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1 Acknowledgments

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2 Executive summary

The focus of this ACIAR study was the development and refinement of the databases for the *dai* fishery of the Tonle Sap, and the *lee* trap and dry-season gillnet fisheries in southern Lao P.D.R. Through this, the study improved the quality of the data employed by the Fisheries Ecology Valuation and Mitigation (FEVM) Component of the Mekong River Commission's (MRC's) Fisheries Programme in its assessment of the possible implications on the fish fauna of the Mekong River of changes in water flow and the effects of future development of the water resources of the Lower Mekong Basin.

The *dai* (bagnet) fishery in Cambodia operates from October to March in the lower portion of the waters of the Tonle Sap River and targets small fish species that are migrating back to the Mekong River from the flooded areas of the Great Lake and Tonle Sap as waters recede at the end of the wet season. Data have been collected for this fishery using a relatively consistent sampling regime since the mid-1990s. The *lee* trap fishery, which operates on the mainstream of the Mekong River in southern Lao P.D.R. from May to August or September, employs bamboo wing traps to catch fish (mainly catfishes) that are attempting to move upstream during the wet season through the rapidly-flowing water in channels at the Khone Falls. The catches taken in one particular channel, the *Hoo Som Yai*, have been monitored since 1994. Drift gillnets are employed by fishers in southern Lao P.D.R. upstream of the Khone Falls to target a number of fish species in deep pools of the Mekong River. These species are believed to undertake upstream migrations over the dry season and drift-gillnet catches at *Ban Hat* and *Ban Hadsalao* have been monitored at each of these villages since 1994 and 2000, respectively.

The datasets for these three fisheries extend back to the mid-1990s, and thus they potentially contain information on changes to the fish fauna since that time. In particular, it was considered that, by exploring the relationships between catch rates and water flow, it might be possible to assess more reliably the likely effect on the fish fauna of changed water flow regimes resulting from the construction of a number of proposed dams on the mainstream and major tributaries of the Mekong River. The current ACIAR project was intended to develop a database for the data for the *lee* trap and gillnet fisheries, thereby collating the separate data files previously used to store these data, and to refine the database for the data for the *dai* fishery, such that the content was more reliable. The resulting data were then to be used to explore relationships between relative fish abundance, biomass, diversity and water flow.

The Access database for the *dai* fishery was refined and, where possible, the integrity of data checked. Changes which had been made to the *dai* fishery, the sampling programme and to the fishery database through the years, as well as its current structure and catch estimation methods, were determined by referring to the available literature and by interviewing the original developers and data custodians. The changes made to both the sampling regime and database structure, together with the implications these changes had for analysing and interpreting the data, were documented. Numerous queries were developed to extract and analyse the data and produce catch summaries. Extracted data were explored to identify factors intrinsic to the sampling programme and fishing operations that had influenced catch rates and species composition. Subsequently, the extracted data were analysed in the FEVM study to assess the extent to which the *dai* fishery depleted stocks and to determine the relationship between water flow and catch rates.

Inconsistencies in the *dai* data were identified. These related to changes in the sampling regime, particularly in the stratification used, and in sampling intensity among years and among rows of *dais*. Marked differences in species composition between data collected for *dais* in Kandal Province and those in the Phnom Penh Municipality were considered to be an artefact of sampling or species identification differences between the two regions.

Analyses undertaken in the FEVM study suggested that approximately 80 % of the fish migrating towards the uppermost row of dais are caught by the fishery. The assumption that catchability was constant may have been inappropriate, however, due to use of different mesh sizes by *dais* and non-random sampling intensity. Multivariate analysis and examination of diversity indices provided no indication that this apparent depletion response was species-selective.

Allowing for the effects of fishing effort, lunar phase, calendar month, and *dai* row, the FEVM found that the *dai* catch per unit of effort was significantly related to an index of flooding, with the resulting model describing almost 70 % on the variation in the natural logarithms of the observed catch rates (Halls *et al.*, in prep). The catch rates increased exponentially with flood index, but so also did the average body weights of the fish that were caught suggesting that the response was growth mediated.

The introduction of the Catch Assessment Survey (CAS) approach, which was described by Doan *et al.* (2005), for the collection of data for the gillnet fisheries of southern Lao P.D.R. and the revised data collection regime for the *lee* trap fishery of *Hoo Som Yai*, provided an opportunity for the FEVM to introduce a single data entry form that allows capture of data from both fisheries. A single Access database was therefore developed to maintain the data collected using the new CAS approach, and to collect and collate earlier data for the gillnet and *lee* trap fisheries, which were contained within various Excel files. The resulting database has brought the data for the different years together within a single file, allowing comparison among years and determination of trends across years. The process of bringing the data together also exposed inconsistencies in sampling regimes among years. A training course on the use of Access was presented in Lao P.D.R. in September 2009 to provide the LARReC staff in Vientiane with a deeper understanding of the database that had been developed for their fishery data.

Subsequent exploration of the gillnet data by the FEVM failed to detect any simple (linear) relationship between catches of the multispecies assemblage by the *lee* trap fishery at *Hoo Som Yai* and water levels recorded at Pakse (Halls *et al.*, 2011). The variability of the timing of the gillnet fishery surveys to 2007 and their short duration raise concern for comparability of data among years and their representativeness of trends in abundance, *e.g.* Halls *et al.* (2011) chose not to include the time series of gill net data at *Ban Hat* and *Ban Hadsalao* prior to 2007 in their analyses.

The current data collection programmes for the three fisheries should be reviewed by a qualified statistician specialising in survey design with the goal of maximising the accuracy and precision of estimates of catch and effort, and to allow for valid inter-annual comparisons of estimates of total catch, effort, and fish biomass, given the available resources. Training and ongoing support to fisheries personnel should be provided to improve consistency of data recorded by enumerators in the *dai* fishery and among fishers providing data at different villages in southern Lao P.D.R. There is a need to collect data from any significant fishing lot, or artisanal or subsistence fishery, that interacts and competes with the *dai*, *lee* trap and gillnet fisheries for the same stocks of fish in the Mekong River. There is also a need to develop an understanding of the extent of migrations and of removals from all fisheries targeting those migrating stocks.

