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## Development of a conservation strategy for the critically endangered Mekong giant catfish



## Quantitative assessment report

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Supported by



**Citation:**

Lorenzen, K., Sukumasavin, N. & Hogan, Z. (2006) Development of a conservation strategy for the critically endangered Mekong giant catfish: quantitative assessment report. Mekong Giant Catfish Working Group Report 3. All MGCWG Reports are available on: <http://www.aquaticresources.org/mekongcatfish.html>

**Cover photograph:**

Harvesting Mekong giant catfish in Nong Khai, Thailand, around 1930.

## **Executive summary**

### Background

The Mekong giant catfish (MGC), one of the world's largest freshwater fish and a charismatic animal revered throughout the Mekong region, is considered critically endangered (IUCN Red List 2003). A range of conservation initiatives for the giant catfish are being carried out.

### Purpose of this report

The present report aims to assess the conservation status of Mekong Giant Catfish, and to evaluate the likely effectiveness of different conservation measures.

### Methodology

Detailed data collected intermittently since the late 1960s were synthesized and analysed through confrontation with a mathematical model. The following assumptions underlie the baseline model:

- MGC in the Mekong basin form a single population (all catches have been taken from the same population)
- The full population is vulnerable to fishing (there are no un-fished and thus, unobserved local populations)
- Reporting of MGC catches is near-complete and not size-biased (There is no unreported harvest of small MGC).

### History of exploitation and environmental change

Historically, targeted giant catfish fishing has always been a special event with spiritual associations. Exploitation seems to have been stable or characterized by 'boom and bust' cycles. It is unlikely that high catches of MGC have been sustained in the recent past (the last 100-200 years).

In the 1970s, catches appear to have been stable at an average of about 20 fish per year. Catches increased substantially, up to a maximum of 80 per year in the late 1980s, driven mainly by a high profile government-supported fishery in Chiang Khong (Northern Thailand). Both catch and catch per unit of effort (CPUE) declined strongly in the 1990s. This was followed by a decline in effort, most likely attributable to the reduced profitability of fishing as well as the development of alternative economic opportunities.

Environmental change in the Mekong basin has been gradual and of moderate magnitude until the very recent past. More dramatic changes may have occurred in the very recent past with 'rapid blasting' and the commissioning of several dams in the upper river, but any effects of these changes on the giant catfish population would not yet be visible in the fisheries data. It thus appears that fishing can be identified as the main driver of past changes in population abundance and structure.

### Population status

Reconstructed spawner abundance was relatively stable at about 250 animals prior to 1983 (11-71% of unexploited abundance). The population then declined dramatically to just 50 spawners in 1995 (2-14% of unexploited abundance). The Chiang Khong fishing 'boom' thus reduced spawner abundance by about 80% in just ten years. The population has since recovered to about 145 animals (7-40% of unexploited abundance) by 2006. Much of this predicted recovery is based on maturation of fish that were spawned about 20 years previously, and would occur even if for any reason reproduction had failed in the recent past.

The spawner population in the absence of fishing on recruited MGC is estimated at about 355-2200 fish. The maximum sustainable catch is uncertain, but likely to be between 20-40 fish per year. Higher catches can be obtained temporarily, but would lead to a decline in abundance and CPUE. It is possible that episodes of overfishing followed by fishery decline and population recovery may have occurred repeatedly in history.

The extent to which small juveniles (< 100 cm length) are subject to exploitation remains unknown. If juvenile harvesting had been significant in the 1970s, the unexploited spawner abundance and sustainable yield from the population could be substantially higher than estimated here.

### Recommendations

Fishing can be identified as the main driver of past changes in population abundance and structure. The exceptionally intensive Chiang Khong fishery in the 1980s and 90s in particular is likely to account for the dramatic population decline observed over this period. The population has since recovered slightly, but remains in a very depleted state. Only very low levels of harvest (up to 10 mature fish basinwide) can be sustained until 2030 if the population is to recover from its current state. Within this limit, the lower the harvest the faster population recovery will occur. A very low level of targeted fishing could be allowed to provide long-term population monitoring data and promote public awareness of the species and the wider Mekong ecosystem.

Habitat and environmental change in the Mekong basin has been gradual and of moderate magnitude until the very recent past, and it is unlikely that this has been a significant factor in past population change. More dramatic changes may have occurred in the very recent past (with 'rapid blasting' and the commissioning of several dams in the upper river), and this trend is likely to continue in the future. Maintaining the overall Mekong ecosystem (flows, physical habitats and connectivity) clearly is important to ensuring the long-term survival of the species in the wild. Given that habitat use and migration patterns of the species are largely unknown, no essential habitat can be identified except for the spawning area. The spawning area is very likely to be located within some 50 miles north of Chiang Khong, and it can be clearly identified as essential habitat. An immediate priority should be to protect this habitat.

Captive breeding. The captive population of MGC maintained by the Thai Department of Fisheries provides a vital 'insurance', safeguarding the survival of the species should it become extinct in the wild. The captive population should be managed carefully so as to conserve its genetic diversity, should re-introduction become necessary. For the time being, captive-bred fish should not be released into the Mekong or its tributaries, for two reasons: (a) The wild population is likely to recover naturally, unless there have been recent and as yet unknown negative effects on recruitment. Releases would have no net benefit but may partially replace wild fish through ecological interactions. (b) Despite of good hatchery management developmental and genetic responses to the culture environment are likely to result in the captive-bred fish being less fit than their wild conspecifics, and reproductive interactions between the wild and captive-bred population segments may reduce spawning success or the survival of offspring. It should be noted that, because the wild population carrying capacity appears to be quite low, releases of even low numbers of captive-bred fish can have significant impacts on the wild population.

Interactions with cultured fish are unlikely to have played a significant role in past population change, but may become a major issue in the future due to both intentional and accidental releases. At present the cultured population is likely to exceed the wild population in abundance. Escapes of MGC grown in commercial aquaculture could pose a significant threat to the wild population. Measures should be taken to minimize the risk of such escapes occurring. It should be noted that, because the wild population carrying capacity appears to be quite low, releases of even low numbers of captive-bred fish can have significant impacts on the wild population.

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## Glossary

Catch	Number of fish harvested in the fishery
Catch rate	Catch per unit of effort (CPUE)
CPUE	Catch per unit of effort (e.g. number of fish caught per boat or net). Often used as an index of abundance in fisheries science.
F	Fishing mortality rate
K	Recruitment compensation ratio (ratio of juvenile survival at very low spawner abundance to juvenile survival at unexploited spawner abundance)
k	Von Bertalanffy growth function parameter (growth rate)
l	Length
$l_{\infty}$	Von Bertalanffy growth function parameter (asymptotic length)
M	Natural mortality rate
$M_r$	Size-dependent natural mortality rate at reference length $l_r$ (here, $l_r=250\text{cm}$ )
MGC	Mekong giant catfish
MRC	Mekong River Commission
NACA	Network of Aquaculture Centers in Asia-Pacific
Selectivity	The selectivity of fishing gear for particular species and sized of fish.
Yield	Fisheries catch by weight

## **1 Introduction**

The Mekong giant catfish (MGC) (*Pangasianodon gigas*) is listed as critically endangered in the IUCN Red List. Its precarious status is likely to be the result of excessive targeted and incidental harvesting over the past twenty years, and to a lesser extent habitat degradation. Given the critical state of the population, conservation and eventual recovery will require a combination of measures such as captive breeding, reduction in harvest, and conservation/restoration of critical habitat.

Although there are a number of conservation initiatives and programmes focusing on the Mekong giant catfish, there is currently no overall conservation and recovery strategy. The effectiveness of measures taken so far is largely unknown, and some measures may be conflicting or detrimental. The Mekong Giant Catfish Working Group was established in 2005 in order to pursue the systematic development of a conservation strategy.

The present report aims to assess the conservation status of Mekong Giant Catfish, and to evaluate the likely effectiveness of alternative conservation measures.

## **2 History of the giant catfish fishery and environmental change in the Mekong region**

### **2.1 Mekong fisheries**

Fishing in the Mekong region has intensified over the past 30 years, in particular with the introduction of nylon gill nets in the 1970s – 1980s. Nets have used increasingly smaller mesh sizes and fishers often describe a decline in the average size of fish caught.

### **2.2 Giant catfish fishing**

#### 2.2.1 Overview

Historically, the MGC has been captured in targeted fisheries, and incidentally in various parts of the lower Mekong basin (Fig. 1). Targeted fisheries for the species have generally been associated with festivals of spiritual significance. The fisheries targeted MGC during their spawning migration, using specially constructed very large-mesh nets. Such fisheries occurred only in certain locations where the fish are forced to migrate through narrow channels at low water level, and are thus very prone to harvesting.

Incidental catches of MGC in fisheries targeting other, or a wide range of species are relatively rare and again, largely confined to migratory ‘bottlenecks’. The most regular incidental catches are taken in just one Dai net in the Tonle Sap river in Cambodia, at a location where the Dai blocks virtually the entire cross-section of the river. Regular but very low incidental catches were also taken in the Khone Falls area. Incidental catches elsewhere are extremely rare and do not appear to follow any identifiable pattern.

A more detailed of the history of MGC fishing at various locations is given in Table 1. Note that there is little information on MGC fishing prior to about 1930. Detailed data are available from the 1970s onwards, and are described in Section 3.3.

## The Lower Mekong Basin

Showing the Mainstream, Major Tributaries,  
Large Reservoirs and Flood Areas.



**Figure 1.** Map of the lower Mekong basin. Green circles indicate the locations where Mekong giant catfish have been regularly caught in fisheries in recent years: (A) Chiang Khong/Huay Xai in Northern Thailand and Laos, and the Tonle Sap River in Cambodia. (Map courtesy of Mekong River Commission).

Interpretation of the pre-1970 data is difficult due to lack of continuity. Most accounts provide snapshots of catches in particular locations, sometimes with vague references to previous ‘average’ catch levels. Several such reports mention catch declines, but it is not clear whether these refer to an overall, long-term decline or ‘boom and bust’ cycles in the fishery. ‘High’ local

catches of about 50 individuals followed by declines in catch and catch per unit of effort have been reported for various locations. It does not appear, however, that catches of this magnitude ever been sustained in the long term.

When interpreting catch data it is important to bear in mind that catches are influenced by both fish abundance and fishing effort, and that catch declines are not necessarily indicative of population decline.

**Table 1:** Catch history of Mekong giant catfish *Pangasianodon gigas* in different locations of the Mekong basin (Updated from Hogan 2005).

Location	Catch history	Source
Chiang Khong (Thailand) and Huay Xai (Lao PDR) (Location A on the map in Fig. 1)	Targeted fishery. Before 1983, 4-5 fish per year were caught during a traditional ceremony. The fishery expanded after 1983 due to demand for fish for the captive breeding programme, and associated publicity which made the fishery a national tourist attraction. The catch peaked with 69 fish in 1990, and declined to just 7 fish in 1997.	Srettacheua 1995, Hogan 1998, Boonrien J. pers. comm.
Luang Prabang, Lao PDR	Targeted fishery. The catch declined from “about 12 fish per year” in the 1940s and 50s to just 3 fish in 1968. No fish were caught in 1972, 1973, or 1974, possibly due to low fishing effort at the height of the Vietnam war. Since that time, no significant catch of <i>P. gigas</i> has been reported for the Luang Prabang area.	Davidson 1975
Nong Khai Province (Thailand), and Vientiane Province (Lao PDR)	Targeted fishery. In the 1930/40s, “as many as 40-50 fish were caught annually”. The catches declined to 11 in 1967. By 1970, <i>P. gigas</i> occurred only rarely as by-catch of beach seine fisheries. Today, very few <i>P. gigas</i> are reported from Nong Khai Province.	Giles 1935 Smith 1945 Phukaswan 1969 Glyki 2006
Khone Falls (Lao PDR)	Incidental catches. Three to four fish reported by fishermen before 1993, almost all caught in the first half of the year. No fish were reported in 1993 and no <i>P. gigas</i> have been reported since that time.	Roberts 1993
Tonle Sap River, Cambodia (Location B on the map in Fig. 1)	Incidental catches. The species is caught regularly in low numbers in the Tonle Sap river. It was described as rare in the 1940s, and there are no records to suggest that it was ever common. An average of 6 fish per year have been caught since 1999.	Durant 1940 Hogan <i>et al.</i> 2001
Mekong Delta, Vietnam	No significant fishery for this species exists in Vietnam. There are reports to suggest that the species was once more abundant in the delta.	Lenormand 1996

In the 1970s, armed conflict throughout the region and the Khmer Rouge regime in Cambodia have resulted in the virtual cessation of MGC fishing in many locations. Fishing was considered dangerous where the Mekong defines the border between Thailand and the Lao PDR, this includes many traditional fishing grounds such as the Chiang Khong / Huay Xai and the Nong Khai /

Vientiane areas. In Cambodia, large-scale fishing became very restricted during the civil war and ceased completely during the Khmer Rouge period.

### 2.2.2 Fishing history at Chiang Khong, Northern Thailand

The targeted fishery in Chiang Khong, Thailand (and the neighbouring Huay Xai, Lao PDR) is a particularly important element of MGC exploitation and assessment. The fishery has dominated overall catches since the 1980s, and provides the most detailed data on the population currently available.

There is no clear record when the fishing of the Mekong giant catfish has begun in Chiang Khong District, Chiang Rai Province in Northern Thailand. However, according to interviews with local fishers, fishing for the Mekong giant catfish has been practiced for more than 70 years. The fishing period in this area is around 1 month during April to May every year when the fish migrate to their spawning ground, thought to be around the Golden Triangle.

