobsters and squids (Silvestre and Pauly 1997). In 1976, a comprehensive assessment of Mekong fish resources estimated that the Mekong capture fish production was comprised of 66% of freshwater capture fish, 31% of brackish and coastal fish, and 3% of reservoir fish (Lagler 1976).

The influence of Mekong outflows on coastal fisheries in Vietnam remains poorly known.
It was recognized as early as 1933 that the very productive coastal fishery was supported by the outflow of nutrients from the Mekong (Chevey 1933) and that fact was confirmed later on (Lagler 1976, Poulsen *et al.* 2002). However no hard data document this relationship (ICEM 2010) and this rivers outflow - coastal productivity connection has been poorly recognized in research and development agendas (Blaber 2002). Milliman and Farnsworth (2011) confirm in their global review of water and sediment outflows in coastal zones that the Mekong River is classified among the data poor rivers.

3.3 Coastal fish resources and river discharge

Although some promoters of irrigated agricultural development feel that “water going to sea is wasted” (Dugan *et al.* 2004), freshwater flows are considered to be one of the most influential factors in the coastal zone due to their influence on geomorphology, salinity and turbidity, as well as on the distribution and abundance of fish and crustaceans (e.g. Montague and Ley 1993, Whitfield 1996, Alber 2002, Kimmerer 2002).

3.3.1 Lessons learnt from other coastal fisheries

River discharge favors fish production and fisheries along the coastal zone. In 1979, Kidd and Sander pointed out the correlation between the total annual volume outflow of Amazon River water and marine production in the Barbados. Strong correlations were also noted between river discharge and coastal fish catches in North America (Chapman 1966, Sutcliffe 1972, 1973; Rozengurt and Herz 1985, Grimes 2001), Central America (Yanez-Arancibia *et al.* 1985) or Australia (Growns and James 2005). Overall the positive effect of river discharge on the production of coastal fisheries is widely acknowledged (reviews in Day *et al.* 1989, FAO 1995, Bunn *et al.* 1998, Loneragan and Bunn 1999, Dugan *et al.* 2004).

However the dynamics of outflows is as important as the total discharge. If the volume of the freshwater inflow is known to be a major driver, timing is also recognized as an important factor in the nekton production, through its influence on spawning and recruitment (Kneib, 1997, Piazza and La Peyre 2007, 2011). In their review, Loneragan and Bunn (1999) qualify the influence of special high discharge events as "*clearly the most important component of the flow regime for many species of commercial importance. The reduction or elimination of large flow events is likely to eliminate the associated high catches of fish and crustaceans*". This role of flow dynamics tends to blur the mere correlation between river discharge and coastal productivity (Dugan *et al.* 2004).

Similarly, river discharge and associated sediment loads have an opposite influence on coastal primary production (Goldberg 1969, Parsons *et al.* 1977, Cadee 1978, Mann 1982): while nutrient input stimulates plant growth, turbidity generated by suspended matter diminishes available irradiance in the water and subsequently affect photosynthesis (Nixon 1981, Boynton *et al.* 1982, Kemp *et al.* 1982). Thus coastal maximum production is often found at some distance from the mouth of a river, where light availability optimizes photosynthesis despite a lower nutrients concentration (Parsons *et al.* 1977, Randall and Day 1987). Binet *et al.* (1995) consider that it is the high turbidity of their waters that explains the unclear correlation between the discharge of the Congo and Niger Rivers and the coastal production in these zones.

Although certain, the impact of flow reduction on the coastal zone is not clearly quantified. In their 2004 review, Dugan *et al.* concluded that although the importance of the relationships between river outflows and coastal ecology are certain, "*few of the studies carried out so far in tropical and sub-tropical regions of Africa, Asia and Latin America allow quantitative analysis and clear prediction of the impacts of reduced water flow in coastal ecosystems*".

3.3.2 State of knowledge in the Mekong

Controlled flows resulting from dam construction will influence the Mekong discharge in the coastal zone and reduce the extent of the Mekong plume. As early as 1976, Lagler predicted that the fishery of the Mekong plume in the South China Sea would also be subject to impacts of the controlled and augmented low-flow regime. However recent predictions about expected hydrological changes vary substantially depending on the development scenarios considered.