A significant outcome of this study was the consolidation, testing and analysis of three of the most important long-term fisheries databases held on fish catches in the Lower Mekong River Basin, thereby providing support to the Inland Fisheries Research and Development Institute (IFReDI), in Phnom Penh, Cambodia, as well as to the Living Aquatic Resource Centre (LARReC) in Vientiane, Lao P.D.R.. It became clear during the course of this study that well-defined data collection regimes and well-documented databases are the key to developing understanding of the effects of fishing and development on fish stocks. This study has established a sound foundation on which Cambodia and Lao P.D.R. may build, but further support to develop skills in survey design and database development and maintenance would assist in adoption of the results from this study.

3 Introduction

The Mekong River rises in the Tibetan Plateau, and runs through China, Burma, Lao P.D.R., Thailand, Cambodia and Vietnam. It is one of the longest rivers in the world, and has an annual flow of approximately 475 km^3. While melting snow provides the source of the water in the upstream reach of the river, rain generated by the Southwest Monsoon drives the highly seasonal but quite variable flow in the lower reaches. The wet season, which is driven by the Southwest Monsoon and typically extends from May to late-September or early-October, is of almost equal duration to the dry season (Mekong River Commission, 2005). Mainstream flow in the Lower Mekong Basin typically peaks in August and September.

During the wet season, because of the increased volume of water in the mainstream, the flow in the Tonle Sap River changes direction and water moves upstream into the Great Lake. In the dry season, the flow reverses and water flows back from the Great Lake to the mainstream of the Mekong River. At the peak of the annual flood, the area covered by the Great Lake is four to six times greater than in the dry season, and maximum water depth increases markedly from 1 m or less to more than ten times this level.

The seasonal flow of water also transports nutrients, which are attached to fine particles in the sediment load, to the floodplains of the Mekong and Tonle Sap Rivers and of the Great Lake. These nutrients are important both for the growth and survival of fish and for agriculture on the flood plains of the river.

Tropical river systems typically display highly seasonal flows, such as that of the Mekong River. These seasonal flows are characterized by extensive flooding of low-lying flood plains adjacent to the river. This pattern of annual flow and flooding has been described in the “flood pulse concept” (Junk *et al*., 1989). It has been proposed that, in such systems, species are likely to have adapted to exploit the increased food and habitat resources that are made available by the annual flooding that accompanies the wet season. Accordingly, many species of adult fish present in the river undertake seasonal migrations to upstream spawning locations. It is likely that, because of movement and water transport, these migrations position their progeny in regions where, because of flooding, food and shelter are readily available. As water recedes at the end of the annual flood, individuals of many fish species migrate back to the refuge afforded by the deeper water of the mainstream and its deep pools (Poulsen *et al*., 2002). Of the fish species in the Mekong Basin, for which there is information on migratory behaviour, 87 % are known to be migratory (Baran, 2006). River flow is believed to provide a strong migratory trigger to which the fish respond (Baran, 2006).

The annual spatial expansion and contraction of the Mekong River as it extends over the floodplains during flooding and contracts during the dry season leads to considerable heterogeneity of habitat, which has supported the development of high species diversity. Thus, it has been estimated that over 1200 species of fish, 768 of which have been documented scientifically (Baran, 2006), are to be found in the Mekong Basin (Coates *et al.*, 2003). Of these, although dominated by about 10-20 species, approximately 120 species are caught and traded by fishers (Coates *et al.*, 2003).

The considerable contribution of fish and other aquatic animals (OAA), *e.g.* molluscs, crustaceans, insects, reptiles and amphibians, to the diets of the inhabitants of the Lower Mekong Basin has been described by Hortle (2007). He estimated that, in 2000, 2.6 million tonnes of fish and OAA were consumed by a population of 56 million people, providing 47 to 80 % of the animal protein consumed each year. The annual harvest of fish and OAA produced from the Mekong is very important to the food security of the region and the livelihoods of its rural population.

The Mekong River offers other resources to the people of the region, however, and exploitation of these has the potential of increasing the threats faced by freshwater fish stocks. A major threatening influence is that associated with harnessing of water flow (by construction of dams) to generate hydroelectric power. Three of the eight cascade dams that China has proposed to develop on the mainstream of the Mekong River are already completed, *i.e.* the Manwan (from 1993), Dachaoshan (from 2001), and Jinghong (from 2008) dams, while two more (Xiaowan and Nuozhadu) are under construction (Kang *et al.*, 2009). The intended construction of a dam at Xayaburi in Lao P.D.R. is the first of eleven proposed hydropower developments on the mainstream of the lower Mekong River, seven of which will be located in Lao P.D.R., two in Cambodia, and two shared between Lao P.D.R. and Thailand (Dugan *et al.*, 2010). Dams have already been constructed or are under construction on many of the tributary rivers.

The effect of the dams that have been constructed and of the potential effect of the dams that are currently under construction (or proposed) on the fish fauna of the Mekong River is yet to be determined. There is little doubt that the dams will create barriers to fish movements, affect flow, and reduce flooding. Hydropeaking, *i.e.* rapid increases or decreases in the volume of water released from dams in response to demands for power, may cause large changes in water levels over 24 hour periods. Dry season water levels are predicted to rise and wet season levels are expected to fall, particularly upstream. Consequences of these effects may be that fish are prevented from spawning in optimal or suitable habitat, that triggers for migration are reduced, that egg and larval drift may be impeded (and survival diminished), that there will be reduced input of terrestrial productivity through loss of flooding, and that there will be less flooded habitat available for fish at particular stages of their life cycles.

Prediction of the potential effect of dam construction on catches of various species is impeded by the lack of data on many aspects of their life history, including the relationships between environmental changes and recruitment, survival and growth. It was postulated, however, that it might be possible to learn something of these relationships by analysing data relating the influence of variation in past water flow on catches recorded for fisheries in Cambodia and the Lao P.D.R. Such a study would offer the potential to collate existing data for the fisheries thereby creating two well-specified relational databases. Through this, staff at LARReC and IFReDI would gain experience in the use of those databases and application of basic methods of fisheries data analysis.