The fishing gear used to catch MGC has changed from a traditional cast net (“Kwag”) to gill nets around 1970. Gill nets were initially made of natural fibres like sisal, but these were replaced with nylon in the early 1980s. At present, nylon gill nets with a mesh size of 30-45 cm are used.

Catch statistics for the Chiang Khong/Huay Xai area have been recorded from 1973 to 1995 by Borkeo Province, Lao PDR. In Thailand, the Department of Fisheries (DOF) has recorded catches since 1983, when the MGC artificial breeding program was started. From 1973 to 1983, the catches varied from 1 to 6 fish per year with an average of 3 fish per year. After 1983, when the Thai DOF succeeded in the artificial spawning of the wild caught fish from the Mekong River, catches have increased to an average of 29 fish per year (from 1984 to 2000), with a maximum of 71 fish. This dramatic increase in MGC catches reflects a massive increase in fishing effort between 1983 and 1990, fuelled by high demand for MGC from the Thai DoF’s captive breeding programme and from the local tourism industry. The latter developed as a result of publicity surrounding the fishery and the captive breeding programme, and a targeted promotion campaign dwelling on the local people’s belief that eating Mekong giant catfish will lead to a long life. Catch rates (CPUE) in the fishery declined to a minimum in the mid-1990s and effort then declined as a result of both the low catch rates and alternative economic opportunities.

No MGC were caught at Chiang Khong from 2000 to 2003. This has been attributed to rapid blasting in the Mekong River mainstream for navigation, and the construction of a port in Chiang Khong. In 2004 (when construction had been completed), 7 fish were caught, and in 2005 4 fish. A conservation campaign by both local and international NGOs led to reduced fishing in 2005 and 2006, with a near-complete cessation of MGC fishing in 2006 when the NGOs bought the fishing gear from all registered Thai and Lao fishers.

### **2.3 Environmental change in the Mekong basin**

Environmental change in the Mekong basin has been gradual and of moderate magnitude until the very recent past. Land use has gradually become more agricultural. Hydrology has shown no marked changes since the start of systematic recording in 1960, contrary to widespread perceptions that dams have caused significant flow changes.

Access to some tributaries and the upper Mekong/Lancang is likely to have been restricted by dams, but the total area potentially lost accounts for only a moderate proportion of the basin.

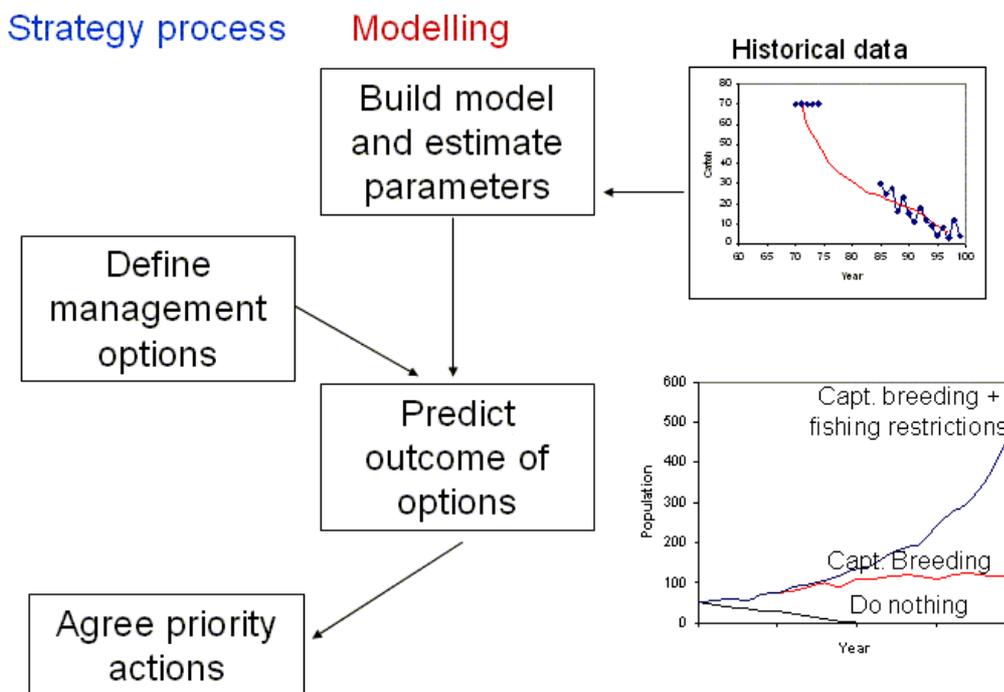
More dramatic changes may have occurred in the very recent past with ‘rapid blasting’ and the commissioning of several dams in the upper river, but any effects of these changes on the giant catfish population would not yet be visible in the data. It thus appears that fishing can be identified as the main driver of past changes in population abundance and structure.

### 3 Giant catfish wild population assessment

#### 3.1 General approach and methodology

The population assessment forms an integral part of the conservation strategy process (Fig. 2). Its main purpose is to allow the Mekong Giant Catfish Working Group to synthesize information on stock status and explore the likely effectiveness of different conservation options.

The general approach to population assessment has been one of confronting a mathematical population model with the available data on MGC fisheries. The mathematical model is formulated to represent our understanding of the MGC population dynamics, and of the observation processes that underlie the available data. Certain model parameters can be estimated directly from sub-sets of data or from comparative information, while the remainder are estimated by confronting model predictions with long-term fisheries data.



**Figure 2** The Outline of the modelling and assessment process.

#### 3.2 Population model and parameter estimation

A length-structured matrix population model was developed as the main assessment tool for this study. The recruited population is divided into length groups, and the model projects population and catch numbers at length over time.

This type of model was chosen for several reasons:

- A structured rather than 'lumped' (e.g. biomass dynamics) model is indicated because age and size structure are important features of the population dynamics of this very long-lived species.
- Virtually all structural data are size- rather than age based, and a size-structured model thus allows direct confrontation of predictions and observations.

Full mathematical details of the model are given in Appendix 1.

The following assumptions underlie the baseline model:

- MGC in the Mekong basin form a single population (all catches have been taken from the same population)
- The full population is vulnerable to fishing (there are no un-fished and thus, unobserved local populations)
- Reporting of MGC catches is near-complete and not size-biased (There is no unreported harvest of small MGC).

The population modelling and assessment uses a range of standard methods in fisheries stock assessment. Readers unfamiliar with such methods may consult Haddon (2001) or Walters & Martell (2004) for general introductions.

### **3.3 Fisheries data**

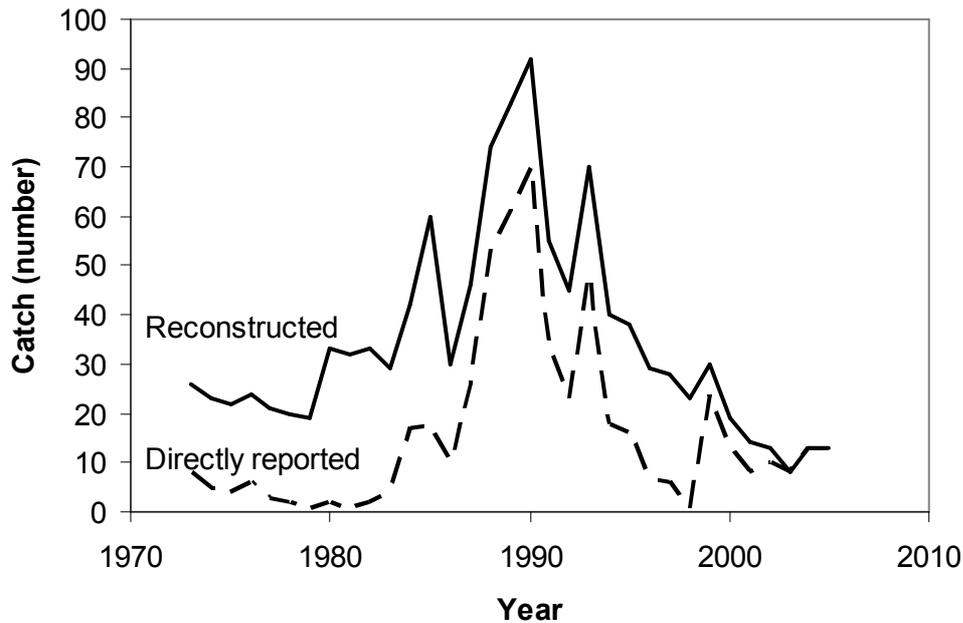
Detailed data collected intermittently since the late 1960s were synthesized and analysed through confrontation with a mathematical model. Three types of data were available:

- Basin-wide catch data
- Catch per unit of effort data for the Chiang Khong fishery
- Size structure of catches taken in Chiang Khong and in the Tonle Sap river

#### **3.3.1 Catches**

Complete and detailed catch data are available for the fishery around Chiang Khong since 1983, with some data for Lao side reaching back to 1973. Data for other fisheries are sketchier, or cover only short time series. It was therefore necessary to reconstruct the pattern of total catches by history of decided to reconstruct total catch figures conduct a 'best

In the 1970s, catches appear to have been stable at an average of about 20-30 fish per year. Catches increased substantially, up to a maximum of 90 per year in the late 1980s, driven mainly by the high profile government-supported fishery in Chiang Khong (Northern Thailand). Catches declined again in the 1990s, dropping below 1970s 'pre-Chiang Khong fishery expansion' levels in 2000.



**Figure 3.** Directly reported catches and reconstructed catch history. The reconstructed history takes into account reported 'average' catches for locations and periods where no direct records exist.

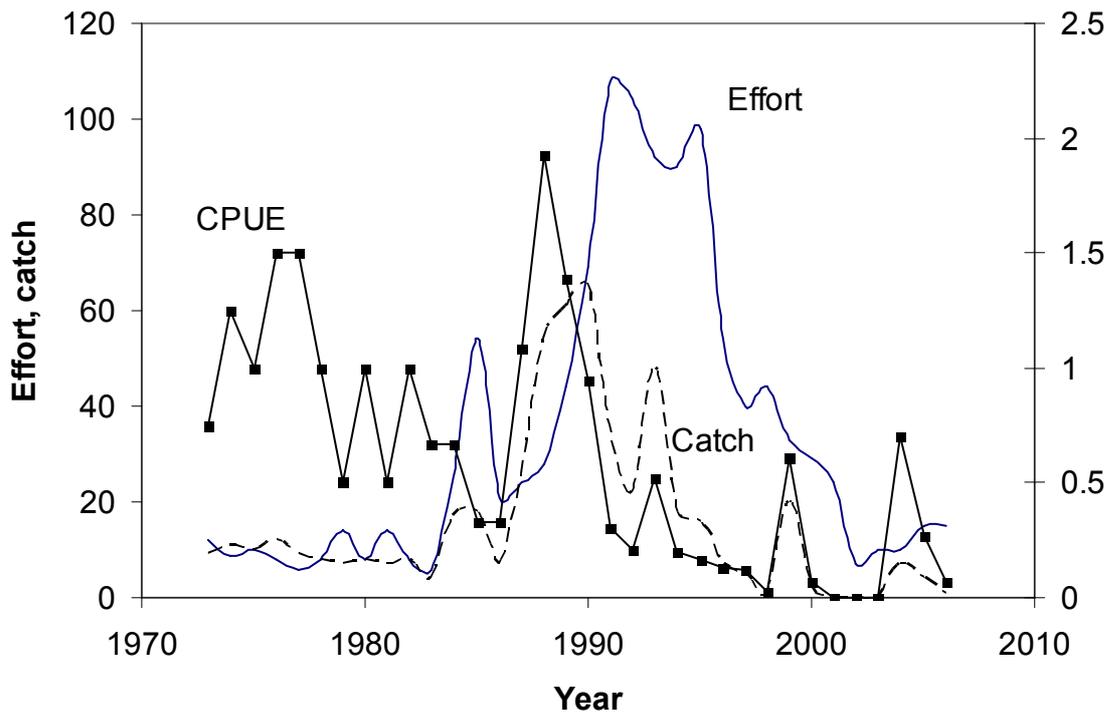
The catch data show the total removal of fish from the population. Because catches depend on both, the abundance of fish and the level of fishing effort, catches alone do not tell us much about population abundance.

### 3.3.2 Catch per unit of effort

Catch per unit of effort data are available for the Chiang Khong fishery since 1973, initially only for the Lao side and since 1986 for both the Thai and the Lao side. Catch is measured in terms of the number of fish. All fish caught in this fishery are mature, and of a length greater than 190 cm.

Effort is measured in terms of the number of boats licensed to fish for giant catfish per year. This is clearly a crude measure of effort, given that the time the boats actually spend fishing can vary considerably between years. There is good anecdotal evidence for example that most licensed boats were active throughout the fishing season in the late 1980s to early 1990s, while in 2001-2003 there was virtually no fishing activity despite a number of boats being licensed. The dimensions of gear used at Chiang Khong have not changed greatly since 1973, but it appears that monofilament Nylon was substituted for natural fibres in the early 1980s.

Catch per unit of effort (CPUE) used in this study is calculated simply as fish caught per licensed boat. Virtually all boats participating in this targeted fishery are licensed and use gill nets specifically designed for giant catfish. There is no incidental catch of the species by boats fishing with other gear.



**Figure 4.** Catch (number of fish), effort (number of licensed boats) and CPUE (fish caught per boat) in the Chiang Khong/Huay Xai fishery.

