Matching-up the Population Dynamics of Mekong Giant Catfish with Conservation and Management Strategies

Naruepon Sukumasavin, K. Lorenzen and *Z. S. Hogan*

A charismatic aquatic species revered throughout the Mekong River, the Mekong giant catfish (*Pangasianodon gigas*) is one of the world's largest freshwater fishes and is considered critically endangered (IUCN Red List, 2003). A range of conservation initiatives for the giant catfish are being carried out, and this article assesses the conservation status of the Mekong giant catfish and evaluates the likely effectiveness of such conservation measures. The synthesis and analysis of detailed data that were collected intermittently since the late 1960s, through the application of mathematical models, seemed to suggest that very low level of targeted fishing could be allowed to provide long-term monitoring of population data, and that public awareness of the species and the wider Mekong ecosystem should be enhanced. Maintaining the overall Mekong ecosystem (flows, physical habitats and connectivity) is however important to ensure the long-term survival of the species in the wild. Although the captive population of the catfish appears to be sustainable, safeguarding the survival of the species should be ensured before this species becomes extinct in the wild. Captive population should also be managed carefully to conserve its genetic diversity, in the event that re-introduction might become necessary. While the wild population carrying capacity appears to be quite low, releases of even low numbers of captive-bred fish could create significant impacts on the wild population. Moreover, considering that escapes of catfish grown in commercial aquaculture could pose significant threat to the wild population, measures should be taken to minimize the occurrence of such escapes.

The Mekong giant catfish (*Pangasianodon gigas*) or MGC is listed as critically endangered in the IUCN Red List as a result of excessive targeted fishery and incidental harvesting over the past twenty years, and to a lesser extent habitat degradation. Given the critical state of the MGC population, conservation and eventual recovery would require a combination of measures such as captive breeding, reduced harvesting, and conservation/restoration of critical habitats. Although a number of conservation initiatives and programs focusing on the MGC had been carried out, an overall conservation and recovery strategy has not been established. Meanwhile, the effectiveness of measures taken so far is largely unknown, and some measures are even believed to be conflicting or detrimental (Sukumasavin, *et al*., 2014).

Giant Catfish Fishery and Environmental Changes in the Mekong Region

Giant catfish fishing

Historically, the MGC is being captured in targeted fishery in various parts of the Lower Mekong Basin (**Fig. 1**). Targeted fishery for the species has generally been associated with festivals of spiritual significance. Although occurring only in

A
Regular catches in Chiang Khong/Huay Xai drift net fishery

B
Tonle Sap bag net fishery

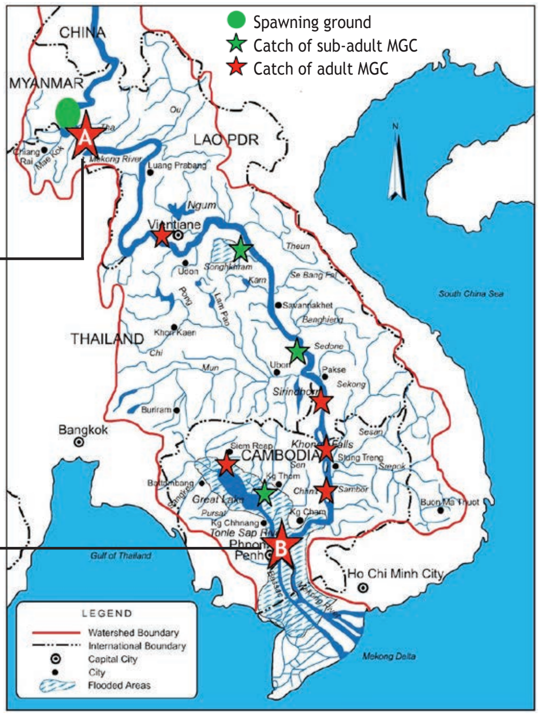

Fig. 1. Map of the Lower Mekong Basin (big stars indicating locations where Mekong giant catfish have been regularly caught in fisheries in recent years: (**A**) Chiang Khong/Huay Xai in Northern Thailand and Lao PDR, and the Tonle Sap River in Cambodia (**B**))

certain locations and making use of specially constructed very large-mesh nets, such fishery targets the MGC during their spawning migration through narrow channels at low water level where MGC becomes prone to harvesting.

Thus, incidental catches of MGC are relatively rare as the fishery is largely confined to what is known as migratory 'bottlenecks'. For example, 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, while low incidental catches have also been reported from the Khone Falls area. Incidental catches elsewhere are extremely rare and do not appear to follow any identifiable pattern. The history of MGC fishing at various locations in the Mekong River could be gleaned from **Fig. 1**. Nevertheless, insufficient information on the MGC fishing prior to about 1930 has made the analysis of the pre-1970 data difficult to undertake due to lack of continuity.