The ultimate objective of the ACIAR SRA was to analyse the data in the resulting fisheries databases and thereby to assess how the relative abundance, biomass and species diversity of key fish species and the species composition in catches from the Mekong River and the Tonle Sap vary with the water height measured at selected recording stations. The results of such analyses would improve stakeholder and institutional capacity to monitor and assess the status and trends of fisheries resources in the LMB and to predict their response to basin development activities. This analysis of the influence of flooding on fish stocks was a key element of the FEVM Component of the MRC's Fisheries Programme, and thus, as it was being undertaken by the FEVM and thereby satisfying this aspect of the objectives of the ACIAR study, the primary focus of the ACIAR study was placed on developing and refining the databases for the three fisheries and thereby supporting the FEVM analysis.

Detailed descriptions of the databases and the results of the analyses are presented in documents that are currently in various stages of publication (Halls and Paxton, 2010; Halls *et al.*, 2011; Halls *et al.*, in press; Paxton, undated). Accordingly, rather than replicating the contents of these publications in detail, this report provides a broad overview and summary of the results of the ACIAR study.

4 *Dai* fishery, Cambodia

A brief history of the bagnet or *dai* fishery in Cambodia is provided by Deap Loeung (1999). The fishery operates from October to March in the lower portion of the waters of the Tonle Sap River, between 4 and 30 km north of Phnom Penh, and predominantly exploits small fish species that are migrating back to the Mekong River from the flooded areas of the Great Lake and Tonle Sap as waters recede at the end of the wet season (Lieng *et al.*, 1995).

A description of the bagnet, *i.e. dai*, is provided by Lieng *et al.* (1995), who advise that each *dai* comprises two bamboo rafts that are linked approximately 25 m apart by bamboo poles and anchored in position. A sampan is placed between the rafts to stabilise the structure. A cone-shaped net, facing upstream and with a mouth diameter of 25 m and length of 120 m and mesh sizes at the entrance and bag of 15 and 1 cm, respectively, is hung by ropes between the rafts. The net is kept open by water current, aided by anchors and two vertical bamboo poles fixed to the rafts. A sampan and a further raft with a platform are placed downstream adjacent to the bag of the net. The bag is winched onto the platform, and the catch is emptied onto the platform for sorting.

While each *dai* is operated independently, they are typically joined together in rows of three to eight *dais* to form a “barrage” across the river (Lieng *et al*., 1995). These authors report that, in 1994/95, 73 *dai* units in 15 rows operated, but that, in 1995/96, the number of *dai* units was reduced to 63 due to a lack of bidders for the fishing lots, where each lot is a concession auctioned by the Cambodian Government that allows the winning bidder an exclusive right to operate the *dai* for two years. Hap Navy and Ngor Peng Bun (2000) advise that 63 *dai* units operated in 15 rows during the 1999/2000 fishing season, and that rows 1–6, which comprised 25 *dai* units, were located in Phnom Penh, and rows 7–15, which comprised 38 *dai* units, were located in Kandal Province.

Noting that previous data collection was limited and unreliable and that sound estimates of catches and species were therefore not available, Lieng *et al.* (1995) proposed a new stratified sampling approach, the design of which was based on data collected during the 1994/95 season. The rows of *dai* units were divided into three strata, *i.e.* rows 1-5, 6-10, and 11-15, and the days within the month into two strata, *i.e.* the peak period of 4-6 days before the full moon and the low period comprising the remaining days. Sampling was random, at an average frequency of 2 days per month.

By 1999, an additional level of stratification, *i.e.* a classification of *dai* units into either high-yielding or low-yielding units on the basis of census data collected by the Department of Fisheries in 1996/97, had been introduced (Deap Loeung, 1999). While Deap Loeung (1999) reported that there were eight high-yield and sixty low-yield *dai* units, Hap Navy and Ngor Peng Bun (2000) advised that, in the 1999/2000 fishing season, there were ten high-catch and 53 low-catch *dai* units. Although Ngor Peng Bun (2000) described the 1996/97 census that was undertaken by the Department of Fisheries, no description of the analysis leading to the classification into high and low yield *dai* units was presented. When collecting data for the fishery, *dai* units were randomly selected, but sampling intensity was greater for the high-yielding *dais* and for the peak periods within the month. For each *dai* visited, the sampling agent recorded the time period over which the *dai* was observed, the number of lifts during that period, and the time and the catch (kg) per lift for at least ten lifts. Deap Loeung (1999) advised that, during peak periods, the number of lifts over the 24 hour period was counted. He also noted that night catches are higher, but that there are typically fewer lifts at night than during the day. The data that were presented in this report provide no indication of whether this increased catch at night was due to the longer interval between successive hauls. Species composition was recorded for weighed and counted subsamples from the catches of three to four lifts, which were collected during the visit.

Although Ngor Peng Bun and Hem Chanthoeun (2000) noted that the new data collection programme, which was described by Lieng *et al.* (1995), was initiated in 1994, catch data for the 1994/95 fishing season were not collected in October and November 1994 and March 1995, and thus the time series of data for full fishing seasons commences with the 1995/96 fishing season. However, based on their analysis of the survey data for this latter fishing season, Ngor Peng Bun and Hem Chanthoeun (2000) concluded that the catch for this season is over-estimated as values of effort used to calculate the catch were excessively high compared with those reported in the census data for 1996/97. These authors decided that, for the 1996/97 fishing season, a more accurate estimate of catch would be derived using census data rather than data derived from the new data collection programme.