The Chiang Khong catch and effort data (Fig. 4) clearly show a relatively stable effort, catch and CPUE between 1973 and 1982. This was followed by a dramatic increase in effort from 1983 to 1990. Catches increased sharply at the beginning, but have declined since 1990 despite a continued high level of effort. CPUE clearly declined dramatically from the 1980s to the 1990s, with the biggest change coinciding with the large catches taken in the late 1980s. CPUE can be regarded as approximately proportional to population abundance, and the patterns seen here are consistent with the interpretation that the observed decline in CPUE (abundance) is a direct result of the large removals by fishing.

### 3.3.3 Size structure

Data on catch size structure are available intermittently from 1967 as follows:

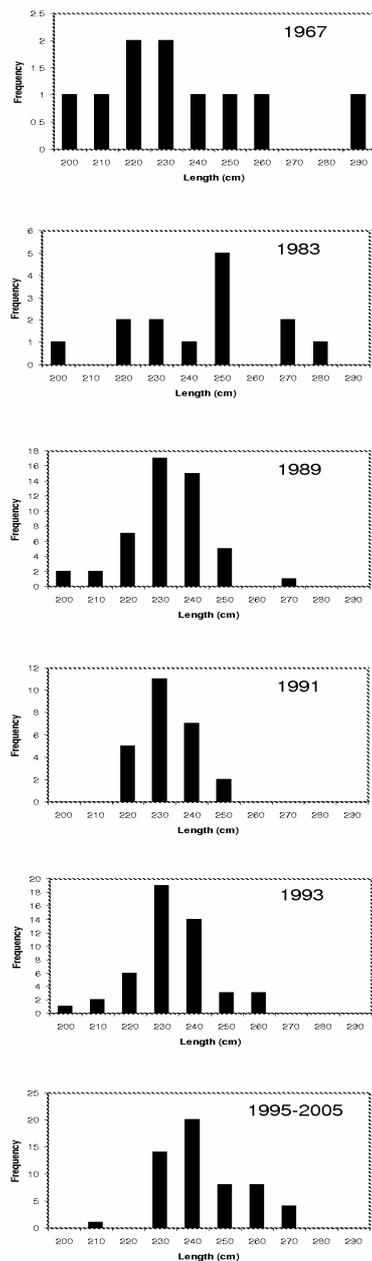
- For catches in Nong Khai Province in 1967 from Phukaswan (1969)
- For catches in the Chiang Khong/Huay Xai fishery for most years since 1983. These data are based on measurements taken of all wild fish brought into the captive breeding programme.
- For catches taken in the Tonle Sap River since 1999, from the Cambodian catch monitoring programme.

The catch length distributions for the upper part of the distribution area (Nong Khai and Chiang Khong) are shown in Fig. 5. Note that the early size distributions are relatively 'flat' and extend to the maximum size of just under 300 cm. This flat distribution indicates a low overall rate of mortality (see also 3.4.4 below). The pattern in the 1989 and 1991 samples is radically different, with a very steep right hand side of the distribution and fish over 260 cm virtually absent. This is indicative of very high mortality, with almost complete removal of larger fish. From 1993, fish can be seen to grow back into the large size range, and the combined 1995-2005 distribution shows the re-emergence of a flat distribution extending to over 280 cm. The overall pattern is consistent with a strong fishing impact on the population between 1983 and 1990, with evidence of very high total

mortality and near complete removal of large fish. Relaxation of fishing in the 1990s may have allowed fish to reach larger sizes again.

### 3.3.4 Mark recapture studies

Several mark-recapture studies using wild giant catfish have been attempted. These have involved marking and release of wild fish caught in the Cambodian Dai fishery, and the Chiang Khong gill net fishery. No marked fish have ever been recovered. Experience with attempts to maintain wild caught fish alive suggests that their survival is extremely poor. It is therefore likely that the tagged fish have died shortly after release. The mark-recapture studies thus have not provided useful information for population assessment of wild Mekong giant catfish.



**Figure 5.** Length distribution of giant catfish catches at Nong Khai (1967) and Chiang Khong (1983-2005). Length distributions in 10 cm intervals, with the lower length bound shown on the length axis.

### 3.3.5 Catch sampling issues

The interpretation of all catch data relies critically on understanding the level and specificity of reporting of MGC catches. If catches were underreported, either selectively (e.g. for smaller fish) or unselectively, then this would have to be taken into account in the analysis.

The capture of giant catfish in general is considered newsworthy throughout the region, and it is unlikely that many catches of large MGC go unreported. The situation may be different with smaller specimens, which may attract less attention and may be confused with other Pangasiid species. A brief overview (Tab. 2, Fig. 8) shows that MGC are almost exclusively caught at lengths above 200 cm, with only occasional incidental catches of smaller fish. While there are a number of other large Pangasiid species in the Mekong, none are typically represented in catches at lengths over 100 cm. It is thus unlikely that MGC over 100 cm are confused with other species, and the fact that very few MGC are caught at less than 200 cm is likely to reflect size selectivity of the fishery rather than a reporting issue.

The situation regarding MGC caught at less than 100 cm length remains perhaps the most uncertain part of the catch assessment. Considerable numbers of other Pangasiids are caught in the length range of 20-80 cm, and the possibility that this may include MGC not distinguished from the more common species (in particular *P. hypophthalmus*) can not be excluded. It must be remembered also that fishing in the Mekong outside Cambodia is carried out mostly will gill nets of relatively small mesh size which are selective mainly for fish in the size range < 100 cm. This suggests that overall fishing mortality rates are particularly high in this size range, and vulnerability of small MGC may be similar to that of other juvenile Pangasiids. The implications of this possibility are considered through modelling below.

**Table 2.** Larger Pangasiid species that could be confused with MGC in catch reporting

Species	Maximum length	Typical length in catch	Total catch (no.)
<i>Pangasianodon gigas</i>	300 cm	200-300 cm	10-80
<i>Pangasianodon hypophthalmus</i>	130 cm	15-80 cm	> 50,000
<i>Pangasius bocourti</i>	100 cm	< 100 cm	
<i>Pangasius conchophilus</i>	120 cm	50 cm	
<i>Pangasius elongatus</i>	100 cm	50 cm	
<i>Pangasius krempfi</i>		80 cm	
<i>Pangasius larnaudii</i>	150 cm	90-100 cm	
<i>Pangasius mekongensis</i>	100 cm	< 100 cm	
<i>Pangasius sanitwongsei</i>	250 cm	< 100 cm	

## **3.4 Life history information and parameters**

### 3.4.1 General life history

It appears likely that there is a single population of MGC in the Mekong, with spawning grounds located north of Chiang Khong in northern Thailand. The possibility of two separate populations above and below the Khone falls has been discussed, but genetic analyses so far have not provided support for this idea (Ngamsiri et al. submitted). Occasional catches of MGC at the Khone Falls suggest that fish from Cambodia may be able to negotiate the falls and migrate to the Chiang Khong spawning area. It is also possible, however, that the lower basin acts as a 'sink' supplied with juveniles from the upper population but with adults unable to return to spawning grounds.

The baseline model used here assumes that there is a single MGC population, and that all mature fish can contribute to spawning. Alternative assumptions can be explored easily.

The model, in line with common practice on fish population modelling, divides the population into a pre-recruit stage (early life stages to juveniles), and a recruited stage (juveniles to adults). The pre-recruit stage is not modelled explicitly, but the number of recruits is predicted from spawning stock biomass via a stock-recruitment relationship. The dynamics of the recruited population are described explicitly in a size-structured matrix model. Recruitment is assumed to occur (somewhat arbitrarily) at a length of 1 m, well below the smallest size of fish caught incidentally. Given the growth model (see 3.4.2 below), a length of 1 m corresponds to an age of about 10 years.

### 3.4.2 Growth

Growth in recruited fish is described by a von Bertalanffy growth function (VBGF) with parameters:

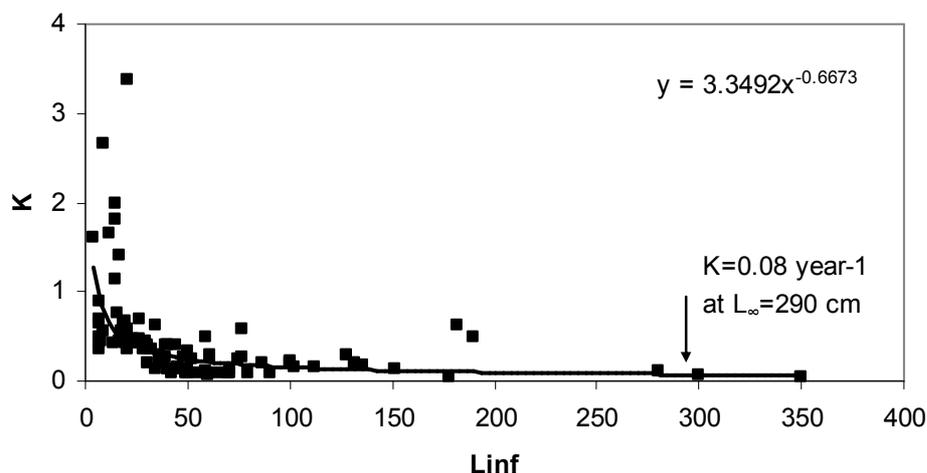
- $L_{\infty}$ : asymptotic length
- $k$ : growth rate
- $\alpha$ : coefficient of the length-weight relationship
- $\beta$ : exponent of the length-weight relationship

Together, these parameters describe growth in length and weight.

No direct estimates of individual growth rates in the wild population are available. Our assessment is thus based on three sources of information:

- Growth data from giant catfish in culture or released into reservoirs
- Comparative growth data
- The size distribution of catches from the wild population

The size distributions show a maximum length of just under 300 cm (Fig. 5). Asymptotic length tends to be marginally smaller than the largest fish recorded, and in this case was assumed to be 290 cm. While the asymptotic length can be inferred with reasonable accuracy from length distributions, this is not the case for the growth rate parameter. We have thus used comparative empirical data (Pauly 1981) and estimated an average growth rate of  $0.08 \text{ year}^{-1}$  for fish with an asymptotic length of 290 cm (Figure 6).



**Figure 6.** Comparative data on the growth rate parameter  $K$  in relation to asymptotic length  $L_{\infty}$  (From Pauly 1980).

### 3.4.3 Mortality

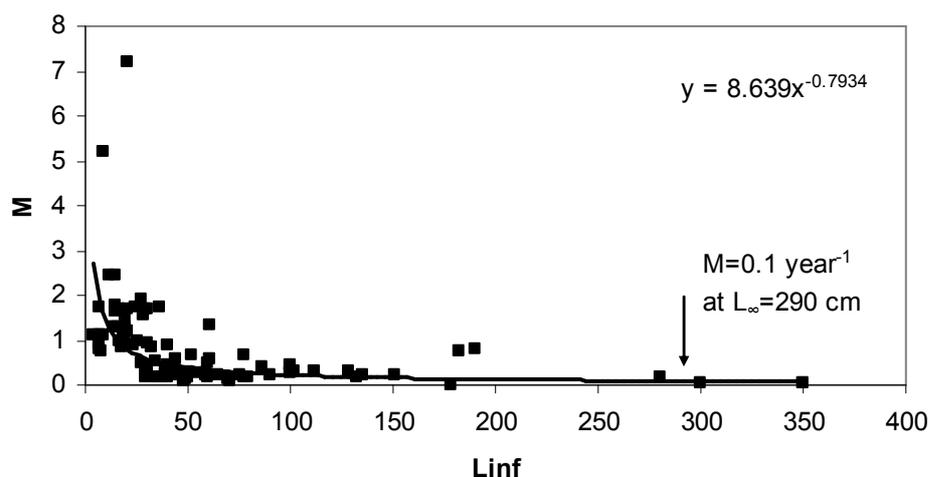
Total mortality  $Z$  in the fished size range can be estimated from length distributions, given the von Bertalanffy growth parameters. We used the 'length-converted catch curve' method (Pauly 1984) to obtain estimates of  $Z$  from the length distributions shown in Table 3. The analysis suggests a moderate level of total mortality of about  $0.2 \text{ year}^{-1}$  prior to the expansion of the Chiang Khong fishery, a peak of about  $0.6 \text{ year}^{-1}$  in the early 1990s, and a subsequent decline to about  $0.28 \text{ year}^{-1}$  as consistently estimated from Thai and Cambodian data. The temporal patterns in total mortality are broadly consistent with independent information on fishing effort.

**Table 3.** Total mortality estimates for the fully exploited length range (230-290 cm) of MGC, based on length-converted catch curve analysis of size distributions.

Place and time	Total mortality $Z$ ( $\text{year}^{-1}$ )
Nong Khai, Thailand, 1967	0.19
Chiang Khong, Thailand, 1983	0.25
Chiang Khong, Thailand, 1989	0.41
Chiang Khong, Thailand, 1991	0.57
Chiang Khong, Thailand, 1995-2005	0.28
Tonle Sap, Cambodia, 1999-2005	0.28

The absolute values of  $Z$  estimated using this method must be regarded with some caution, because the method assumes that the population is in equilibrium and that the catch curve therefore represents the action of current mortality levels. This is clearly not the case here where fishing effort has varied dramatically. To illustrate the issue, consider that while effort was substantially higher in 1983 than in the previous years, the catch size structure observed in this year reflects the mortality level of previous years. An alternative approach to estimating mortality (see 3.5) leads does not rely on equilibrium assumptions.

Total mortality is the sum of natural mortality  $M$  and Fishing mortality  $F$  ( $Z=M+F$ ). It is not possible to separate these components of mortality on the basis of the data available here (or in most fisheries assessments). We therefore estimated the natural mortality rate from comparative life history information for a range of species.