Nonetheless, most accounts provide only snapshots of catches in particular locations, sometimes with vague references to previous 'average' catch levels. Although several reports mentioned catch declines, such reports do not clearly state whether these refer to overall, long-term decline or 'boom and bust' cycles in the fishery. As a matter of fact, 'high' local catches of about 50 individuals followed by declines in catch and catch per unit of effort have been reported for various locations. Such reports however do not indicate whether catches of such magnitude have ever been sustained in the long term.

In interpreting the catch data, it is important to consider that catches are influenced by both fish abundance and fishing effort, and that catch declines are not necessarily indicative of population decline. The armed conflict throughout the region in the 1970s, particularly the Khmer Rouge regime in Cambodia resulted in the virtual cessation of MGC fishing in many locations. Fishing that time was considered dangerous in the Mekong River Basin especially the area that borders Thailand and Lao PDR, including 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.

Fishing history at Chiang Khong District, Chiang Rai Province in Northern Thailand

The targeted fisheries in Chiang Khong District of Northern Thailand and in neighboring Huay Xai of Lao PDR, is a particularly important element of MGC exploitation and assessment. Such fisheries dominated the overall catches since 1980s providing the most detailed data on the currently available population. There is however, no clear record when MGC fishing begun in Chiang Khong District of Chiang Rai Province in Thailand. Nonetheless, based on interviews with local fishers, fishing for the MGC has been practiced for more than 70 years, and fishing period is about one (1) month from April to May every year when the fish migrate to their spawning grounds, which is somewhere around the "Golden Triangle," the area that overlaps the mountain ranges of Myanmar, Lao PDR and Thailand. Meanwhile, the catch statistics for MGC from Chiang Khong/Huay Xai area from 1973 to 1995 were recorded by Borkeo Province of Lao PDR. In Thailand, the Department of Fisheries (DOF) recorded the MGC catches since 1983, when its program on the artificial breeding of the Mekong giant catfish was started.

Based on recorded data from 1973 to 1983, the catches varied from 1 to 6 heads per year with an average of 3 heads per year. After 1983, when the DOF Thailand had succeeded in the artificial spawning of wild-caught MGC from the Mekong River, catches from 1984 to 2000 increased to an average of 29 heads per year, with a maximum of 71 heads. This dramatic increase in MGC catches reflected a massive increase in fishing effort between 1983 and 1990, fuelled by the high demand for MGC of DOF Thailand for its captive breeding program, as well as from the local tourism industry. This developed as public awareness about the fisheries and on the captive breeding program had increased, and massive promotion campaign dwelling on local people's belief that eating MGC would lengthen one's life, had been intensified. Furthermore, catch rates (CPUE) in the fishery declined to a minimum in the mid-1990s while the effort also diminished resulting from both low catch rates and alternative economic opportunities. Nevertheless, from 2000 to 2003, no MGC were caught at Chiang Khong District which was attributed to rapid blasting in the mainstream of the Mekong River for navigation and construction of a port in Chiang Khong. When the said construction was completed, 7 heads were caught in 2004, and 4 heads in 2005. However, a conservation campaign advocated 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 MGC fishers in Thailand and Lao PDR.

Environmental changes in the Mekong River Basin

Environmental changes in the Mekong River Basin had been observed to be gradual and considered moderate in magnitude until the very recent past. Land had also gradually become more agricultural and the hydrology showed no marked changes since the start of a systematic recording in 1960, contrary to widespread perceptions that dams cause significant changes in the water flow. Although access to some tributaries and the upper Mekong/Lancang might have been restricted by the dams, the total area potentially lost accounted for only a moderate proportion of the basin. Nonetheless, more dramatic changes may have occurred in the very recent past with the 'rapid blasting' and the commissioning of several dams in the upper river, but any effects of these changes on the MGC population have not been visible in the data. Therefore, fishing has been identified as the main driver of the past changes in the population abundance and structure of MGC in the Mekong River Basin.

Assessment of the Wild Population of Mekong Giant Catfish

Population model and parameter estimation

Length-structured matrix population model was adopted as the main assessment tool for determining the status of the wild population of MGC. The recruited population was divided into length groups, and the model population and catch numbers grouped into length over time. The detailed data collected intermittently since the late 1960s were then synthesized and analyzed with the use of a mathematical model, taking into consideration certain assumptions that underlie the baseline model (**Box 1**). An overview of the model parameters and their baseline values is shown in **Table 1**.