The database, which was originally developed using ARTFISH software (Stamatopoulos, 1994, 1995, 1996), was subsequently transferred to Access, a process that exposed a number of issues (Baran *et al.*, 2001). These included problems relating to species names, constraints on the number of species for which catch data could be entered, the absence of data for October 1996, deviations between raw and compiled data for December 1995, January and December 1996, and March 1997, and the absence of data for 1999/2000 in the raw data files. Cans and Ngor Peng Bun (2006) subsequently described the methods that were used to convert the databases from ARTFISH to Access. In their report, they also noted that an Access database needed to be developed to store length frequency data collected from the *dai* fishery.

5 The gillnet and *lee* trap fisheries of Lao P.D.R.

The hydrology of the Mekong River, as described by the ASEAN Regional Centre for Biodiversity Conservation (http://www.arcbc.org.ph/wetlands/lao_P.D.R./lao_mekriv.htm), is broadly as follows (see also van Zalinge *et al*., 2004; Gupta and Liew, 2007). The Mekong River descends through the mountainous country in the north of Lao P.D.R. to be joined near Vientiane by the *Nam Ngum*. This tributary, which is joined by the *Nam Lik*, passes through the Vientiane Plain, a large alluvial plain that lies along the north bank of the Mekong, before joining the Mekong downstream from Vientiane. From Vientiane, the Mekong River flows through a wide valley as it traverses the Korat Plateau. In this section of the River, the Mekong is joined from the east by several major tributaries, one of which is the *Se Bang Fai*. A short distance after its confluence with this latter tributary, the Mekong descends through a rocky gorge for approximately 160 km before entering the plains above Pakse. It then flows through the lowlands of southern Lao P.D.R. to the Great Fault Line, where it forms an inland delta, spreading out in numerous channels that stretch over a distance of 16 km, before plunging over the Khone falls to the lower Mekong plain. From here, it combines to flow southward through Cambodia, then Vietnam, and finally reaches the sea.

Relatively long time series of catch data, which are maintained by LARReC, have been collected for gillnet fisheries at sites on the Mekong River near the villages of Hat and Hadsalao (Warren *et al.*, 1998; Phayvan Chomchanta *et al.*, 2000), and for the *lee* (*Li*) trap fishery in the *Hoo Som Yai*, a narrow channel at the Khone Falls, *i.e.* in the region where the Mekong River traverses the Great Fault Line in southern Lao P.D.R. (Warren *et al.*, 2005).

During the dry season, which extends from November to April, a number of species in the Mekong River are believed to undertake upstream migrations and it is these migrations that are targeted by the drift-gillnet fisheries at *Ban Hat* and *Ban Hadsalao* (Warren *et al.*, 1998). Warren *et al.* (1998) reported that, at *Ban Hat*, these migrations, which are dominated by Cyprinidae, occurred during the darkest periods of the lunar month within at least the first two lunar cycles following the (northern hemisphere) winter solstice. They noted that the second new moon phase after the winter solstice is associated with the Chinese New Year, and that Roberts and Baird (1995) considered the movements to be daytime, non-reproductive migrations that occurred as waves, the strongest of which occurred on or about the Chinese New Year. While Warren *et al.* (1998) did not find a lunar cycle of catch rates at *Ban Hadsalao*, they noted that limited data were available for this analysis.

Ban Hat, which is described by Warren *et al.* (1998) as being located in the Muang Khong district, lies on the eastern bank of the Mekong River opposite the southern end of Khong Island (*Don Khong*) at 14° 13' N, 105° 50' E. Warren *et al.* (1998) reported that the fishing grounds at *Ban Hat* lie over a depression in the river bed directly in front of the village, and that dry season catches from this village are among the highest reported for the Muang Khong district. *Ban Hadsalao* lies on the west bank of the Mekong River, at a latitude of approximately 15° N, approximately 2 km south of Pakse (Warren *et al.*, 1998). At this site, Warren *et al.* (1998) noted that the river has narrowed to a single channel, which is less than 1 km wide.

Catches that have been monitored at *Ban Hat* and *Ban Hadsalao* were taken in the daytime by fishers who used drift gillnets (Warren *et al.*, 1998). The drift-gillnet fishery at these two villages operates between about December and April, with greatest intensity of fishing effort around the new moon phase of the lunar month (Warren *et al.*, 1998). Warren *et al.* (1988) reported that, at *Ban Hat*, catch per unit of effort increases to a maximum around the period of the new moon. This differs slightly from the timing of the peak catch rates for the *dai* fishery, which typically occur during the second quarter of the lunar cycle, *i.e.* the period of approximately 7 - 14 days after the new moon. The driftnets that were used by fishers at both *Ban Hat* and *Ban Hadsalao* were constructed of monofilament mesh with mesh sizes of 5, 6 or 7 cm, and were between 60 and 120 m long and 5 to 7 m deep (Warren *et al*., 1998).

In contrast to the drift-gillnet fishery, which targets fish migrating upstream in the dry season, the *lee* trap fishery at *Hoo Som Yai* focuses on the nocturnal upstream movement of catfishes (Pangasiidae and Siluridae) and the downstream movement of about six small cyprinid species, either just before or after spawning, that occurs during the wet season (Warren *et al.*, 2005).

Warren *et al*. (2005) describe the location of *Hoo Som Yai*, a rocky channel at the Great Fault Line, as the second channel on the west side of Papeng Waterfall. The *Hoo Som Yai* diverges from the Khonephapeng channel above the falls where it flows in a narrow vegetated channel between 10 and 20 m wide for roughly 800 m before rejoining the main channel another 600 m downstream of the falls. Water depths in the predominantly bedrock channel vary between 0.5 m over the dry season and roughly 3.5-4.0 m over the wet season (Singhanouvong *et al.*, 1996). Of the estimated 18 channels that pass over the Great Fault Line, the *Hoo Sahong* to the west of the *Hoo Som Yai* is believed to be the most important in terms of fish migration because of its great depth and width (Baird 2006). However, the *Hoo Som Yai* is the most accessible for sampling purposes and was therefore selected as a monitoring site for this reason.