**Figure 7.** Comparative data on the natural mortality rate  $M$  in relation to asymptotic length  $L_{\infty}$  (From Pauly 1980).

Three estimates were obtained as follows:

- A simple plot of  $M$  against asymptotic length gives the relationship shown in Fig. 7, and provides an estimate of  $M=0.1 \text{ year}^{-1}$  for  $L_{\infty} = 290 \text{ cm}$ . This estimate applies to the recruited stock.
- Pauly's 1980 multiple regression model for the same data gives  $M=0.15 \text{ year}^{-1}$  (based on  $L_{\infty} = 290 \text{ cm}$ ,  $K= 0.1 \text{ year}^{-1}$  and  $T=25^{\circ}\text{C}$ ). This estimate applies to the recruited stock.
- The empirical relationship for size dependent natural mortality of Lorenzen (1996) gives  $M=0.06 \text{ year}^{-1}$  at the mean length of fish caught in the targeted fishery,  $l = 250 \text{ cm}$ .

The population model uses a length-inverse natural mortality function (Lorenzen 2000) with one parameter:  $M_r$ , Mortality rate at reference length  $l_r$ . The above estimates suggest a plausible range of values of  $M_r$  from 0.06 to 0.15  $\text{year}^{-1}$  at  $l_r=250 \text{ cm}$ . Given a total mortality rate the estimate of  $Z=0.2 \text{ year}^{-1}$  in the 1960s/1970s (Table 3), fishing mortality rates  $F$  in the fully selected size range would have been between 0.05 to 0.14  $\text{year}^{-1}$ . We constructed a range of natural mortality and associated exploitation rate scenarios for the 1960s/1970s to provide initial conditions for the population model (Table 4).

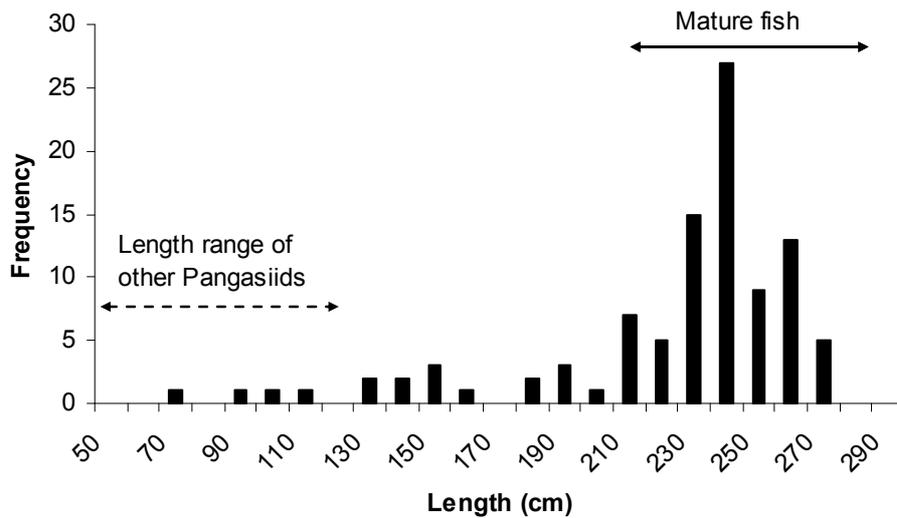
**Table 4.** Possible natural mortality rates and associated pre-Chiang Khong 'boom' exploitation rates, given a total mortality rate  $Z=0.2 \text{ year}^{-1}$  and different plausible values for natural mortality  $M$ .

$M_r$ at $l_r=250\text{cm}$	$F$ in fully selected size range	Total mortality $Z$ at $l=250 \text{ cm}$	Exploitation rate ( $E=F/Z$ )	Corresponding to $M$ estimate from
<b>0.16</b>	0.04	0.20	0.8	
<b>0.14</b>	0.06	0.20	0.7	Pauly 1980
<b>0.12</b>	0.08	0.20	0.6	
<b>0.10</b>	0.10	0.20	0.5	
<b>0.08</b>	0.12	0.20	0.4	
<b>0.06</b>	0.14	0.20	0.3	Lorenzen 1996
<b>0.04</b>	0.16	0.20	0.2	

#### 3.4.4 Gear selectivity

The 'length-converted catch curve' method (Pauly 1984) also provides a convenient way of estimating the size selectivity of fishing gear. This is done by reconstructing the population size distribution and then calculating the proportion of each size class that has been caught.

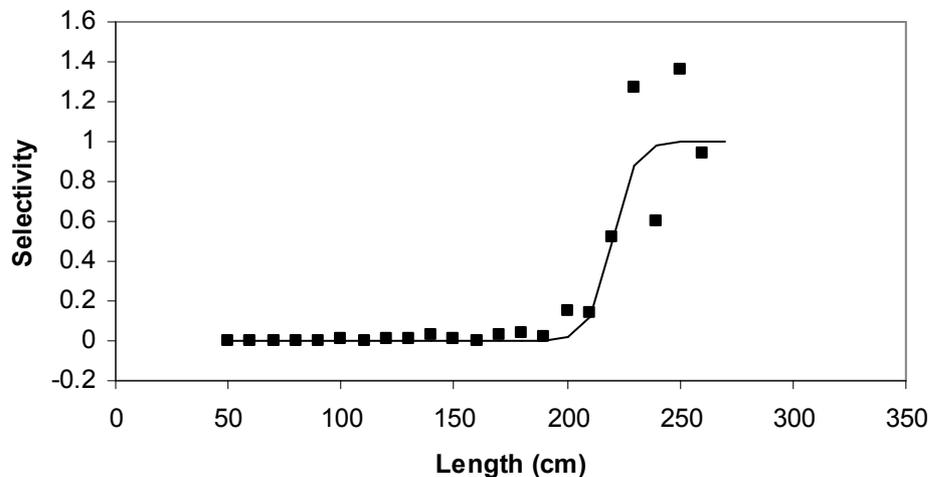
To obtain a basin-wide catch size distribution, the Thai, Lao and Cambodian catches for 1999-2005 are combined (Fig. 8). Note that the bulk of catches are taken of fish over 200 cm in length, with occasional catches of smaller fish exclusively in the Cambodian Dai fishery. While the catches of fish below 200 cm in length may seem significant, it must be remembered that these smaller and younger fish are far more abundant in the population than those over 200 cm. Hence the occasional catches of MGC below 200 cm reflect a very low level of fishing mortality on these juveniles. As mentioned above, it is difficult to assess the level of harvesting of very small (< 100 cm) MGC. While very few such fish have ever been reported, some may be mistaken for other species. Given that a large share of fishing in the Mekong is carried out with gill nets that are selective for fish below 100 cm length, there is the possibility of a significant incidental fishing mortality on MGC of this size.



**Figure 8.** Size distribution of the combined basinwide catches 1999-2005.

The resulting selectivity curve (Fig. 9) clearly shows that selectivity is extremely low for fish below 200 cm, but increases steeply thereafter. For the population model, selectivity is described by a length-based logistic model with two parameters:

- $l_m$ : Length at 50% gear selectivity
- $p$ : Steepness of selectivity curve



**Figure 9.** Length selectivity of fishing gear for MGC, showing empirical estimates (squares) and a fitted logistic curve..

Fishing for MGC is thus very strongly size-selective, with fish below 200 cm virtually excluded from harvesting. This high degree of size selectivity is likely to reflect behavioural patterns of the fish more than the technical selectivity of gear. The nets used in the Chiang Khong fishery catch smaller specimens (150-200 cm) of the similar *P. sanitwongsei*, suggesting that MGC in this size range would also be vulnerable to the gear. Also, strong size selectivity is observed even in the Cambodian Dai fishery which quantitatively ‘filters’ a very wide range of fish sizes from the Tonle Sap outflow. It appears therefore that only large and maturing fish undergo the migrations that force them through bottlenecks such as the Tonle Sap river or the narrow channels of the mainstream at Chiang Khong. Away from these bottlenecks, vulnerability to fishing gear of large MGC appears to be extraordinarily low.

### 3.4.5 Maturity

The proportion of mature fish at length is described by a length-based logistic model with two parameters:

- $l_m$ : Length at 50% maturity
- $p$ : Steepness of maturity curve

It appears that the proportional maturity curve is virtually identical with the selectivity curve, as all fish caught in the Chiang Khong fishery are mature and ready to spawn. This suggests that length at first maturity is similar to the gear selection length, at about 224 cm (see 3.5.5). Fish caught in Cambodia at lengths similar to those of mature fish in Chiang Khong do not show advanced maturity stages, but clearly are caught during a migration not undergone by younger fish. The peak of the MGC harvest in Cambodia is several months prior to the arrival of fish at Chiang Khong, and it is possible that the large Cambodian fish mature and migrate northwards during the intervening period. This would of course be a very long-distance migration and there is no direct evidence so far of this occurring.

### 3.4.6 Stock-recruitment relationship

The MGC population is assumed to be regulated primarily in the pre-recruit phase of the life cycle, an assumption likely to hold true in populations that are intensively exploited (Lorenzen in press). Density-dependence in the pre-recruit phase is quantified in a stock-recruitment relationship. Recruitment  $R$  as a function of spawner biomass  $B$  is described by a Beverton-Holt stock-recruitment relationship, written in terms of the Goodyear recruitment compensation ratio (Walters & Martell 2004):

$$R = \frac{K(R_0 / B_0)B}{1 + [(K - 1) / B_0]B}$$

With parameters

- $K$ : Goodyear recruitment compensation ratio
- $B_0$ : Unexploited population biomass
- $R_0$ : Recruitment at  $B_0$

The Goodyear recruitment compensation ratio  $K$  is the ratio of juvenile survival at very low population size to juvenile survival at unexploited population size. Meta-analysis shows that  $K=5$  on average for many fish populations (Myers *et al.* 1999). Direct estimation of a stock-recruitment relationship for MGC has not been possible, hence we conducted all analyses for a baseline value  $K=5$  and the extreme values of  $K=2$  (low recruitment compensation) and  $K=100$  (very high recruitment compensation). The corresponding parameter  $R_0$  was estimated by fitting the population model to data. Note that  $B_0$  and  $R_0$  have a fixed ratio (the spawning biomass per recruit,  $B_0 / R_0$ ) which is determined by mortality, growth and maturation schedules in the recruited phase and is independent of  $K$ .

### 3.4.7 Summary of model parameters

An overview of the model parameters and their baseline values is given in Table 5.

**Table 5.** Model parameters and their baseline values

Parameter	Definition	Value
Life cycle $L_r$ $a_r$	Length at recruitment Age at recruitment	100 cm 10 years
Growth $L_{\infty}$ $K$ $\alpha$ $\beta$	Asymptotic length Growth rate Coefficient of I-w relationship Exponent of I-w relationship	290 cm $0.1 \text{ year}^{-1}$ $4.0 \times 10^{-5} \text{ cm}$ 2.8
Natural mortality $M_r$ $L_r$	Natural mortality rate at $L_r$ Reference length for $M_r$	$0.15 \text{ year}^{-1}$ 200 cm
Reproduction $L_m$ $p$	Length at maturity Steepness of maturity curve	224 cm -0.2
Recruitment For $M_r$ at 250cm		0.12    0.12    0.12    0.06    0.06
$K$	Recruitment compensation	5    2    100    5    100
$B_0$	Unexploited spawner biomass	95 t    179 t    81 t    544 t    180 t
$R_0$	Recruitment at $B_0$	345    650    296    320    106 t
Fishing $F$ $L_c$ $q$ $c$	Fishing mortality rate in fully exploited size groups Gear selection length Steepness of selectivity curve Catchability coefficient	Variable 224 cm -0.2 $0.00417 \text{ boat}^{-1}$

## 3.5 Assessment of population status

### 3.5.1 Model fitting

Most model parameters were estimated from subsets of data or comparative information as detailed above. Only the level of recruitment in the unexploited population  $R_0$  and the catchability coefficient  $c$  (a constant of proportionally relating CPUE to absolute abundance) were estimated by fitting the model to time series of fisheries data. The data set used for model fitting was the CPUE time series for the Chiang Khong/Huay Xai fishery.

To fit the model to CPUE data, the model was started from equilibrium solutions for a variety of plausible exploitation scenarios for the 1960s/70s and levels of recruitment compensation (see Table 4), and run forwards through the period 1973-2005. In each year, the model population was reduced by the actual (reconstructed) catches (Fig. 3) and the action of natural mortality, but gained new recruits according to the stock-recruitment relationship. Recruitment in the unexploited population  $R_0$  and the catchability coefficient  $c$  were the estimated by numerically searching for those values that provided the best fit to the CPUE data. See Appendix 1 for details of the fitting procedure.

