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RHYTHMS OF THE RIVER: LUNAR PHASES AND MIGRATIONS OF SMALL CARPS (CYPRINIDAE) IN THE MEKONG RIVER

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ABSTRACT

Throughout history, many different cultures have associated lunar cycles with changes in a variety of human and animal behaviors. In the southern-most part of Laos, in the area known as "Siphandone" or the 4,000 islands, rural fishers living on islands in the middle of the mainstream Mekong River are especially conscious of the influence of lunar cycles on aquatic life. They associate upriver migrations of large quantities of small cyprinid fishes from Cambodia to Laos at the beginning of each year with lunar phases. This article examines the fishery for small cyprinids in the Khone Falls area, Khong District, Champasak Province, southern Lao PDR, and a five-year time series of catch-effort fisheries data for a single fence-filter trap are presented. These data are then compared with catch data from the bag-net fishery in the Tonle Sap River in Cambodia. It is shown that the migrations of small cyprinids, particularly *Henicorhynchus lobatus* and *Paralaubuca typus*, are highly correlated with new moon periods at the Khone Falls. Many small cyprinids migrate hundreds of km up the Mekong River to Khone Falls from the Tonle Sap River and probably the Great Lake in Cambodia. The evolutionary conditions that have led to the behavior of these fish are discussed, and management implications are considered.

Key words: Cambodia, Laos, Mekong River, artisanal capture fisheries, Cyprinidae, lunar cycles, migrations

INTRODUCTION

As the moon follows its natural phases, orbiting the earth once per month, our view of it dramatically changes. It begins as a new moon, hidden from Earth's view, and over the course of 29.5 days becomes fully visible and bright. Throughout history, many different cultures have associated the cyclic lunar transformations with predictable changes in a variety of human and animal behaviors. The scientific evidence for the existence of these relationships is mixed. Investigations into the behavioral effects of lunar phases on fish are often inconclusive (e.g., ROBERTSON *ET AL.*, 1990; ROOKER & DENNIS, 1991). Nevertheless, strong associations between lunar phases and some behaviours of particular fish and crustacean species have been documented; In particular, spawning cycles (e.g., CRABTREE, 1995; JERLING AND WOOLDRIDGE, 1992; JOHANNES, 1981). Fishers around the world have long believed that the most successful fishing times are associated with particular lunar

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periods. While this body of knowledge based on personal experiences makes up fishing folklore, scientific evidence also supports the association between fish catch and lunar cycle (e.g., OTUBUSIN, 1990).

In the Lao People's Democratic Republic (Lao PDR or Laos) rural ethnic Lao people still predominantly use a lunar calendar. They are well aware of how lunar cycles affect natural and human processes. In the southern-most part of Laos, in an area known as "Siphandone", or the 4,000 islands, rural fishers living on islands in the middle of the mainstream Mekong River are especially conscious of the influence lunar cycles have on aquatic life. They associate upriver migrations of large quantities of small cyprinid fishes from Cambodia to Laos at the beginning of each year with lunar phases (BAIRD, 1998; SINGHANOUVONG *ET AL.*, 1996; ROBERTS & BAIRD, 1995; ROBERTS & WARREN, 1994; ROBERTS, 1993).

Highly migratory populations of small cyprinids are extremely important to the people of the lower Mekong River basin in several ways (BAIRD *ET AL.*, 1998; ROBERTS, 1997; JENSEN, 1996; ROBERTS & BAIRD, 1995; LIENG *ET AL.*, 1995; ROBERTS, 1993; BARDACH, 1959). Ecologically, they are important primary consumers of phytoplankton in the mainstream Mekong River during the dry season (SINGHANOUVONG *ET AL.*, 1996; ROBERTS & BAIRD, 1995; ROBERTS & WARREN, 1994). They produce the largest proportion of animal protein consumed by people in the lower Mekong River basin (BAIRD *ET AL.*, 1998; ROBERTS, 1997; LIENG *ET AL.*, 1995). Socially and culturally, they support ways of life based around the many artisanal fisheries that target them over their long journey.