The catches from *Hoo Som Yai*, which have been monitored by LARReC since 1994, were caught by fishers using *lee* (*Li*) traps (Phayvan Chomchanta *et al.*, 2004; Warren *et al*., 2005). These bamboo wing traps are used by fishers to capture fish (mainly catfishes of the families Pangasiidae and Siluridae) that, nocturnally, are attempting to move upstream during the wet season through the rapidly-flowing water in channels within the region in southern Lao P.D.R. where the Mekong crosses the Great Fault Line (Warren *et al.*, 2005). While catches are dominated by fish that are attempting to migrate upstream, anecdotal data suggest that some fish that are moving downstream at this time may also be caught. The bamboo traps are positioned directly in the current, and with half of the bamboo mat in the water, within sections of the channel where total ascent of the channel by the fish is blocked by natural or man-made barriers, *i.e.* bamboo fences. Those fish that attempt to ascend eventually weaken and some are forced backward into the traps, where they beach themselves on the bamboo platforms and are collected by fishers (Warren *et al*., 2005). The fishery operates during the wet season, which encompasses the months from May to October, but does not extend completely to the end of this period. Traps are re-constructed or renovated during April, and the fishery typically begins in the latter half of May, when flow increases with the onset of the first flood-cycle rains, and finishes in August or September, by which time traps are often physically destroyed by flooding or submerged and migratory activity diminishes (Warren *et al.*, 2005).

6 Results of study

The commencement of this project was delayed to December 2008 because of difficulties encountered in recruiting a suitably-qualified postdoctoral research fellow. As a consequence, much collation and checking of the catch and effort data for the *dai* fishery against records held at the Inland Fisheries Research and Development Institute (IFReDI) in Phnom Penh, Cambodia had been completed by MRC prior to the project's commencement. Electronic records had been verified against the data entry forms, errors that had been detected at this stage had been removed and relationships among fields within the tables of the Access database had been revised. That this work had been done by the MRC before the ACIAR project commenced was due, in part, to the considerable overlap that existed between the objectives of the ACIAR project and the needs of the Fisheries Ecology Valuation and Mitigation (FEVM) Component of the MRC's Fisheries Programme to analyse the catch data and advise on the implications of the results for Fisheries management and planning future development of the water resources of the Lower Mekong Basin. Indeed, because of this overlap and integration between the ACIAR and FEVM studies, much of ACIAR project's value derives from the contribution of the ACIAR study to refining the catch databases and the subsequent use that was made of the resulting data in the analyses undertaken for the FEVM programme.

For the project to achieve its intended benefits for the Lower Mekong Basin, it was necessary for the structure of the three fisheries databases to be refined, the data within those databases to be validated, and complete documentation of the data collection regimes and factors affecting the quality of the data within the three datasets to be produced. At the same time, this would provide reliable data that could be used in the project to assess whether changes in water flow had affected relative fish abundance and biomass and whether species composition had changed through time.

A fishery database, such as that of the *dai* fishery of the Tonle Sap River, and the *lee* trap and gillnet fisheries of southern Lao P.D.R., typically contains details of catch, fishing effort, fishing methods used to take the catch, the species composition of the catch, and the size composition of the individuals of each species. Intuition would suggest that if the catch rate recorded by one of these fisheries declines, the cause is likely to be a decline in the abundance of fish. If such inferences regarding changes in abundance are to be drawn from changes in catch rate, however, it is important to consider whether catch rate is really an index of abundance, *i.e.* is proportional to abundance, and what other factors might influence its value. When analysing the *dai* data, it is currently assumed that fishing effort and gear used by other fishers to catch fish from the same stocks as those exploited by the *dais* has remained unchanged through time.

To be used appropriately in statistical analysis or stock assessment, it is essential that metadata, *i.e.* data about data, are provided to describe how the data in the fishery database were collected, how the fishery and its management have changed, and whether other factors, such as socio-economic or environmental factors, might have influenced the data. In the cases of the *dai, lee* trap and gillnet fisheries, a key to understanding their databases is knowledge of the sampling programmes employed, the ways in which collection of data were modified, and how other fisheries, which have not yet been monitored, have changed.

6.1 The *dai* fishery

The Access database that had been developed for the *dai* fishery by the MRC continued to be refined during the course of the ACIAR study. In close collaboration with staff at IFReDI and the MRC, changes which had been made to the *dai* fishery, the sampling programme and to the fishery database through the years, as well as its current structure and catch estimation methods, were determined by reviewing the available literature on the development of the databases, as well as by interviewing its developers and present and past data custodians at IFReDI and LARReC. These changes have been documented in the technical report that has been produced as a result of this study (Halls *et al.*, in press). As analyses of the *dai* catch data progressed, further anomalies were unearthed and, where possible, data discrepancies were resolved.

Numerous Access queries were developed to extract and analyse the data in the *dai* fishery database and to produce catch summaries that could be used to advise IFReDI of fisheries product landed by the *dai* fishery. Daily, monthly and seasonal catch estimates for the *dai* fishery were calculated for the 1997-98 to 2008-09 fishing seasons. Reliable catch estimates for the 1994-95 and 1995-96 fishing seasons could not be determined because of a curtailed sampling season in the former case and the absence of effort information in the latter. These years therefore must be excluded from analyses.

Since the mid-1990s, data have been collected from the *dai* fishery using a stratified-sampling approach that has been relatively consistent. Changes in stratification have been introduced, however, with the inclusion of classification of *dais*, *i.e.* low or high-yielding *dais*, and administrative zones, *i.e.* Kandal Province of Phnom Penh Municipality. Despite a recommendation to adopt the *dais* sampled in 2003-04 as fixed for future surveys, *dais* have apparently continued to be selected randomly. Sampling intensity has declined from that in 2001-02 to the level recorded in 2003-04, but has subsequently remained at approximately this level. Sampling intensity declines with distance downstream. More hauls are sampled in Kandal Province than in Phnom Penh Municipality.