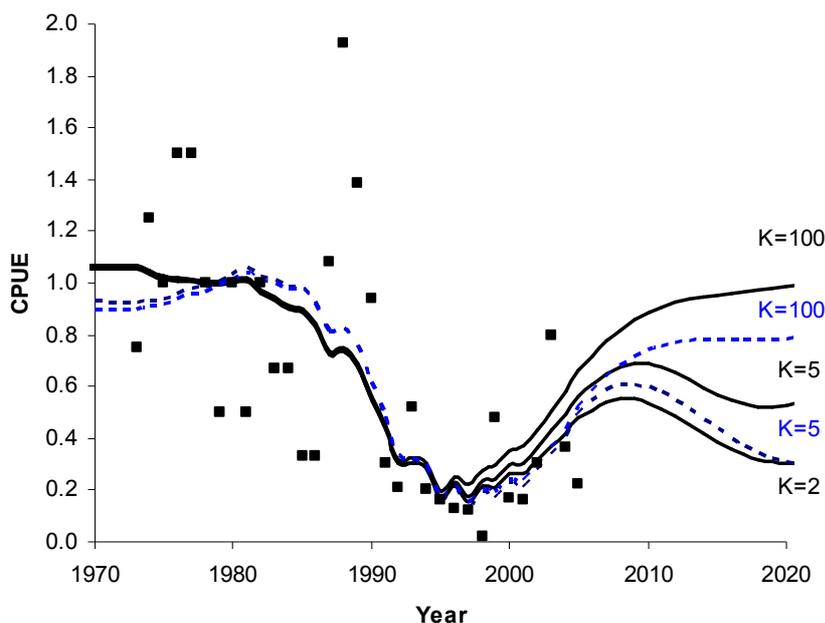
As highlighted previously (Sections 3.4.3 and 3.4.5), key uncertainties in population assessment concern the level of natural mortality (and thus, exploitation rate prior to the Chiang Khong fishing boom), and the level of recruitment compensation. A variety of scenarios E1970 and K allowed acceptable model fits to be obtained to the available catch and CPUE data (Table 6). There is no strong basis for discriminating among the fits associated with these alternative scenarios. All

acceptable model fits predicted a spawner abundance of about 250 fish at the start of the Chiang Khong fishing boom. Estimates of unexploited spawner abundance varied from 355 to 2200 fish. Hence the abundance at the start of the Chiang Khong fishing boom represents between 11% and 71% of the unexploited abundance. For further analysis, we have adopted a natural mortality rate  $M_r = 0.12 \text{ year}^{-1}$  at  $L_r=250 \text{ cm}$  as a baseline (grey column in Table 6), but also provide some predictions for  $M_r = 0.06 \text{ year}^{-1}$  at  $L_r=250 \text{ cm}$  (blue column in Table 6).

**Table 6.** Equilibrium catch, unexploited spawner population ( $N_0$ ) and relative spawner population prior to the Chiang Khong fishing boom (rel N) estimated for different combinations of exploitation rate in the 1970s and recruitment compensation K. Combinations marked in red lead to predictions that are inconsistent with the available data. The scenarios used in predictions are highlighted in grey ( $M_r=0.12\text{year}^{-1}$ ) and in blue ( $M_r=0.06\text{year}^{-1}$ ).

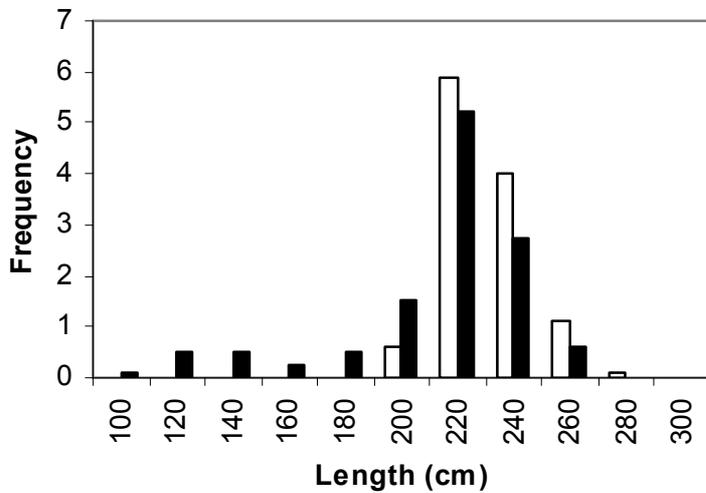
Mr at Lr=250cm	0.04	0.06	0.08	0.10	0.12	0.14	0.16
E (1970s)	0.8	0.7	0.6	0.5	0.4	0.3	0.2
<b>K=100</b>							
Catch	-	27	29	24	20	15	-
N0	-	860	622	501	414	355	-
rel N	-	0.294186	0.406752	0.50499	0.611111	0.712676	-
<b>K=5</b>							
Catch	-	23	29	24	20	15	-
N0	-	2200	1149	694	490	404	-
rel N	-	0.114948	0.220191	0.364553	0.516327	0.626238	-
<b>K=2</b>							
Catch	-	-	-	-	20	15	-
N0	-	-	-	-	1480	745	-
rel N	-	-	-	-	0.170946	0.339597	-

The models provide a good overall fit to the observed CPUE time series (Fig. 10). Note that the models provide very similar CPUE (and thus, abundance) estimates for much of the period, but diverge somewhat towards the end. The models thus predict the same abundance prior to the Chiang Khong fishing ‘boom’ (about 250 spawners) and a similar pattern of reduction during the fishing ‘boom’, but differ in the predicted recovery pattern.



**Figure 10.** Observed (squares) and predicted (lines) catch per unit of effort in the Mekong giant catfish fishery. Predictions for  $M_r = 0.12 \text{ year}^{-1}$  (black solid lines) and  $M_r = 0.06 \text{ year}^{-1}$  (blue dotted lines).

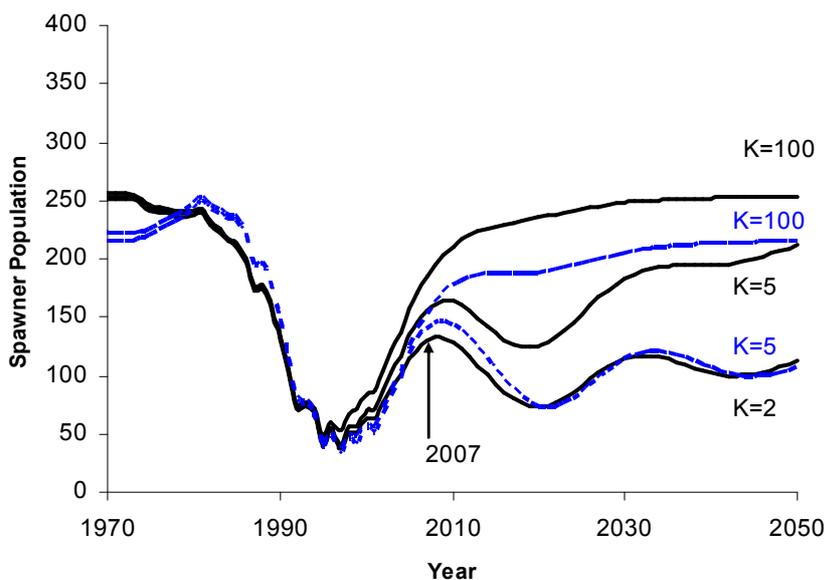
The model also reproduces the catch length distribution in 1999-2005 well (Fig. 11).



**Figure 11.** Observed (solid bars) and predicted (open bars) size distribution of the catch in 1999-2005.

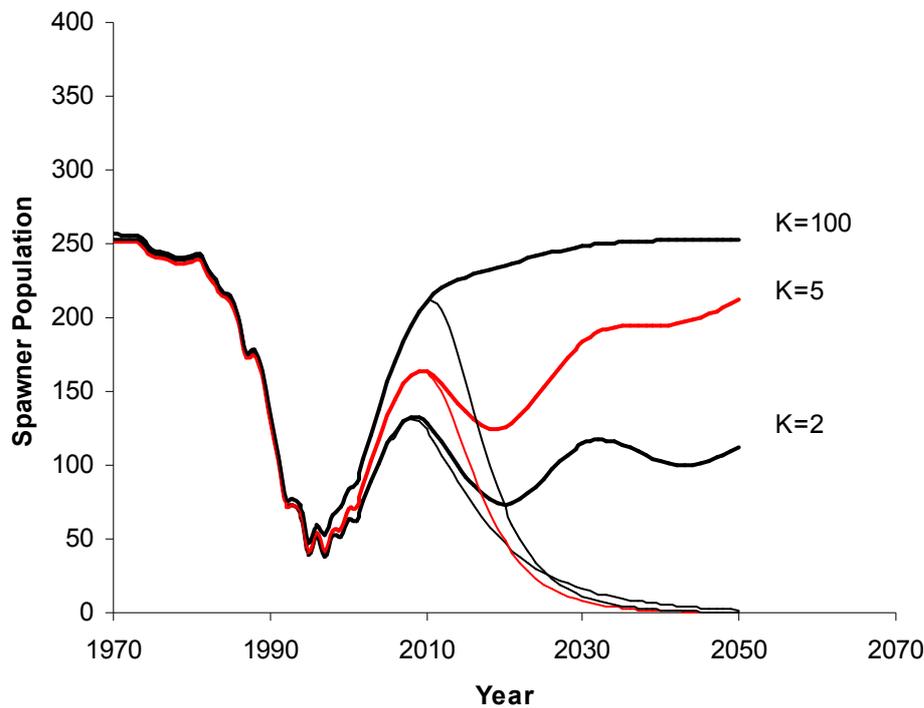
### 3.5.2 Reconstructed population and fishing history

Reconstructed spawner abundance (Fig. 12) shows a relatively stable spawner population of about 250 animals prior to 1983 (11-71% of unexploited abundance). The population then declines dramatically to just 50 spawners in 1995 (2-14% of unexploited abundance). The Chiang Khong fishing 'boom' thus reduced spawner abundance by about 80% in just ten years. However, the model predicts that the population has since recovered significantly. The predicted current (2006) level of spawner abundance is estimated at 145 animals (7-40% of unexploited abundance).



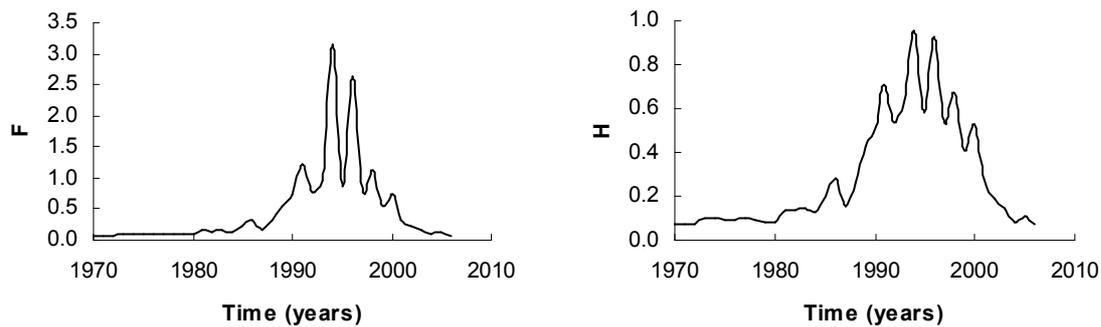
**Figure 12.** Spawner population abundance reconstructed by the population model. The figure shows predicted recovery trajectories for different levels of compensatory density-dependence in recruitment. Predictions for  $M_r = 0.12 \text{ year}^{-1}$  (black solid lines) and  $M_r = 0.12 \text{ year}^{-1}$  (blue dotted lines).

The predicted recovery of spawner numbers up to about 2010 is based largely on growth and maturation of fish spawned before the period of intensive fishing, and would occur even if there had been no successful reproduction since 1990. Subsequent population development depends on reproduction during and after the period of very low spawner abundance. Unless recruitment compensation is extremely high ( $K=100$ , Fig. 12), spawner abundance is predicted to decline again between 2010 and 2020 as a result of low spawner abundance and thus reproductive output during the 1990s. If reproduction had failed entirely from 1990 onwards (e.g. as a result of Allee effects, or due to environmental factors), this would become apparent only after 2010 (Fig. 13). This shows the importance of considering the giant catfish's basic life history when interpreting catch and abundance trends, and the need for long-term monitoring.



**Figure 13.** Spawner population abundance predicted by the population model assuming normal recruitment, or complete reproductive failure since 1990. Predictions for  $M_r = 0.12 \text{ year}^{-1}$ .

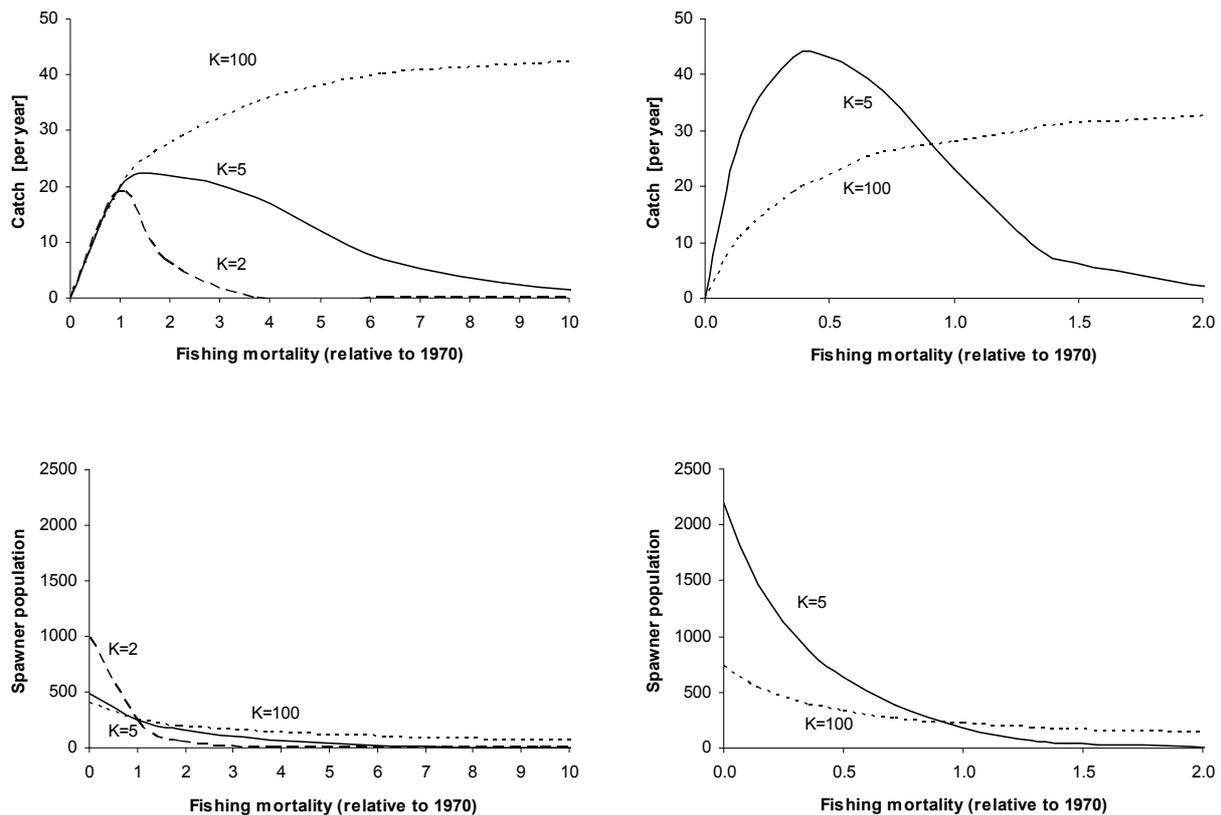
The model-based population reconstruction also provides us with direct estimates of fishing mortality rates. The fishing mortality pattern (Fig. 14, shown only for  $M_r = 0.12 \text{ year}^{-1}$ ) clearly shows a dramatic increase in fishing pressure on the mature population between 1983 and the early 1990s. Fishing mortality rates then declined and returned to pre-1983 levels by 2004. Instantaneous fishing mortality rates  $F$  can be translated into proportional harvest rates  $H$ , i.e. the proportion of the available population harvested in the fishery. The fishery pre-1983 and post-2004 removed about 10% of the population per year. During 1990-2000, over 50% of the available population was harvested annually, with a maximum of 96% in 1995.



