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ON THE RIVER OF NO RETURNS: THAILAND'S PAK MUN DAM AND ITS FISH LADDER

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Monitoring of. fish species and fisheries activities after completion of the [Pale Mun] dam has been haphazard. Performance of the fish ladder has never been properly evaluated.
-SCHOUTEN *ET AL.*, 2000

ABSTRACT

Most fish species living in the Mun River are unable to climb or are for other reasons not using the ladder installed on Pak Mun Dam. This is especially true for large species most important in wild-capture fisheries. The ladder is unsuccessful in maintaining fish spawning migrations because few or no gravid females of any species climb it. Various proponents of Pak Mun Dam claim that its main impact on fish is that they cannot swim upstream and downstream past the dam. This is far from the only impact. The real problem is not with the ladder. Rather Pak Mun Dam itself is ecologically unfriendly to fishes.

A reservoir outflow is not a normal river. The abnormal flow regime and other artificial features in the outflow of Pak Mun Dam have severe impacts on fishes for 4.5 km until it joins the Mekong mainstream which dissipates (but is also effected by) its negative impacts. Pak Mun Reservoir is also very unfriendly to fish. This apparently is due mainly to having its bottom smothered by silt and its open water with an exceptionally heavy silt load at all times because of the highly abnormal "run of the river" flow conditions.

When the water level in Pak Mun Reservoir is at 108 m, "peak electricity generation" causes daily fluctuations in water flow downstream from Pak Mun Dam and daily draw-downs in the reservoir that disturb fish habitats and disrupt fish migration. If reservoir water levels are too low, the amount of water released from the sluice gates may be less than the lowest flow that normally occurs for only a few days or weeks of particularly dry years (if the reservoir level falls below 94 m the outflow will stop altogether). During minimum outflow the water quality also can be much poorer than that of normal dry-season low water without the dam. The other extreme occurs when water has to be released to prevent the reservoir itself from over-flowing. Opening the sluice gates on the spillways when the reservoir level is high can create a destructive torrent far stronger than any that occurred during the worst floods in the Mun River before Pak Mun Dam. Maximum as well as minimum outflows from Pak Mun Reservoir are lethal to fish.

The problem of Pak Mun Dam and fisheries may be summarized as follows: an artificial and hostile downstream environment (reservoir outflow) and an artificial and hostile upstream environment (reservoir) are connected by artificial and hostile corridors (fish ladder and dam spill-ways). The resulting impact accumulation has devastating over-all effects on fish habitats and fish species. Pak Mun Dam together with its 35-km long reservoir and 4.5 km reservoir outflow is a major bigeographic barrier to all kinds of fish movements between the Mekong and the Mun.

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INTRODUCTION

The Mun River (Menam Mun) is Thailand's largest Mekong tributary. Its fish resources have been exploited for well over 1000 years. Construction of Pak Mun Dam, just 4.5 km upstream from where the Mun flows into the Mekong mainstream, was completed by EGAT (Electricity Generating Authority of Thailand) in 1994. It rapidly became one of the most controversial and contentious environmental issues in Thailand's history. Indecision on how to deal with problems arising from Pak Mun was a factor—many would say the decisive factor—in the defeat of the previous Thai government.

This article examines Pak Mun Dam as a barrier to movement of fish between the Mekong mainstream and the Mun river system and evaluates performance of the fish ladder installed by EGAT. Three previous publications on Pak Mun fish ladder are utilized. The first (PHOLPRASITH *ET AL.*, 1997) is a report by the Thai fisheries biologists who provided the basic fish ladder design and who supervised monitoring of the ladder's performance for 14 months in 1994–96. The second (SCHOUTEN *ET AL.*, 2000) is a more general article on Pak Mun Dam fisheries including performance of the fish ladder through 1999. The third (AMORNSAKCHAI, *ET AL.*, 2000), based upon SCHOUTEN *ET AL.*, although received very late, is also utilized because it includes some additional relevant information on fishes and also EGAT's refutation or objections to some of the information on fish-related topics. Some of these concerns are addressed here.

Many people fishing the wild fish of the Mun River are highly skilled, organized and equipped professional fishermen. Their lifestyle and livelihood are based almost entirely upon fishing. Other people make their living in other ways, including farming, but fishing is still very important to them. Still other people including children often or occasionally fish, for fun as well as for food.

Loss of Mun River wild-capture fish products to consumers has passed almost entirely unnoticed. Before construction of Pak Mun Dam, Ubol Ratchatani and Warin Chamrap had the finest freshwater fish markets anywhere in Thailand. They were paradises for fish consumers, with a spectacular variety of high quality fresh fish available around the year (personal observation, June 1985–June 1993). Some of the fish came from the Mekong mainstream but the great majority came from the Mun itself. The largest and the best fish markets along the Mekong mainstream of Thailand including the main markets of Nakorn Phanom, That Phanom, Mukdahan and Nonghkai had less fish than Ubol and Warin (personal observation).

Pak Mun fish ladder is the only fish pass device installed on a major dam in the Mekong basin. Benefits predicted by various proponents of the fish ladder included the following:

1. Minimizing negative impacts of Pak Mun Dam upon fisheries above the dam and throughout the Mun River basin;

2. minimizing impacts on fisheries below the dam including those at the mouth of the Mun River;
3. maintaining upstream passage of migratory fish species in the Mun River system;
4. permitting upstream movement of such non-migratory fish species as would be naturally replenished in the Mun River system by movements from the Mekong River mainstream; and
5. providing a readily available source of brood stock for hatchery production of fish fry to be released into Pak Mun Reservoir and elsewhere.

The extent to which these benefits have been met is examined below.

MUN RIVER

The Mun is Thailand's largest Mekong tributary. The catchment is generally characterized by low rainfall. Its area, comprising most of the Khorat plateau, corresponds to 15 percent of the total catchment of the Mekong basin but its average yearly flow contributes only 5 percent to the average yearly flow into the Mekong Delta. The southern rim of the basin is formed by the Danghrek Ranges along the Thailand–Cambodia border. Except in mountainous parts of the basin the natural vegetation including lowland riparian forest is largely gone. Much of the area has been cultivated for centuries. It has a long dry season and is frequently subject to drought. Peak discharge occurs in August. Water levels begin dropping in September and are much lower in October.

In contrast, the Mekong mainstream has two major peak discharges. The first occurs in July and is due to melting of ice in the Himalayas and Hengduan Mountains in China. The second and larger peak in September–October is due to monsoon rains in the Lao portion of the middle Mekong basin. The height of the Mekong at the mouth of the Mun River varies by about 20 m. The Mekong floods of September–October dam up and possibly even reverse the flow of the lower Mun. The reverse flow or "backing up" which used to extend upstream at least as far as Geng Sapue and Phibun Mangsahan, a distance of some 40 km, is stopped by Pak Mun Dam. The resulting rise in water level below the dam prevents generation of electricity for up to two months each year around September–October. At this time the powerhouse has to be shut down. The sluice gates are opened to release water that would otherwise have been discharged through the powerhouse.

Water from Ubol Ratana, a large hydropower dam near Khon Kaen on the Nam Pong, enters the Mun River just upstream from Ubol Ratchatani via the Nam Chi (River). Water from Sirindhorn hydropower dam flows into Pak Mun Reservoir about one km upstream from Pak Mun Dam via the Lam Dom Noi (Fig. 1). Rasi Salai, a large irrigation dam, releases water directly into the Mun mainstream upstream from the mouth of the Chi. All of these dams and their reservoirs and reservoir outflows have negative impacts on Mun fishes. At times they may be employed to "regulate" the amount of water flowing to Pak Mun Dam but negative consequences of their presence outweigh positive benefits to wild fishes in Pak Mun Reservoir and its outflow as well as other parts of the Mun basin.

Reservoirs cause two large-scale changes in the water supply. In the dry season (when not much water is coming in but stored water is released to generate electricity) there usually is an increase over normal flow. Conversely, in the wet season (when the reservoirs

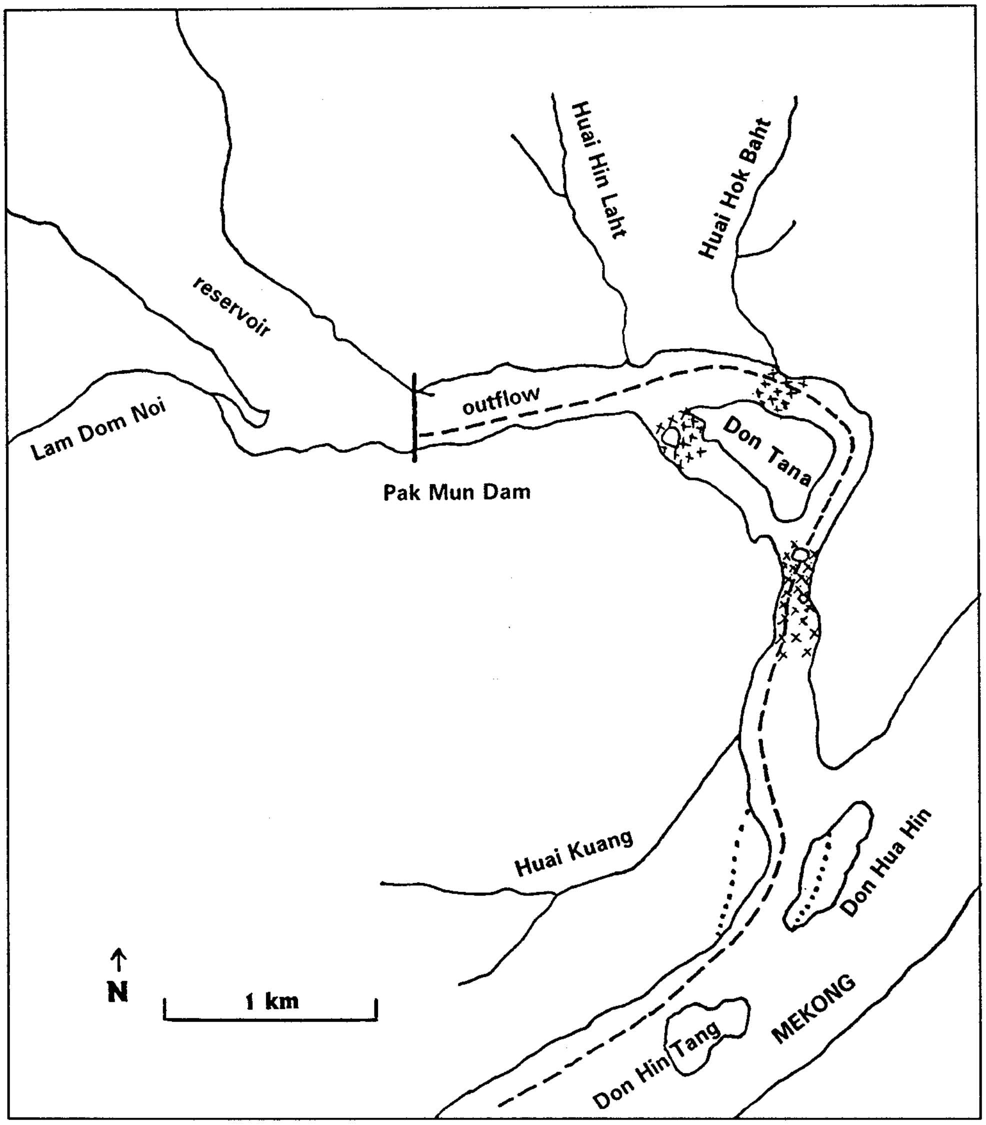

Figure 1. Map of Pak Mun Dam and immediate area. Dashed line=main channel and migratory pathway of larger fish; dotted lines = areas being eroded away by Pak Mun outflow; hatched area = Kaeng Tana rapids (modified from PHOLPRASITH *ET AL.*, 1997).

generally store water for release later) less water is released than normal flow. However in very dry years the reservoir may not release as much water as normal during the dry season, and in very wet years it may have to release more water than normal during the wet season (for safety reasons). All of these abnormal fluctuations generally have negative impacts on fish.

PAK MUN HYDROPOWER PROJECT

Pak Mun Dam is 22 or 23 m high (with an operating head of 17 m) and 300 m wide (Figs. 2, 5). Length of the reservoir outflow from the dam to the Mekong mainstream is 4.5 km (Fig. 1). When the water level at Pak Mun Dam reaches the 108.5 m level, water flowing into it is backed up for 35 km to Phibun Mangsahan. The reservoir thus formed is prevented from backing up farther by the rapids known as Kaeng Sapue.

The reservoir outflow channel extends due east from Pak Mun Dam for a little more than 1 km. Here its width varies from about 200 to 250 m. It then makes a sharp 90° turn south and expands to about 1000 m wide. A large forested island, Don Tana, lies in the middle of this bend (Figs. 1, 3). Don Tana formerly was home to a number of traditional fishing families of the lower Mun. It is the site of the Kaeng Tana Rapids of Thailand's Kaeng Tana National Park. The rapids for 2 km below the dam were excavated and physically removed down to bedrock (Figs. 3, 4, 6). Just after the island, the outflow abruptly narrows to about 100 m. This is the site of the lowest and most important of the rapids, Kaeng Tana. These rapids were not excavated and are still physically intact but their formerly diverse rheophilic fish community has vanished. All fish going up or down the lowermost part of the Mun must pass this "choke point," where the outflow from Pak Mun Dam during the rainy season is strongest (Figs. 1, 3). From here the outflow rapidly widens to over 500 m where it joins the Mekong mainstream.

The dashed line in Figure 1 indicates the path of the main channel in the Pak Mun reservoir outflow. Larger fish migrating up or down stay in this channel. It proceeds downstream from the right side of the dam (where the Pak Mun powerhouse is located) for about 1 km, then swings to the left side of the reservoir outflow and curves around Don Tana. At the western end of the island it swings back to the right side and continues on this side on down to the Mekong mainstream and then along the right side of the mainstream itself (Kamthon Su-aroon, personal communication, 9 March 2001). Although the mouth of Menam Mun is over 500 m wide, the tremendous rainy season discharge from Pak Mun reservoir is seriously eroding Don Hua Hin (an island in the Mekong mainstream off the Mun mouth) and also the lower lip of the Mun mouth. The main areas subject to erosion are indicated by the dotted line in Figure 1.

The dam itself consists of a cement framework with a powerhouse on its right side and eight spillways extending the rest of the way across the river. The powerhouse consists of four turbines. The turbines may be used singly or in combination to produce electricity. The capacity of each turbine is rated at 250 m^3/sec (cubic meters per second). Water passing through all four turbines operating at once could theoretically generate a current of 1000 m^3/sec. Fish probably cannot under any circumstances pass upstream past Pak Mun Dam via the powerhouse. Adult fish, especially if they are large, are not likely to survive passage through the turbines.

Water also can be released from the reservoir by a series of eight sluices or spillways. Each spillway is 20 m wide. The spillways are opened and closed by metal sluice gates. It takes an hour or longer for the doors to be fully opened or shut. During August–September the gates may have to be opened to permit the annual floods of the rainy season to pass the dam so that its level does not exceed the 108.5 m level. At least at the beginning of this period, particularly when the gates are only partially open, the current in the reservoir outflow is far stronger and more turbulent than any current that would normally occur in the Mun River, even for brief periods during the worst natural floods (Fig. 6). For this and several other reasons biologists find it misleading for Pak Mun to be called a "run-of-the-river" project (ROBERTS, 1995). Whether fish can pass upstream through the spillways depends upon many factors. Among the most important are water level in the reservoir and whether the sluice gates are fully or only partially opened. At worst the spillways are an absolute barrier to upstream fish movements. At best they are certainly more favorable to upstream movements of fish than the fish ladder but they may still be a formidable obstacle to many fish (including catfishes, etc., and gravid fish of all species).