Depending on development scenarios considered, outflows in the Mekong delta are expected to vary between -8% and +26% in the dry season, and to be almost unchanged in the rainy season. Baran *et al.* (unpublished) reviewed in 2009 for the MRC the conclusions of five studies

of hydrological changes expected to result from 5 development scenarios; these studies are the *WorldBank* Mekong development scenarios (Podger *et al.* 2004), the *Nam Theun 2* Cumulative Impact Analysis (Norplan and Ecolao 2004); the *BDP 1* scenarios for strategic planning (MRC 2005), the *Built Structures* hydrological modelling study (Koponen *et al.* 2007) and the *BDP 2* results (BDP 2008, Thanapon Piman 2008). The scenarios are the *Baseline* (common to all studies), the *Chinese dams* scenarios (WorldBank and BDP 1); the *Low development scenario (*WorldBank, BDP 1, Built Structures and Nam Theun 2 CIA), the *Agriculture* scenario (WorldBank and BDP 1) and the *High development* scenario (WorldBank, BDP 1, Built Structures, Nam Theun 2 CIA, BDP 2).
The review concludes that in Vietnam (in Tan Chau), *Chinese dams* are expected to increase the discharge by 26% during the dry season and would not influence it in the rainy season. In the case of *Low development scenarios*, the discharge would increase by 5% in the dry season and would not change in the rainy season. Under the extractive *Agriculture scenarios*, discharge would decrease by 8% in the dry season but water level would not vary during the monsoon. For the *High development scenario*s, predictions include a 10% discharge increase in the dry season and a minimal 20cm reduction in water level during the monsoon (Figure 15).

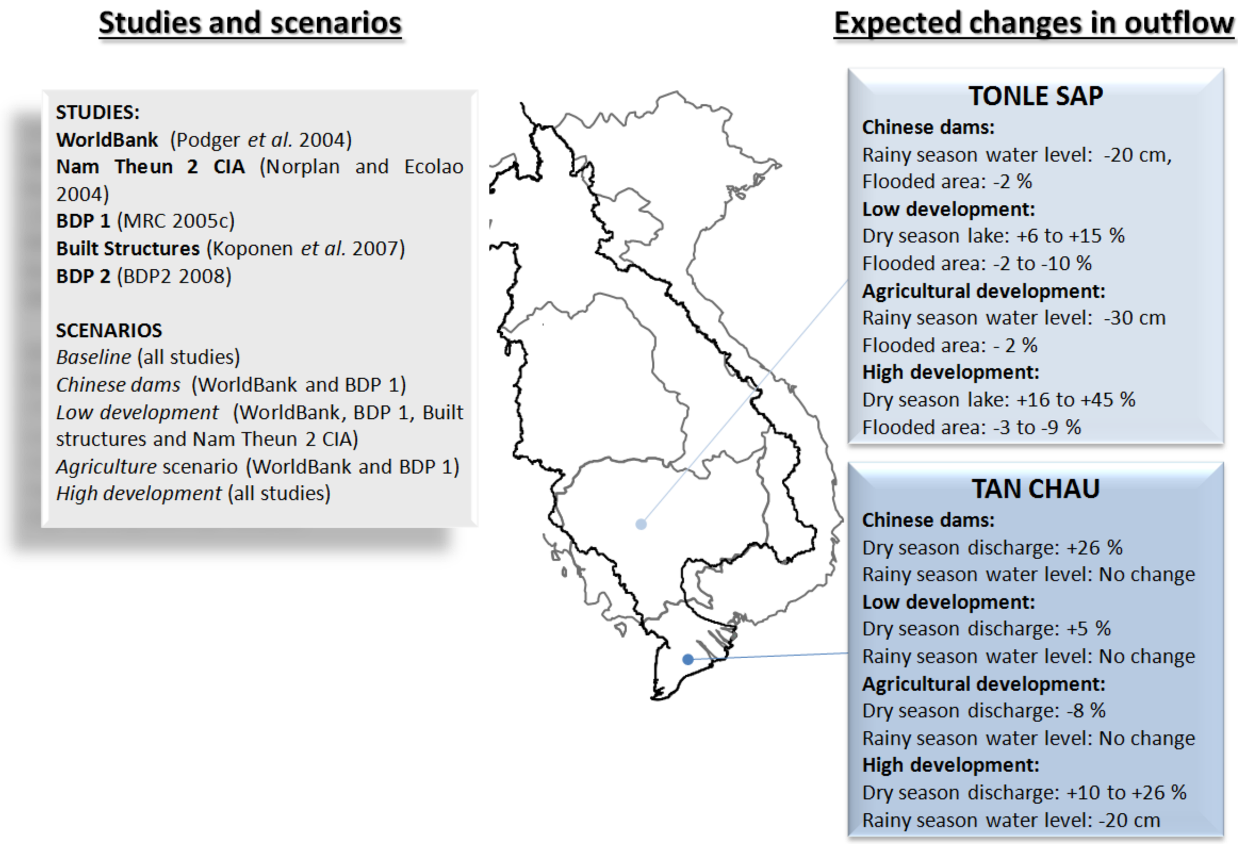

Figure 15: Predicted changes in Mekong outflows depending on development scenarios. Source: modified from Baran *et al.* 2009 unpublished.