Box 1. Assumptions on the parameters considered for the baseline population model

Assumptions	Means of verification
MGC in the Mekong Basin form a single population	All catches have been taken from the same population
Full population is vulnerable to fishing	No reports on un-fished and unobserved local populations
Reporting of MGC catches is near-complete and not size-biased	There is no unreported harvest of small MGC

Assessment of the population status of MGC: Model Fitting

Most of the parameters used for model fitting were estimated from the subsets of data or comparative information shown in **Table 1**, but only the level of recruitment R_0 in the unexploited population B_0 and the catchability coefficient **c** (a constant proportionally relating CPUE to the absolute abundance) were estimated by fitting the model into a time series for fisheries data. The data set used for model fitting was the CPUE time series for the Chiang Khong/Huay Xai fisheries. Fitting the model to CPUE data started with equilibrium solutions for a variety of plausible exploitation scenarios during 1960s-70s and levels of recruitment compensation running forward through 1973-2005. In each year, the model population was reduced by the actual (reconstructed) catches and the action of natural mortality but new recruits were also gained based on the stock-recruitment relationship. Recruitment of the unexploited population R_0 and the catchability coefficient **c** were then estimated by numerically searching for values that provide the best fit to the CPUE data. As previously highlighted, key uncertainties in population assessment include the level of natural mortality such as exploitation rate prior to the Chiang Khong fishing boom, and the level of recruitment compensation. A variety of scenarios, *i.e.* E1970s and K, allowed acceptable model fits based on the available catch and CPUE data (**Table 2**). However, there is no strong basis for discriminating among the fits those that

Table 1. Model parameters and their baseline values

Parameter	Definition	Value				
Life cycle						
• L_r	• Length at recruitment	100 cm				
• a_r	• Age at recruitment	10 years				
Growth						
• L_∞	• Asymptotic length	290 cm				
• K	• Growth rate	0.1 $year^{-1}$				
• α	• Coefficient of l-w relationship	4.0 x 10^{-5} cm				
• β	• Exponent of l-w relationship	2.8				
Natural mortality						
• M_r	• Natural mortality rate at L_r	0.15 $year^{-1}$				
• L_r	• Reference length for M_r	200 cm				
Reproduction						
• L_m	• Length at maturity	224 cm				
• p	• Steepness of maturity curve	-0.2				
Recruitment for M_r at 250 cm		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	• Fishing mortality rate in fully exploited size groups	Variable				
• L_c	• Gear selection length	224 cm				
• q	• Steepness of selectivity curve	-0.1				
• c	• Catchability coefficient	0.00417 $boat^{-1}$				

Source: *Adapted from Sukumasavin,* et al. *(2014)*

were associated with these alternative scenarios. As a result, all acceptable model fits predicted a spawner abundance of about 250 heads which could have been possible at the start of the Chiang Khong 'fishing boom.' At any rate, the estimates of unexploited spawner abundance vary from 355 to 2,200 heads (**Table 2**). Hence, the abundance at the start of the Chiang Khong 'fishing boom' represented between 11% and 71% of the unexploited abundance. Furthermore, natural mortality rate $M_r = 0.12$ year^{-1} at l_r=250 cm which was used as baseline (grey column in **Table 2**), while some predictions were made for $M_r = 0.06$ year^{-1} at l_r=250 cm (blue column in **Table 2**). The results indicated that the models provide a good overall fit to the observed CPUE time series as shown in **Fig. 2**. The models which provided very similar CPUE and abundance estimates for much of the period but diverged somewhat towards the end, thus predicted the same abundance prior to the Chiang Khong 'fishing boom' of about 250 spawners and similar pattern of reduction during the 'fishing boom' but differ in the predicted recovery pattern. The model also reproduced the catch length distribution in 1999-2005 as shown in **Fig. 3**.

Reconstructed Population and Fishing History

The reconstructed spawner abundance (**Fig. 4**) shows a relatively stable spawner population of about 250 heads 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' therefore led to the reduction of spawner abundance by about 80% in just ten years, although the model also predicted that the population has since recovered significantly. The predicted current (2006) level of spawner abundance is estimated at 145 heads or 7-40% of the unexploited abundance.

Table 2. 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 year^{-1}) and in blue (M_r=0.06 year^{-1})

M_r at L_r=250cm E (1970s)	0.04 0.8	0.06 0.7	0.08 0.6	0.10 0.5	0.12 0.4	0.14 0.3	0.16 0.2
K=100							
Catch	-	27	29	24	20	15	-
N_0	-	860	622	501	414	355	-
Rel N	-	0.294186	0.406752	0.50499	0.611111	0.712676	-
K=5							
Catch	-	23	29	24	20	15	-
N_0	-	2200	1149	694	490	404	-
Rel N	-	0.114948	0.220191	0.364553	0.516327	0.626238	-
K=2							
Catch	-	-	-	-	20	15	-
N_0	-	-	-	-	1480	745	-
Rel N	-	-	-	-	0.170946	0.339597	-

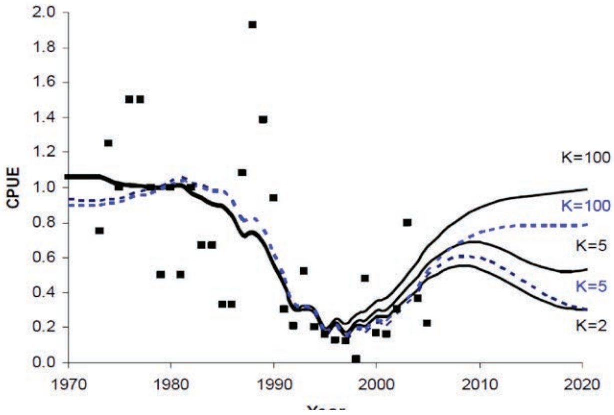

Fig. 2. Observed (*squares*) and predicted (*lines*) catch per unit of effort in the Mekong giant catfish fishery, predictions are for M_r = 0.12 year^{-1} (*black solid lines*) and M_r = 0.06 year^{-1} (*blue broken lines*)