Exploration of the data revealed a tendency for the mean size of fish sampled in the *dai* fishery to increase with downstream location. This was ascribed to a possible increase in mesh size used by the more downstream *dais*, but the poor quality and paucity of mesh size data did not permit confirmation of this hypothesis. Fishing power of the *dais* had increased over the last decade through the use of diesel engines to close and haul nets, thereby increasing effective soak time of nets. Water depth and velocity of the current underneath the *dais* were not found to have a significant influence on the catch rates of the units. Changes in sampling intensity, *i.e.* number of *dais* and number of hauls per season, month and lunar phase in Kandal province and Phnom Penh municipality, were explored (Halls *et al.*, in press).

Data exploration was undertaken by the FEVM to examine the extent to which catches decline between successive rows of *dais*, and thus to assess the possible depletion of the fish moving downstream in the Tonle Sap as they pass the rows of *dais*. While the results of this analysis suggested that approximately 83 % of the fish migrating past the rows of *dais* are caught by the fishery, the assumption that catchability was constant may have been inappropriate due to use of different mesh sizes by *dais* and non-random sampling intensity. The possibility that fish may have migrated from locations adjacent to the fishery might have also biased this estimate. Multivariate and univariate analyses failed to indicate that this depletion was species-selective. Plots of the number of species and of the Shannon Diversity Index, which accounts for both abundance and evenness, by row number, and non-parametric multi-dimensional scaling (MDS) plots, which indicated that species composition differed markedly between data collected for *dais* in Kandal Province and those in the Phnom Penh Municipality, suggested that the species differences were an artefact of sampling differences in the two regions, *e.g.* changes in sampling intensity or possible differences (i.e. inaccuracies) in species identification between the teams collecting data in the two provinces.

As has been previously recognised, the analyses confirmed that the *dai* catches are strongly influenced by the lunar cycle and reach a peak around December or January, coinciding approximately with the end of the flood season. MDS ordinations suggested that species composition changed between the beginning and end of the fishing season, and that some dissimilarity between species assemblages existed between lunar cycles.

The *dai* data have been employed by Halls *et al.* (in prep) to explore the relationship between catch per unit of effort and an index of flooding, and allowing for the effects of fishing effort, lunar phase, calendar month, and *dai* row, with the resulting model describing almost 70 % of the variation in the natural logarithms of the observed catch rates. The catch rates increased exponentially with flood index, but so also did the average body weights of the fish that were caught.

Aspects of the work undertaken in the ACIAR project have been reported in Halls and Paxton (2010). Two other documents that have been prepared and are close to publication are Halls *et al.* (2011), and Halls *et al.* (in press). Halls (2011) has also produced a policy brief for the *dai* fishery which draws upon the results of the ACIAR study.

6.2 The gillnet fisheries of *Ban Hat* and *Ban Hadsalao*

Based on information obtained in 1992 and 1993 from interviews of local fishers, villagers and district authorities, sampling of gillnet catches of fish was initiated at *Ban Hat* in 1994 and continued till 1997. Guided by the advice obtained from the fisher surveys that catches peaked around the time of the Chinese New Year, the sampling period was set to begin four days prior to the Chinese New Year and to end approximately 15 days after this. The timing of the earlier annual surveys of the drift gillnet fisheries of southern Lao P.D.R. has thus varied with the time of the Chinese New Year. The primary purpose of the monitoring programme was to obtain information on fish migrations.

Data were collected from the drift-gillnet catches of five randomly-selected fishers at Hat village in 1994 and 1995, and from ten fishers in both 1996 and 1997 (Warren *et al.*, 1998). In 1996, data were also collected from five randomly-selected gillnet fishers from Hadsalao village, using the same sampling regime as was employed at Hat village in that same year (Warren *et al.*, 1998). Biological data, *i.e.*, weight (g), total and fork lengths (cm), sex (if it could be determined), gonad and viscera weight (g), etc., were obtained in 1996 from samples of fish from the gillnet catches purchased daily at local markets and from fishers at Hat and Hadsalao villages (Warren *et al.*, 1998). Lack of funding precluded sampling at *Ban Hat* in 1998 and 1999. Subsequently, data from six fishers were collected from both Hat and Hadsalao villages from 2000, except in 2003 in the latter village, where data only exist for five fishers. Catches were sampled at intervals of approximately every two to three days but increasing to a daily frequency around the new moon (Warren *et al.*, 1998). Catches were converted to a catch per unit of effort measured as the number of fish per 100 m^2 of gillnet per hour.

Sampling at both villages has continued to the present day. Following a recommendation by the Fisheries Ecology, Valuation and Mitigation (FEVM) component of the MRC, however, the survey period was extended on 2 December 2007 and now covers the entire year. Data are entered now by fishers rather than staff of the District Agriculture and Forestry Office (DAFO). Thus, since 2008, data are recorded by three fishers at each village onto forms provided by LARReC staff, which are collected at three-monthly intervals. Catch weight and number by species, net dimensions and soak hours were recorded. Until 2006, catch data were recorded for nine species only, *i.e.* those considered to be the most important migratory fish species. In 2007, an additional field was added to the data collected by LARReC's agents to capture details of the combined catch of species other than the nine important migratory species. Since 2008, all species are monitored.

At the commencement of this ACIAR project, catch data for the drift-gillnet fishery were stored in Microsoft Excel format, one file per year. Species names were recorded in the database using the Laotian name of the species or group. Biological data were not available on computer or raw data sheets, but were summarized in published reports. Raw data are not available for many of the survey years, and the computer files of data for 2004 have been lost. Data for Ban Hadsalao are not available for 1996. Although fish weights were recorded for the earlier survey years, the records have been lost and only numbers of fish caught have been recorded. Fisher's identities have not been recorded in the databases, and thus it is not possible to assess differences in efficiency among different fishers.

Details of the collation of these gillnet data, and of the database that was established, are presented in Section 6.4.

6.3 The *lee* trap fishery of *Hoo Som Yai*

The *lee* trap fishery of *Hoo Som Yai* was first monitored in 1994. Funding constraints precluded sampling in 1995, but monitoring re-commenced in 1996 and, with the exception of 1999, in which year funding constraints again precluded sampling, has continued to the present day. Between 1994 and 2007, catch data from the fishery were collected during the earlier period of the wet season, on specific dates at intervals of 2 to 3 days during the 35 days between May 24 to June 28 each year (Warren *et al.*, 2005). This had been identified in earlier fisher surveys as the peak period for the fishery. Although limited fishing continues after these months, conditions were considered to become too dangerous to continue sampling.