PAK MUN DAM AS A BIOGEOGRAPHIC BARRIER

Pak Mun Dam is a highly effective barrier to upstream and downstream migrations, dispersal and any other kind of movements or displacements of fishes in the lower Mun. This barrier has three components: 1) the 4.5 km of reservoir outflow; 2) the dam itself, including its powerhouse and spillways; and 3) the 35 km of reservoir.

Effectiveness of individual components of the Pak Mun biogeograpjhic barrier depends upon the particular organism under consideration as well as numerous factors varying mainly with operational and seasonal conditions. They constitute another example of the important phenomenon of cumulative environmental impacts (CADA & HUNSAKER, 1990; ROBERTS, 1994, and references cited therein). The effect of different negative impacts acting together to the detriment of an ecosystem, a biota, a species, or an individual organism, usually is much greater than the sum of its parts.

Fish species of the Mun River evolved under natural conditions and have behavioral and other adaptations to deal with natural environmental hazards. They did not evolve in rivers with hydropower projects and man-made reservoirs. The relatively few fishes that do manage to successfully climb the fish ladder face poor prospects. They may be worn out or injured as a result of climbing the ladder. In the reservoir they are likely to be disoriented as well as subject to unfavorable water quality, disease and parasites they would not encounter in natural river conditions.

Reservoirs in tropical rivers are often characterized by water of much higher temperature than that of the rivers flowing into them or into which they flow. This is characteristic of reservoirs created by most hydropower dams in Thailand, including Ubol Ratana, Sirinthorn, and Chulaporn (SCHOUTEN *ET AL.*, 2000, Fig. 1). Temperature might explain why these reservoirs have relatively low fish biodiversity. The basal metabolism and oxygen demands of fish species generally increase by 160–270 percent with each increase in temperature of 10°C (JOBLING, 1993). This accounts in part for why tropical reservoirs tend to be permanently inhabited by a greatly reduced sub-set of the wild fish species available to them. Such a reduced sub-set is comprised largely of fishes that are air-breathing or otherwise heat and hypoxia tolerant, and small non air-breathing species with a relatively high ratio of gill surface area to body volume, and almost no large air-breathing species.

When filed to the normal wet-season operating level of 108 m the Pak Mun reservoir is 35 km long with a surface area of some 60 km^2 and a maximum depth of about 17–20 m. Its shape closely conforms to that of the streambed of the Mun River. Despite its importance there do not seem to be any ecological or limnological studies including such

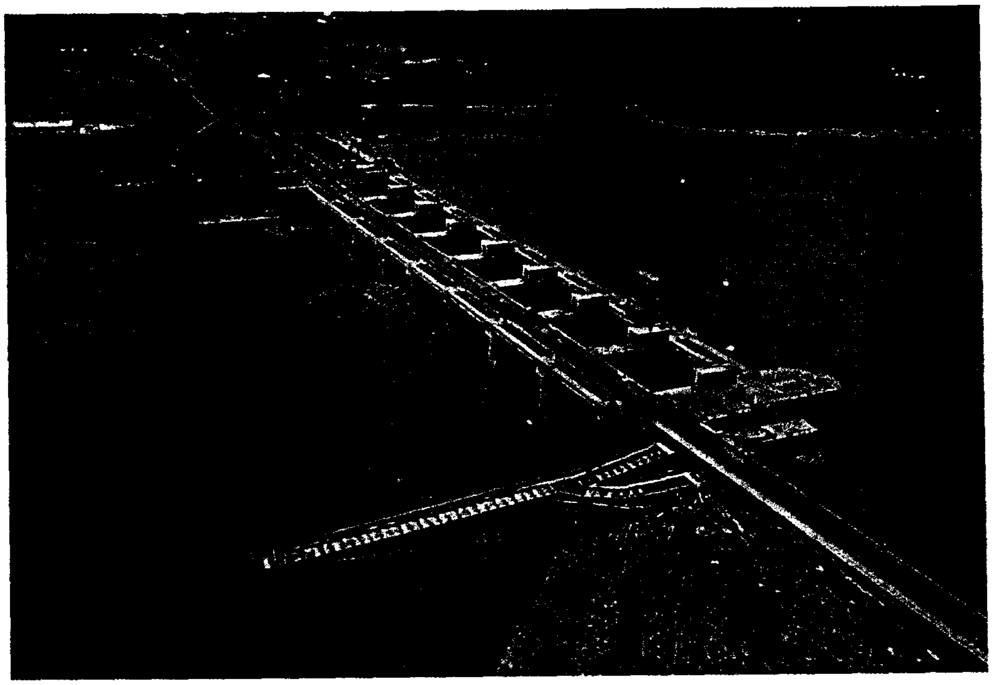

Figure 2. Aerial view of Pak Mun Dam (looking south). Fish ladder in foreground (courtesy of Prapard Phanaram and EGAT).

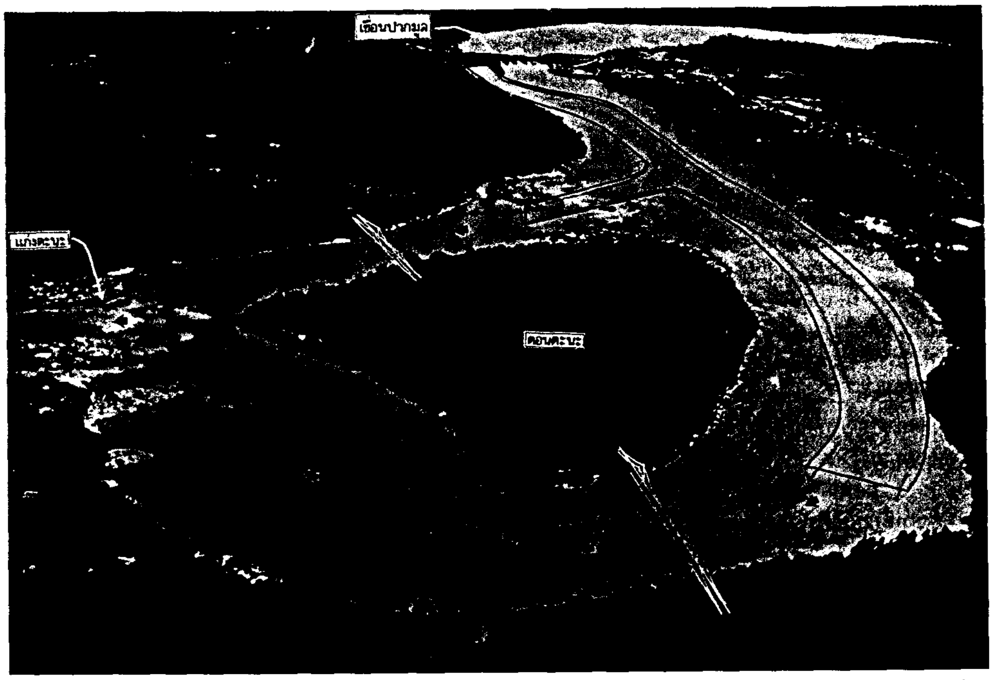

Figure 3. Aerial view of Don Tana prior to construction of Pak Mun Dam. Viewed from the west, 23 November 1991 (courtesy of Prapard Phanaram and EGAT).

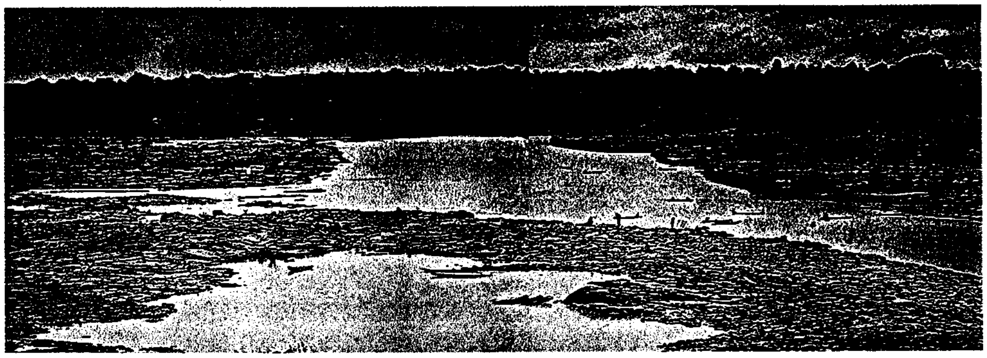

Figure 4. Partially exposed bed of Mun River (held back by coffer dam) immediately downstream from Pak Mun Dam. Note the relatively deep channel (with fishing boats) on right side of river. This is the main pathway taken by migratory fish moving up the Mun River. Also note extensive hard-rock reef on the left side blocking the way to the fish ladder. EGAT excavated a narrow channel about 1–2 m deep through the reef as access for fish to the fish ladder (see also Fig. 5) (courtesy of Sanay Pholprasith).

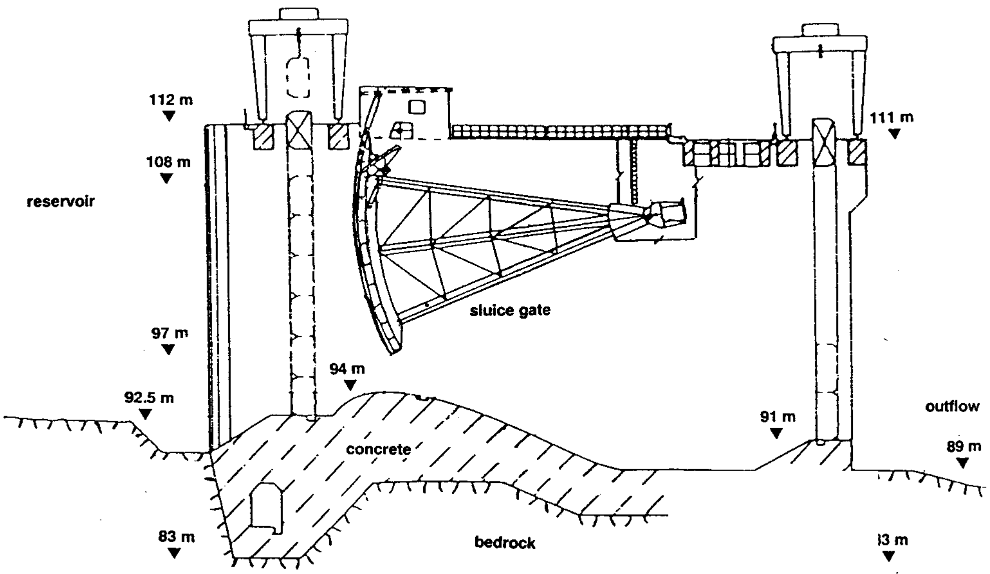

Figure 5 Transverse section through one of the Pak Mun Dam spillways (modified from diagram provided by Prapard Phanaram, EGAT).

basic parameters as dissolved oxygen, BOD, temperature, and so on. It is not known whether the waters of Pak Mun Reservoir stratify, giving rise to an upper epilimnion and a lower hypolimnion.

Sedimentation is probably the single worst environmental impact within the Pak Mun Reservoir so far as fish are concerned (Fig. 8). When tropical rivers with heavy silt loads flow into reservoirs, the silt is deposited in the upper end of the reservoir. As the years go by and the silt deposit inexorably increases, it fills more and more of the reservoir, lessening its ability to store water and making it progressively less useful for its intended purpose, electricity generation, irrigation, flood control or whatever.

The entire 35-km long bottom of Pak Mun Reservoir is covered with sediment. Due to its relatively shallow depth and continual disturbance caused by the so-called "run-of-the-river" conditions, the open waters of Pak Mun Reservoir have an exceptionally heavy year-round silt load for a reservoir. Peak generation and thus daily draw-downs coupled with strong flow-through regularly mobilizes the sediment. Impacts of Pak Mun sediment upon fishes include silt deposit on the bottom and especially rocky areas (including former rapids) so that they are no longer offer habitats, shelter, food or spawning sites for fish. Also highly significant is the mid-water silt load. This has cumulative impacts on fishes, depending on their behavior and biology. Fishes utilizing vision to find food are badly impacted. This includes not only fishes feeding in the daytime, when light levels are high, but also crepuscular and nocturnally active fishes (including many catfishes) that see enough to detect prey movement in reduced light. Fishes that feed on very small prey or food items are often unable to feed in water with high silt-loads. High silt loads make it difficult for fish to use their gills and destroy organisms fed upon by fish.

Gill-net fishermen confirmed deterioration of water quality between Ubol Rathchatani (some 60 km upstream) and Pak Mun Dam, noting that fish caught in gill-nets die before the nets are lifted. They generally set their nets at sundown and lifted them to remove the catch early the next morning. Before Pak Mun Dam the fishermen did not experience this problem (AMORNSAKCHAI *ET AL.*, 200:41). Unless attacked by predators most fish caught in gill-nets in rivers such as the Mun will survive over-night. Excessive silt in the water column is probably the main reason for the observed mortality. Exhausted fish caught in gill-nets are not able to ventilate the gills and clear them of silt nearly as well as they can when swimming freely.

Very few fish species live in the reservoir itself. These are mainly small Cyprinidae mostly of the genera *Rasbora and Systomus*. They tend to stay in shallow water close to shore. The mid-water and bottom habitats of the reservoir are nearly devoid of fish life. When the sluice gates of Pak Mun Dam close and water rises in the reservoir, nearly all of the fishes living in the 35-km effected stretch evacuate it by fleeing upstream above Geng Sapue until they encounter flowing conditions in the Mun mainstream. The reservoir by itself thus constitutes a very effective barrier to movements of fish in either direction.

Effectiveness of the reservoir outflow as a barrier varies enormously depending upon conditions. At times when the sluice gates are closed, the power station is shut down, and no water is flowing in the fish ladder, the dam is an absolute barrier to up-stream and down-stream fish movements. When the reservoir is filling or full is at least partially effective as a barrier for up-stream and down-stream movements of many fish species that require flowing water. Whenever it becomes polluted or deoxygenated it may at least temporarily be a nearly complete barrier for all fish species except those capable of breathing air or otherwise resistant to anoxic conditions.

It must be emphasized that the lower Mun River, from Phibun Mangsahan to its mouth, is the only pathway for fishes to enter the Mun river system from the Mekong River. With its extensive development of rocky rapids habitat (ROBERTS, 1994) the lower Mun was also an extremely friendly place for fish moving up the Mun or residing permanently in the Mun. The rapids have been destroyed for 2 km between the dam and the island of Don Tana, creating an exceptionally harsh and unfavorable place for fishes (ROBERTS, 1994). The rapids above the dam are now under 10–15 m of water and increasingly suffocated by siltation.

The Pak Mun biogeographic barrier just described of course has major consequences for up-stream movements of migratory fishes upon which the traditional artisanal wild-capture fisheries of the Mun are (or were) mainly based. It also has major consequences for continued upstream and downstream movements of all kinds of aquatic organisms, for whatever biological reasons. As the entire Mekong ecosystem is being progressively simplified and degraded due to human encroachments and other impacts, blockage of recruitment from the Mekong mainstream into the Mun river system and vice versa will be increasingly significant.