3.4 Coastal fish resources and nutrient loads

Studies of riverine outflows in the coastal zone tend to focus on turbidity or sediment load, without necessarily distinguishing these factors from nutrient load, organic matter or carbon concentration which are the actual drivers of the coastal productivity. In the following section we review the state of knowledge on the influence of turbidity, nutrients and carbon on coastal fisheries, before reviewing the case of the Mekong.

3.4.1 Lessons learnt from tropical coastal fisheries

The role of nutrients in sustaining primary production and fish production in the coastal zone is well established. The positive role of nutrients, in particular phosphorus and nitrogen, vis-à-vis primary production is widely acknowledged (reviews in Nixon and Buckley 2002, Dugan *et al.* 2004, Nagelkerken 2009) and the positive correlation between primary production and fish production is also well established (Nixon 1981; Day *et al.* 1989, Iverson 1990; Loneragan and Bunn 1999; Oczkowski and Nixon 2008). Thus a correlation between fisheries yield and primary production was established for number of coastal environments worldwide (Nixon 1982, Day et al. 1989, Blaber 2009).

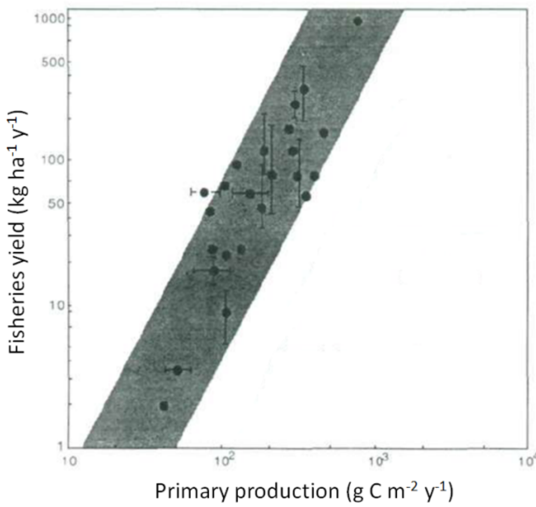

Figure 16: Relationship between aquatic primary productivity and fisheries yields for a number of different coastal systems worldwide. Source: Day *et al.* 1989

Yet the influence of nutrients vis-à-vis coastal fisheries is under the influence of numerous factors that modulate their role and impact. The presence of nutrients in water does not mean that they are systematically available for primary producers: nutrients can be temporarily adsorbed to sediment particles or bound in refractory organic matter (Nagelkerken 2009), which might blur correlations between nutrient concentration and catches. Near shore production can be also partly driven by coastal upwellings characterized by nutrients transfers from marine sediments carried upwards by currents. In Ivory Coast, the flood periods coincide with the main upwelling season at sea, which long blurred the importance of continental inputs (Binet *et al.* 1995). In Morocco, sardine catches are higher during dry years because corresponding trade winds trigger stronger upwellings and higher nutrients inputs from marine sediments (Belvèze 1991). In Israel phytoplankton blooms off the coast are usually associated with storm-induced turbulence (El-Sayed and van Dijken 1995). However the case of Mekong sediments the upwelling phenomenon might not play a major role since the delta is located on the eastern side of Southeast Asia while upwellings occur along western coasts of continents. Last, primary production in tropical coastal systems is often limited by one nutriment in particular, usually nitrogen or phosphorus, which can also blur the overall correlation between yields and nutrients concentration (Nagelkerken 2009).

Nutrient load reduction following sediment trapping behind dams leads to coastal fishery yield depletion. Numerous cases of coastal oligotrophication and losses in fish yields following dam construction have been recorded and are well documented[2]. In Cuba the reduction in sediment flow following the combination of river damming and reduced fertilizer use caused a dramatic decrease in the catches of estuarine species (Baisre and Arboleya 2006). In Brazil, a cascade of dams on the Sao Francisco river trapped 95% of the suspended sediment, reduced the nutrient concentration in the river plume by 90% and caused the estuary to become transparent, oligotrophic and unproductive (Knoppers *et al.* 2012). In Egypt, oligotrophication due to sediment trapping by the Aswan Dam had a catastrophic effect on coastal fisheries at the mouth of the Nile River, with a reduction of sardine catches from 15,000 tonnes per year before dam completion down to 550 tonnes; the overall fish catch declined by 75% between 1962 and 1969 (Aleem 1972; El-Sayed and van Dijken 1995;Bebars *et al.* 1996).