In Cambodia, the bulk of the bag-net fishery (*dai* in Khmer) catch in the Tonle Sap River, one of the largest inland commercial fisheries in the world, is dominated by small cyprinids. The most important are the labeoin cyprinids *Henicorhynchus lobatus* and, to a lesser extent, *Henicorhynchus siamensis* (LIENG *ET AL.*, 1995). These species and many others, migrate out of the Great Lake and other seasonally inundated areas in central Cambodia at the end of the monsoon rainy season between November and March of each year, and move into and up the Mekong River via the Tonle Sap River (VAN ZALINGE *ET AL.*, 1999; BAIRD, 1998; DIEP *ET AL.*, 1998; ROBERTS, 1997; LIENG *ET AL.*, 1995). ROBERTS & BAIRD (1995) note that *H. lobatus* (referred to by them as *Cirrhinus lobatus*) is an ecologically significant species in the lower Mekong River in southern Laos due to its large biomass, and it may be the single most important species in the Mekong River below the Khone Falls (ROBERTS, 1997).

Important artisanal fisheries in the Khone Falls area are also based on migrations of *Henicorhynchus* spp., *Paralaubuca typus, Labiobarbus leptocheilus, Lobocheilus melanotaenia, Botia modesta* and a number of other species (BAIRD, 1998; ROBERTS & BAIRD, 1995; ROBERTS & WARREN, 1994; ROBERTS, 1993). These fish migrations are similarly significant for fishers living in other parts of Siphandone above the Khone Falls. BAIRD *ET AL.* (1998) found that approximately 40 percent of the families in Khong District, Champasak Province (Siphandone area) reported that *Henicorhynchus* spp. were the most abundant fish species caught. Despite the small size of individual fish, the total catch surpassed all other groups in terms of weight.

BAIRD (1998) proposed that the small cyprinid fence-filter trap (*tone* in Lao) fishery at the Khone Falls targets largely the same populations of fish that are caught in the bag-net fishery in central Cambodia. Moreover, it is believed that some of these small cyprinids migrate past the Khone Falls to the border between Laos and Thailand, and possibly as far upriver as Vientiane or beyond. The migration of important fish stocks 100s or possibly over 1,000 km between three countries, highlights the need for the nations in the Mekong basin to cooperate in improving their understanding of the biology and socio-economic significance of *Henicorhynchus lobatus* and other migratory small cyprinid fishes. Joint research and management efforts are warranted to ensure the long-term sustainability of the fisheries based on such species.

This paper examines the fishery for small cyprinids in the Khone Falls area, Khong District, Champasak Province, southern Lao PDR. The nature of the fishery is reviewed and a time series of catch-effort fisheries data for a single fence-filter trap are presented. These data are then compared with catch data from the bag-net fishery in the Tonle Sap River in Cambodia.

STUDY AREA

The Mekong River basin supports one of the most diverse fish faunas in the world, and probably the most fish species for a single river basin in Asia. Approximately 1,200 species of fish occur in the Mekong basin, including brackish water areas, although many have not yet been taxonomically described (VAN ZALINGE *ET AL.*, 2000; RAINBOTH, 1996). As of 2000, 201 fish species in 109 genera and 39 families had been identified from the Mekong River and adjacent tributaries below the Khone Falls in Khong District (BAIRD, 2001). Many species seasonally migrate long distances up the Mekong River from as far away as the Great Lake in Cambodia and the South China Sea in Vietnam (BAIRD *ET AL.*, 1999; BAIRD, 1998; VAN ZALINGE *ET AL.*, 2000; LIENG *ET AL.*, 1995; ROBERTS & BAIRD, 1995). Other species are relatively sedentary (BAIRD *ET AL.*, 2001b; BAIRD *ET AL.*, 1999).