The so-called "run-of-the-river" concept originated in the field of hydropower engineering and has to do with the potentially continuous generation of electricity. Hydropower engineers consider that a dam that has a short water retention time (such as Pak Mun Dam) falls in this category (no matter how tall it is) because its electricity output will fluctuate roughly in the same manner as river discharge. In this case China's 100-m high Manwan Dam on the Lancang or upper Mekong mainstream in Yunnan could be classed as "run-of-the-river." As pointed out previously (ROBERTS, 1995), and as I hope is clear from the present discussion, application of this term to any projects with large dams is utterly inappropriate from the standpoint of river ecology.

PREVIOUS MUN FISH STUDIES

Fisheries biologists and limnologists did relatively little study on the Mun, so that there is a dearth of baseline data on hydrology, limnology, water chemistry, and related topics (SCHOUTEN *ET AL.*, 2000; personal observation). Presumably Pak Mun Reservoir does not become stratified into upper epilimnion and lower hypolimnion layers but even this is not documented. Little is known about the fish migrations in the Mun River system or in the part of the Mekong into which it flows before construction of Pak Mun Dam. Hydrological and other relationships between the Mekong and the Mun under conditions existing prior to Pak Mun Dam and their relationship to fish biology including migratory behavior were not studied.

Artisanal fisheries of the Mun River, including different types of fishing gear and their specific uses (including targetted fish species), fishing techniques, seasonality, yields, and catch composition were not well documented despite their importance. Because of the lack of pre-dam study and baseline data, assessments of the impacts of Pak Mun Dam on fisheries are difficult and can be disputed (SCHOUTEN *ET AL.*, 2000; AMORNSAKCHAI *ET AL.*, 2000 including remarks by EGAT).

Systematic inventory of fish species in the Mun River, on the other hand, was essentially completed before construction of Pak Mun Dam. Although problems remain with scientific identification of species in some of the families and genera, the basic baseline data of Mun River fish biodiversity are quite good. Knowledge of the Mun fish fauna has now reached the point where probably 95 percent of the species have been collected and preserved in scientific research collections and perhaps 90 percent of the species have been correctly identified. A few species are not yet scientifically described and named. Probably no migratory fish species contributing to fisheries have been overlooked. Thus sufficient baseline data is available to access the impacts of Pak Mun Dam on fish species richness in the Mun River basin.

The Mekong Secretariat's former Senior Fisheries Advisor V. K. Pantulu insisted for many years that "the Mekong does not have any true migratory fish species." His concept of "true migratory fish species" was narrowly limited to diadromous species such as salmon, which must migrate between freshwater and marine habitats in order to complete their life cycle. This limited view of what constitutes migratory fish behavior is now rejected by virtually all biologists familiar with Mekong fishes, but for far too long it dominated the thinking of those promoting development of Mekong hydropower.

We know now that most of the fish species important in Mekong (including Mun) wild-capture fisheries are strongly migratory (ROBERTS, 1993; ROBERTS AND BAIRD, 1995; WARREN *ET AL.*, 1998, BARAN *ET AL.*, 2001). In some—perhaps many—instances, fish species may be unable to complete their life history without migration. In addition to migrations to spawning grounds, many species have migrations not involved with reproduction. The reason or reasons for these non-reproductive migrations are not well understood, but they clearly are necessary for the welfare of the fish. Fishermen are largely dependent upon the migratory movements to make their catches.

Fish species naturally occurring in the Mun River that supposedly could utilize fish passes to pass by Pak Mun Dam and contribute to the maintenance of the wild-capture fisheries and its supporting food chains are presented in Table 1. Excluded from this list are exotic or introduced species. Also excluded are species able to maintain their populations indefinitely in the Mun River system regardless of Pak Mun Dam. It should also be noted that this list does not include many Mun River fish species adversely effected by Pak Mun Dam for reasons other than blockage of their up- and down-stream movements. Many species in this category inhabited the rapids of the lower Mun River before construction of Pak Mun Dam.

Nearly all discussions of the impact of large dams on fish movement focus on fish migration. Dams also interfere with other essential fish movements, including passive downstream dispersal of fish eggs and larval stages, "random" dispersal of juveniles and adults upstream and downstream, and active upstream and downstream exploratory, opportunistic, and evasive movements.

Fish species make evasive movements upstream or downstream to escape unfavorable environmental conditions such as water that becomes too warm, deoxygenated, or polluted. These movements may be short or long distance. Opportunistic and exploratory movements are also important. This is especially true for large, long-lived, and rare species (such as *Aaptosyax grypus, Catlocarpio siamensis, Dasyatis laoensis, Himantura polylepis, Pangasianodon gigas, Pangasius sanitwongsei*, and *Wallagonia leerii*). For rare species with low population densities it may be essential in finding mates for spawning. Large predatory fish species such as *Aaptosyax grypus, Pangasius sanitwongsei, Wallagonia* *leerii*, and *Bagarius yarrelli* may spend much of their time and effort making exploratory or opportunistic movements to find or follow prey. Predatory fish tend to remain in areas with abundant prey and to move upstream or downstream away from areas with insufficient prey.

Discussion of impacts of Pak Mun Dam on specific fish habitats has focused strongly on rapids (ROBERTS, 1994; SCHOUTEN *ET AL.*, 2000; AMORNSAKCHAI *ET AL.*, 2000), which of course are important for fish and other riverine organisms in many ways. Almost unnoticed has been the severe impact of Pak Mun Dam on the mouth of the Mun River. Although seldom remarked upon, the mouths of large tributaries into the mainstream of large rivers are important to fishes from a variety of standpoints. Involved are fish movements in four directions (upstream and downstream, to and from mainstream and tributary), unique habitat features, and a host of factors little discussed and poorly understood that require much more study. Under natural conditions mixing of tributary and mainstream waters generally creates conditions highly favorable to fish. River mouths offer opportunities for many kinds of fish movements, including exploratory, opportunistic and evasive as well as migratory.

Fish species probably or potentially very badly effected by the impacts of Pak Mun Dam upon the mouth of the Mun River include *Aaptosyax grypus, Catlocarpio siamensis, Chitala blanci, Himantura polylepis, Probarbus jullieni*, and *P. labeamajor* and perhaps also *Pangasius krempfi* and *P. sanitwongsei* as well as many others. The important seine and gill-net fisheries in the mouth of the Mun River also have been badly impacted by Pak Mun Dam.

It is no exaggeration to say that the ecologically important rapids in the lower 40 km of the Mun River have been totally destroyed as habitat for special rapids-inhabiting species of fish and other animal groups. The rapids-inhabiting species of groups such as crustaceans (including crabs, prawns and shrimps) and mollusks (clams and snails) apparently have not been well documented in the lower Mun. Specialized fish species formerly present in the rapids of the lower Mun can be listed here (after CHAVALIT in SCHOUTEN *ET AL.*, 2000; and personal observation):

Notopteridae
- *Chitala blanci*

Cyprinidae
- *Bangana behri*
- *Epalzeorhynchus coatesi*
- *Garra fasciacauda*
- *Garra sp or spp*
- *Labeo pierrei*
- *Lobocheilus* spp (at least two)
- *Mekongina erythrospila*

Gyrinocheilidae
- *Gyrinocheilus aymonieri*
- *Gyrinocheilus pennocki*

Cobitididae
- *Acantopsis* spp (at least two)
- *Botia beauforti*

Botia caudipunctata
Botia eos
Botia longidorsalis
Botia splendida
Botia sp or spp

Balitoridae
Balitora spp (at least two)
Homaloptera spp (at least two)
Schistura spp (at least two)

Sisoridae
Bagarius suchus
Glyptothorax sp or spp

Tertraodontidae
Tetraodon abei
Tetraodon baileyi
Tetraodon barbatus
Tetraodon suvattii

Gobiidae
Genus and sp undet (two)

Some of the species in this list occur in stretches of rapids further upstream in the middle and upper parts of the Mun basin but this is not well documented. All of them probably have been extirpated from the lower Mun River (from Phibun Mangsahan on down) due to Pak Mun Dam. At least 33 species of specialized rapids fishes inhabit the lower Mun River, but a complete list cannot be given mainly due to uncertainties in identification of species in the genera *Acantopsis, Balitora, Botia, Garra, Glyptothorax, Homaloptera* and *Schistura* and of genera and species in family Gobiidae. Some of these species are not probably not yet scientifically described and named. The rapids of the lower Mun were never thoroughly sampled for fishes before construction of Pak Mun Dam despite the numerous opportunities provided by the blasting of the rapids (ROBERTS, 1994). Had this been done a number of additional species probably would have been discovered.

The rapids in the lower Mun were important not only to specialized rapids-inhabiting fish but also to many other fish species including migratory species that used them as feeding and spawning grounds and as refuges during upstream movements. The rapids in the lower Mun probably had by far the highest over-all biodiversity of any fish habitat in the Mun River. They may also have had the highest bioproductivity.

A SUCCESSFUL FISH LADDER?

The Pak Mun fish ladder (Figs. 9–12) is similar in design to that on the much smaller Menam Payao on the Payao Irrigation Dam in the Chao Phraya basin of northern Thailand, built in 1950 (WARREN & MATTSON, 2000). It is a "combined pool and weir type fish pass with submerged orifices" (PHOLPRASITH *ET AL.*, 1997). There are two widely separated orifices or square openings 15x15 cm in the bottom of the submerged part of each weir. The purpose of the openings is to permit passage of so-called "skin-fish" (mainly catfishes and loaches) that do not jump at all and tend to pass under rather than over barriers. The species most commonly observed to use the orifices in the Pak Mun fish ladder are the loach *Botia modesta* and the bagrid catfish *Hemibagrus filamentus* (formerly referred to as *Mystus nemurus*) (personal observations; Kamthon Su-aroon, personal communication, 6 March 2001).

The Pak Mun fish ladder is 92 m long and 15 m high. Therefore the slope or gradient up which the fish must move is 1:6 or 17 percent. This gradient is substantially greater than that naturally encountered by fish species anywhere in the middle and lower parts of the Mekong basin except in some waterfalls in mountain tributaries. The total width of the ladder is 4 m, but the actual width of the fish passageway in the ladder is only 3 m. This represents only one-hundredth (1%) of the 300-m width of the Mun River up and down which fishes moved before installation of Pak Mun Dam.

In order for the ladder to facilitate upstream movement of fishes at all times of the year, the uppermost part is divided into two (Figs. 10–11). One division, for use during the wet season at high water levels in the reservoir, opens into the reservoir at 108.5–107.0 m in elevation. The other division, for use during the dry season at low water levels in the reservoir, opens into the reservoir at 107.0–105.5 m elevation. Fish traveling up the ladder during high water times must pass 48 weirs, while fish traveling up during lower water have to pass only 44 weirs. The divisions join each other at 104 m elevation to allow the water to travel the rest of the way down the ladder. The trough of the ladder is 3 m wide and the weirs that slow up the water flow and create pools and resting places for the fishes are 1.2 m high. The weirs are vertical. They alternate from side to side to reduce speed of the water flow. Water level and volume of flow in the ladder can be partially controlled by manual adjustment of wooden boards or stop-locks. An auxiliary water supply, to help attract fish to the opening of the fish ladder, is provided by a pipe 30 cm in diameter. Footpaths about 0.5 m wide on each side permit workers to move up and down the ladder to adjust the wooden stop locks or baffles and do other tasks such as monitoring migratory fish.

For the Pak Mun fish ladder to be a true success it would have to at least permit upstream movement past the dam of large numbers of most or many of the migratory fish species inhabiting the Mun River. In this respect it has been a total failure (PHOLPRASITH *ET AL.*, 1997; SCHOUTEN *ET AL.*, 2000). In the early years after dam completion the highest quantity of fish found on the ladder was 200 kg/day during peak migration periods (Fig. 14). Even this probably represents only a small percentage of fish actually migrating. During 1999 the maximum quantity of fish monitored at the top of the ladder was only 12 kg/day, and the average only 2 kg (SCHOUTEN *ET AL.*, 2000: 34). Only 61 native fish species were able to climb all the way to the top of the Pak Mun fish ladder (PHOLPRASITH *ET AL.*, 1997). This number represents scarcely one-fourth of the 258 native fish species inhabiting Mun River before construction of Pak Mun Dam.

Only a small percentage of the individuals of the 61 native species fish found on the Pak Mun fish ladder[2] made it all the way to the top of the ladder and into the reservoir (PHOLPRASITH *ET AL.*, 1997). The majority of fishes only made it part way up the ladder,

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[2]The number of species originally was reported as 63. It has been adjusted to 61 to exclude the exotic species *Cyprinus carpio* and a redundant species of *Labiobarbus*.

then fell back (Pinit Sihapitukgiat, personal communication, June 2000). No provisions were made for obtaining data on the proportion of fish that fell back, as opposed to those that actually made it all the way to the top and on into the reservoir, but it was probably very high. Among 34 fish species entering the fish ladder on the Brazil's Salto do Morais hydroelectric dam of the rio Tijuco in the upper Parana basin, only 2 percent of the individual fish reached the top of the ladder (GODINHHO, *ET AL.*, 1991). This 78.3 m long and 10.8 m high ladder, with only 25 steps or levels, presumably is a less formidable obstacle than the Pak Mun fish ladder. Reasons for failure of the fish ladder on Pak Mun Dam are explored more fully below.

An ichthyological survey of the Mun River conducted in 1999 recorded only 96 species upstream of the Pak Mun Dam (SCHOUTEN *ET AL.*, 2000). Many species not found in 1999 presumably disappeared because of Pak Mun Dam.

The water body created upstream of a hydropower dam may be called a head pond, an impoundment, or a reservoir. It should never be called a lake; lakes are natural features and reservoirs are not. Conditions prevailing in Pak Mun reservoir are not found in any naturally-occurring water body. Few fish species can survive in it, let alone prosper. The main reason apparently is the heavy sedimentation or siltation of the reservoir bottom and heavy silt-load of the reservoir waters due to constant mixing by the hydropower flow regime.

The outflow from a dam, although it looks like a river, has almost none of the life-sustaining qualities of a natural river (ROBERTS, 1994; 1995, 1996). I refer to it as the "reservoir outflow". Pak Mun reservoir outflow is particularly unfriendly to fish.

MIGRATORY FISH SPECIES AND PAK MUN FISH LADDER

We now proceed to discussion of particular migratory fish species of the Mun River in relation to Pak Mun Dam (Table 1). This exercise provides some idea of the biodiversity and richness of the Mun fish fauna, and the problems in conserving it in the face of continued negative impacts. Hopefully it will better inform those promoting fish ladders as useful mitigation devices on dams in the Mekong basin and elsewhere.

Many writers use the term "extinction" when they should be using "extirpation." Extirpation is when a species disappears from part of its range. It implies that the species is not extinct, because it still occurs elsewhere. Extirpation of a species throughout its entire range is the same as extinction. Several species recorded from the Mun River system were probably extirpated or nearly extirpated before construction of Pak Mun Dam: *Anguilla marmorata, Tenualosa thibaudeaui, Catlocarpio siamensis, Macrochirichthys macrochirus, Tor* sp or spp (cf. *Tor sinensis* and *T. tambroides*), *Pangasianodon gigas* and *Wallagonia leerii.* So long as they continue to occur elsewhere in the middle Mekong basin their eventual return to the Mun River was at least a possibility prior to construction of the dam.