The response of coastal ecosystems to river nutrient deprivation is complex and varies depending on local characteristics. Stratification, water depth, marine sediment inputs vary dramatically among systems and there is no generic response of coastal fisheries to flow regulation and sediment load reduction (Howarth and Marino 2006, Oczkowski and Nixon 2008). For decades eutrophication (i.e. excess of nutrients) of rivers and coastal zones was the main concern, however oligotrophication (i.e. nutrient depletion) is now emerging as a new global concern (Cozzi *et al.* 2012).

River flows also provide carbon inputs to the coastal zone, but the relative role of this riverine carbon versus that of the coastal vegetation is unclear. It is largely recognized that riverine flows provide to estuaries and coastal zones carbon readily assimilated by primary and secondary consumers such as fish (Rose and Summers 1992; Houde and Rutherford 1993; Lane *et al.* 2004, Wissell and Fry 2005, Piazza and La Peyre 2007; Kimmerer *et al.* 2009). However it is also argued that little evidence is available regarding the value of this riverine carbon subsidy (Piazza and La Peyre 2011) or that inputs of terrestrial carbon make a direct contribution to coastal food webs (Loneragan and Bunn 1999). Along tropical coasts this discussion is complemented with a debate about the role of mangrove, salt marshes and coastal vegetation as a source of carbon to the coastal zone. If the role of mangrove in supporting coastal fisheries is undisputed (reviews in Baran and Hambrey 1998, Kathiresan and Bingham 2001, Dugan *et al.* 2004), numerous articles have agreed about the positive role of mangrove as an habitat (Robertson and Blaber 1992, Blaber 2002) but have disputed the fact that these mangroves export organic matter to the coastal zone (Haines and Montague 1979; Peterson and Howarth 1987; Newell *et al.* 1995; Loneragan *et al.* 1997); overall it seems that mangroves do produce a lot of organic matter but that the relationship between mangroves and coastal production is strongly modulated by coastal morphology and energy, which drives the export rate of that organic material (John and Lawson 1990, Baran 2001, Manson *et al.* 2005, Vorwerk and Froneman 2009, Blaber 2009, Bouillon and Connolly 2009).

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[2]Several cases summarised here are detailed in another report of the present series:
Baran E. and Guerin E. 2012 Fish bioecology in relation to sediments in the Mekong and in tropical rivers. Report for the Project “A Climate Resilient Mekong: Maintaining the Flows that Nourish Life” led by the Natural Heritage Institute. WorldFish Center, Phnom Penh, Cambodia.

Could anthropogenic effluents compensate the loss in natural nutrient input?

There is strong evidence worldwide that anthropogenic effluents can stimulate coastal productivity production and enhance fishery production in coastal ecosystems (Nixon and Buckley 2002). This appears to be the case for example with the Mississippi River (Grimes 2001). In Egypt, the coastal fishery recovery since the mid-1980s (figure 17) coincides with large increases in fertilizer application along the Nile, and it was recently demonstrated using nitrogen isotopes ($\delta^{15}N$) that 60 to 100% of the current fishery production might be from primary production stimulated by nutrients from fertilizer and sewage runoff from Cairo, a city of 16 million (Oczkowski and Nixon 2008, Oczkowski *et al.* 2009).

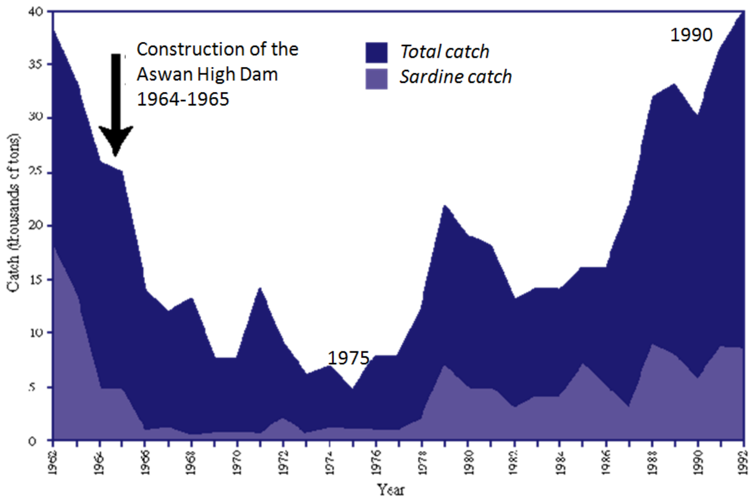

Figure 17: Catches of the Egyptian coastal fishery. Source: El-Sayed and van Dijken 1995

