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ECOLOGICAL AND MODELLING APPROACH TO FLOOD-FISH RELATIONSHIPS IN THE MEKONG RIVER BASIN

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Abstract. In tropical floodplain systems and rivers, how to address the relationships between environmental modification due to development (dams construction, extracting water, etc...) and natural fish production? Environmental modelling is a promising tool, provided that the frequent paucity of data can be circumvented. We present here the three parts of an approach that has been developed in 2000-2001 in the Mekong River Basin:

1) Study of all ecological parameters involved in the prediction of fishery harvest. Looking beyond hydrology and encompassing subtle ecological factors such as the nature of flooded vegetation has proven essential to a comprehensive assessment of the driving factors in fish production.

2) Identification of the corresponding data required for classical modelling. The requirements of such modelling are highlighted, and the drawbacks arise mostly from a lack of such data in tropical regions.

3) Development of a Bayesian network to model the functioning of the system, in which fish groups and environmental factors are considered as interacting agents of a system. Interactions between agents are thus specified in terms of probability distributions.

The latter approach, or more broadly multi-agent modelling, is promising as the interactions between multiple groups can be easily made more complex to better mimic reality. Thus the model of fish-floodplains relationships can be extended to include users groups (fishers, peasants, etc..) and environment managers (interacting national bodies).

Introduction

In the Mekong River Basin, the very high flow regime in the rainy season, combined with low altitudinal gradient in the Lower Basin, create an area of floodplain amounting 84,000 km^2, including 35,000 km^2 in Cambodia and 39,000 km^2 in Vietnam (Scott 1989, Lacoursiere *et al.* 1998). This exceptional area of wetlands favours the abundance and diversity of fish, with a total number of species estimated at 1200 (Rainboth 1996) and a total fish production in the Lower Mekong Basin of at least one million tonnes (Jensen 1996, 2000).

This fish production benefits the 55 million people living directly within the catchment area. In Cambodia for instance, fish constitute up to 65-75 per cent of total protein in the diet (Guttman 1999) and the value of the catch is between US$ 150 and 200 million yearly (Van Zalinge *et al.* 2000).

However fishing is threatened by rapid development in the Mekong River Basin, and managers as well as decision-makers need tools to evaluate the consequences of various development options. For this reason, in 2000-2001, ICLARM – The World Fish Center, in collaboration with the Mekong River Commission (MRC) and the International Water Management Institute (IWMI), developed a research programme on the relationships between hydrology, environmental factors and fish production in the Mekong River Basin.

This article details the three parts of the approach consisting in i) identification of ecological parameters influencing the fish harvest; ii) identification of data required for classical modelling; iii) development of a Bayesian network to model the functioning of this production system.

Environmental parameters influencing annual fish production

Baran *et al.* (in press) have shown that the most important environmental parameters for the abundance of fish in the Mekong River Basin were:

Water level
The correlation between the *total catch* (in tonnes) and river discharge in the same year (which is proportional to the area of floodplain available to fish) has been well documented in tropical rivers worldwide (Welcomme 1985). This relationship has also been demonstrated for the "dai" fishery of the Tonle Sap River (Baran *et al.* 2000).

Duration of the flood
A long period of flooding allows fish a long access to food sources; as they have more time to grow, this results in higher yields. This correlation has been clearly demonstrated in the Danube River for instance, based on a 38 year long time-series (Stankovic & Jankovic 1971).

Timing of the flood
For most tropical freshwater fish species, spawning is triggered by the beginning of the flood (Lowe-McConnell 1987, Bayley & Li 1992). In the Mekong River, several authors (Poulsen 2000, Poulsen *et al.* 2000, Baird *et al.* 2000) have shown that rising water levels also trigger spawning in many species (e.g. Pangasiids). The eggs and juveniles follow the flood and drift into the Tonle Sap system where they grow. Thus the timing of the flood is a parameter that influences recruitment and therefore total fish production.

Regularity of flooding
After the beginning of migrations to the floodplain, short periods of drought can result in massive mortality of eggs, fish larvae and fry trapped in small ponds which are drying up. This phenomenon is not rare in the Tonle Sap region, and might also significantly affect the recruitment success.