Another term employed in the present discussion is "disappearance", when a formerly relatively common or at least readily observed and identified species is no longer reported and cannot be found when searched for. Its survival status is uncertain and it might be extirpated (or in the case of an endemic species, extinct).

The lower Mun River or at least its mouth was frequented by two large species of freshwater stingrays, *Dasyatis laoensis* and *Himantura polylepis.* The first attains 30 kg;

Table 1. Native migratory and other fish species the continued presence of which in the Mun River ecosystem is doubtful because they are no longer able to move upstream in sufficient numbers (if at all) past Pak Mun Dam. Species reportedly utilizing Pak Mun fish ladder by PHOLPRASITH ET AL. (1997) indicated by a plus sign (+). Species naturally occurring but extremely rare (and in some instances possibly extirpated from the Mun system before installation of Pak Mun Dam) indicated by an asterisk (*).

Dasyatidae (whiptaled stingrays)
- *Dasyatus laoensis*
- *Himantura polylepis*

Notopteridae (featherbacks)
- *Chitala blanci*
- *Chitala ornata*

Anguillidae (true eels)
- *Anguilla marmorata**

Clupeidae (herrings)
- *Clupeichthys aesarnensis*+
- *Tenualosa thibaudeaui**

Engraulididae (anchovies)
- *Lycengraulis crocodiles*
- *Setipinnis melanochir*

Cyprinidae (carps)
- *Aaptosyax grypus*
- *Amblyrhynchichthys truncatus*
- *Bangana behri*
- *Barbichthys nitidus*
- *Barbodes altus*
- *Barbodes schwanenfeldi*
- *Catlocarpio siamensis**
- *Cirrhinus microlepis*+
- *Cirrhinus molitorella*+
- *Cirrhinus* (or *Henicorhynchus*) *lobatus*
- *Cirrhinus* (or *Henicorhynchus*) *siamensis*+
- *Cosmochilus harmandi*
- *Cyclocheilichthys enoplos*+
- *Cyclocheilichthys heteronema*
- *Cyclocheilichthys mekongensis*
- *Cyclocheilichthys* spp
- *Garra* sp or spp
- *Hypsibarbus lagleri*
- *Hypsibarbus malcolmi*
- *Hypsibarbus vernayi*
- *Hypsibarbus wetmorei*
- *Labeo pierrei*
- *Labiobarbus* (or *Dangila*) *leptocheilus*+

Labiobarbus (or *Dangila*) *siamensis*
Leptobarbus hoeveni
*Macrochirichthys macrochirus**
Mekongina erythrospila
Morulius barbatulus
Morulius chrysophekadion+
Mystacoleucus spp
Neolissochilus blanci
Oseochilus melanopleura
Osteochilus waandersi
Parachela oxygastroides
Parachela siamensis
Paralaubuca harmandi
Paralaubuca riveroi+
Paralaubuca typus+
Poropuntius deauratus+
Probarbus jullieni
Probarbus labeamajor+
Probarbus labeaminor
Puntioplites proctozysron+
Puntioplites spp
Scaphognathops bandonensis+
Scaphognathops stejnegeri+
Sikukia gudgeri+
Sikukia stejnegeri
Tor sinensis
Tor tambroides

Cobitidae (spiny loaches)
Acantopis spp
Botia modesta+
Botia rubripinnis

Gyrinocheilidae (algae suckers)
Gyriocheilus aymonieri+
Gyrinocheilus pennocki

Pangasiidae (catfishes)
Helicophagus waandersi+
*Pangasianodon gigas**
*Pangasianodon hypophthalmus**
Pangasius bocourti+
Pangasius conchophilus
Pangasius larnaudiei+
Pangasius macronema
Pangasius micronema
Pangasius pleurotaenia
Pangasius sanitwongsei

Siluridae (catfishes)
Belodontichthys truncatus
Hemisilurus mekongensis
Kryptopterus cheveyi
Kryptopterus hexapterus+
Kryptopterus limpok
Kryptopterus palembangensis
Kryptopterus schilbeoides
Micornema apogon
Micronema bleekeri
Micronema micronema
Wallago attu
*Wallagonia leerii**
Bagridae (catfishes)
Bagrichthys macracanthus
Bagrichthys macropterus
Hemibagrus microphthalmus
Hemibagrus wyckii
Mystus bocourti
Schilbeidae (catfishes)
Laides hexanema+
Laides sinensis
Sisoridae (sharkskin catfishes)
Bagarius yarrelli
Datnioididae (tigerfishes)
Datnioides undecimradiatus
Sciaenidae (croakers)
Boesemania microlepis

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the second 500 or 600 kg, making it by far the largest fish species in the Mekong basin. Neither species has been observed on the fish ladder. The presence of both species in the Mun River probably depended upon continual recruitment or movements from the Mekong mainstream. They have not been observed in the lower Mun since construction of Pak Mun Dam.

The Mun River was inhabited by three species of featherbacks or Notopteridae. All three are used to prepare fish balls used in Thai cooking. The small species, *Notopterus notopterus*, does well in swamps (including swampy margins of reservoirs and weedy canals) and will almost certainly be able to maintain its populations in the Mun River. *Chitala ocellifer* lives in a variety of habitats and might maintain its populations in the Mun River without recruitment from the Mekong mainstream. *Chitala blanci* lives only in very large rivers, such as the Mekong mainstream and the Mun river, and has a marked preference for rocky habitat. Destruction of the rapids in the lower Mun as well as obstruction of its movements by Pak Mun Dam has probably eliminated this species from the Mun fauna. None of the three species of Notopteridae found in the lower Mun has been observed on the fish ladder.

Two endemic Mekong species of freshwater herrings were present in the Mun. *Clupeichthys aesarnensis* was one of the most important forage fish for many predatory Mun fish species, and was also caught for human consumption. The population of this species in Sirinthorn Reservoir (on a tributary of the Mun River) exploded and has remained high despite being heavily fished for years. It is present in Pak Mun reservoir but apparently in low numbers. At least in the early years of Pak Mun Dam it suffered mass mortality when it was flushed out of the reservoir into the reservoir outflow during peak operating periods or when the spillways were opened. *Clupeichthys aesarnensis* has successfully climbed the ladder but in insignificant numbers (PHOLPRASITH *ET AL.*, 1997).

Tenualosa thibaudeaui was formerly one of the most important forage fish species and wild-capture fish species in the lower and perhaps also middle Mekong basin, and is still moderately important in Cambodia. It has declined sharply in recent decades. No doubt it was severely impacted by the introduction of "invisible" mono-filament nylon gill nets in the early 1970's. A few *Tenualosa thibaudeaui* climbed the ladder part-way but none made it all the way (PHOLPRASITH *ET AL.*, 1997).

The true eel *Anguilla marmorata* (family Anguillidae) is widely distributed in mountain tributaries in the lower and middle Mekong basin, including Cambodia, Thailand and especially Laos. It is an obligate diadromous species, which must migrate between the sea and fresh water in order to complete its life cycle. Although rarely recorded from the Mun River, it may still live in deep rocky pools (its preferred habitat) in remote mountainous headwaters in the Mun basin. Because of its long life span of 15–20 years it will not disappear from the Mun immediately but its extirpation from the watershed because of Pak Mun Dam is presumably only a matter of time. This extremely hardy, strong, and capable climber undoubtedly could succeed in climbing Pak Mun fish ladder but it has not been reported on the ladder. Its apparent absence on the ladder might be due to its rarity. It also could be due to the positioning of the ladder entrance far away from the main channel used by most fish migrating up the Mun and to negative impacts of the reservoir and its outflow. In July 2001, after the Pak Mun Dam spillways gates were opened, fishermen from Ban Mae Mun captured two large *Anguilla marmorata* near the Dam. One of them, about 80 cm long, was examined and identified by me on 21 July 2001.

Two species of freshwater anchovies or Engraulididae, *Lycengraulis crocodilus* and *Setipinna melanochir*, were moderately common in the Mun River. Little is known of their biology, but they are probably migratory. Their presence in the Mun probably depends upon recruitment from the Mekong mainstream. Neither species has been reported on Pak Mun fish ladder. They are almost certainly too delicate to survive a climb up the ladder.

Cyprinidae (carps) is the most important fish family in the Mun River and throughout the Mekong basin. It has the largest number of genera and species, and their biology and behavior is extremely diverse. Many species have been badly impacted by Pak Mun Dam.

Aaptosyax grypus is a newly discovered predatory carp that lives only in the Mekong basin. Reaching at least 1 m in length and 24 kg (personal observation), it is one of the most spectacular cyprinid fish species in the world. The only known specimens are from the mouth of the Mun River and the mainstream of the Mekong in the vicinity of Khone Falls. The smallest known specimens, 10–20 cm long, were collected just inside the mouth of the Mun River. It seems likely that their parents spawned in the lower Mun, perhaps in rapids habitats. The species has not been observed on the Pak Mun fish ladder and has not been recorded again from the Mun since construction of Pak Mun Dam. Young fish of

20–30 cm or so probably could utilize the ladder but adults and sub-adults approaching sexual maturity could not use the ladder because they are too big. Survival of the species probably is dependent upon spawning migrations and a few spawning grounds. It used to be moderately common just below Khone Falls in Laos. It is now rarely caught by Khone fishermen (ROBERTS & BAIRD, 1995; Ian C. Baird, personal communication, June 2001). It is particularly susceptible to gill-net fishing. It has not yet been recorded from Cambodia.

Amblyrhynchthys truncatus is a migratory species. It has not been reported on Pak Mun fish ladder. It might not survive in the Mun without recruitment from the Mekong mainstream.

Bangana behri, *Labeo pierrei* and *Mekongina erythrospila* are important food fishes. Fishermen catch them mainly when they migrate for spawning. These large rheophilic (current-loving) species occur only in large rivers, typically near rocky situations, and are absent from rivers that do not have extensive stretches of rocky bottom. Their feeding and spawning grounds in the rapids of the lower Mun were destroyed by construction of Pak Mun Dam. Existence of these species in the Mun probably depended on favorable habitats now largely gone, as well as spawning migrations and recruitment from the Mekong mainstream no longer possible due to Pak Mun Dam. When the Pak Mun spillways were opened in June 2001 fair numbers of *Labeo pierrei* were caught by fishermen immediately below and above the dam. These were mostly small fish, perhaps a year old.

Barbichthys nitidus, *Cirrhinus lobatus*, *C. microlepis*, and *C. siamensis* prefer rivers with extensive muddy bottoms, from which they filter microscopic algae. *Cirrhinus lobatus* and *C. siamensis* are important both as food for man and as forage for predatory fish. They are among the most abundant fish species the Mekong basin. *Cirrhinus lobatus* has been described as an "ecological keystone species" in the Mekong mainstream at Khone Falls in southern Laos (ROBERTS & BAIRD, 1995; ROBERTS, 1998). *Cirrhinus siamensis* probably is the main species shown jumping up the fish ladder in Fig. 13. The larger species *C. microlepis* is a particularly important species for human consumption in the Mekong basin. It is, or was, also one of the most important in the Mun River.

Barbichthys nitidus is a relatively rare species, but may not have always been rare. At any time it might become abundant, and then it would become an important resource targeted by fishermen. All of these species are strongly migratory. Until construction of Pak Mun Dam they probably made spawning migrations up the Mun. The presence of all of these species in the Mun may have depended upon their recruitment from the Mekong mainstream and upon their successful spawning and non-spawning migrations up the Mun River. It probably is only a matter of time before these species either disappear from the Mun or become very rare there.

Cirrhinus lobatus and *C. siamensis* deserve additional mention. In the lower Mekong these two species have been identified as the major components of the largest fish reproductive migrations. Some of these migrations extend for over 1000 km. It is unlikely that individual fish complete such long-distance migrations. Instead they follow the migrating mass of conspecifics for relatively short distances until they spawn and then drop back, to be replaced by recruitment all along the route (ROBERTS, 1998). There seem to be many local populations of both species that undergo relatively short migrations within a tributary or part of a headwater, without participating in the more spectacular long-distance mass migrations. The populations of greatest importance to fisheries and also ecologically are of course those undergoing large-scale migration. *The Cirrhinus lobatus* and *C. siamensis*

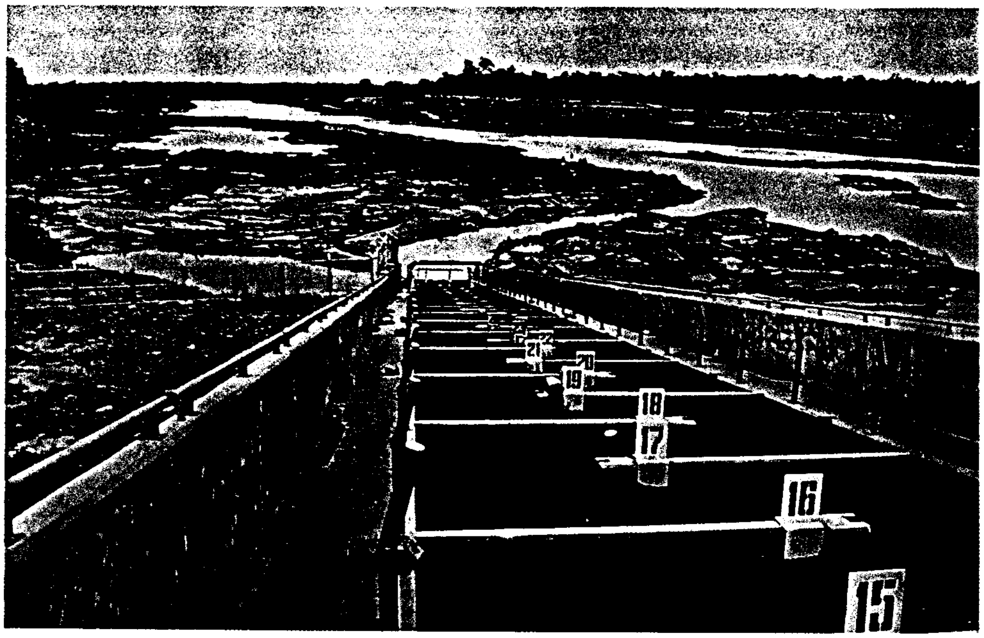

Figure 6. Fish ladder during late stage of construction viewed from top of dam before completion of construction. Note narrow artificial channel through reef leading to mouth of fish ladder (courtesy Prapard Phanaram and EGAT). Compare with Fig. 4).