It should be noted that the data from the *lee* traps set in the *Hoo Som Yai* are not necessarily representative of the catches in the traps set in the 17 other major channels as the ascent channels selected by the fish may differ among species. The *Hoo Som Yai* is, however, the most accessible channel for sampling as catches can be monitored at a location close to a trading point passed each morning by fishers on their return from the traps (Warren *et al.*, 2005).

Landings from each trap were separated by species or, in the case of a number of small cyprinid species, group of fish species. In 1995 and 1996, 18 selected species were monitored. Subsequently, from 1997, six of these species were removed and another three added. From 2000, however, data were recorded only for 14 selected species that were considered to be migratory.

Until 1997, total lengths and weights were recorded for individuals but subsequently, in 1997 and 1998, landings of each species were counted then weighed as a batch (Warren *et al*., 2005). A count was then made of the number of operational traps, *i.e.* traps that were not flooded or damaged, and values of catch per unit of effort (kg.trap^{-1}.night^{-1}) were calculated for each species and for the pooled species (Warren *et al.*, 2005). Biological data, *i.e.*, weight (g), total and fork lengths (cm), sex (if it could be determined), gonad and viscera weight (g), etc., were obtained in 1996 from samples of migratory fish purchased daily at local markets and directly from fishers.

Data collection was and continues to be undertaken by the Living Aquatic Resources Research Center (LARReC) of the Ministry of Agriculture-Forestry, Vientiane, Lao P.D.R., which is the custodian of the data. While the total lengths and weights of individual fish were recorded in samples from earlier years of the data collection for this fishery, those data have been lost through computer malfunctions and inability to read diskettes. Weight-length relationships and length compositions derived from those data have been published and now represent the only available information on the sizes of fish in the catches. Fortunately, the catch composition data were not affected by these computer problems.

Although the volume of water flowing through the channel was estimated each day from data on water depth at five locations across the channel, the width of the channel and the velocity of the water, the resulting data were not stored within the datasets for this fishery. Similarly, biological data from fish (mainly caught by *lee* traps) purchased from markets and fishers, comprising body weight, total and fork lengths, sex (if it could be determined), macroscopic gonad stage, gonad weight, viscera weight, viscera fat deposition, stomach fullness and stomach contents, were not available within the datasets. While these latter data were not available on computer or raw data sheets, they were, however, summarized in published reports.

At the commencement of this project, the data set for the *Hoo Som Yai lee* Trap Fishery covered the years from 1994, excluding 1995 and 1999. These catch data were stored in Microsoft Excel format, one file per year. Raw data are not available for many years. Valuable information for earlier survey periods had been lost through data pooling and summation of data for individual fishers. Thus, data on variability of catch rates among fishers, which are essential for detailed statistical analysis and comparison among years, have been lost. The appropriateness of pooling by summing had not been assessed and the relative abundance information appeared to be dominated by an extremely high value recorded for 1994. Species names were recorded in the database using the Laotian name of the species or group. A possible source of confusion and potential risk to the integrity of the data was the fact that, in this database, the group termed *Pba Soi* represents two small cyprinids (*Henichorynchus siamensis* and *Cirhhinus lobatus*) but, in other sectors of the fishery, the same name has often been used to refer to a group of these and other small species. CPUE and data were recorded only as numbers until 2000. The mean weights over 1993 to 1996, as published in the project summary reports, had been used to convert catches in numbers to equivalent weights. From 2000 onwards, both numbers and weights (g) had been recorded. Species weights were usually in grams and total weights in kg. Anomalies were present in the data, *e.g.* an infeasible catch exceeding 7 tonnes in one record within the database.

In recent years, there had been concern that the short monitoring period did not cover the entire fishing period, and thus important information was being missed. Following a recommendation by the Fisheries Ecology, Valuation and Mitigation (FEVM) component of the MRC, the survey period was extended in 2008 and now begins in May and extends through October.

Details of the collation of these *lee* trap data, and of the database that was established, are presented in the next section of the report, *i.e.* in Section 6.4.

6.4 The new FEVM database

The introduction in 2008 of the Catch Assessment Survey (CAS) approach (Doan *et al.*, 2005) for the collection of data for the gillnet fisheries of southern Lao P.D.R. and the revised data collection regime for the *lee* trap fishery of *Hoo Som Yai* provided an opportunity for the FEVM to introduce a single form that allows capture of data from both fisheries. A single Access database was therefore developed to maintain the data collected using the new CAS approach, and to collect and collate the data contained within the various Excel files for the gillnet and *lee* trap fisheries. Records containing details of catches of different species were processed to form separate records for individual species. Codes and data were processed to ensure consistency among years (where possible). The species names used in the original data files were related to their associated scientific names, as determined by LARReC field biologists.

Numerous queries were developed in Access to extract data from the database for subsequent presentation or analysis. A range of different queries were required to extract different types of data from the database, however, to allow for the fact that monitoring had been conducted in an inconsistent manner since it commenced in 1994. A training course on the use of Access was presented in Lao P.D.R. in September 2009 to provide the LARReC staff in Vientiane with a deeper understanding of the database that had been developed for their fishery data.

Subsequent exploration by the FEVM failed to detect any simple (linear) relationship between catches of the multispecies assemblage by the *lee* trap fishery at *Hoo Som Yai* and water levels recorded at Pakse (Halls *et al.*, 2011). The variability of the timing of the gillnet fishery surveys to 2007 and their short duration raise concern for comparability of data among years and their representativeness of trends in abundance. For these reasons, Halls *et al.* (2011) chose not to include the time series of gill net data at *Ban Hat* and *Ban Hadsalao* prior to 2007 in their analyses.