Quality of the flooded zone
For fish, the quality of a flooded zone is proportional to the diversity of microhabitats and of sources of primary production. Thus a flooded forest provides more resources and shelter than a flooded grassland, the latter being of better quality than bare land. The abundance of fish will therefore be proportional to the quality and surface of these different habitats.

Migrations
Migration is a dominant feature of Mekong River fishes (Sao-Leang & Dom-Saveun 1955, Shiraishi 1970, Roberts & Warren 1994, Roberts & Baird 1995, Baird *et al*. 2000, Poulsen *et al*. 2000). Longitudinal migrants constitute 63% of the catch of the major fisheries in the Tonle Sap area (Van Zalinge *et al*. 2000). Impediments to migration are factors likely to have a dramatic impact on fish recruitment and on total production the following year(s).

Dry season refuges
Deep pools in the river mainstream and ponds in floodplains serve as refuges for fish in the dry season (Pellegrin 1907, Welcomme 1985, Roberts & Baird 1995). The area of ponds available to fish in the dry season is a parameter likely to influence the recolonization rate (and therefore the catch) the following season.

Data required for modelling

The overall aim of modelling is to draw relationships between catches that result from a certain fishing effort, and the environmental parameters listed above. A prerequisite is the availability of fishery statistics over a period of time long enough to allow statistical testing.

Fishery statistics
The main source of statistics in the Mekong River Basin consists of official statistics produced by the Departments of Fisheries in Laos, Thailand, Cambodia and Vietnam. However, in Cambodia the validity of these statistics has been questioned (CNMC/Nedeco 1998, Ly Vuthy *et al.* 2000, Degen & Nao Thuok 2000) and they exhibit almost no

variability over the years, although there is consensus that the catch varies widely from year to year depending on the hydrological regime of the river. As the catches in Cambodia represent 35-45% of the total catches of the four riparian countries (Van Zalinge *et al.* 2000), the statistics for the whole Lower Mekong Basin may be skewed. Furthermore, effective monitoring of the total fishing effort is not yet established in all these countries.

Two alternative sources of fisheries statistics have been identified in the region: 1) those of the Mekong River Commission Project on Management of the Cambodian Freshwater Capture Fisheries project (CCF), which has consistently monitored the *dai* fishery of the Tonle Sap River since 1995 (Lieng *et al.* 1995), and 2) those of Ian Baird, who has consistently monitored the fishing community of Khong Island (Southern Laos) since 1993 (Baird 1998).

Water level

Data needed are water levels in the fishing areas. Such statistics are available in the Hydrology Unit of the MRC, although some data is missing.

Duration of the flood

The various combinations of area and duration of a flood can have different biological consequences: the impact of a 5-day flood over 100 km^2 is very different from that of a 100-day flood over 5 km^2 (500 km^2-days in both cases), so the simple product of area by duration is not precise enough to assess fish production. In fact the pair duration-surface can be approached by multiple regression, when the time series is long enough:

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

However the data requirement of such a classical approach cannot be fulfilled as only 6 to 7 years of fish production data is available.

Timing of the flood

The timing of flooding can be expressed by the number of the week in which the flood starts. For instance if the flood starts the 2nd week of May (19th week of the year), the timing factor = 19. In that case, a "starting point" must be defined; for instance the week of the annual minimum water level (after averaging over a period of several years). In that case the starting point will vary depending on the location along the river (upstream with early floods or downstream with later flooding), which makes comparison between fisheries more complex.

Regularity of flooding

The regularity of flooding can be expressed by a Consistency Index, defined as the number of days with a water height (H) *decrease* between the beginning of the flood and the peak (i.e. number of recession days in the flooding period).

Quality of the flooded zone

Assessing the nature and quality of the flooded zone for fish production requires mapping land cover types and measuring the surface flooded daily or weekly for each land cover type. This has been done in the course of the ICLARM/MRC/IWMI project, but only for the Tonle Sap Great Lake zone (due to lack of precise digital terrain models for the other regions of the Mekong Basin).

Migrations

Quantifying the role of migrations and barriers to migration on the total catch is a major challenge, as this would in theory require a number of local case-studies (before/after barriers to migration were interposed on the migration route) that do not exist. The qualitative evaluation of such environmental modifications, drawn from experiences worldwide (e.g. Pak Mun dam), provides clear evidence of the negative effect on the total fish catch, but at the moment this qualitative assessment cannot be put into equations in a regional model.