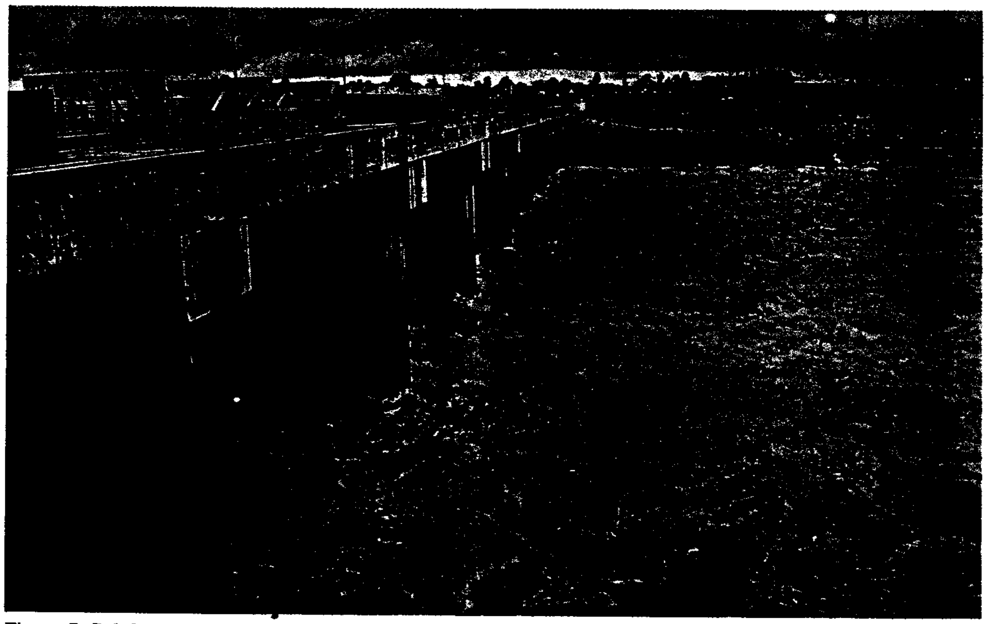

Figure 7. Pak Mun Dam with spillways wide open. The violently turbulent conditions continue down the reservoir outflow to the Mekong mainstream; date unrecorded. Few if any of the naturally occurring fish species of the Mun River can survive such conditions. Such flooding is one of the reasons it is objectionable to call Pak Mun Dam a "run-of-the-river" installation; (courtesy of *The Nation*). See Fig. 15.

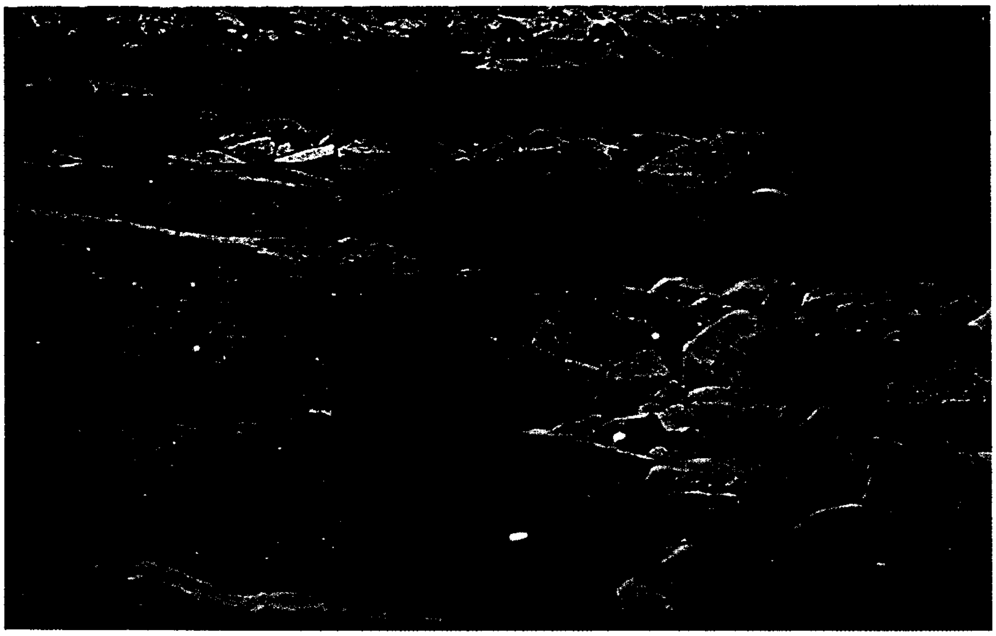

Figure 8. Thick deposits of fine silt or mud in the bed of the Pak Mun reservoir near Pak Mun Dam, June 2001 (courtesy of Assembly for the Poor). Such deposits extend for the entire 35-km length of the reservoir. They are only partially removed when the spillway gates are opened, and are regularly stirred up during peak electricity generation. (Courtesy of Assembly for the Poor).

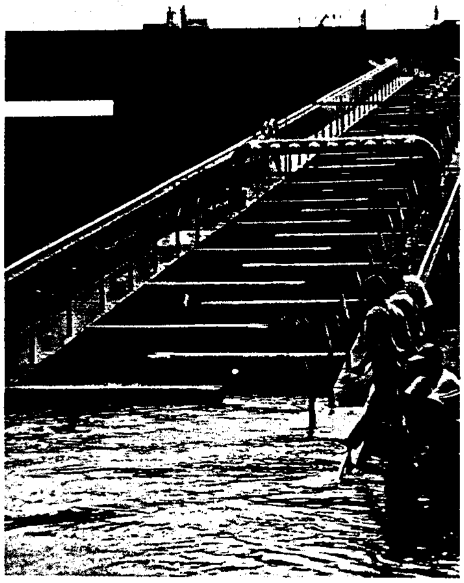

Figure 9. Completed fish ladder ready for fish, viewed from reservoir outflow with water conditions favorable to fish movement upstream (courtesy of Prapard Phanaram and EGAT).

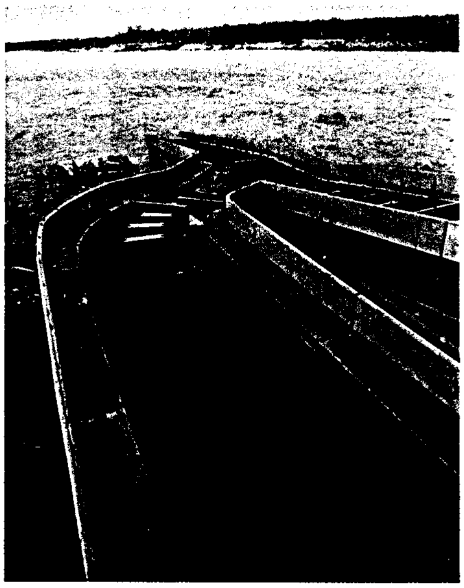

Figure 10. Fish ladder from above looking down. Flow in reservoir outflow too strong and flow in fish ladder too weak; date unrecorded (courtesy of *The Nation*).

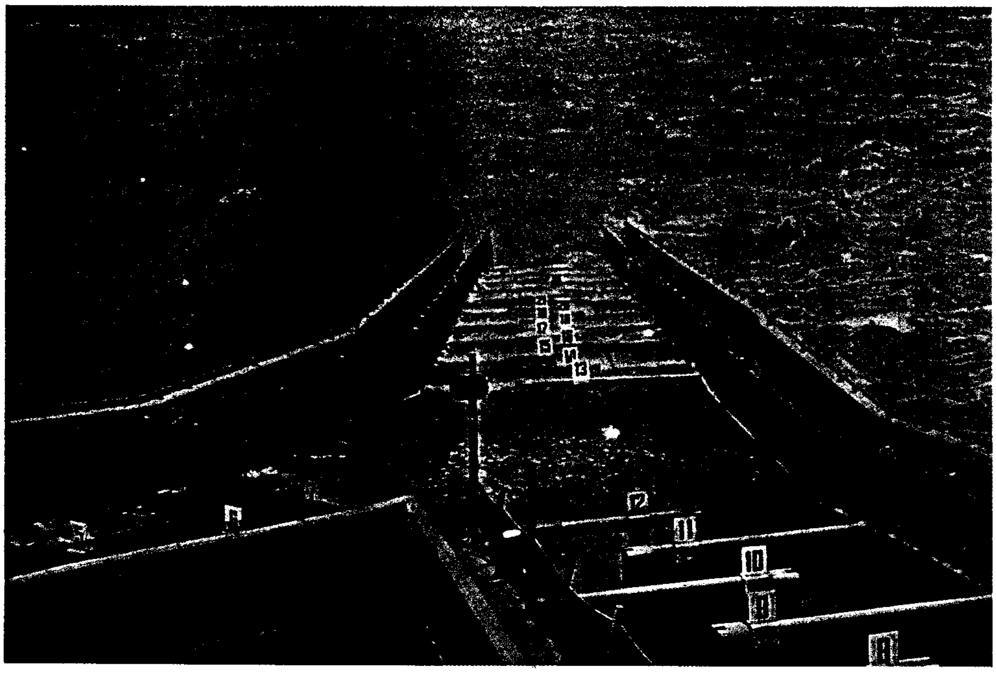

Figure 11. Close up of fish ladder looking down from dam. Water flow in reservoir outflow and in fish ladder favorable for fish; date unrecorded (courtesy of Sanay Pholprasith).

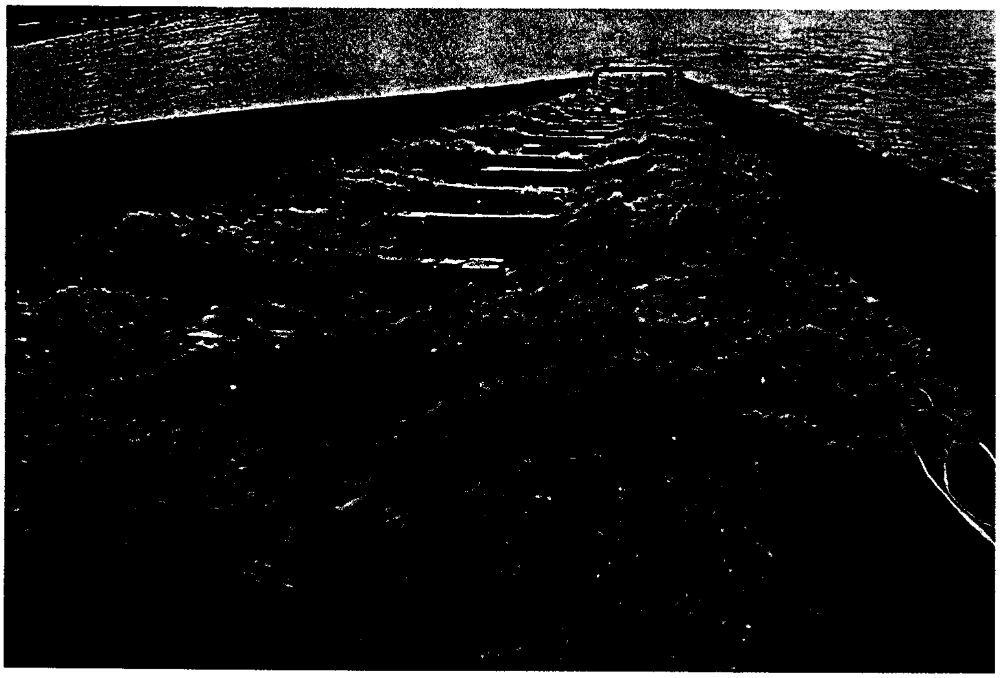

Figure 12. Close-up of fish ladder looking down from the dam. Current in reservoir ouflow favorable but current in fish ladder far too strong; 15 June 1994 (courtesy of Prapard Phanaram and EGAT).

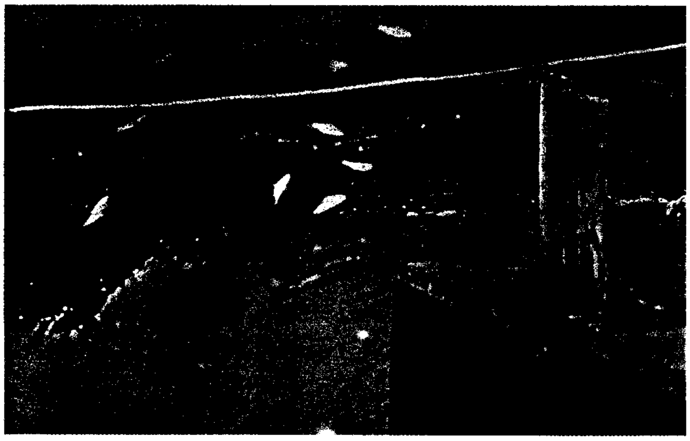

Figure 13. Cyprinid fish (mainly pla soi, *Cirrhinus siamensis*?) jumping up fish ladder (courtesy of Sanay Pholprasith).

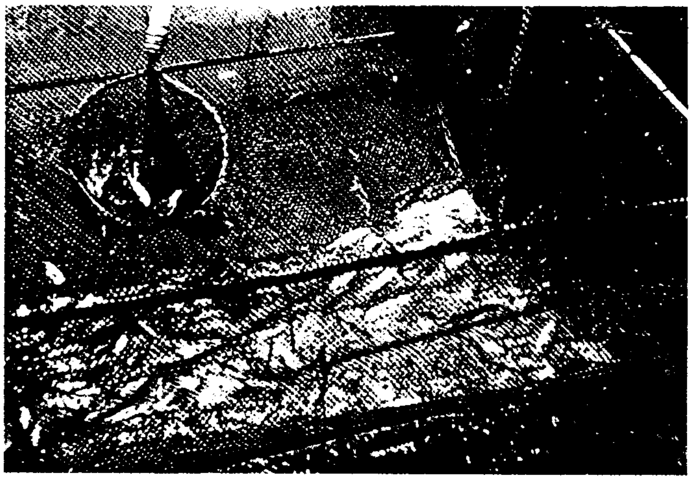

Figure 14. Wire basket trap used by Department of Fisheries team to survey fish species on ladder. Note that although there are a fair number of species, individual fish tend to the same size (there are no fish below about 10 cm or over about 25 cm) (courtesy of Sanay Pholprasith).

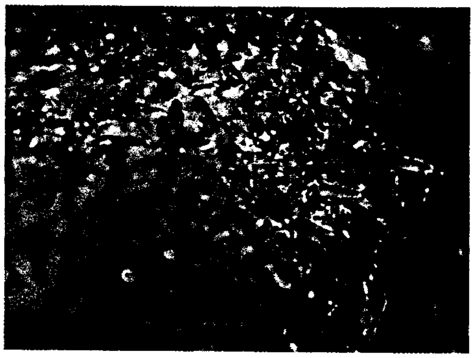

Figure 15. Young prawns (*Macrobrachium rosenbergii*) on footpath beside Pak Mun fish ladder (courtesy of Sanay Pholprasith).

Figure 16. Gravid *Catlocarpio siamensis* caught in the Pak Mun Dam reservoir outflow in July 1999 after repeatedly butting its head on the foot of the fish ladder (courtesy of Assembly for the Poor).

undergoing such migration from the Mekong mainstream up the Mun River are effectively blocked by Pak Mun Dam. Both species probably will persist in the Mun basin represented by local populations with less marked migratory behavior and of less importance to wild-capture fisheries.

Cosmochilus harmandi and *Cyclocheilichthys enoplos* are very important food fishes and were formerly heavily fished in the Mun, especially during their migrations. They often occur together in large rivers, and tend to migrate together. Large adults in spawning condition are probably too big to use the fish ladder. Both species are likely to disappear from the Mun River due to Pak Mun Dam.

The four species of *Hypsibarbus*, (*H. lagleri, H. malcolmi, H. vernayi*, and *H. wetmorei*) are large deep-bodied carps important in wild-capture fisheries throughout the middle and lower Mekong. Large fish are caught mainly during their spawning migrations. Quantities of the young fish are caught when they make massive non-reproductive migrations. The presence of these species in the Mun probably depends upon continual recruitment from the Mekong mainstream as well as unimpeded migratory and other movements up and down the river.