It is intended that aspects of the work undertaken on the *lee* trap and gillnet fisheries of southern Lao P.D.R. during the course of the ACIAR study will be published as an MRC Technical report. A preliminary draft of this report has been prepared but further data analysis remains to be completed (Paxton, undated).

7 Conclusions and recommendations

This study collated the data for the *dai* fishery of the Tonle Sap River, Cambodia, and for the *lee* trap and gillnet fisheries of southern Lao P.D.R - three of the most important long-term fisheries datasets in the Lower Mekong Basin. The database containing the *dai* data was refined and a new Access database was developed to store and maintain the data for the *lee* trap and gillnet fisheries. The sampling regimes and the data sets were described and documentation was prepared to describe each of the two databases. This documentation will prove invaluable to future researchers, for whom a knowledge of changes in sampling regimes and data capture procedures is crucial for correctly analysing data and interpreting outputs. These databases provide valuable baseline data against which to compare future data, where those latter data are likely to be affected by climate change and by the changes in flow resulting from construction on the Mekong River of the numerous dams that are currently proposed.

The analyses that were undertaken by the FEVM using the *dai* data illustrate the value of this dataset, which provides a unique long-term time series of data for one of the largest and most intensively fished flood-pulse river systems in the world. These analyses demonstrated that the biomass of fish targeted by the *dai* fishery increases with flood extent and duration, and that this, in turn, is largely explained by the effect of these factors on growth of fish. The depletion analysis undertaken by the FEVM during the course of this study represented a first attempt to estimate the effect of the *dai* fishery on the stocks that it targets. These studies concluded that changes to monitoring activities, including recording net mesh size for each sampled haul in the *dai* fishery and accounting for changes in fishing effort in other locations, could improve the accuracy and precision of these predictions and estimates.

Numerous queries were developed in Access for both the *dai* fishery database and the *lee* trap and gillnet fisheries database to assist future reporting and analyses. It is recommended, however, that standard reports are programmed in Access for each database to automatically generate basic information that is routinely required by IFReDI and LARReC.

There would be value in adopting a consistent and well-defined sampling approach for each fishery. Without consistency of the data collection regime, it is impossible to assess whether changes in recorded species abundance or species composition are artefacts of changes in the sampling regime. Data collection regimes based on a sound statistical design, and which are implemented in accordance with that design, should be adopted. Having adopted a design, there is potential that modification of that design will introduce inconsistency, and thus care should be taken to ensure that the long-term integrity of the data is not jeopardised by inappropriate changes in design. Overlap between sampling regimes can provide data that allow the effect of design changes to be determined.

For the *dai* fishery, the changes in stratification, differences in sampling intensity recorded between Kandal Province and the Phnom Penh Municipality, decline in sampling intensity with distance downstream, changes in sampling intensity recorded among years, and the apparent discontinuity between species compositions recorded in the two administrative regions suggest that serious consideration should be given to adopting a more integrated and well defined sampling regime. Hauls that are made at night should be distinguished from those made during the day. In particular, the current sampling programme for the *dai* fishery should be reviewed by a qualified statistician specialising in survey design to maximise the accuracy and precision of estimates of catch and effort, and to allow for valid inter-annual comparisons of estimates of total catch, effort, and fish biomass indicated by *dai* catch rates, given the available resources. The ability of enumerators to correctly identify species in the *dai* fishery should also be checked and training provided where necessary.

Data collection for the *lee* trap and gillnet fisheries has been restricted to periods that are short and not representative of the full period over which each fishery operates. Collection of biological data has been insufficient to allow characterisation of the size compositions of the catches of the different species. By aligning sampling for the gillnet fishery to the Chinese New Year, the sampling period has varied among years. The extended sampling regimes that have been adopted since 2008 should assist in producing data that are more likely to be representative of the fish stocks that are targeted. It is also pleasing to note that constraints on the species that are monitored have been removed and that catches of all species are now being recorded. As with the *dai* fishery, now that several years of data have been collected for the *lee* trap and gillnet fisheries with the new sampling regimes, it would be useful for those data collection regimes to be reviewed by a statistician specialising in survey design.

The *dai* fishery of the Tonle Sap River, the *lee* trap of the *Hoo Som Yai* and the gillnet fisheries of *Ban Hat* and *Ban Hadsalao* provide valuable data relating to the fish stocks of the Lower Mekong Basin, but, by themselves, provide inadequate coverage. Thus, a decline in catches of one of the monitored fisheries does not provide data on the total removals from those stocks or the status of those stocks. While it is appealing to assume that fishing effort remains constant in other fisheries that exploit the stocks targeted by the fisheries that are monitored, such an assumption is unlikely to be true given population growth and possible changes in fish abundance.

Additional data collection programmes need to be established to monitor the abundance and biological characteristics of catches taken by other fisheries from the same and different stocks. These programmes might collect basic statistics, *i.e.* catch by species and effort by gear type, from the major sectors of the fishery, *i.e.* lot fisheries, artisanal and subsistence fisheries, stratified by habitat type. A research programme to identify the migratory ranges of key fish species should be established, possibly through mapping the monthly catches by species reported in such an extended monitoring programme. If resources are constraining, there would be advantage in extending such monitoring initially to fisheries likely to be targeting the same stocks as those of the currently monitored fisheries, as this would improve the value of the data for these existing data sets (Halls *et al*., in press).

The greatest risk to the adoption of the results of this study is likely to be the lack of Access database experience of the individuals at the MRC and within IFReDI and LARReC, who are given the responsibility of maintaining the databases that have been developed. Continued support and guidance are required in both Lao and Cambodia to ensure fisheries personnel become familiar with the data collection, data capture and backup procedures that will ensure these databases remain valuable resources into the future. A relatively simple ACIAR project that might assist in ensuring adoption would be a study that undertook to provide training in Access and, in collaboration with the trainees, to develop the Access reports that are likely to be required by IFReDI and LARReC. This might be coupled with a review of the data collection designs for the three fisheries by a statistician such as Ken Pollock, Murdoch University, whose expertise in survey design is well recognised.

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