However anthropogenic influence upon coastal productivity oscillates between enhancement and pollution. Thus, increasing nutrient loads via agriculture fertilizers and sewage might initially increase ecosystem productivity up to a threshold, beyond which a decline is expected from eutrophication, algal blooms and hypoxia (Oczkowski and Nixon 2008). In the coming decades the supply of agricultural fertilizers must also be considered in the context of the foreseeable global phosphorus supply crisis (Roberts and Stewart 2002, Vaccari 2009, Cordell *et al.* 2009, Rosemarin *et al.* 2009). Actually the resilience of coastal production systems is still unclear: 30 years after the completion of the Aswan dam, the coastal ecosystem at the mouth of the Nile has not yet reached a new ecological equilibrium (El-Sayed and van Dijken 1995).

3.4.2 State of knowledge in the Mekong

The Mekong River releases each year at least 16,000 to 17,000 tonnes of nutrients in the coastal zone. According to Ketelsen and Ward (in ICEM 2010) about 16,000 – 17,000 tonnes of Mekong nutrients reach each year the coastal zone. The river sediments and nutrients result in a wide turbid area extending as far as 400 km beyond the mouth of the river into the Southern China Sea, as shown by remote sensing turbidity measurements in the Mekong plume (Mangin and Loisel 2012 and Figure 18).

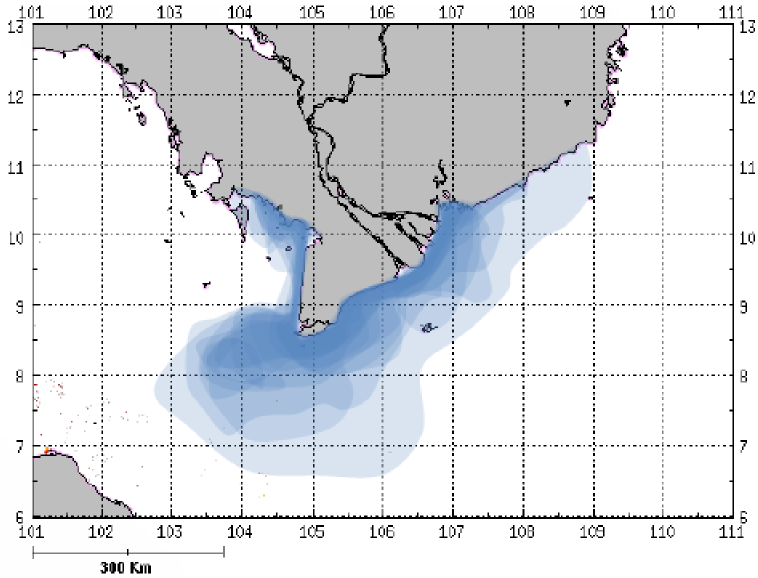

Figure 18: Annual extent of turbidity concentration measured in the Mekong plume in 2005, a representative average year. Source: Mangin and Loisel 2012.

A relationship between coastal fish production and Tonle Sap outflow –rather than Mekong outflow- was already pointed out 80 years ago. In the coastal zone of Vietnam 68% of the fish species feature inshore ecological features rather than oceanic features, with in particular spawning grounds in shallow waters along the coastline (Vu Huy Thu 1997). In 1933, Chevey noted that "*a remarkable concentration of fish can be noticed at the mouths of the Bassac and Mekong Rivers […] at the beginning of the dry season […].Their scales do, in fact, carry the very clear mark of a rhythm of acceleration and diminution of growth, when normally no rhythm should be marked on them in this particularly tropical region of the China Sea. It is to the enormous quantity of nitrogenous material in all forms brought down from the Great Lake of Cambodia that this bank of sea fish owes its temporary existence. The animals which compose it, attracted by the influx of nutrient material, migrate and concentrate there and their scales register the sharp acceleration of growth that results*". Interestingly both Chevey (1933) and Nguyen Phi Dinh (1995) note that it is in summer, at the time of the flood, that coastal fish disperse and their growth slows down, while the fast growth period is related to increased food abundance at the time of decreasing water levels; this relates nutrient abundance to the emptying of the Tonle Sap rather than to the Mekong mainstream peak outflow. Chevey explicitly concludes that "*it is really by an induced influence that the Great Lake of Cambodia succeeds in imposing its rule and its rhythm on a distant population of the sea*". This calls for a

comparative analysis of the respective role of inorganic nutrients (from the runoff) and of organic matter (from flooded vegetation in particular) on fish production in the coastal zone.
The relationship between outflows and coastal productivity was later confirmed by Lagler (1976) who foresaw that "*the loss of nutrients, either dissolved or in organic silt, from the plume of the Mekong/Bassac will certainly diminish productivity in the near-shore areas and to a lesser extent in the off-shore areas*" but recognized that "*while the characteristics of the fishery are anticipated to change, little is known scientifically of the migratory patterns of fish to and from the plume*".