The Siphandone Wetland area is a complex ecosystem found in the mainstream of the Mekong River in the extreme south of Laos. It is made up of large and small inhabited and uninhabited islands, channels, seasonally inundated forests, deep-water pools, rapids and waterfalls (DACONTO, 2001; ALTOBELLI *ET AL.*, 1998; CLARIDGE, 1996). The Siphandone Wetland area is largely situated in Khong District, which is in the southern-most part of Champasak Province (Fig. 1). The aquatic environment of the area is characterized by high biodiversity and productivity (BAIRD, 2001).

There are approximately 65,000 people in Khong, the vast majority of whom are ethnic Lao peasants. For the most part, these people are semi-subsistence paddy rice farmers, who have a long history of habitation in the area. Approximately 94% of families in the district are involved in subsistence artisanal fisheries and many market part of their catch. The estimated total fish catch for the district in 1996 was 4,000 metric tons, and US$ 1 million worth of fish was reportedly exported from Khong during that year (BAIRD *ET AL.*, 1998). The wild-capture fisheries of Khong may be more important to local people than in any other district in Laos. Of the 136 villages in Khong, 86 are situated on islands, and most of the rest lie along the eastern bank of the Mekong River (BAIRD *ET AL.*, 1998).

The Khone Falls, in the southern-most part of Khong District, is the most important area in Siphandone for wild-capture fisheries, especially for those targeting migratory species (Fig. 2) (BAIRD, 2001; BAIRD *ET AL.*, 1998; SINGHANOUVONG *ET AL.*, 1996; ROBERTS & BAIRD, 1995; ROBERTS, 1993).