Dry season refuges

A simple index of refuges in the dry season can be used:

Cumulative area of ponds / total area of floodplain

However another important factor to integrate is the fishing pressure exerted on the fish concentrated in these ponds: if they are completely fished out, which is often the case in Cambodia and Thailand, quantifying the area of these refuges becomes useless.

Impediments to classical fisheries modelling

Classical (analytical or global) fisheries models require data on harvested biomass (catch statistics) but also, depending upon models, on stock virgin biomass, growth, length frequencies, natural mortality, recruitment, or fishing effort and selectivity. In the case of the Mekong River Basin, such data are not available even for dominant commercial fish species. Furthermore most of these models do not address environmental variability and do not allow simulation of different options for land and water use. Last, these classical fishery models have been heavily criticised for their simplistic initial assumptions, ignorance of social and economic factors, and general failure (Caddy & Mahon 1995, Beverton 1998, Holt 1998, Pitcher *et al.* 1998*)*. Ecosystem models such as *Ecopath* or *Ecosim* (Christensen & Pauly 1992, 1993, Walters *et al.* 1997) require data on biomass of certain groups (e.g. zooplankton, meiobenthos, macrophytes, etc…) and on trophic flows that are non-existent for the Mekong system.
The impact of a certain environmental or resource change on the users (here the different groups of fishers) is also an issue of critical importance that classical fisheries models do not take into account. Figure 1 illustrates how reduction in the catch of certain groups of fishes has different impacts on various social groups:

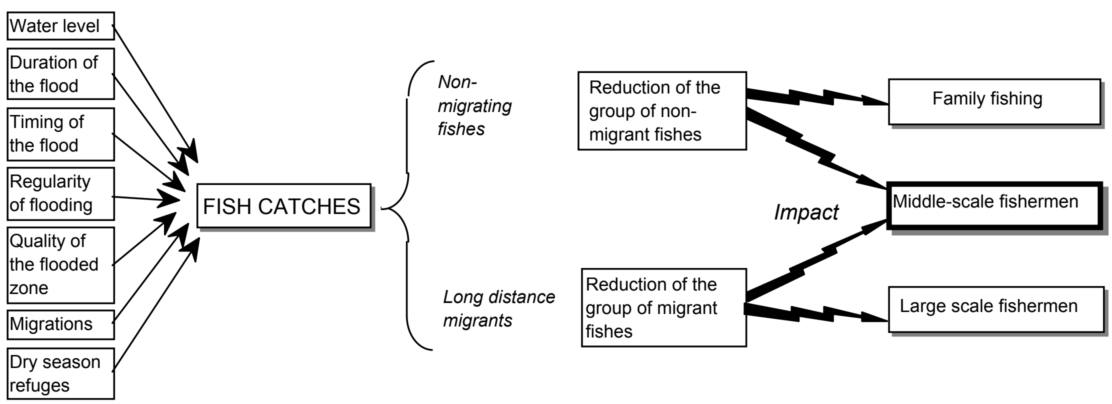

Figure 1: Hydro-environmental parameters, their impact on fish catches and on different groups of fishers

Bayesian modelling as an alternative approach

As an alternative to the classical modelling approaches when the lack or paucity of data is a major impediment, we are developing a modelling approach based on Bayesian networks (Spiegelhalter *et al.* 1993, Heckerman *et al.* 1995).
In this approach, the major interacting variables of the system are identified (*cf*. above); a synthetic representation of the system is built; the interactions between variables are characterised, and the consequences of a given management decision, based on the aggregated interactions, is predicted.
This modelling is based on three elements:

1) nodes representing management system variables (e.g. flood duration, flooding regularity, refuges index, etc…). Each variable can either be discrete or continuous and has a finite set of mutually exclusive states (e.g. high/low, regular/irregular, etc…);
2) links representing causal relationships between these nodes (from parent node to child node, i.e. from cause to effect);
3) probabilities attached to each node and quantifying the believed relationships between connected links

In the absence of quantitative data, but using expert and traditional ecological knowledge, it is possible to define probabilistic links between nodes. For each state of a given child node the model calculates a probability, based on the configuration and states of all mother nodes (Figure 2). This model is currently being developed at ICLARM in collaboration with the International Water Management Institute, using Netica software (www.norsys.com).