In Vietnam coastal fisheries in the Mekong provinces yield 500,000 to 726,000 tonnes per year. Baran (2010), observing the extent of the Mekong plume (Figure 14) reviewed coastal fisheries statistics in the Vietnamese provinces adjacent to the Mekong plume; the catch in these 8 provinces evolved from 312,000 tonnes in 1995 to 544,000 tonnes in 2007 and reached 726,000 tonnes in 2009 (ICEM 2010). This is probably an underestimate since Mangin and Loisel (2012 and Figure 18) have recently shown that the Mekong plume extends to additional provinces northwards in Vietnam (Ba Ria – Vung Tau and Binh Thuan provinces) and as far as Kampot and Sihanoukville provinces in Cambodia, and the coastal fisheries statistics of these provinces might be included as well (Figure 19).

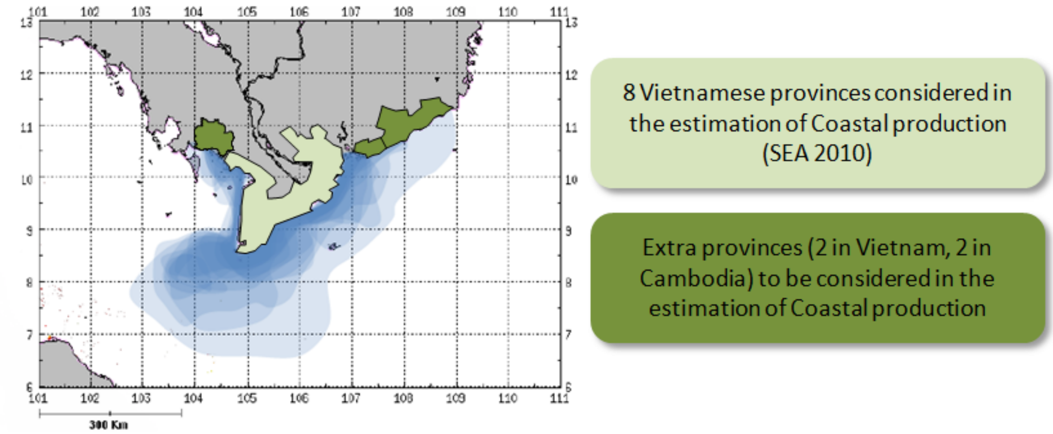

Figure 19: Area to be considered for the evaluation of Coastal fishery influenced by the Mekong discharge, based on Mekong plume extent.

Currently very little is known about the possible impact of nutrient load reduction on coastal fish resources in Vietnam and Cambodia. Sarkkula and Koponen (2010) underline that the main impact of sediment trapping will be felt in the Mekong Delta and at sea rather than in the Tonle Sap area, since the Tonle Sap receives 5 million tonnes of upstream sediments only, compared to 100 million tonnes that feed the Mekong plume in the Southern China Sea. Sediment/nutrient trapping will result in a reduced turbidity at sea, but the degree of turbidity reduction, the reduction of the plume extent and the subsequent nutrient concentration and composition remain to be assessed. In economical terms, the sediment reduction would affect not only coastal fisheries but also the aquaculture sector dependent upon protein supply from marine "trash-fish" used to feed high value carnivorous cultured fish.

In the Mekong the role of the terrestrial carbon outflow vis-à-vis the coastal system is not known. To our knowledge no study so far has quantified the carbon flow from the river to the coastal zone, nor its possible reduction in case of dam construction. The relative importance of this carbon input compared to that of coastal cities effluents and to that of the (remaining) mangrove also remains to be assessed.

3.5 Coastal fish resources and fishing

3.5.1 Lessons learnt from tropical coastal fisheries

Fish production in the coastal area is influenced by multiple factors whose relative influences cannot be easily distinguished. Along the coastal zone the fish stock is influenced by physical dynamics (hydrodynamic convergence, water column stratification, transport and retention of fish larvae, etc), chemical dynamics (nutrient fluxes, carbon inputs, turbidity, etc), biological dynamics (recruitment success, natural mortality, etc) and human factors (fishing pressure and mortality) (Grimes 2001; Blaber 2002, 2009). We briefly review below the fishing factors that also influence -or skew- the correlation between sediment outflows and coastal fish production.