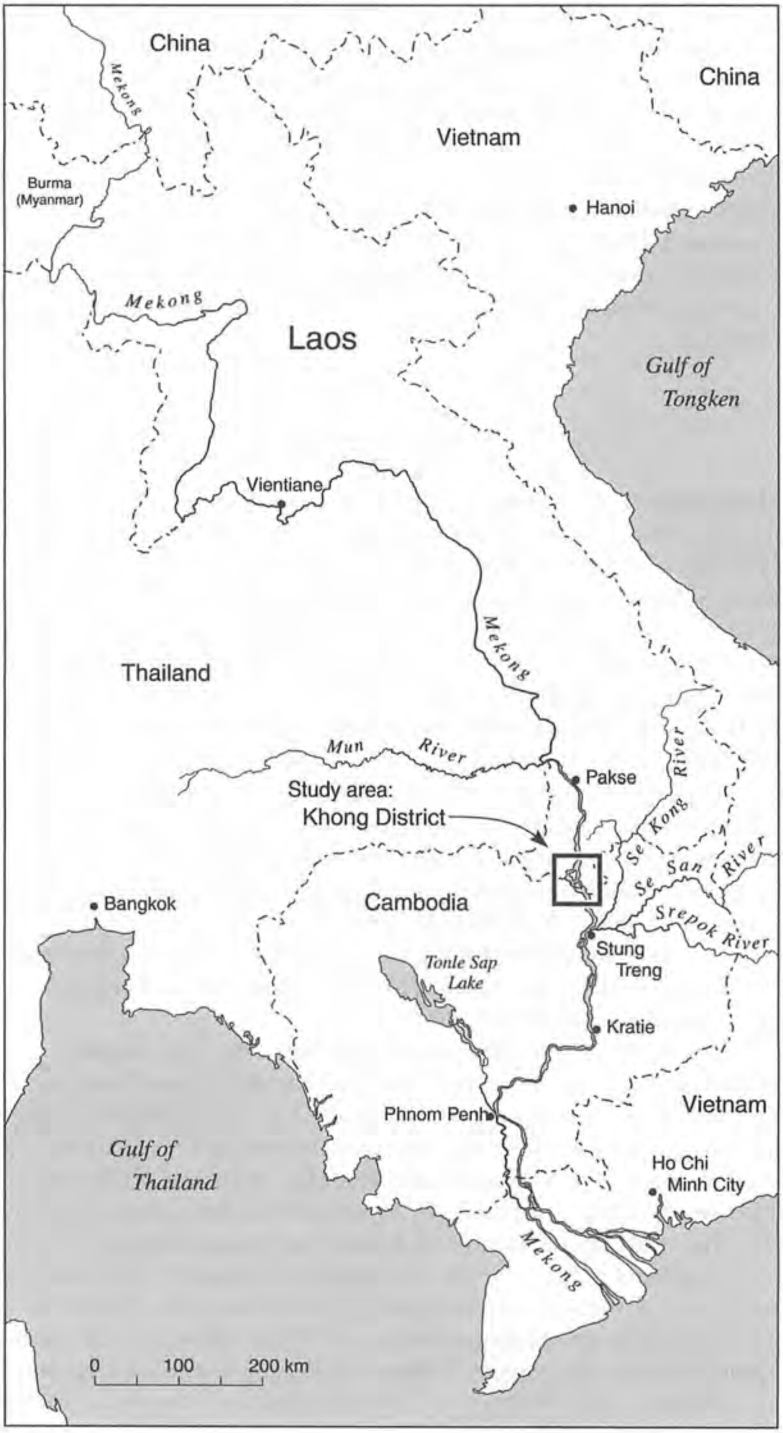

Figure 1. The study area - Khong District, Champasak Province, Southern Lao PDR

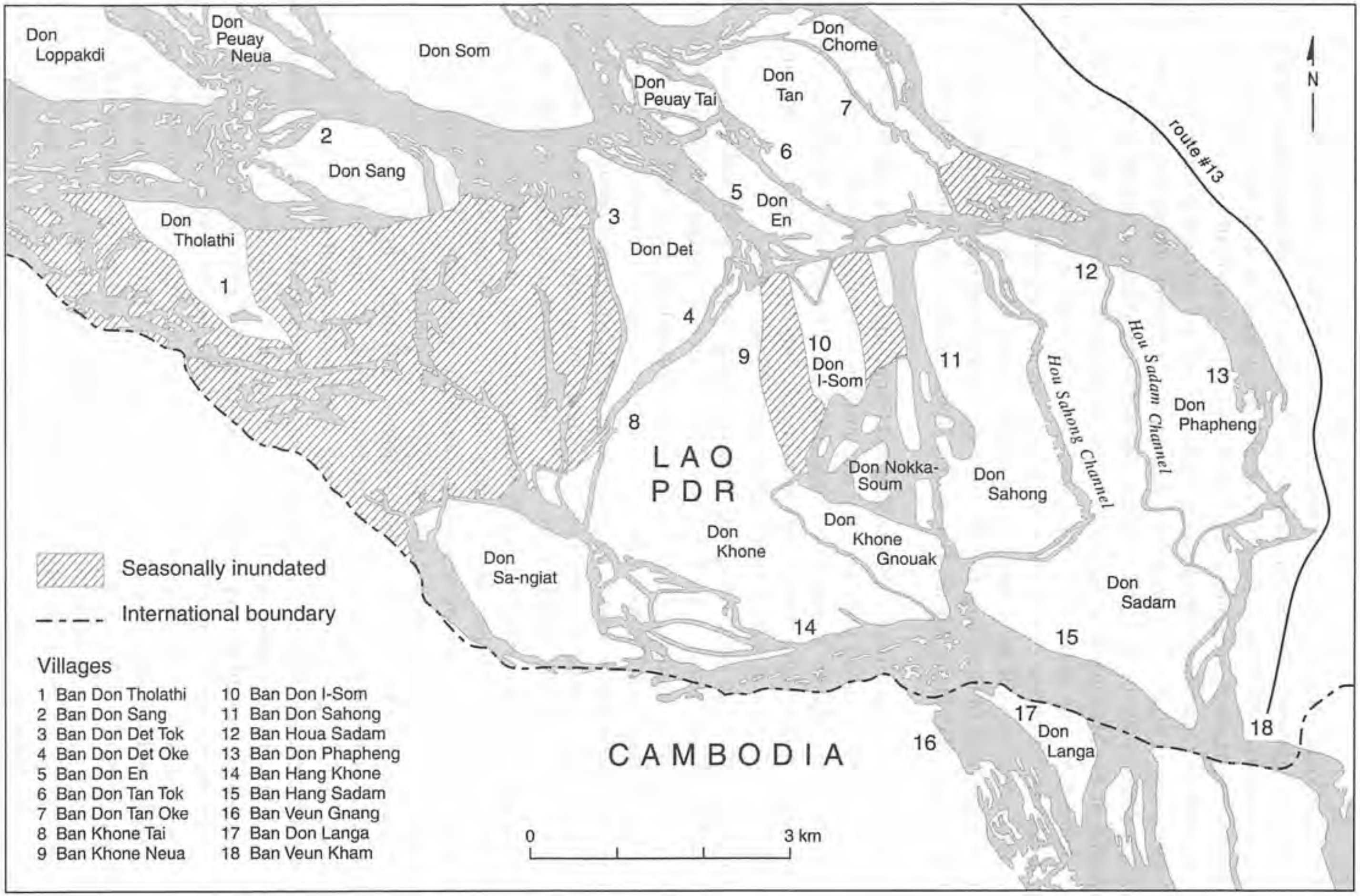

Figure 2. The Khone Falls area, Khong District, Champasak Province, Southern Lao PDR

PROJECT BACKGROUND, AND THE FENCE–FILTER TRAP FISHERY

The Lao Community Fisheries and Dolphin Protection Project (LCFDPP) was established as a small, non-governmental organization (NGO) supported, government project in Khong District in January 1993. The LCFDPP's main objectives were to work with local officials from Khong District's Agriculture and Forestry Office (AFO) and villagers to facilitate the establishment of community-based living aquatic resources co-management systems. In April 1993, the LCFDPP also established a systematic fisheries monitoring program just below the Khone Falls in Ban Hang Khone, a rural fishing village situated on an island in the middle of the Mekong River adjacent to the border with Cambodia (Fig. 2). The dry season fence-filter trap fishery is of great importance to villagers living near the Khone Falls, including inhabitants of Ban Hang Khone. It supplies them with considerable amounts of animal protein as well as income. The southern end of Nok Kasoum Island, which is about 2 km northeast of Ban Hang Khone, is the site of important fence-filter traps belonging to villagers from Ban Hang Khone, Ban Khone Neua and Ban Don Som (see ROBERTS & BAIRD, 1995).

In July 1997, the Environment Protection and Community Development in Siphandone Wetland Project (EPCDSWP) took over the responsibilities of the LCFDPP, including work related to the living aquatic resource co-management program and the fisheries monitoring program based in Ban Hang Khone. The new project, however, continued to monitor the fence-filter trap fishery at Nok Kasoum Island in 1998 and 1999.

The fence-filter trap fishery has long been extremely important for villagers living in Ban Hang Khone and others in the Khone Falls area. Fence-filter traps are commonly used at the edges of rice paddies and in small streams throughout Laos and other parts of mainland Southeast Asia. The *tone* trap fishery dealt with here is, however, fundamentally different and unique, and is found nowhere else in the Mekong basin outside of the Khone Falls. The *tone* traps used at the edges of paddy fields and in streams are generally smaller than those situated at the Khone Falls. They target different species of fish, and are generally used right at the end of the rainy season rather than at the height of dry season, as is the case for the *tone* fishery at the Khone Falls. They also generally catch fish as they are moving downstream out of seasonally inundated areas, rather than when they are moving upriver in the Mekong, and they are often designed differently than *tone* traps in the Mekong (see CLARIDGE *ET AL.*, 1997; ROBERTS & BAIRD, 1995).