Labeobarbus leptocheilus and *Sikukia gudgeri* were abundant in the lower Mun River right up to the time Pak Mun Dam was built. Both are now rare or absent in the river below Phibun Mangsahan. Their continued presence in the Mun River might require recruitment from the Mekong.

The elongate silvery predatory carp *Macrochirichthys macrochirus*, an extremely delicate species which apparently cannot survive captivity, has been greatly reduced throughout its range in the Mekong basin and elsewhere. It still occurs abundantly in large rivers of Sumatra such as the Batang Hari, but it is close to total extirpation in the Chao Phraya, Mun, and other rivers of Thailand where it was formerly moderately abundant. It is extremely susceptible to gill-netting and pollution, two impacts of increasing frequency virtually throughout its range. It grows to nearly a meter in length, although rarely seen over 30 cm long. It is probably extirpated from the Mun River. Pak Mun Dam was too late to have had much to do with this, but it will prevent re-colonization of the species into the Mun River from the Mekong mainstream.

Parachela oxygastroides, P. siamensis, Paralaubuca riveroi and *P. typus* are small slender silvery carps with strongly compressed bodies. They are highly migratory and can be extremely abundant. In parts of the Mekong basin they are the most important prey for larger fish species. In recent years the most important of the species in the Mun River probably were *P. riveroi* and *P. typus*. *Paralaubuca riveroi* was particularly abundant on the Pak Mun fish ladder in 1994–96 (PHOLPRASITH *ET AL.*, 1997).

Prior to construction of Pak Mun Dam the lower Mun River may have been inhabited or at least frequented by three species of the cyprinid genus *Probarbus* (SCHOUTEN *ET AL.*, 2000). Quite possibly they had spawning grounds in the lower Mun. The danger to these species posed by hydropower dams was previously noted (ROBERTS, 1992). All three species are likely to disappear from the Mun River due to Pak Mun Dam. *Probarbus jullieni* is particularly noted as a high quality food fish.

Scaphognathops bandonensis and *S. stejnegeri* are intermediate-sized deep-bodied silvery carps with markedly different mouths. They differ from all other Mekong fish species in having distinctive juveniles with much less deep bodies than adults and the scales darkly outlined. I have observed small numbers of individuals of both species caught together in the Mun River and elsewhere in the Mekong basin and regarded them as about equally abundant, without any evident differences in behavior or habitat preference. It comes as somewhat of a surprise that sexually immature *S. bandonensis* were the single most abundant fish on Pak Mun fish ladder in the early years of its operation while during the same observation period there were very few *S. stejnegeri* on the ladder (PHOLPRASITH *ET AL.*, 1997). Both species are likely to disappear from the Mun River due to Pak Mun Dam.

The spiny loaches or cobitids *Botia modesta* and *B. rubripinnis* (the two species invariably have been confused in the past) presumably make use of the orifices in the base of the weirs if they used the fish ladder. Very few *Botia* were observed on the fish ladder. The horseheaded loaches, *Acantopsis* spp, have not been observed on the ladder. They have probably disappeared from the lower Mun River at least as far upriver as Phibun Mangsahan due to Pak Mun Dam.

The second most important large group of fish species after Cyprinidae are the several families of catfishes including Pangasiidae, Siluridae, Schilbeidae, and Bagridae. The most important catfishes in the Mekong basin and in the Mun watershed from the standpoint of fisheries belong to Pangasiidae. Included in this family is the giant Mekong catfish *Pangasianodon gigas*. The most important pangasiid in the Mun wild-capture fisheries was *Pangasius conchophilus*. There are also several relatively small species collectively known as "pla yon" and caught in large numbers with special traps in the lower Mun River. These pla yon fisheries have stopped since construction of Pak Mun Dam (SCHOUTEN *ET AL.* 2000). The most important species of pla yon are *Pangasius macronema* and *P. pleurotaenia*. None of the pangasiid species have been able to climb the fish ladder in significant numbers. All of the species formerly present in the Mun River system may be extirpated from it mainly because of Pak Mun Dam. Removal of the dam would permit several species of Pangasiidae to repopulate the Mun River and its major tributaries from the Mekong mainstream.

Pangasianodon gigas has been perhaps most heavily impacted by the changing ecology in the Mekong mainstream beginning around 1960 or earlier, and involving changes in mainstream water quality from cooler and clearer to warmer and siltier. It is often supposed that the nearly complete disappearance of naturally occurring pla buk from the Mekong basin is due to over-fishing. This popular idea is contradicated by the failure of the many hundreds of thousands of fry released into the Mekong River by the Thailand Department of Fisheries each year since 1986 to survive. The most important factor in the disappearance of naturally occurring pla buk from the middle Mekong and the failure of artificially reproduced pla buk to survive probably is the greatly increased siltation. Unfavorable living conditions are caused by the year-round high sediment load in the water column and greatly increased silt deposits in critical habitat on the streambed. Similar changes have occurred in the Mun River but it is unclear whether they had any impact on *P. gigas* because so far as known the species has always been extremely rare in the Mun.

P. gigas grows to 300–350 kg but such large individuals have not been reported in Thailand since 1970. Young pla buk introduced into reservoirs sometimes survive but grow very slowly, sometimes attaining only 20 kg or at most 100 kg after many years. The biology of the species under natural conditions is almost totally unknown. The species is almost certainly strongly migratory but its migrations have not been properly studied.

Despite success of Sanay Pholprasith and his colleagues in artificially propagating and releasing many hundreds of thousands of fry since 1986, the extinction of *Pangasianodon gigas* seems a foregone conclusion. Only very small numbers of artificially propagated fry released into natural waters grow to maturity, and apparently none of them have reproduced in nature. Thus their continued presence in the Mekong basin requires the uninterrupted success of the artificial breeding program. During the 19th century the species was reasonably abundant in the Mekong mainstream, at which time numbers of individuals may have migrated into and out of the Mun River. But there seem to be no records of this. All records of the species in the Mun River since 1986 presumably are due to release of artificially propagated individuals. No *P. gigas* have been caught anywhere in the Mekong basin of Thailand since 1999 (Kamthon Su-aroon, personal communication, June 2001).

Closely related to the giant Mekong catfish, *Pangasianodon hypophthalmus* is an important aquaculture species in Thailand. All aquaculture stock has been bred in captivity for many generations. Wild stock of the species is rare or non-existent in Thailand. Naturally occurring populations apparently have been nearly or entirely extirpated from the Chac Phraya basin and from most rivers in the middle Mekong basin including the Mun. The few fish caught in rivers in Thailand are probably escapees from aquaculture stock released into reservoirs or fishponds. Wild fish still occur fairly abundantly in the Mekong in southern Laos, below Khone Falls, and in Cambodia, where the species is not yet much used in aquaculture. The quality of wild fish is almost always much better than that of cultured fish, and hence wild fish command a correspondingly higher price.

The biology of the diadromous Mekong species *Pangasius krempfi* is still very poorly known. Apparently it migrates to and from the South China Sea and the Mekong River as far upstream as the Mun River and perhaps even as far as Vientiane or Luang Prabang. Details of its life history and migratory activity have not been fully illucidated. We do not know yet whether it spawns in fresh water, brackish water, or in the sea. If it is extirpated from the Mekong, it presumably will become extinct, because it is unknown to ascend any other river. A single mainstream dam on the lower Mekong could totally block its migrations and cause its extinction. The species is of some importance in catches along the coast of southern Vietnam as well as at Khone Falls on the Mekong in southern Laos. It was formerly at least occasionally present in the lower Mun River but has not been seen there since construction of Pak Mun Dam (SCHOUTEN *ET AL.*, 2000).

Pangasius sanitwongsei, attaining 300 kg, is the largest predatory bony fish species in the Mekong. Unlike *Pangasianodon gigas* its young were fairly abundant in parts of the Mekong mainstream (personal observation), at least until recently. Its occurrence in the Mun River is not well documented but it probably was present in the lower Mun and may have spawned there. It is at probably at least threatened and may already be an endangered species.

Siluridae is the second most important family of catfishes in the Mekong basin. A suite of "white" or silvery species known as "pla neua awn" ("soft-flesh fish") are particularly esteemed by consumers. This includes several species of *Micronema* attaining close to a meter in length (but rarely seen at such large size in Thailand any more). There are three large "black" or dark-colored species, *Hemisilurus mekongensis, Wallagonia leerii,* and *Wallago attu*, all attaining 1 m or more in length. There is also the incredible *Belodontichthys truncatus*, with its upwards-directed mouth, fang-like teeth, and huge pectoral fins. In the middle Mekong of Thailand and Laos I have seldom seen specimens larger than about 30 cm. Fish nearly 1 m long are common in the lower Mekong in Cambodia (personal observation, May 2001). All silurids are predators. Larger species and individuals prey almost exclusively on fish. They tend to live in open water habitats and prey mainly on fish species that are strongly migratory. Anything that diminishes stocks of migratory Clupeidae and especially Cyprinidae is likely to have a strong negative impact upon them. *Wallago attu* was by far the most important of the large silurids in the Mun River. Its present status in the Mun River is unknown. It is perhaps less likely to be eliminated from the Mun River by Pak Mun Dam than any other large species of Siluridae. *Wallagonia leerii* is presently moderately abundant in the Mekong mainstream in Thailand south of the mouth of the Mun River (personal observation, July 2001).

The migratory behavior of these fishes is poorly known. They move mainly at dusk and during the night. They are among the least successful of fishes it terms of using Pak Mun fish ladder. Some species probably are truly migratory. But some of their seemingly migratory behavior may be due to their habit of following migrating clupeids and cyprinids to prey upon them. The largest silurid species in the Mekong basin and in the rest of Southeast Asia is *Wallagonia leerii*, which attains a length of more than 2 m and a weight of 100 kg or more. This magnificent predator has been extirpated or nearly extirpated throughout most of its range. It is (or was until recently) still present in the Mun, but is nearly if not entirely extirpated now. Apart from *Ompok* and *Wallago* all of the silurids probably will be extirpated from the Mun watershed due to unfavorable ecological changes including decline in their food supply, disruption of migrations of their own and of other fish species, and lack of recruitment from the Mekong mainstream. Siluridae illustrate particularly well the effects of "multiple" or "cumulative" environmental impacts upon fishes of the Mun River. Some of the impacts were there before Pak Mun Dam, but they have been exacerbated by it, and it has added new impacts.

Excepting the bagrid *Hemibagrus filamentus* (formerly reported as *Mystus nemurus*), none of the members of the catfish families Bagridae, Siluridae, Schilbeidae or Pangasiidae have been recorded in significant numbers on the fish ladder. Of all the Mun River catfishes *H. filamentus* is the one species most likely to survive indefinitely in the Mun ecosystem without recruitment from the Mekong mainstream. *Hemibagrus microphthalmus*, by far the largest bagrid species in the Mekong, attains 80 kg. It was formerly abundant in the fish markets of Ubol Ratchatani and Warin Chamrap. Without recruitment from the Mekong mainstream it might soon disappear from the Mun.

Mystus (formerly *Heterobagrus*) *bocourti* occurs throughout the lower and middle Mekong and Chao Praya basins, where its preferred habitat is large lowland rivers. Due to its extraordinarily elongate dorsal fin spine it is highly susceptible to gill-nets. It has become increasingly rare throughout most of its range except in Cambodia. While apparently rare in the Mun mainstream, it is (or was until 1993) relatively common in parts the watershed such as Menam Chi near Yasothon. Recruitment from the Mekong mainstream may be essential for its continued existence in the Mun watershed.

The large sisorid catfish *Bagarius yarrelli* attains up to 30 kg in the Mekong basin and the Mun River. Although not indicated as having successfully climbed Pak Mun fish ladder in the report by PHOLPRASITH *ET AL.*, 1997, it did in fact successfully climb the ladder (Kamphon Su-aroon, personal communication, 6 March 2001). *Bagarius yarrelli* may be confused with the much smaller species *B. bagarius* that also occurs in the Mun. The larger species may well disappear from the Mun River due to Pak Mun Dam.

The family Schilbeidae is represented by only two species in the Mekong basin. They are caught by fishermen targetting pla yon (see remarks above under Pangasiidae). Both of the species, *Laides hexanema* and *L. sinensis*, were present in the Mun prior to construction of Pak Mun Dam but may now be absent.

The sciaenid *Boesemania microlepis* is a large high quality fish now very rare in the wild. The Thailand Department of Fisheries has bred it in captivity for many years, mainly for stocking in reservoirs. The true rarity of the species in nature is hard to determine in Thailand because of the presence of fish bred in captivity. Naturally-occurring stocks of the species may disappear from the Mun River because of Pak Mun Dam. The species probably will disappear from most rivers in Thailand when the Department of Fisheries rearing and stocking program is stopped.

PRAWNS ON THE FOOTPATH

To augment its fisheries productivity, the Department of Fisheries introduced the long-armed prawn *Macrobrachium rosenbergii* into Pak Mun reservoir. Hundreds of thousands of juvenile prawn were washed out of the reservoir via the powerhouse and sluice gates. Large numbers found their way to the entrance of the fish ladder but were unable to go up due to the strong flow of water on the ladder. They then crawled overland to the cement footpath next to the fish ladder, climbed the footpath, and then gained access to the fish ladder higher about one-half to two-thirds of the way up (Fig. 15). Upon entering the ladder they were washed by the current back into the reservoir outflow below the dam. This entire activity only occurred for about an hour, at twilight (around 6–7 p.m.) (Kamthon Su-aroon, personal communication, 6 March 2001).

In order to permit the prawns to complete their journey up the ladder and return to the reservoir, DOF provided a manila rope 1.5–2" in diameter extending the length of the fish ladder for the prawns to cling to and climb on. Local people stole the rope with the prawns on it, and the attempt was abandoned.

This incident illustrates a number of things. Fish are not the only higher aquatic organisms with upstream movements that can be blocked by dams. Biologists are more and more aware of the migratory activities of crustaceans including crabs and prawns. This particular *Macrobrachium* species, *M. rosenbergii*, is a diadromous species that must migrate between fresh- and brackish-water to complete its life history. The prawn cannot perpetuate itself in Pak Mun reservoir and will disappear soon after the stocking program is discontinued.

It also provides another clear example (if one were needed) of how very difficult it is to design a single fish pass that will accommodate diverse kinds of fishes and other organisms. It also prompts the question: what, if anything, is the equivalent of the manila rope utilized by prawns (and crabs in other places) in their upstream movements past obstacles such as rapids under natural conditions? Masses of submerged tree roots in overhanging banks probably are important. Such overhanging banks also provide habitat or refuge and spawning sites for fish species. They were formerly abundant in the lower Mun but disappeared from the first 2.3 km of the reservoir outflow downstream from Pak Mun Dam reservoir when the forest was cleared and artificial embankments created by rocky rubble excavated from the rapids and stream bed of the Mun River. Such embankments are of course unfavorable to fish. They do not offer significant habitat, feeding grounds, spawning grounds, temporary refuge or shelter to fish from predators or floods, or other benefits to fish.

As of June 2001 the Thai Department of Fisheries continues to stock Pak Mun reservoir with fry of *Macrobranchium rosenbergii* (albeit with only about one-third as many fry per annum as formerly). Many of the large adult prawns are caught in the Mekong River in Laos about 120–150 km downstream from Pak Mun Dam, near Pakse and Ban Wern Kam just below Khone Falls (Kamthon Su-aroon and Prapard Panaram, personal communication, June 2001).