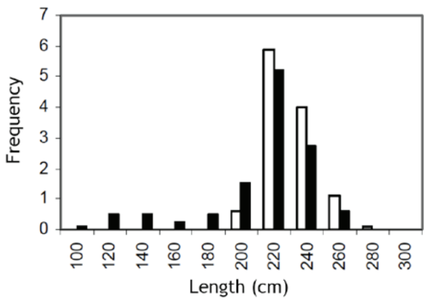

Fig. 3. Observed (*solid bars*) and predicted (*open bars*) size distribution of MGC catch in 1999-2005

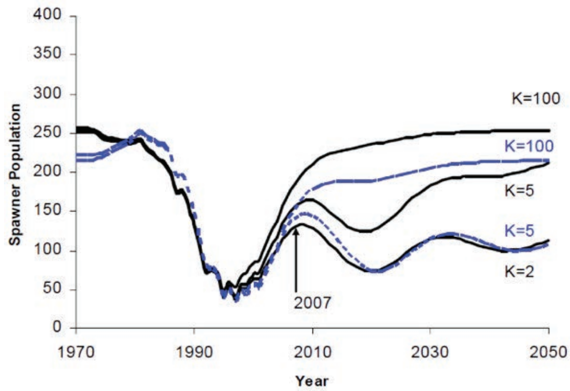

Fig. 4. Spawner population abundance reconstructed by the population model, and predicted recovery trajectories for different levels of compensatory density-dependence in recruitment, predictions are for M_r = 0.12 year^{-1} (*black solid lines*) and M_r = 0.06 year^{-1} (*blue broken lines*)

The predicted recovery of spawners until about 2010 is based largely on growth and maturation of the fish that spawned before the period of intensive fishing, which would still occur although there was no successful reproduction since 1990, and even if subsequent population development would

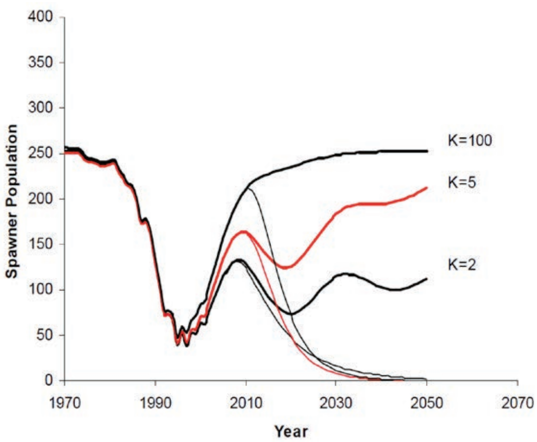

Fig. 5. Spawner population abundance predicted by the population model assuming normal recruitment or complete reproductive failure since 1990, predictions for M_r = 0.12 year^{-1}

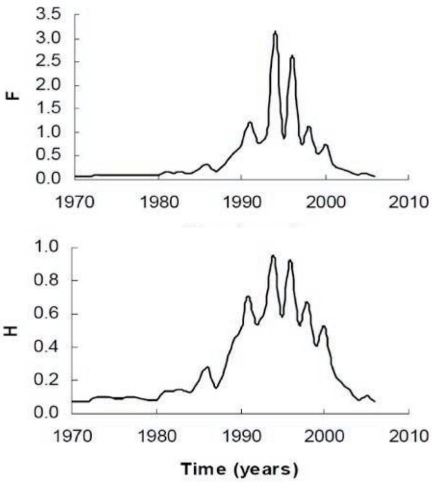

Fig. 6. Reconstructed fishing mortality **F** (*above*) and corresponding proportion of the available population harvested **H** (*below*) from 1970 to 2006, reconstruction for 1970s exploitation rate of 0.4

depend on reproduction during and after the period of very low spawner abundance. Unless recruitment compensation is extremely high (K=100, **Fig. 4**), spawner abundance is predicted to decline again between 2010 and 2020 as a result of low spawner abundance and reproduction output during the 1990s. However, even if reproduction failed entirely from 1990 onwards (*e.g.* as a result of the Allee effects or due to environmental factors), the effect would only become apparent after 2010 (**Fig. 5**). This implies that the basic life history of MGC should be taken into consideration when interpreting catch and abundance trends, and that long-term monitoring would be necessary. The model-based population reconstruction had also provided direct estimates of fishing mortality rates, where the fishing mortality pattern for M_r = 0.12 year^{-1} clearly shows a dramatic increase in fishing pressure on the mature population between 1983 and the early 1990s (**Fig. 6**). 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.* proportion of the available population harvested in the fishery. Thus, the pre-1983 and post-2004 fisheries had removed about 10% of the population per year, and in 1990-2000, over 50% of the available population was harvested annually at a maximum rate of 96% in 1995.