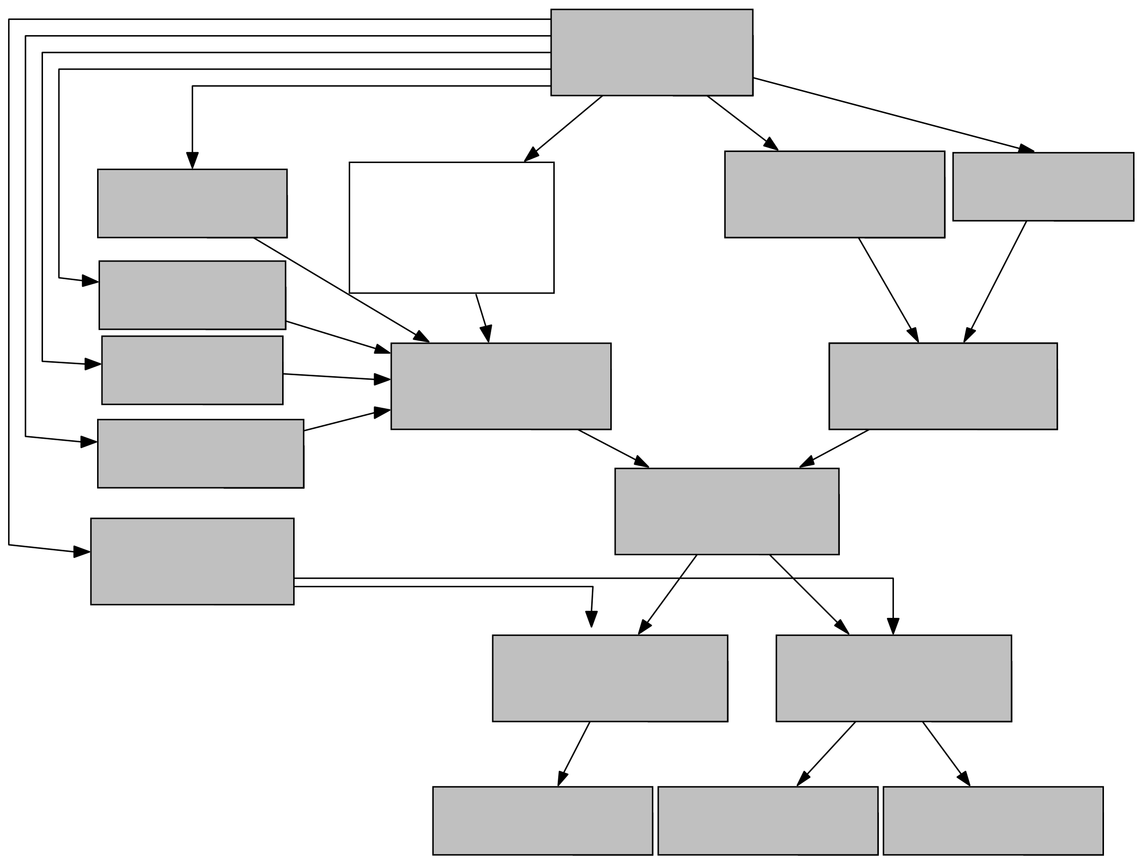

Figure 2: A preliminary Bayesian network of the Lower Mekong Basin fisheries

Conclusions

Bayesian networks seem to be a promising tool for modelling Mekong fisheries *sensu lato*. This allows the lack of quantitative data critical for other approaches to be overcome, and also allows the integration of broader issues linked to environment, user groups and even management bodies (such as the Departments of Fisheries or of Agriculture in the riparian countries) that other modelling tools usually do not encompass.

Ultimately, if this approach seems fruitful but limited by constraints due to software or insufficiently underpinned probabilities, multi-agent models (Weiss 1999, Ferber 1999) may provide a useful alternative which allow a similarly holistic approach but with added flexibility. Such models (e.g. Bousquet *et al.* 1998, 1999) have already been applied to tropical floodplain fisheries (Bousquet 1994) and are being developed in Europe for freshwater integrated resource management (FIRMA 2000).

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