DISCUSSION

Additional Comments on the Report by SCHOUTEN *ET AL.* (2000)

The report on Pak Mun Dam by SCHOUTEN *ET AL.*, 2000) served as the main basis for WCD's definitive statement on Pak Mun Dam (personal observation; Schouten personal communication, April 2001). It includes much valuable information, often from sources that are difficult to access and have not been cited previously.

Its discussion of Pak Mun fish ladder and of fish ladders in general is disappointing and unsatisfactory. Firstly there is the prominent introductory statement that "the scant human knowledge of aquatic ecology in tropical fresh waters, together with the set of relatively new and unique features of the Pak Mun Dam have made impacts on aquatic biodiversity, fish migration and fisheries by the dam difficult to predict." This is not so. Detailed and explicit predictions concerning the impacts of Pak Mun Dam on aquatic (i.e. fish) biodiversity, fish migration and fisheries were made before construction of Pak Mun Dam was completed (ROBERTS, 1994). Between then and publication of the WCD report, additional information on Mekong fish biology and particularly migrations became available. The mistaken notion that we do not known enough about Mekong fish ecology and biology to predict the impacts of hydropower dams has been reiterated recently by high-ranking members of the Cambodian government, who possibly were influenced by the WCD report. And why should the report be concerned with the difficulties of *prediction* of the impacts of Pak Mun Dam? The dam was completed in 1993, and the report should be telling us about what has actually happened.

Continuing in the same vein, we find the following statement: "Long term programs of basic biological research on the physiology and behavior of migrating fish species . . . would enable engineers and biologists to design fish facilities at dams that would potentially protect valuable fish migrations. For the Mekong River Basin a program is needed to study in more detail the migratory habits and locations, life history, swimming ability, size of fish runs, and size of fish, *before design and construction of fish passes can guarantee success*" (p. 31; italics mine).

Of course we need to learn more about the fishes. But it is wrong to suggest that more knowledge or information will facilitate building fish passes on Mekong dams that will guarantee success in maintaining species negatively impacted by gross environmental impacts due to large hydropower projects such as Pak Mun.

Predicted benefits from installing fish ladders on high dams for hydropower generation in the middle and lower Mekong basin, if they could be realized, would perhaps justify their installation. But they are unlikely to achieve the benefits predicted. What use is a fish ladder or fish pass (or any other sort of artificial corridor) enabling fish to move from one extremely unfavorable set of environmental conditions downstream (in the reservoir outflow) to a totally different but also unfavorable set of environmental conditions upstream (in the reservoir)? Unlike Pak Mun Dam, nearly all large hydropower dams proposed for the middle and lower Mekong Basin will create enormous storage reservoirs. The downstream length impacted by the reservoir outflow will also be far greater. Pak Mun Dam created a hostile but exceptionally small reservoir and a hostile but exceptionally short reservoir outflow.

The report provides two extensive tabulations of fish species present in the Mun River. Table 5, "Fish species recorded from the Mun/Chi watershed before and after construction of the Pak Mun Dam" includes a lot of information, particularly valuable in view of the lack of any better documentation published elsewhere. The scientific identifications and most of the data, the work of Chavalit Vidthayanon of the Thailand Department of Fisheries, provide the only published list of Mun fishes with a reasonable claim to be nearly complete.

Attention should be drawn to Table 7, labeled "Pictures of fish species shown to fisherfolk and fish species identified by fisherfolk as occurring in their catch in the Mun River." The data it presents were collected by means of a "flipchart" for identification of Mekong fish species developed by MRC. This table is full of misinformation and should not have been included in the report.

Because of the rapidity with which false information on Mekong fish species tends to become widely spread and embedded in the literature, use of this method to send poorly trained data-gatherers to obtain information about migratory fish species should be minimized (except perhaps as a training exercise).

Properly used, the MRC identification guide could contribute to Mekong ichthyology, fish biology and fish conservation. It can be used to teach national biologists, fisheries personnel and researchers to learn how to identify actual specimens of Mekong fish species. Table 7 does include one new record for the Mun which might be valid. The recently described spectacular "buck-toothed giant gouramy" *Osphronemus exodon* has been recorded from the middle and lower Mekong in Laos and Cambodia, but it has not been recorded previously from the Mun. According to the table, fishermen were catching it in the Mun as recently as 10 years ago. This might be true. Large adults of *O. exodon* are extremely distinctive and memorable, and could hardly be confused with any other species, even in photographs. On the other hand I did not observe the species during Ubon Ratchathani/ Warin Chamrap fish market surveys conducted in 1985–1993 and it is not listed in Chavalit's list of Mun River fish species. Of the more serious mistakes, only one will be noted here: 18 records of the tarpon *Megalops cyprinoides* from the Mun basin. Tarpon occur in the Mekong basin only in the lower reaches of the lower Mekong, in the Mekong Delta.

The Mekong River Commission could do more to improve the quality of Mekong fish identifications by facilitating the fieldwork and research of systematic ichthyologists currently working on Mekong fish species. It should have a teaching collection of preserved fish specimens identified by specialists. It should also maintain voucher specimens from significant fisheries surveys in a permanent collection with open access to qualified researchers. Such procedures should be applied to mollusks, crustacea and other taxa as well.

The report notes that the Mun River has been subject to deforestation and other human activities that have negatively impacted its fish fauna long before Pak Mun Dam was built (SCHOUTEN *ET AL.*, 2000). Some of these impacts are reported upon in detail in ROBERTS (1994). Still other impacts on the Mun River fish fauna prior to Pak Mun Dam have not been previously noted. Such is the practice of digging ditches and canals to divert water from the Mun mainstream and tributaries of all sizes down to the very smallest for irrigation and other practices. Such diversions favor the relatively few species adapted to life in ponds and paddies, but always have negative impacts on the more numerous, larger, and generally more valuable fish species living in the affected rivers. Another practice that undoubtedly has impacted fishes in the Mun basin is farming in riverbeds. This widespread practice reduces perennial streams to intermittent, and intermittent to dry. Both of these agricultural practices are widespread in the Mun basin. These are typical examples of the age-old environmental conflict between fishing and farming interests. Throughout Southeast Asia this struggle is complicated by the fact that many people divide their food-producing activities about equally between hunter-gathering and farming. This is especially true in Laos and Cambodia and still occurs to some extent in Thailand's Mun watershed.

I reiterate here that my previous report provided an accurate forecast of the negative impacts on fishes, especially migratory species, of Pak Mun Dam (ROBERTS, 1994). Rereading this report in the light of the latest available information about the Mun River, I find only two predictions not born out by subsequent events. On the first page, in the abstract itself, is the prominent statement: "Pollution from riverside industrialization at Ubol Ratchatani, the mouth of the Mun River, and on the Mekong mainstream based on Pak Mun hydropower will pose direct threats to the mainstream Mekong fisheries of Laos, Cambodia, and Vietnam." Elaboration of this statement is provided in the text (ROBERTS, 1994). This conclusion was based on the reasonable expectation that electrification from Pak Mun Dam would stimulate riverside industrialization like Ubol Rat Dam did in the vicinity of Khon Kaen. Pak Mun did not realize its predicted electrical production and the industries failed to materialize. The lower Mun River and the Mekong mainstream below Pak Mun were spared the chronic low grade and periodic massive impacts from toxic chemicals that inevitably would have resulted.

The second prediction in which I erred concerns the fisheries potential of Pak Mun Reservoir: "Short term prospects for fisheries in Pak Mun Reservoir are fair. Due to inundation of some 60 square kilometers . . . riverine fish populations will have favorable short-term conditions for reproduction and feeding . . ." (ROBERTS, 1994: 114). Favorable conditions for reservoir fisheries based on wild fish never materialized. I did not foresee the disastrous impacts of sedimentation and suspended silt that precluded any such development.

EGAT's Refutation and Objections to the Work on Fishes of the Mun River by Chavalit Vidthayanon

The AMORNSAKCHAI *ET AL.* (2000) version of the WCD report on Pak Mun includes a number of objections and refutations of the work on Mun River fishes by Chavalit Vidthayanon of the Thailand Department of Fisheries. Some of these most relevant to the discussion of the impacts of Pak Mun Dam on fish species biodiversity should be mentioned here. They regard the total number of fish species inhabiting the Mun, the number of migratory fish species in the Mun, and the number of fish species extirpated from the Mun before construction of Pak Mun Dam.

EGAT questions Dr. Chavalit's total of 265 fish species inhabiting the Mun River, citing several earlier reports in which far fewer species were reported. EGAT noted that Chavalit's fieldwork and methods were not reported or discussed and suggested that immediately before construction of Pak Mun Dam the Mun River was inhabited by only 139 fish species (AMORNSAKCHAI, *ET AL.*, 2000: 119).

It should first be noted that Chavalit's count of 265 includes eight exotic or introduced fish species that are not native to the Mun River or the Mekong basin. Deducting these brings Chavalit's list of native Mun River fish species to 258.

Based on collections and field observations entirely independent of Chavalit's work I believe that the number of fish species inhabiting the Mun River immediately before construction of Pak Mun Dam is close to that given by him. My own work resulted in recording of 230 different native fish species in the Mun River by June 1993 (ROBERTS, 1994: 116). Since then I have added about eight more species not noted by Chavalit, bringing the count of Mun species based only upon my records to 238.

My ichthyological field work in the Mun basin extended from 1970 to 1993. Fish specimens were collected in the Mun mainstream, in the Pong and Chi and many lesser known Mun tributaries, and in scattered irrigation reservoirs or ponds and canals. Observations were made at many localities including but not limited to the mouth of the Mun River, Phibun Mangsahan, fishing villages between these places, Ubol/Warin fish markets, Sisaket, Yasothon, Mahachanachai, Khon Kaen, and also in Ubolratana, Sirinthorn and Chumporn Reservoirs. Many species records were obtained by fishing with a one-man nylon-screen push-net. Others were obtained by direct examinations of fishermen's catches on site. Only a few records are based solely upon fish observed in markets and then only if the species was repeatedly observed and it could be confirmed that it was caught in the Mun basin.

While my own efforts have resulted in records of only some 238 species in the Menam Mun, the list published by Chavalit includes some 16 additional species that are probably valid new records. If these are confirmed the total number of *known* native fish species in the Mun River before construction of Pak Mun Dam is at least 254.

In additional to Chavalit's 16 probable valid new records there are some 15 species in his list that require further investigation. Thus the actual number of recorded species that can be confirmed is likely to exceed 258. While discussions as to the identification and scientific names that should be applied to the species will continue, there is no disagreement among ichthyologists that at least this number of species was present in the Mun River before construction of Pak Mun Dam.

EGAT suggested that as many as 19 fish species were extirpated from the Mun River before construction of Pak Mun Dam and at least by 1990 (AMORNSAKCHAI, *ET AL.*, 2000: 110, 119).

In this category I would include no more than half a dozen species, including *Macrochirichthys macrochirus* and *Pangasianodon gigas* and perhaps *Catlocarpio siamensis*. Like all river systems with extremely rich fish faunas, the Mekong has a number of fish species that have long been known to science but have rarely been collected or observed. Some species seem to be naturally quite rare. Unless specimens have been collected recently and competently identified their survival status may be difficult to evaluate.

In July 1999 a large female *Catlocarpio siamensis* swam up the Mun River and reached the fish ladder of Pak Mun Dam. After butting its head repeatedly against the foot of the ladder until it was wounded and dazed it was caught by local fishermen (Fig. 16). She weighed 90 kg and was in spawning condition. The ripe ovaries weighed 20 kg (Wanida Tantivittayapitak, personal communication, July 2001). Had she managed to continue up the Mun River, find a mate, and spawn, she could have re-populated the Mun River and re-invigorated the Mekong mainstream population of her species.

EGAT reported that *Botia lecontei, Cyclocheilichthys mekongensis, Garra fasciacauda, Mystacoleucus chilopterus, Opsarius koratensis, Rasbora myersi, Rasbora retrodorsalis, Systomus aurotaeniatus, S. "spilopterus", Clarias macrocephalus, Xenentodon canciloides, Parambassis siamensis, Tridentiger ocellatus,* and *Euryglossa harmandi* had not been collected during fish surveys after 1990. This evidence does not warrant EGAT's conclusion that therefore these 14 species were extirpated from the Mun river before construction of Pak Mun Dam. *Botia lecontei, Garra fasciacauda* and *"Tridentiger" ocellatus* surely continued to exist in the rapids of the lower Mun River until they were blasted during construction work on Pak Mun Dam. *Mystacoleucus chilopterus, Opsarius koratensis, Rasbora retrodorsalis, Systomus aurotaeniatus, S. "spilopterus", Clarias macrocephalus, Parambassis siamensis,* and *Euryglossa harmandi* surely still exist and are locally abundant in appropriate habitats in the middle and upper Mun River and tributaries. *Rasbora myersi* and *Xenentodon canciloides* probably are incorrectly identified and never did occur in the Mun River. Failure to find these in surveys from 1990 to 1993 is likely to be due to problems in specimen identification combined with sampling error. Even three years of field surveys by experienced and knowledgeable fish collectors are likely to miss 14 of 258 species. In extensive and intensive fieldwork on fish of the Mun River from 1970–1993 I evidently missed at least 20 species.

EGAT suggested Chavalit's figure of 77 migratory fish species is too high. Based on my observations and other information the Mun River fish fauna includes no fewer than 89 and possibly over 100 migratory fish species. Here I am speaking of species undertaking more or less long-distance longitudinal migrations in large numbers upstream and/or downstream.

Failure of Fish-stocking Programs

Stocking programs, such as that of *Macrobranchium rosenbergii* into Pak Mun Dam undertaken by the Thailand Department of Fisheries since 1993, often are successful in terms of short-term fisheries productivity. But they are seldom successful in terms of restoring biodiversity. Attempts at re-establish endemic species that have become locally extirpated by means of stocking programs usually end in failure. Artificially bred stock, even if widely and abundantly released into natural conditions for the species, usually fail to become re-established. After fish ladders this is perhaps the most notable example of a fisheries mitigation procedure that has been nearly a total failure.

In 1993 the Department of Fisheries announced that up to 25 exotic and native fish species would be artificially bred for stocking in Pak Mun reservoir. Little more was said about this after a year or two and not much came of it except for introduction of two exotic species, the common carp *Cyprinus carpio* and the Nile tilapia *Tilapia nilotica*. Cage culture of tilapia in Pak Mun Reservoir has not been very successful. Fish farmers complain of loss of stock due to poor water quality. Establishment of such exotic fish species is probably detrimental to the native species. *Cyprinus carpio* is notorious for eating the eggs and muddying or otherwise disturbing the spawning grounds of other fish. It is virtually impossible to eradicate exotic fish species once they become established.

The main problem for most species is that artificially bred fish released into nature do not undergo normal gonadal maturation and breed on their own. In Thailand including the Mun River this is particularly true of *Pangasianodon gigas* and *P. hypophthalmus*, and probably also of *Probarbus jullieni* and *Boesemania microlepis*. Artificially bred *Catlocarpio siamensis* released into the Chao Phraya River below Chainat Dam reportedly have been found breeding (Prajit Wongrat, personal communication, 1998). If true, this is surely a rare occurrence.