Potentials for Sustainable Exploitation

In assessing the potentials for sustainable exploitation of the MGC, the equilibrium (=sustainable) catch and the corresponding spawner abundance of the population were calculated, given different levels of natural mortality and recruitment compensation as shown in **Fig. 7**.

The level of natural mortality and pre-boom exploitation assumed major implications for the assessment of the

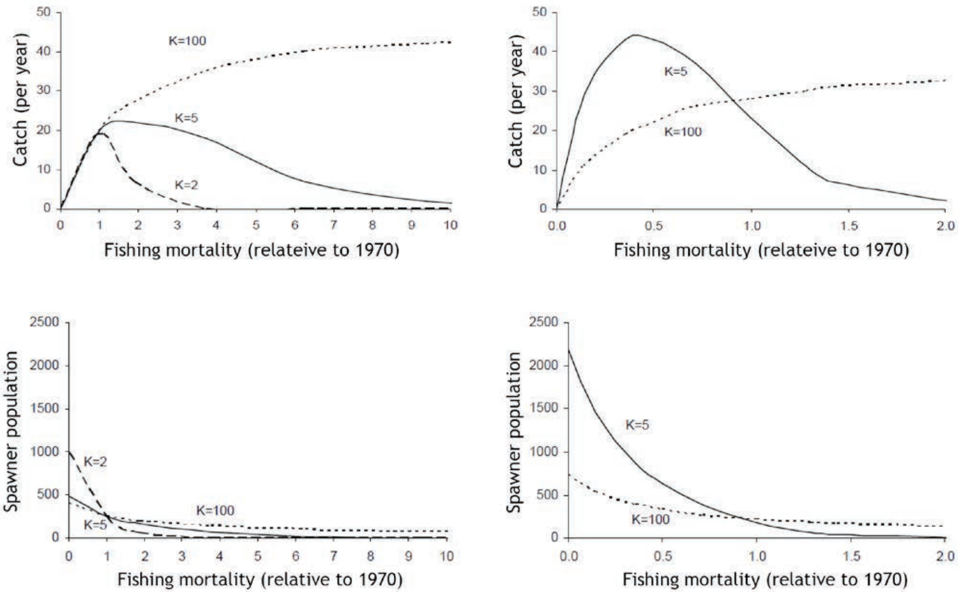

Fig. 7. Equilibrium catch (*top*) and spawner population abundance (*bottom*) of MGC in relation to fishing mortality rate F, predictions are for M_r = 0.12 year^{-1} (*left hand side*) and M_r = 0.06 year^{-1} (*right hand side*)

'traditional' (pre-boom) level of fishing. For M_r = 0.12 year^{-1} at l_r=250 cm (E1970s=0.4), traditional fishing conducted at or below the effort level provided the maximum sustainable catch. For M_r = 0.06 year^{-1} at l_r=250 cm (E1970s=0.7), traditional fishery overexploits the population if K=5, and represents a very high level of exploitation if K=100, although it is not possible at present to discriminate between these scenarios, as the true level of natural mortality and pre-boom exploitation is unknown. Such a situation however 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 attained, even for the next at least 2-3 decades. Nonetheless, the different models have very similar implications for population management in the medium term.

Release of captive-bred fish

Captive-bred MGC 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 the natural carrying capacity, this would raise the abundance of spawner population starting from about 2025 onwards but only with medium-low recruitment compensation (**Fig. 8**). Nonetheless, in all cases except for very low recruitment compensation (K=2), complete cessation of MGC fishing would lead to faster recovery than releasing captive-bred fish.

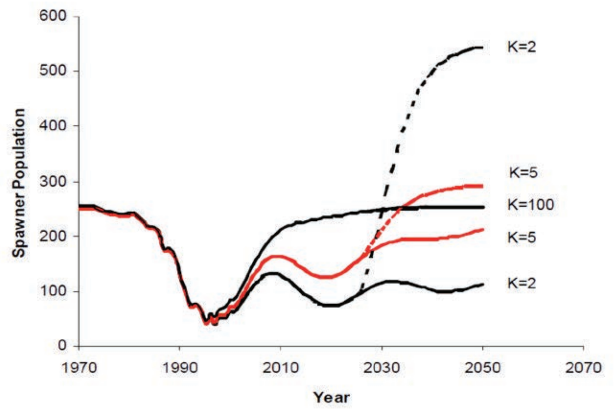

Fig. 8. Impact of releases of captive-bred recruits on predicted spawner population change, at 'traditional' levels of fishing mortality, where broken lines show the effect of releasing captive-bred recruits at a rate that raises the total recruitment to R_0 (recruitment in the unexploited population), predictions for M_r = 0.12 year^{-1} only