**Figure 14.** Reconstructed fishing mortality  $F$  (left) and the corresponding proportion of the available population harvested  $H$  (right) for the period 1970 to 2006. Reconstruction for a 1970s exploitation rate of 0.4.

### 3.5.3 Potential for sustainable exploitation

To assess the potential for sustainable exploitation of the giant catfish, we have calculated the equilibrium (=sustainable) catch and the corresponding spawner abundance for the giant catfish population, given different levels of natural mortality and recruitment compensation (Fig. 15). The level of natural mortality and thus, pre-boom exploitation assumed has major implications for the assessment of the ‘traditional’ (pre-boom) level of fishing. For  $M_r = 0.12 \text{ year}^{-1}$  at  $l_r=250 \text{ cm}$  ( $E_{1970s}=0.4$ ), traditional fishing is conducted at or below the effort level that provides the maximum sustainable catch. For  $M_r = 0.06 \text{ year}^{-1}$  at  $l_r=250 \text{ cm}$  ( $E_{1970s}=0.7$ ), the traditional fishery overexploits the population if  $K=5$ , and represents a very high level of exploitation if  $K=100$ . It is not possible at present to discriminate between these scenarios, as the true level of natural mortality (and thus, pre-boom exploitation) is unknown. This may seem unfortunate, but it does not present a major problem for management in the short-to-medium term because the population is currently depleted and unlikely to rebound to levels at which the maximum sustainable catch could be taken for at least 2-3 decades. As shown in Section 3.5.5, the different models have very similar implications for population management in the medium term.



**Figure 15.** Equilibrium catch (top) and spawner population abundance (bottom) of Mekong giant catfish in relation to fishing mortality rate  $F$ . Predictions for  $M_r = 0.12 \text{ year}^{-1}$  (left hand side) and  $M_r = 0.12 \text{ year}^{-1}$  (right hand side).

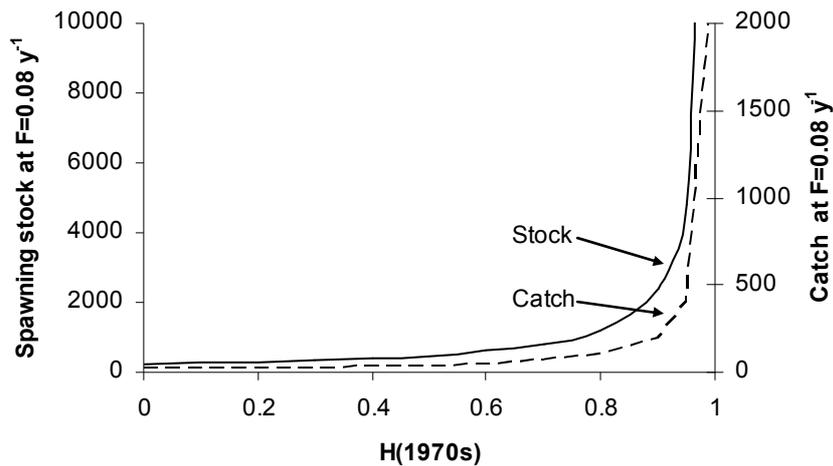
### 3.5.4 The implications of possible exploitation of small juveniles

As outlined above, whether and to what extent juveniles of less than 100 cm length are exploited is unknown. If exploitation occurs at this stage, it would affect recruitment to the population of large (> 100 cm length) MGC exploited by the known fisheries. It is thus possible to model the effect of juvenile exploitation by introducing a juvenile harvest rate  $H_j$  into the stock-recruitment function:

$$\text{Recruitment of large juveniles} = \text{recruitment of small juveniles} \times (1 - \text{juvenile harvest rate } H_j)$$

It is important to realize that the juvenile harvest rate  $H_j$  acts simply as a scaling factor to recruitment and does not affect the above analyses of population dynamics as long as  $H$  remains constant.

The baseline analysis has estimated a level of maximum recruitment of about 345 fish (of 100 cm length). This figure corresponds to the time of the Chiang Khong fishing 'boom' and thus, the level of recruitment in the 1970s. If this recruitment level had been influenced by juvenile harvesting at the rate of  $H_j(1970s)$ , then the natural recruitment level in the absence of juvenile harvesting would be higher by  $1/(1-H_j)$ . Likewise the spawner population abundance and sustainable yield in the absence of juvenile fishing would be proportionately higher, as shown in Fig. 16.



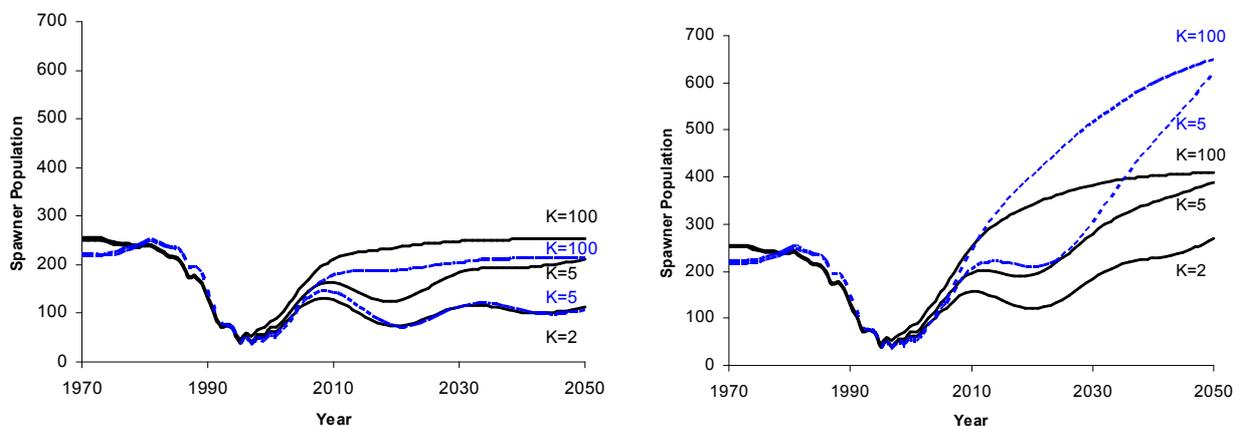
**Figure 16.** Spawner population size and sustainable yield at the ‘traditional’ level of targeted fishing ( $F=0.08 \text{ year}^{-1}$ ) in the absence of juvenile exploitation, given different assumed juvenile harvest rates  $H_j(1970s)$  in the 1970s.

### 3.5.5 Future population change

Future population trends have been predicted for several different scenarios with respect to fishing, releases of captive-bred fish, and reproductive failure.

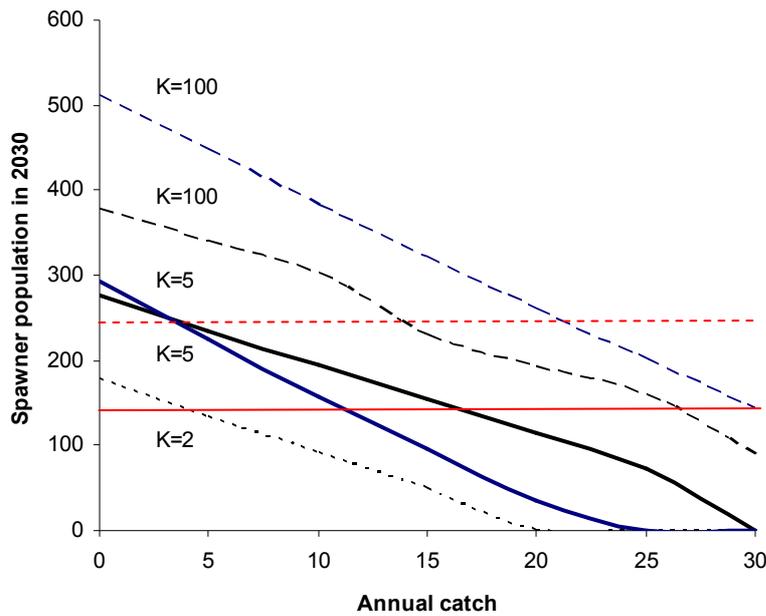
#### Fishing

Predictions are given for a ‘traditional’ level of fishing mortality, and for a scenario where all fishing for MGC is stopped from 2007. The ‘traditional’ fishing scenario is deemed most likely in the medium term, though closure of the Chiang Khon/Huay Xai fishery and decommissioning of the Dai net responsible for the bulk of MGC catches in the Tonle Sap river would lead to the ‘no fishing’ scenario. The MGC population is expected to recover under both scenarios (Fig. 17), but recovery would be faster and to a higher level of abundance if fishing were discontinued. For recruitment compensation  $K=5$ , the population would recover to pre-1983 abundance around 2025 in the absence of fishing, but would still be below pre-1983 abundance in 2050 if fishing continued at the ‘traditional’ level.



**Figure 17.** Predicted spawner population change given ‘traditional’ levels of fishing mortality (left) or no fishing (right). Predictions for  $M_r = 0.12 \text{ year}^{-1}$  (black solid lines) and  $M_r = 0.12 \text{ year}^{-1}$  (blue dotted lines).

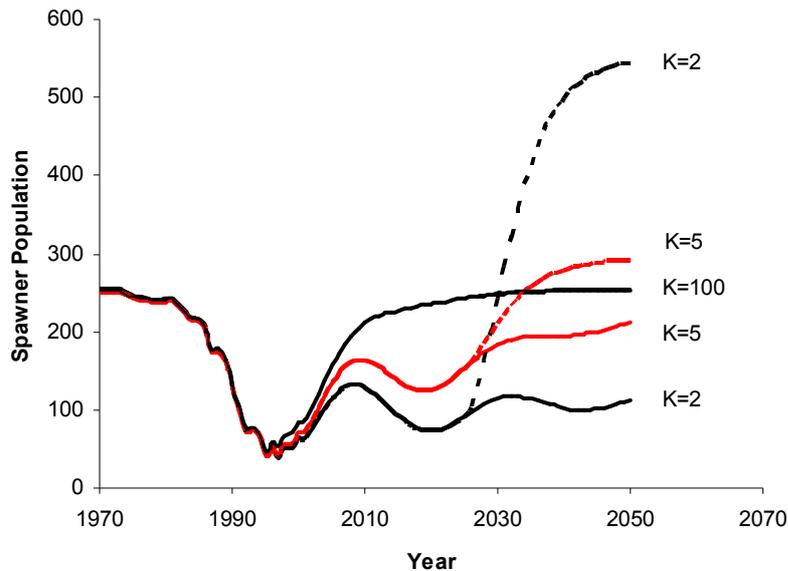
Predictions of spawner population abundance in 2030 for different levels of annual catch (numbers of mature fish caught) between 2007 and 2030 are given in Fig. 18. Predictions for the most likely level of recruitment compensation ( $K=5$ ) are similar for the two assumed levels of natural mortality. Only if harvesting is restricted to less than five mature fish per year will the spawner population rebuild to 'pre-boom' level of abundance of 250 fish by 2030. Harvesting 10-15 fish per year would stabilize the population at the current, very low level of about 145 spawners. Harvesting more than 15 fish would lead to further population decline. The analysis shows clearly that, if population rebuilding is to be achieved at all, harvests should be limited to a basinwide maximum of 10 mature fish per year. Lower harvest levels are desirable to achieve faster rebuilding.



**Figure 18.** Predicted spawner population in 2030 for different levels of annual catch (number of mature fish caught) between 2007 to 2030. Red horizontal lines show the abundance in 2006 (solid line) and prior to the Chiang Khong fishing boom. Predictions for  $M_r = 0.12 \text{ year}^{-1}$  (black solid lines) and  $M_r = 0.12 \text{ year}^{-1}$  (blue dotted lines).