Predictions that Pak Mun fish ladder would serve as a significant source of brood stock for hatchery production of fish fry have not materialized. Apparently no native fish species have been introduced or re-introduced successfully into the Mun River since construction of Pak Mun Dam. The most "successful" introduction has been of the exotic long-armed prawn *Macrobrachium rosenbergii*. This species cannot become established in the Mun River because it can only reproduce in brackish water.

Is there any need for fish ladders or passes on dams in Southeast Asia? Many thousands of low-head (2–6 m) irrigation structures have been built on rivers in Thailand and other countries in Southeast Asia during the past three decades. Such projects have provided some benefit to rural communities, particularly for dry-season agricultural production including that of cash crops. But they also have caused widespread negative impacts to fisheries, the most obvious being obstruction of migrations and unfavorable habitat changes.

In Australia blockage of fish migration routes is recognized as a major contributor to the declining range and abundance of many freshwater fish species (HARRIS & MALLEN-COOPER, 1993). A variety of devices have been developed for use with low-head weir and dam structures to at least partially restore riverine ecological continuity or "linearity", and facilitate some degree of fish movement (BERGHUIS & LONG, 1998). Of particular interest in a larger geographic context are the methods involving retro-fitting, or up-grading, of fish passage facilities at existing structures (ANON., 1999). Fisheries biologists and engineers in Queensland, Australia now view the retro-fitting of fish passage facilities as the first stage in river-catchment rehabilitation (COTTERELL & JACKSON, 1999).

Should such devices be applied successfully to existing low-head irrigation dams in Southeast Asia? The best remedial approach may be to try fitting out a fair number of sites of different kinds in different places and see what happens (WARREN, 1999). It would be better for fish if fewer irrigation dams were installed and some of those already present were removed.

Will Opening the Pak Mun Dam Spillways Restore Fish Species Biodiversity and Fisheries of the Mun River?

In May of 2000, protestors halted operation of Pak Mun powerhouse. Many public pronouncements and media accounts stated without hesitation that opening the sluice gates would permit fishes to move freely up the Mun as if the dam were not there. After two months of protests and demonstrations in Bangkok it was agreed to open the sluice gates during the period of peak fish migration. The sluice gates were opened from 17 August to 24 October 2000. In 2001 the gates were opened on 2 June [actually on 14 June?] and will supposedly remain open until 31 August (Prapard Phanaram, personal communication, 21 June 2001).

In the short term this action provided opportunities for many fishermen. In 2000, and again in 2001, fish responded to the current produced by the open sluice gates and moved upstream towards Pak Mun Dam. Most of the fish have been small but there have been a few large fish species (species identifications not available as of July 2001). At least some fish were able to move all the way past the sluice gates when the water level in the reservoir was not too high above the downstream water level. Some observers feel that many fish would move through the sluices and continue up the reservoir were it not for the numerous fishermen actively catching them immediately below the dam.

Thinking of the spillways as a transverse series of eight identical waterfalls may help to understand the problems involved for fish swimming upstream. Unlike natural waterfalls, the spillways lack features such as overhanging ledges, jumbled rocky bottom and passageways that facilitate fish moving upstream to pass them. The hydrological properties of the eight spillways are identical if their gates are opened to exactly the same extent or if the gates are opened above the water level in the reservoir. The hydrology of the individual spillways can be varied if the gates are opened by different amounts below the reservoir water line, or open to above the reservoir water line.

Some bottom-moving fish (e.g. catfishes, loaches) and many small fish are likely to be stopped by the 2 m vertical barrier at the downstream opening of the spillways (Fig. 7). The reservoir outflow, whenever subject to discharges for peak hour electricity generation, should still be a substantial barrier. When the reservoir goes down, the seriousness of that component of the Pak Mun Dam biogeographic barrier will be lessened. Due to the 94 m high reservoir level established by the spillways, however, problems related to bottom sediments and midwater silt-load may present negative impacts for the next 35 km.

Numerous structural features of the 45-m long sluices (Fig. 7) create extremely complex currents and turbulence when the gates are not opened sufficiently to provide free passage of water downstream. With reservoir levels above 98 m the major problem for any fish passing up- or down-stream through the sluices is the extremely strong and turbulent current passing under the metal sluice gate over the concrete floor at the height of 94 m. This probably would be an absolute barrier to upstream fish movements when reservoir water levels are much above 98 or 99 m.

Gravid females, especially of Cyprinidae, may have difficulty making their way upstream through the spillways even under optimal conditions. Their body weight typically is increased by 30 percent due to egg production, and bellies bulging with eggs impair their hydrodynamic body shape. Having invested food supplies and energy in egg production, gravid females also have far less energy for upstream movement than male fishes.

Most observers feel that opening the Pak Mun Dam sluice gates on 2 June 2001 led to an immediate improvement of fishing in the Mun River above the dam. This they attribute to fish being able to move upstream from the Mekong River, up the 4.5 km outflow of the Pak Mun Dam, past the open spillways, and on up the Mun River. This probably is happening. But most of the fish now present in the reservoir area above Pak

Mun Dam are likely to have been carried downstream from far up-river once the sluices gates were opened. Opening the sluice gates created a strong continuous current bringing fish downstream. At the same time the flow created relatively favorable for fish so that they could survive in the 35-km stretch of river-turned-reservoir upstream from the dam. Should the sluice gates be closed, almost all fish probably will disappear again from this stretch of the Mun River.

In medical terms opening of the Pak Mun spillways is probably more palliative than remedial. It may make the patient temporarily look and feel better but offers little hope for a long-term cure or major improvement.

CONCLUSIONS

Even a pregnant woman cannot walk up this [Pak Mun Dam fish] ladder, so how can a fish with a full stomach of eggs tolerate the water torrent and swim up this tall fish pass to get to the other side of the dam?

—Plodprasop Suraswadi, Director General, Department of Fisheries
September 1996

An error refuses to be a mistake until you refuse to correct it.

—John Fitzgerald Kennedy

Why has Pak Mun fish Ladder Failed so Badly?

Because this topic exemplifies an even bigger topic it is worth looking at in some detail. The bigger topic, of course, is the frequent failure of so-called mitigation measures to make up in any real measure for environmental damage inflicted by large infrastructure projects involving major environmental modification such as hydropower dams. This concluding examination of Pak Mun fish ladder emphasizes the difficulty inherent in maintaining ecological integrity (including fish diversity) when dealing with cumulative environmental impacts of large projects.

1. Of the fish entering the ladder, very few make it all the way to the top. Most fish go only a short distance, perhaps less than a third of the way or only half way up, before being washed back down the ladder to the reservoir outflow (Pinit Sihapitukgiat, personal communication, June 2000). In not one instance is the number of individual fish using the ladder likely to be sufficiently large to insure the continued presence of the species above the dam.

2. There are no observations of a ripe female of any species passing the fish ladder (SCHOUTEN *ET AL.*, 2000: 34). This is one of the most damning observations to be made about Pak Mun fish ladder. How can a ladder possibly preserve the all-important spawning migrations of the major migratory fish species if it cannot accommodate gravid females?

3. Important reproductive migrations of many small species, and non-reproductive migrations of young of many large species, have been totally blocked by Pak Mun Dam. These have either never been noted on the fish ladder, or have been found only in insignificant numbers (usually just a few individuals—sometimes only one!). Among the most important of these are species very important in food chains of other species, such

as *Clupeichthys aesarnensis* and *Cirrhinus lobatus*, and the highly migratory juveniles less than 40 mm long of species such as *Scaphognathops bandonensis*.

4. Entire groups of fish species of importance to fisheries are totally unable to utilize the fish ladder. This includes almost all of the catfishes, including all species of Siluridae and Pangasiidae. These two families include the most important migratory catfish species in Mekong and Mun River wild-capture fisheries.

5. Many small fish species that attain a maximum size of less than about 6 cm probably will not be able to use the ladder. This includes a large part of the total number of Mun river fish species. Many of these, such as numerous species of *Rasbora* and *Nemacheilus*, probably will survive in the Mun River. Perhaps the most important small species that cannot use the fish ladder is the herring *Clupeichthys aesarnensis*.

6. Discussions of ecology of riverine fish species tend to describe movements of very young fish as exclusively down-stream. This presumably is so for the earliest life stages of fish incapable of locomotion and therefore randomly dispersed by drifting downstream. But from the moment fish larvae living in flowing water are developed enough to swim, they probably tend to make directed movements either upstream into the current or out of the current. Structures like Pak Mun Dam represent a total barrier to the motile early life history stages of nearly all fish species inhabiting the Mun River.

7. Many Mekong and Mun river fish species might be too large—even far too large—to use a fish ladder like the one constructed for Pak Mun Dam, at least not as adults or large juveniles. The two freshwater stingrays, *Dasyatis laosensis* (attaining 30 or more kg) and *Himantura polylepis* (attaining 500 or 600 kg, the largest fish species in the Mekong) probably are both simply too large, and their behavior also is such that they are unlikely to go up a fish ladder. Other fishes too large to utilize the fish ladder as adults include *Aaptosyax grypus, Catlocarpio siamensis, Probarbus jullieni, P. labeamajor, Pangasianiodon gigas, Pangasius sanitwongsi,* and perhaps *Osphronemus goramy* and *Channa micropeltes*.

8. Many large fish stay in the main Mun channel flowing away from the Pak Mun powerhouse. Thus they will not come near the entrance of the shallow artificial canal leading to the mouth of the fish ladder (Kamphol Su-aroon, personal communication, 6 March 2001).

9. A number of Mekong and Mun open-water fish species probably are too delicate to use a fish ladder. Any bumping or scraping contact with cement or other rough surface is likely to be fatal. These include the herring *Tenualosa thibaudeaui* and the carp *Macrochirichthys macrochirus*. Many catfishes, especially in the family Siluridae, probably have skin too delicate to use the Pak Mun fish ladder without being painfully and dangerously lacerated. Others are unlikely to survive bumping head-on into structures on the ladder. I recognize that this statement is somewhat speculative, because rough surfaces occur naturally in rivers such as the Mun. Open-water fishes such as *Tenualosa* and *Macrochirichthys*, however, can avoid such surfaces in nature but may not be able to avoid being scraped while climbing a fish ladder.

10. The ladder is too steep for many fish species. Plans prepared by the Department of Fisheries called for a longer ladder, with a much more gradual slope (Sanay Pholprasith, personal commication, June 2000). This advice was ignored (reportedly because of the high cost) and a shorter and steeper version of the ladder built instead. A gentler slope of 1:8 or 1:7 rather than the actual 1:6 would make it easier for fish to go up the ladder.

11. The ladder is badly placed. The obvious site for the placement of the fish ladder was on the far right-hand side of Pak Mun Dam leading directly upstream from the deep channel that is the main passageway for fish migrating upstream (Sanay Pholprasith, pers. comm. June 2000). Instead, the ladder was placed on the far left side of the dam. This place is not at all a natural passage-way for fish, as it is obstructed by an extensive reef-like bed of sharp rock reaching nearly to the surface (Fig. 4). Excavating a straight narrow channel through the reef (Fig. 5) probably increased the number of small fish finding their way to the beginning of the ladder.

12. The artificial channel leading to the fish ladder is too narrow and much too shallow. During the dry season the water in the channel is too little for all but smallest fishes. During the rainy season high water levels completely cover the channel, creating turbulence and other unfavorable conditions.

13. The strong water current discharged daily from the powerhouse turbines attracts fish away from the poorly placed narrow entrance to the fish ladder. This may be true only when 3 or 4 of the 4 turbines are in use at the same time.

14. Unless Pak Mun is shut down, every day throughout the year the powerhouse is turned on at about 6 p.m. A strong water current flows from the powerhouse into the reservoir ourtflow until the powerhouse is turned off at around 9. This unnatural flow regime might be a major reason why so few fish species are observed on the fish ladder during the early hours of darkness.

15. During the dry season months if the water level in the reservoir falls below 105.5 m no water flows in the fish ladder for weeks or months at a time. At such time major upstream fish migrations stop, but some fish might still be moving up as well as down stream.

16. The flow regime in the fish ladder is not electronically monitored and automatically adjusted. The upper channel flows when water levels in the reservoir at the dam are 107–108.5 m. At 107.1–107.3 cm very little water flows into the ladder. The flow can be increased by switching on a pump that puts more water into the ladder. The only way to lessen the flow in the ladder when the reservoir level is high is by manually inserting wooden baffles or stop-locks into the slots on the weirs. This requires workers to descend the footpaths on the fish ladder. The same applies for the lower channel of the fish ladder when water level in the reservoir has dropped to 105.5–107 m. Such a system is far too cumbersome and prone to human error. This is part of what is meant when Pak Mun fish ladder is described as "state of the art".

17. In September–October the Pak Mun sluice gates are opened. The resulting torrent is sometimes so strong that it probably kills most fish present in the 4.5-km long reservoir outflow (Fig. 6).

18. A fish ladder with an effective passageway only 3 m wide and averaging around 50 cm deep could never accommodate the numbers of fish involved in a full-scale migration up the Mun when its fish populations were relatively unexploited. Such full-scale migrations still occur in some rivers in Laos and Cambodia but perhaps nowhere in Thailand any more unless in Thung Yai or some other wildlife sanctuary.

19. Pak Mun Reservoir has a relatively minor problem of infestation by floating water hyacinth (*Eichhornia crassipes*). Even so, water hyacinth from the reservoir piled up against the top grill of the fish ladder and blocked fish from completing their run up the ladder after heavy rains in May 2000 (David J. H. Blake, personal communication, April 2001).

20. During the hottest months of the year, March–April, water temperature on the fish ladder rose to 32–34°C. There is no data for water temperature in the reservoir outflow during these months. It would fluctuate considerably depending upon the operation of the sluice gates of the dam, but probably always would be several degrees cooler. Water temperature in the Mekong mainstream in March–April is around 25–26°. Such sudden temperature difference represents an extremely effective barrier to fish movement in either direction.

21. Water discharged from Sirinthorn Dam flows into Pak Mun Reservoir via the Lam Dom Noi about 1.5 km upstream from Pak Mun Dam. At times when Sirinthorn Reservoir is full this water is deoxygenated and toxic due to hydrogen sulfide. Water flowing into Pak Mun Reservoir from Sirinthorn via the Lam Dom Noi hugs the right bank of the reservoir until reaching Pak Mun Dam. Thus a disproportionate amount of toxic water from Sirinthorn may be discharged directly from Pak Mun powerhouse into the main channel used by fish migrating up the Pak Mun reservoir outflow.

Serious problems arise because Pak Mun Dam creates unfavorable environmental conditions for fish species in the reservoir outflow as well as in the reservoir itself. Even the perfect fish ladder permitting *all* migrating fish to move upstream could not help when ecological conditions in the downstream and upstream environments are so unfavorable. It should be emphasized that dams interfere not only with migratory fish movements but with other important kinds of fish movements, including downstream movements, and non-migratory movements including evasive, exploratory and opportunistic (including colonizing) movements. And this is only the beginning of the long list of negative impacts of dams upon fish.

In closing, the following rhetorical question may be posed: of what use is a fish ladder that permits fish to pass from one killing field (the reservoir outflow) to another killing field (the reservoir)? This question must be answered by those proposing fish ladders or other kinds of fish passes on large dams.

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