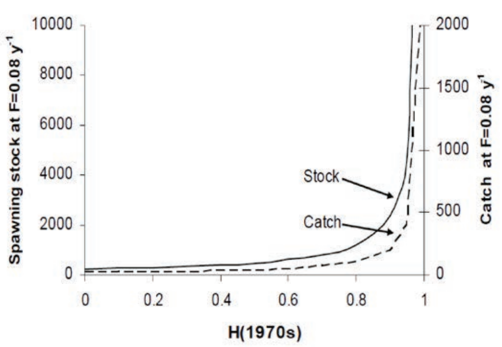

Fig. 9. Spawner population size and sustainable yield at the 'traditional' level of targeted fishing (**F**=0.08 year^{-1}) in the absence of juvenile exploitation, given different assumed juvenile harvest rates H_j(1970s) in the 1970s

Implications of possible exploitation of small juveniles

Exploitation of MGC juveniles less than 100 cm in length has remained unknown. However, any exploitation occurring at this stage would affect recruitment to the population of large MGC (>100 cm in length) that are exploited by known fishery. Thus, it is also necessary to model the effect of juvenile exploitation by introducing a juvenile harvest rate $\mathbf{H_j}$ into the stock-recruitment function, *i.e.* **Recruitment of large juveniles = recruitment of small juveniles x (1-juvenile harvest rate $\mathbf{H_j}$)**. The juvenile harvest rate $_{\mathbf{Hj}}$ acts simply as a scaling factor to recruitment and does not affect the analysis of the population dynamics as long as **H** remains constant. Baseline analysis estimated that the level of maximum recruitment of about 345 fish (100 cm in length) corresponds to that of the Chiang Khong 'fishing boom' and the level of recruitment in the 1970s. If this recruitment level had been influenced by juvenile harvesting at the rate of $\mathbf{H_j}$ (1970s), then the natural recruitment level in the absence of juvenile harvesting would be higher by 1/(1-$\mathbf{H_j}$). Likewise the spawner population abundance and sustainable yield in the absence of juvenile fishing would be proportionately higher as shown in **Fig. 9**.

Future Population Change

From the abovementioned results, the future population trends have been predicted for several different scenarios, especially with respect to fishing, releases of captive-bred fish, and reproductive failure.

Fishing

Predictions had been given for 'traditional' level of fishing mortality and a scenario where all fishing for MGC is stopped from 2007. Although 'traditional' fishing scenario is deemed most likely in the medium term, closure of the Chiang Khong/ Huay Xai fisheries and decommissioning of the Dai net fisheries responsible for the bulk of MGC catches in the Tonle Sap River would lead to a 'no fishing' scenario.

Nevertheless, since the MGC population is expected to recover under both scenarios (**Fig. 10**), recovery would be faster towards 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 the pre-1983 abundance in 2050 if fishing is continued at the 'traditional' level.

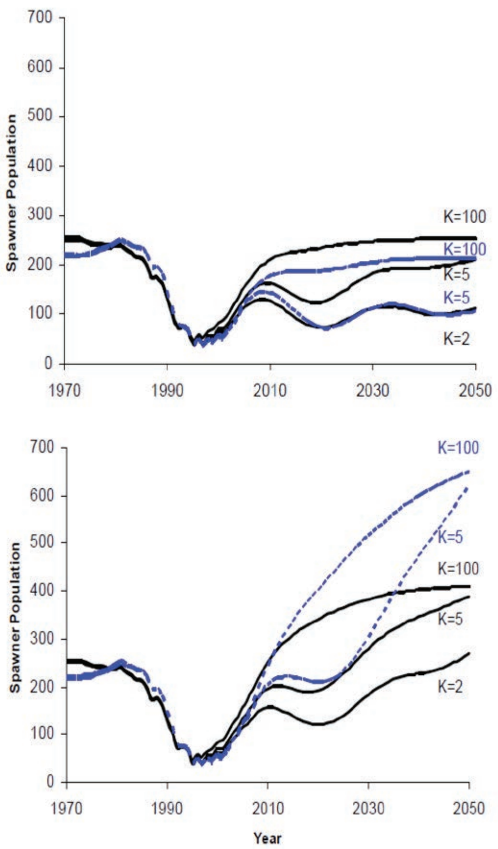

Fig. 10. Predicted spawner population change given 'traditional' levels of fishing mortality (above) or no fishing (below), predictions for M_r = 0.12 year^{-1} (*black solid lines*) and M_r = 0.06 year^{-1} (*blue broken lines*)

Recruitment failure

Recruitment failure could be a result of destruction of spawning and juvenile habitats or from depensatory (Allee) effect at low spawner abundance. However, the effects of recruitment failure could be visible only after some 15-20 years since its first occurrence (**Fig. 5**).