Sediment discharge/plume influence fish catchability. In the river plume a higher fish yield can result from a higher productivity stimulated by nutrient inputs, but it also reflects the concentration of fishes into areas where they get more accessible to the fishery (Whitfield 1996, Loneragan and Bunn 1999). Conversely in some coastal zones or estuaries where fishes are concentrated in the dry season, river flushes result in reduced yields; this phenomenon is the consequence of a lower fish catchability when fishes migrate or get distributed over a larger area on the continental shelf (Cadwallader and Lawrence 1990, Lowenberg and Kunzel 1991, Binet *et al*. 1995).

Variable fishing effort blurs the correlation between sediment outflows and fish catches. Fish yields result from a combination of fish stock, fish catchability and fishing pressure. The latter parameter depends upon several factors such as local technological level, access rights or market demand. Thus the status of the fishery sector introduces a very significant bias in the assessment of the relationship between sediments/nutrient flow and coastal fish yield: increasing catches might reflect an increasing fishing effort rather than a growing stock, and conversely a decline in the stock might not be immediately visible as in most cases the fishing effort grows in inverse proportion. In Egypt it is not clear whether the recovery of the fish catch off the coast since the late 1980s is due to increasing fish stocks or increasing fishing effort (El-Sayed and van Dijken 1995, Bebars *et al*. 1996).

3.5.2 State of knowledge in the Mekong

The study of the correlation between coastal fish catches and sediment outflows is hampered by issues in fisheries data. In Vietnamese fisheries statistics the South China Sea coastal fishing grounds under Mekong influence are not distinguished from other fishing grounds. If marine fisheries catches are recorded by marine sector at the commune level then compiled at the district level at monthly intervals, they are later on aggregated at different administrative levels and thus lose the original resolution necessary for biological research and management (van Zwieten *et al*. 2002). Although it is acknowledged that most pelagic stocks are found off the southeast and central region of Vietnam (Nguyen Phi Dinh 1995, Vinh and Thu 1997), i.e. in the zone under the influence of the Mekong plume, we could not find published information with a higher resolution that the two ZEE zones 3 and 4 around the Ca Mau peninsula (Figure 20; Son and Thuoc 2003). Nguyen Phi Dinh (1995) published more detailed maps of fish catches per coastal sector in dry and wet season, but data at the mouth of the Mekong are missing for the dry season, which does not allow pattern interpretation.

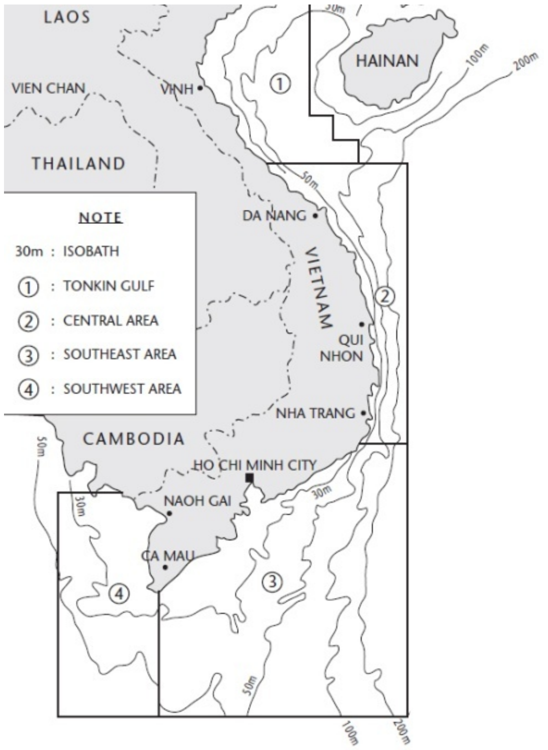

Figure 20: Sectors of the Exclusive Economic Zone of Vietnam. Sectors 3 and 4 correspond to the zone under the influence of the Mekong outflows. Source: Son and Thuoc 2003.

The most accessible catch time series lie in the archives of the ADB/WorldFish TrawlBase project. The results presented by Son and Thuoc were actually compiled during the TrawlBase project completed in 2003 (*http://trawlbase.worldfishcenter.org*; Silvestre *et al.* 2003). In this project Vietnam data cover the 1977 – 1995 period but accessing them for new analyses in relation to sediment loads during the same period would require an agreement of the Vietnamese line agencies in charge. Nguyen Phi Dinh (1995) details the multiple biological research and monitoring programs implemented in this zone before 1977 (1959-1962, 1963-1968, 1968-1973) but data are not readily accessible. More recently Van Zwieten *et al.* (2002) detailed the statistical collection system for coastal fisheries in Vietnam and highlighted the intricacies and pitfalls of that system in which catches and fishing effort are recorded independently by different agencies. As for the past ten years, we could not access during the short time frame of this project recent data on coastal fisheries, except aggregated province statistics already cited in section 3.4.2. An extensive literature search surprisingly harvested no recent publication in English about coastal fisheries in Vietnam.