### ***Releases of captive-bred fish***

Captive-bred could be released to raise recruitment to the level estimated for the unexploited population, thereby speeding up recovery without exceeding the estimated carrying capacity for recruits. If 'traditional' levels of fishing are maintained and captive-bred fish are released from 2010 onwards at a level commensurate with natural carrying capacity, this would raise spawner population abundance from about 2025 onwards, but only under medium-low recruitment compensation (Fig. 19). In all cases except for very low recruitment compensation ( $K=2$ ), complete cessation of fishing for MGC would lead to faster recovery than releases of captive-bred fish.



**Figure 19.** Impact of releases of captive-bred recruits on predicted spawner population change, at ‘traditional’ levels of fishing mortality. Dotted lines show the effect of releasing captive-bred recruits at a rate that raises total recruitment to  $R_0$  (recruitment in the unexploited population). Predictions for  $M_r = 0.12 \text{ year}^{-1}$  only.

### **Recruitment failure**

Recruitment failure could result from destruction of spawning or juvenile habitat, or from depensatory (Allee) effects at low spawner abundance. The effects of recruitment failure would be visible only some 15-20 years after it first occurs (Fig. 13).

### **3.6 Implications of violating model assumptions**

What are the implications of violating the key assumptions underlying the baseline model?

- MGC in the Mekong basin form a single population (all catches have been taken from the same population). If there were several populations, for example one above and one below the Khone Falls, then the assessment would be representative primarily of the population best represented in the data. This is clearly the population upon which the Chiang Khong fishery acts.
- The full population is vulnerable to fishing (there are no un-fished and thus, unobserved local populations). If there are un-fished population segments, these would simply add to the total population which would thus be larger than estimated. The assessment based on known catches would then over-estimate the impact of fishing on the population.
- Reporting of MGC catches is near-complete and not size-biased (There is no unreported harvest of small MGC). If there was a significant unreported catch of small MGC, this would not affect the assessment of the known fishery for larger fish. However, it would imply that the unexploited population may have been substantially larger than estimated here.

### **3.7 Key uncertainties and need for further research**

The population assessment for the period 1980-2000 is likely to be fairly robust, i.e. there is limited uncertainty regarding the population abundance immediately prior to, and during the Chiang Khong fishery 'boom'. This is because the catches have had a strong impact on CPUE and population structure which allows us to estimate population numbers with a high degree of certainty.

Longer-term changes prior to this period are somewhat less certain, for two reasons:

- If there has been significant harvesting of early juveniles, the abundance of a fully unexploited population may have been substantially higher than predicted by the baseline model.
- It is also possible that population carrying capacity has undergone long term, directional or cyclical changes in the past.

In addition to this, there are two issues that may impinge on future recovery:

- Recent habitat modifications may have reduced spawning and nursery habitat and thus, recruitment.
- Extreme reduction in spawner abundance due to the Chiang Khong fishing 'boom' may have pushed the population into a depensatory range of the stock-recruitment relationship (Allee effect).

The scope for resolving these uncertainties by anything other than long-term monitoring is extremely limited. The only area that could be addressed by short-term research is the question to what extent small juvenile MGC may be harvested but not reported. All other issues will be resolvable only in the long term thorough continued monitoring and confrontation of such data with model predictions. Given catfish life history and selectivity of the known fisheries, any impacts on reproduction or early juveniles would become apparent only 10-20 years after their occurrence.

Long-term data series are of utmost importance to conservation management of the MGC. Such data should be collected in the most consistent way possible and efforts should be made to increase consistency in historical data by carefully investigating changes in fishing practices. The Chiang Khong fishery provides an invaluable long-term record of an MGC abundance indicator. The value of past data could be greatly increased by revising the measure of fishing effort, from the number of licensed boats to estimates of days fished or a similar measure. This may be done through careful research of oral and written history. Continuation of the Chiang Khong data series into the future, with improved effort recording and strict limits on the level of total harvest, would make a key contribution to monitoring population change.

## **4 Role of captive bred and cultured fish**

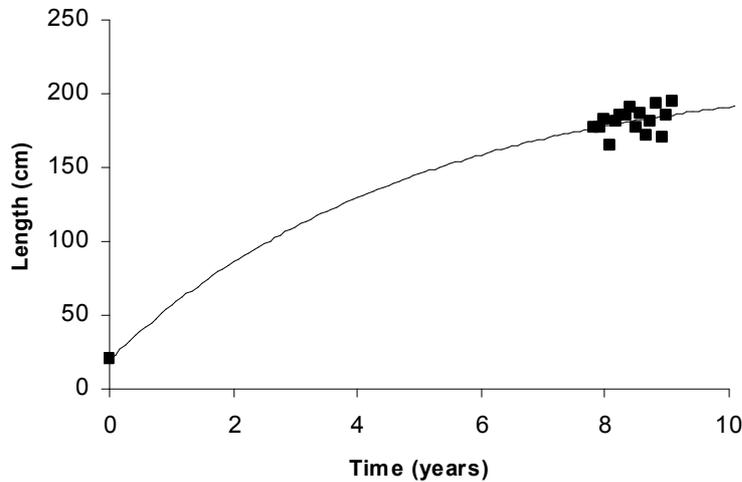
Captive bred and cultured fish could play an important role in future population change, due to either deliberate release or accidental escape from aquaculture facilities. We have briefly examined the impacts of captive releases on recovery of the spawner population in Section 3.5.5. In this chapter we estimate survival and growth parameters for MGC released into the semi-natural environment of reservoirs, and provide an exploratory analysis of likely impact of Mekong releases on the wild population.

### **4.1 Survival, growth and reproduction of released giant catfish**

#### **4.1.1 Reservoir stocking**

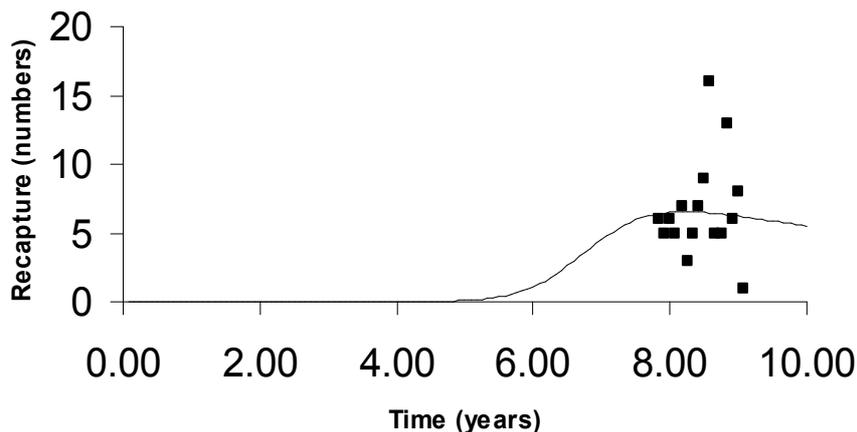
Giant catfish are widely stocked into reservoirs in Thailand, where they appear to survive and grow well but are not known to mature or spawn. Stocking and recapture data were analysed for Sirikit reservoir in Thailand.

Growth parameters of MGC in Sirikit reservoir were estimated as  $L_{\infty} = 210$  cm and  $K = 0.2 \text{ year}^{-1}$  (Fig. 20). The stocked fish thus appear to grow at a higher rate but to a lower asymptotic size than the wild fish in the Mekong. This is consistent with the general observation that cultured fish, even after release, show an accelerated life history (Lorenzen 2000, Thorpe 2004).



**Figure 20.** Growth of giant catfish stocked into Sirikit reservoir

It is not possible to estimate natural and fishing mortality rates from the recapture data because the time series is too short and does not include the period when stocked fish first entered the fishery (Fig. 21). It is possible, however, to determine broad limits to both parameters. It appears that natural mortality in the stocked reservoir population can not be much higher than the wild population baseline value of  $M_r = 0.15 \text{ year}^{-1}$  at  $L_r = 200$  cm, as otherwise the observed catches could not be achieved. We therefore conclude that released captive-bred fish survive well in reservoirs.



**Figure 21.** Recapture of giant catfish stocked into Sirikit reservoir. Note that no data were collected for the first 7.5 years after release.

#### 4.1.2 Mekong river stocking

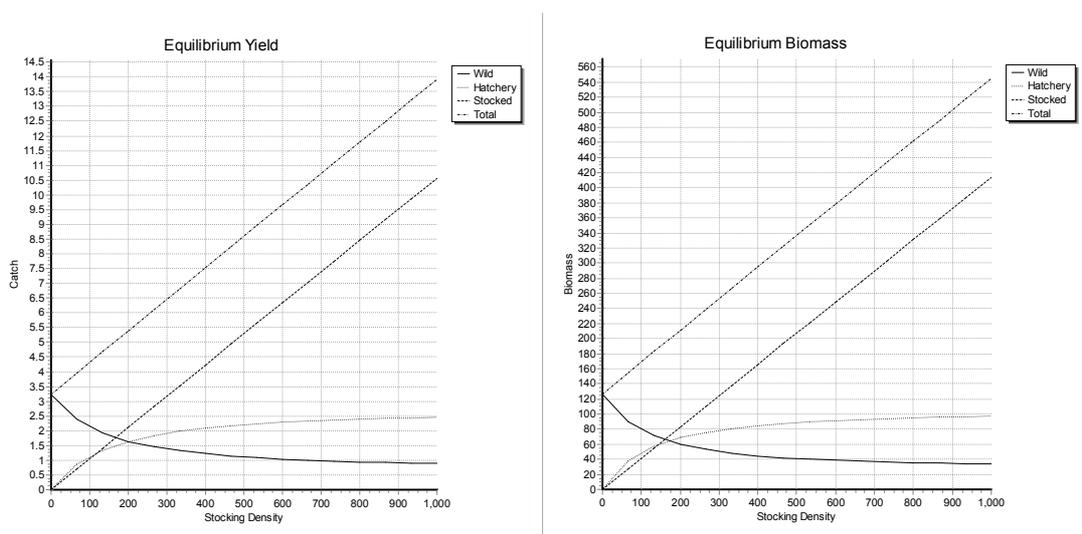
There have been several releases of marked and unmarked, captive bred fish into the Mekong River. The fate of these fish is poorly known. A small number of stocked fish are typically recaptured by fishermen shortly after release. Mitamura (2005) reports that 4 out of 28 released

MGC (75 cm total length) were recaptured, all within two weeks of release. The remaining fish could be radio-tracked for up to three months. Given the gear selectivity patterns established above, stocked fish are unlikely to enter the fishery for some 10-20 years after release. Releases only started in the mid-1980s and therefore any survivors may only now enter the fishery. Hence lack of recaptures so far need not indicate lack of stocking success.

#### 4.2 Potential effects of releases on the wild population

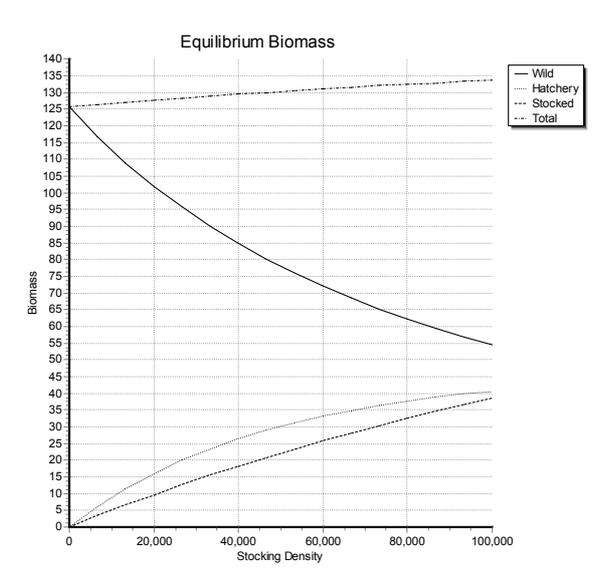
To assess the impact of deliberate or accidental releases of cultured fish on the wild population, the fisheries enhancement model of Lorenzen (2005) was used as implemented in the *EnhanceFish* package.

Captive-bred and cultured fish were assumed to show the same growth and mortality patterns as wild fish, and to be reproductively competent. The impacts of releasing large 'recruits' (fish of 100 cm length) are shown in Fig. 22. Releases are predicted to increase total fisheries yield and population biomass, but to depress the wild population component. Even a moderate release of about 300 recruits would result in a significant wild population impact. This of course is a result of the estimated, very low wild population carrying capacity combined with wild-like fitness of released fish.



**Figure 22.** Impact of releasing recruits (100 cm fish) on yield and total biomass of MGC population components.

Most deliberate MGC releases have been of smaller fish of about 10-20cm length. Such fish undergo relatively high and most likely, density-dependent mortality before even reaching the 100cm length considered above. Releases of a few hundred or even thousands of 20cm fish per year are predicted to have little impact on total yield, and depress wild population biomass only moderately (Fig. 23). Limited, e.g. ceremonial releases of small captive-bred MGC can be conducted without posing a major threat to the wild population.



**Figure 23.** Impact of releasing juveniles of 20 cm length on biomass of MGC population components.

## 5 Implications for conservation strategy development

### 5.1 Threat assessment

#### 5.1.1 Fishing

The know fishery targeting large MGC appears to be less of a threat to population persistence than previously thought. The highly size-selective nature of the fishery and the low level of incidental harvesting imply that the population is quite resilient to overfishing. A moderate level of traditional fishing can probably be allowed without compromising population viability, and may be overall beneficial in terms of providing long-term monitoring data and maintaining public interest in the species. It is important however to ensure that fishing intensity remains well below the levels seen at the height of the Chiang Khong fishery, and that there is no increase in incidental catches (e.g. due to new gear development). The current assessment of sustainable catch levels may need to be revised should population dynamics be affected by other threats.