Role of captive-bred and culture fish

Captive-bred and cultured fish could play an important role in future population change, whether the fish comes from deliberate releases or accidental escape from aquaculture facilities. While examining the impacts of captive releases on the recovery of spawner population, the survival and growth parameters for MGC released into semi-natural environments or reservoirs could also be estimated although the impacts of such releases on the wild population should be taken into consideration.

Potential effects of releases on wild population

In assessing the impacts of deliberate or accidental releases of cultured fish on the wild population, the fisheries enhancement model of Lorenzen (2005) in the EnhanceFish package could be used, with the assumption that captive-bred and cultured fish show the same growth and mortality patterns as wild fish, as well as in terms of reproductive competence. Using such package, the impacts of releasing large 'recruits' (100 cm in length) as shown in **Fig. 11** indicate that although releases are predicted to increase the total fisheries yield and population biomass, the wild population component could be depressed. Even if a moderate release of about 300 recruits would result in a significant wild population impact as a result of the estimation, the wild population carrying capacity would be very low combined with the wild-like fitness of released fish.

In the deliberate releases of MGC, smaller fish of about 10-20 cm in length could be used but such fish could undergo relatively high and most likely, density-dependent mortality before even reaching the 100 cm length. Releases of few hundreds or even thousands of 20 cm fish per year would also have little impact on the total yield while moderately depressing the wild population biomass (**Fig. 12**). Thus limited, *e.g.* ceremonial releases of small captive-bred MGC could still be conducted without posing a major threat to the wild population.

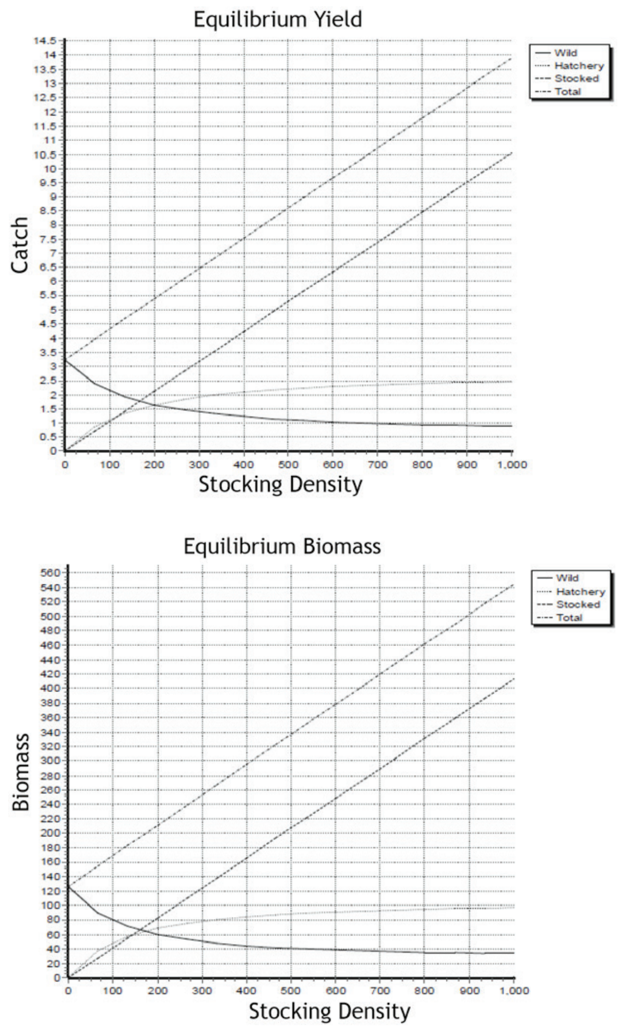

Fig. 11. Impact of releasing recruits (100 cm fish) on yield (*above*) and total biomass (*below*) of MGC population components

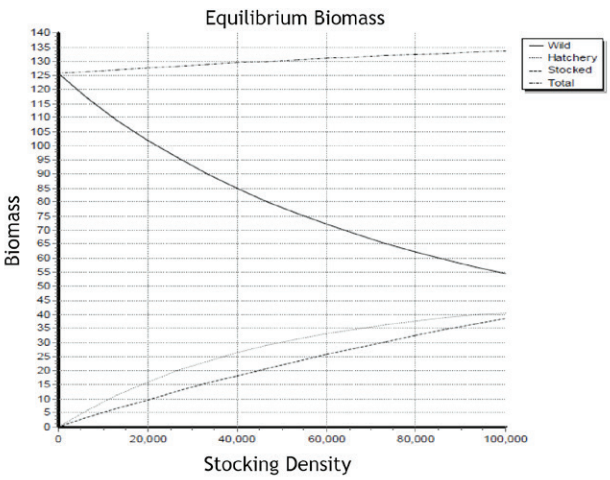

Fig. 12. Impact of releasing juveniles of 20 cm length on biomass of MGC population components

Implications for Conservation Strategy Development

Threat assessment
The factors that threaten the survival of MGC could include fishing, habitat degradation, and interactions with culture-bred fish. However, the known 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 low level of incidental harvesting imply that the population is quite resilient to overfishing. Thus, a moderate level of traditional fishing could still be allowed without compromising population viability. This could have an overall beneficial effect in terms of providing long-term monitoring data and maintaining public interest in the species.