An assessment of the relationships between sediment outflow and fish catches would absolutely require that the fishing effort is factored in: between 1981 and 1999 in Southern Vietnam marine capture fisheries production increased three-fold but the fishing pressure (expressed as total horsepower) increased more than fivefold (Son and Thuoc 2003). The overfishing of Vietnamese coastal waters underlined by Stobutzki *et al.* (2006) and its subsequent changes in fish sizes and species composition introduces further bias in that relationship.

4 CONCLUSIONS

The influence of sediment loads on the Mekong floodplains fisheries was addressed through the case of the Tonle Sap. A review of the multiple drivers of the fish production showed that the latter depends upon many more factors than just sediments, which led to an analysis of the relative role of sediments compared to that of other factors. This approach echoed the Bayesian model of the Tonle Sap fish resource initiated in 2005 and providing an overview of the Tonle Sap ecosystem from a fishery perspective. The conceptual framework of that “BayFish-Tonle Sap” model was then updated to integrate a “Sediment” component, which constitutes a preliminary step in the perspective of a more thorough research initiative aimed at parametrizing in detail the model and comprehensively assessing the relative role of sediments vis-à-vis fish production.

In the second part the literature review highlighted the central importance of river and sediment outflows vis-à-vis coastal fish production, but also the complexity of interactions in the coastal zone and the relative paucity of information on that topic in tropical systems. Overall, fish production in coastal zones is influenced by multiple intercorrelated environmental factors whose relative influence is difficult to distinguish, and by fishing effort (Figure 21). Sediment retention following dam construction is expected to have a significant impact on the coastal fish production, but the current level of knowledge and the data available on coastal fish resources do not allow modelling this impact yet. A detailed analysis would require in particular an in-depth examination of fisheries data in the coastal zone.

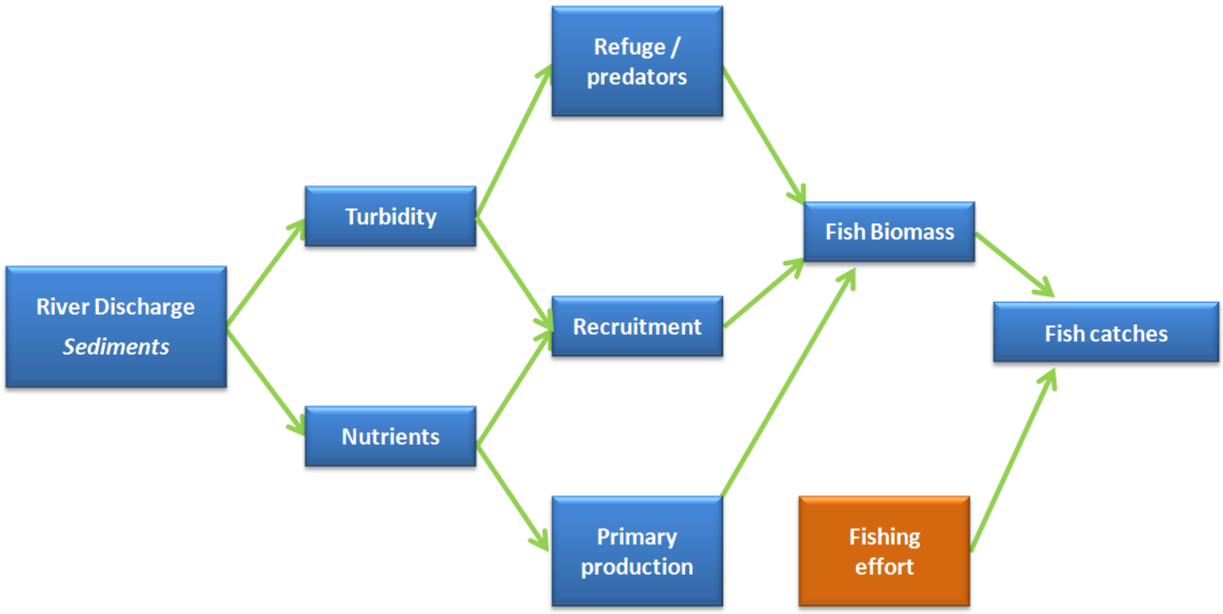

Figure 21: Crossed influence of environmental and fisheries parameters on fish catches in the coastal zone

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