The extent to which small juveniles of less than 100 cm length are subject to exploitation remains unknown. If there was significant exploitation at this stage, this could have a strong effect on population abundance. Such exploitation would however be entirely incidental (MGC are neither targeted, nor indeed known to be caught by the gill net fisheries exploiting this size range), and very difficult to address without placing strong restrictions on the mainstay of Mekong fisheries. The latter of course is not a realistic proposition and therefore possible exploitation of juvenile MGC is in effect an external factor.

#### 5.1.2 Habitat degradation

Habitat degradation is unlikely to have played a major role in past population change, but may play a larger role in the future as population growth and economic development lead to increased utilization of the Mekong and associated natural resources.. The most important known threats are likely to be navigational improvements and hydrological change at the spawning grounds, and loss of access to juvenile habitat due to damming of Mekong tributaries. Modification of spawning habitat may be the most acute threat, and one that will be detectable in the adult population only about 20 years after any impact. Loss of access to juvenile habitat is likely to result in a reduction of carrying capacity.

### 5.1.3 Interactions with cultured fish

The small population size and low carrying capacity of the Giant catfish make the population vulnerable to ecological and genetic interactions with released cultured fish.

## **5.2 Prioritisation of conservation measures**

A synthesis and preliminary appraisal of current and potential conservation measures was carried out at previous workshops (see MGCWG 2005). It was noted on these occasions that there was little 'hard' information on the effectiveness of any of the conservation measures. The quantitative assessment provides new insights with important implications for the prioritisation of conservation measures.

### 5.2.1 Reducing exploitation of the wild population

Reducing exploitation of the wild population was seen as the most important immediate conservation priority, and related initiatives have been targeted at the Chiang Khong and Tonle Sap River fisheries.

Our analysis has identified fishing as the main driver of past changes in population abundance and structure. The exceptionally intensive Chiang Khong fishery in the 1980s and 90s in particular is likely to account for the dramatic population decline observed over this period. The population has since recovered slightly, but remains in a very depleted state. Only very low levels of harvest (up to 10 mature fish basinwide) can be sustained until 2030 if the population is to recover from its current state. Within this limit, the lower the harvest the faster population recovery will occur. A very low level of targeted fishing could be allowed to provide long-term population monitoring data and promote public awareness of the species and the wider Mekong ecosystem.

The extent to which small juveniles of less than 100 cm length are subject to exploitation should be further investigated. It is unlikely that any such incidental exploitation can be reduced significantly in the short term, however. In the longer term, fishing effort may decline overall as economic development provides alternative opportunities for fishers.

### 5.2.2 Habitat management

Habitat conservation was perceived to be a major priority for current and future conservation action, due to the fact that potentially detrimental activities such as rapids blasting and construction of dams on major tributaries are likely to intensify. This priority remains unchanged. Perhaps the most important habitat conservation priority concerns the likely spawning grounds of the MGC near Chiang Khong, which may be crucial to the survival of the whole wild population.

### 5.2.3 Supportive breeding

The captive breeding programme was identified as an important 'insurance' for species survival in case of wild population extinction. This view remains unchanged. Captive bred fish could be used to re-establish a wild population should this indeed become extinct.

The assessment suggests, however, that at present the MGC population is undergoing natural recovery from excessive harvesting of large fish during the 1980s/90s, and that releases of captive bred fish would make at best a very minor contribution to recovery. At worst, releases would threaten recovery of the wild population through ecological and genetic interactions with captive fish that are likely to be moderately compromised in their fitness in the wild. Hence releases of captive-bred fish into the Mekong should not be carried out at present, or only in very small numbers.

#### 5.2.4 Aquaculture escapees

Prevention of escapes into the Mekong mainstream from MGC aquaculture was tentatively identified as important. The current analysis suggests that even moderate escapes of a few tens or hundreds of animals can lead to significant replacement of wild with captive/cultured types provided that the latter survive well in the wild and reproductively competent. Results of MGC stocking in reservoirs suggest that cultured fish can survive well in semi-natural environments. Preventing escapes should be a high conservation priority.

## **6 Conclusions and recommendations**

Population status. Reconstructed spawner abundance was relatively stable at about 250 animals prior to 1983 (11-71% of unexploited abundance). The population then declined dramatically to just 50 spawners in 1995 (2-14% of unexploited abundance). The Chiang Khong fishing 'boom' thus reduced spawner abundance by about 80% in just ten years. The population has since recovered to about 145 animals (7-40% of unexploited abundance) by 2006.

Fishing can be identified as the main driver of past changes in population abundance and structure. The exceptionally intensive Chiang Khong fishery in the 1980s and 90s in particular is likely to account for the dramatic population decline observed over this period. The population has since recovered slightly, but remains in a very depleted state. Only very low levels of harvest (up to 10 mature fish basinwide) can be sustained until 2030 if the population is to recover from its current state. Within this limit, the lower the harvest the faster population recovery will occur. A very low level of targeted fishing could be allowed to provide long-term population monitoring data and promote public awareness of the species and the wider Mekong ecosystem.

Habitat and environmental change in the Mekong basin has been gradual and of moderate magnitude until the very recent past, and it is unlikely that this has been a significant factor in past population change. More dramatic changes may have occurred in the very recent past (with 'rapid blasting' and the commissioning of several dams in the upper river), and this trend is likely to continue in the future. Maintaining the overall Mekong ecosystem (flows, physical habitats and connectivity) clearly is important to ensuring the long-term survival of the species in the wild. Given that habitat use and migration patterns of the species are largely unknown, no essential habitat can be identified except for the spawning area. The spawning area is very likely to be located within some 50 miles north of Chiang Khong, and it can be clearly identified as essential habitat. An immediate priority should be to protect this habitat.

Captive breeding. The captive population of MGC maintained by the Thai Department of Fisheries provides a vital 'insurance', safeguarding the survival of the species should it become extinct in the wild. The captive population should be managed carefully so as to conserve its genetic diversity, should re-introduction become necessary. For the time being, captive-bred fish should not (or only in very low numbers) be released into the Mekong or its tributaries because the wild population is likely to recover naturally.

Interactions with cultured fish are unlikely to have played a significant role in past population change, but may become a major issue in the future due to both intentional and accidental releases. At present the cultured population is likely to exceed the wild population in abundance. Escapes of MGC grown in commercial aquaculture could pose a significant threat to the wild population. Measures should be taken to minimize the risk of such escapes occurring. It should be noted that, because the wild population carrying capacity appears to be quite low, releases of even low numbers of captive-bred fish can have significant impacts on the wild population.

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## Appendix 1: Details of the population model

### Population and catch equations

The fish population is divided into length groups, so that the population at time  $t$  is represented by a vector  $n_t$ , of numbers at length. The population equation computes this vector for time  $t + dt$ :

$$n_{t+1} = G S (n_t + r_t)$$

where  $G$  is the growth projection matrix,  $S$  is the survival matrix, and  $r_t$  is the vector of fish stocked at length at time  $t$ .

The corresponding catch equation gives the vector  $c$ , of catch at length obtained during the time interval from  $t$  to  $t + dt$ :

$$c_t = G H (n_t + r_t)$$

where  $H$  is the harvesting matrix.

### Growth projection matrix

The element  $g_{ij}$  of the growth projection matrix is the proportion of fish in the initial length group  $j$  that contributes to the final group  $i$ . The matrix is constructed using the algorithm of Shepherd (1987), based on a von Bertalanffy growth model:

$$l_t = l_\infty - (l_\infty - l_{t-dt}) \exp(-k)$$

where  $l_\infty$  is the asymptotic length and  $k$  is the growth rate parameter.

### Survival matrix

The elements  $s_{jj}$  of the diagonal survival matrix are the proportions of fish in length class  $j$  at time  $t$  survive to time  $t + dt$ . Survival  $s_{jj}$  is a function of the size dependent natural mortality rate  $M_j$ , fishing mortality rate  $F$ , and gear selectivity  $v_j$ :

$$s_{jj} = \exp(-(M_j + F v_j) dt)$$

Natural mortality is modelled as an inverse function of length:

$$M(l) = M_1 \frac{1}{l}$$

where  $M(l)$  is the natural mortality rate at length  $l$ , and  $M_1$  is the natural mortality rate at unit length.

Gear selectivity is given by a logistic function

$$v_j = \frac{1}{(1 + \exp(q(l_c - l_j)))}$$

where  $l_c$  is the length at 50% gear selection and  $q$  describes the steepness of the selectivity curve.

### **Harvesting matrix**

The elements  $h_{jj}$  of the diagonal harvesting matrix are the proportions of fish in length class  $j$  that are harvested during the time interval  $[t, t + dt]$ :

$$h_{jj} = [Fv_j / (M_j + Fv_j)] [1 - \exp(-(M_j + Fv_j)dt)]$$

The corresponding catch equation gives the vector  $c$ , of catch at length obtained during the time interval from  $t$  to  $t + dt$

### **Recruitment**

The spawning stock biomass at length is described by a vector  $b_t$ :

$$b_t = G W (n_t + r_t)$$

The elements of the diagonal reproduction matrix  $W$  are given by

$$w_{jj} = m_j \alpha l_j^\beta$$

where  $m_j$  is the proportional maturity, given by a logistic curve

$$m_j = \frac{1}{(1 + \exp(p(l_m - l_j)))}$$

with  $l_m$  the length at 50% maturity and  $p$  the steepness of the maturity curve.

The total spawning stock biomass is then

$$B_t = \sum_j b_j$$

and the recruitment vector is

$$r_j = \begin{cases} \frac{K(R_0 / B_0)B_t}{1 + [(K - 1) / B_0]B_t} & \text{for } j \text{ the size class of recruits} \\ 0 & \text{for all other size classes} \end{cases}$$

where  $K$  is the compensation ratio,  $R_0$  is the maximum number of recruits, and  $B_0$  is the spawning stock biomass for an unfished population with recruitment  $R_0$ .

### **Model fitting to data**

The model was fitted to the time series of fisheries CPUE as follows. Fishing mortality rates  $F_t$  for each year were estimated from the observed catches  $C_t$  and the predicted population vulnerable to fishing:

$$F_t = -\ln \left( 1 - \frac{C_t}{\sum_j v_{j,t} N_{j,t}} \right)$$

The fishing mortality rates estimated in this way were then used to project the population to the next year, i.e. observed catches were used to 'drive' the population trajectory, along with the modelled recruitment, growth and mortality processes.

Predicted catch per unit of effort (CPUE) was calculated as

$$U_{t,pred} = c \sum_j v_{j,t} N_{j,t}$$

where  $c$  is the catchability coefficient.

Recruitment parameters and catchability were then estimated by minimizing the sum of squared differences between observed and predicted CPUE, using numerical search.

## Appendix 2: Quantitative assessment workshop

A preliminary version of this report was discussed, and the analyses refined, at a quantitative assessment workshop held in Vientiane, Lao PDR, 10-11 August 2006. The workshop was attended by 23 members of the Mekong Giant Catfish Working Group.



**Figure A2.1.** Mekong Giant Catfish Working Group members at the quantitative assessment workshop.

The following issues were discussed at the workshop:

### The number of boats fishing may not be a good measure of fishing effort.

More detailed measures such as days fished may be desirable but can not be developed retrospectively. The CPUE time series used (measured in fish per boat per season) shows a clear pattern of decline with increasing removal from the population, and thus does appear to be a reasonably sensitive (if not necessarily proportional) measure of relative abundance. Quality of the CPUE time series is flagged up as a source of uncertainty in the analysis.

### What is a reasonable baseline for population recovery – 1970s or much earlier?

The model-based reconstruction provides estimates of unexploited population abundance, and these are the best estimates of historical abundance available to us. Lack of quantitative historical catch data makes it difficult to estimate historical population abundance. However, it appears that even under the most “positive” assumptions the population has never supported very high catches, and is unlikely to have been much larger than the unexploited abundance estimates obtained from the analysis.

### What are the implications if there were two separate populations of MGC above and below the Khone Falls?

See main report Section 3.6.

Can the effects of environmental changes be included in the model?

It appears that past population change was driven primarily by fishing, while habitat and environmental change were limited and gradual. Hence it was not possible to detect environmental influences in the data or to estimate related functional relationships. Environmental influences can be incorporated into the predictive model, but the underlying functional relationships have to be based on assumptions (e.g. carrying capacity could be assumed to be linearly related to floodplain wetland area).

Can the model be applied to other large migratory fish species in the Mekong?

In principle, yes. However, the model and analysis have been so informative mainly because (1) fairly detailed and long-term data were available for the Northern Thai/Lao fishery and (2) the fishery had a strong impact on population abundance over the period for which data are available. No comparable data exist for other species, and any analyses are therefore likely to be less informative.

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3	Mr Sam Nuov	Deputy Director	Department of Fisheries
4	Mr Srun Lim Song	Director	IFReDI/Department of Fisheries
5	Mr Thach Phannara	Researcher	IFReDI/Department of Fisheries
<b>LAO PDR</b>			
6	Mr Sompanh Phanousith	Head of Aquaculture Unit	Living Aquatic Resources Research Center (LARREC)
7	Mr Khamphet Roger	Deputy Director	Living Aquatic Resources Research Center (LARREC)
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<b>VIETNAM</b>			
12	Nguyen Van Trong	Deputy Director	Research Institute for Aquaculture No. 2
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13	Dr Thuy Nguyen	Genetics specialist	NACA
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