Nevertheless, such effort should ensure that fishing intensity remains well below the levels seen at the height of the Chiang Khong fisheries, and that there is no increase in incidental catches (*e.g.* due to new gear development). Furthermore, the current assessment of sustainable catch levels may be revised should population dynamics be affected by other threats. Since the extent to which small juveniles of less than 100 cm length are subjected to exploitation remains unknown, and if there is significant exploitation at this stage, this could have a strong effect on population abundance. Such exploitation would however be entirely incidental, *i.e.* MGC are neither targeted nor indeed known to be caught by gill net fisheries exploiting this size range, although this is 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. 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 River Basin and its associated natural resources. The most important known threats are likely to be navigational improvements and hydrological change in the spawning grounds, and loss of access to juvenile habitats due to the damming of Mekong tributaries. Modification of spawning habitats may be the most acute threat, and would be detectable in the adult population only about 20 years after any impact.

While loss of access to juvenile habitats could result in reduction of carrying capacity, the small population size and low carrying capacity of the MGC make the population vulnerable to ecological and genetic interactions with released cultured fish. Nonetheless, as noted in many fora, there has been little 'hard' information on the effectiveness of any of the conservation measures. The quantitative assessment in **Box 2** could provide new insights with important implications for the prioritization of conservation measures.

Conclusion and Recommendations

Results of the reconstructed spawner abundance indicated a dramatic decline of MGC spawners to just 50 in 1995 but recovered to about 145 heads by 2006. Fishing had affected the abundance and structure of the MGC population, specifically contributing to the depletion of the MGC stock. However, very low levels of harvest (up to 10 mature fish basinwide) could still be allowed until 2030 for the population to recover from its current state, and also for long-term population monitoring of population data. Recent changes in the environment of the Mekong River Basin have not affected the population abundance of MGC but it is still necessary to maintain the overall Mekong ecosystem, *i.e.* water flows, physical habitats and connectivity, to ensure long-term survival of the species in the wild. Considering that habitat use and migration patterns of the species are largely unknown, the essential habitats of MGC could not be established except for the spawning area, which is most likely some 50 miles north of Chiang Khong District in Chiang Rai Province of Thailand. It is therefore an immediate priority that this habitat should be protected.

Box 2. Possible conservation measures that should be prioritized based on the population dynamics of MGC

- **Reducing exploitation of the wild population:** This could be the most important immediate conservation priority, and related initiatives have been targeted at the Chiang Khong and Tonle Sap River fisheries. In the analysis, fishing has been 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 depleted state. Only very low levels of harvest (up to 10 mature fish basinwide) could 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 would 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 subjected to exploitation should be investigated. It is unlikely that any such incidental exploitation can be reduced significantly in the short term. In the longer term, the overall fishing effort may decline as economic development provides alternative opportunities for fishers.
- **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 rapid blasting and construction of dams on major tributaries are likely to intensify. This priority remains unchanged. Perhaps the most important habitat conservation priority concern is likely the spawning grounds of the MGC near Chiang Khong, which may be crucial to the survival of the whole wild population.
- **Supportive breeding:** captive breeding programs had been 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 the 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.
- **Aquaculture escapees:** prevention of escapees into the Mekong mainstream from MGC aquaculture has been 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 fish provided that the latter survive well in the wild and are 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.

The efforts of the Department of Fisheries (DOF) of Thailand to maintain captive population would provide vital 'insurance' for safeguarding the survival of the species should it become extinct in the wild. However, such captive population should be managed carefully so as to conserve genetic diversity, should re-introduction become necessary. For the time being, captive-bred fish should not (even only in very low numbers) be released into the Mekong River or its tributaries because the wild population is likely to recover naturally. Although interaction with cultured fish might not have played a significant role in past population change, this might be a major issue in the future in view of both intentional and accidental releases, especially that the present cultured population is likely to exceed the wild population in terms of abundance. Nevertheless, escapes of MGC from commercial aquaculture operations could pose a significant threat to the wild population. Measures should therefore be taken to minimize the occurrence of such escapes for although the wild population carrying capacity appears to be quite low, releases of even low numbers of captive-bred fish could have significant impacts on the wild population.

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About the Authors

Dr. Naruepon Sukumasavin is from the Office of Experts, Department of Fisheries, Bangkok, Thailand.

Mr. K. Lorenzen is with the Program in Fisheries and Aquatic Sciences, School of Forest Resources and Conservation, University of Florida, 7922 NW 71st St., Gainesville, Florida, FL 32653 USA.

Mr. Z. Hogan is with the Center for Limnology, University of Wisconsin-Madison 680 N. Park Street, Madison, Wisconsin, WI 53706 USA.