Each year at the beginning of the dry season, villagers construct fence-filter traps of various sizes and designs using locally obtained wood, bamboo, rattan and vines. Each trap is slightly different, as it is built to fit the particular geographical and hydrological conditions found at the site it is designed for. These traps are constructed to target the large masses of small cyprinids that migrate up the Mekong River from Cambodia each year. The fish swim up the many small channels and rapids that make up the Khone Falls. However, some of the channels cannot be easily ascended due to the presence of impassible rapids and waterfalls so they must move up and down the channels until they find a channel they can get up (ROBERTS, 1997; ROBERTS & BAIRD, 1995). Only a few channels, the most notable being Hou Sahong and, to a lesser extent, Hou Sadam are easily passable year round (BAIRD *ET AL.* 2001a; ROBERTS, 1997; BAIRD, 1996; ROBERTS & BAIRD, 1995). Villagers understand the local movements of these fish very well. They construct their fence-filter traps so as to catch the migrating fish not when they are moving upstream, as might be expected, but when they move downstream after unsuccessfully attempting to pass a particular channel with a high waterfall or steep rapid at its upper end. Returning fish are sometimes caught in large quantities over a few days each year during peak periods of the highly seasonal fishing period (BAIRD, 1998; ROBERTS & BAIRD, 1995).

One of the most important fishing areas for the dry season fence-filter trap fishery at Khone Falls is the southern tip of Nok Kasoum Island (Fig. 2). Located in the geographical center of the Khone Falls, local fishers who hold traditional tenure over particular trap sites generally catch large quantities of fish during peak catch periods (ROBERTS & BAIRD, 1995). Owing to the strategic location of Nok Kasoum Island, the relatively large catches from the area, and its close proximity to project's base at Ban Hang Khone, it was decided that this would be an ideal place to study and monitor the fence-filter trap fishery.

Several fence filter traps are operated in the Khone Falls area. It was decided, however, to concentrate data collection at one key fence-filter fishing operation at Nok Kasoum Island (Figs. 3–10). Accurately monitoring more sites would have required much more project labor than was available. We were fortunate in that the third author is the son-in-law of one of the co-owners of a good fence-filter trap site on Nok Kasoum Island. His in-laws are from Ban Hang Khone while the other owner lives in Ban Khone Neua. The two communities are situated at either end of the 5-km long Khone Island, which straddles the Khone Falls at its center.

The fence-filter trap fishery in the Khone Falls area is subject to a long-practiced tenure system that dictates the nature of the fishery. Because there are only a limited number of high quality *tone* trap sites in the Khone Falls area, and since some sites are more effective than others, high quality fence-filter trap sites have long been in high demand. As a result, an indigenous *tone* trap tenure system has developed over generations. It gives individual families, or groups of two or more families, exclusive rights for constructing *tone* traps at particular sites. Tenure is initially established through building a *tone* trap at a particular location. If the site has never been used or claimed by another family for fish trapping, and does not negatively impact on the ability of previously established traps nearby to catch fish, the first claimants become de facto owners of the site. These ownership rights are not unlike other private property rights in that fishing site rights can be freely traded or rented to others, and can also be inherited through family lines. For example, if a family owns a particular *tone* site but for some reason decides not to build a trap there during a particular year, others who do not hold traditional tenure over the site must ask permission of the owner to build a trap there. They may also be obliged to pay rent to the owner for the right to fish there for a single season. After the end of the fishing season, tenure reverts to the original owner (BAIRD *ET AL.*, 2001a; ROBERTS & BAIRD, 1995).

In many cases *tone* fishing sites are owned by single families. These families may or may not have sufficient labor to run a particular *tone* fishing operation on their own. If family labor is insufficient, the owner may decide to bring in one or more partners to assist in building the trap and subsequently running the fishing operation. However, these agreements rarely take the form of normal employer/employee relationships. Although only one family owns the trap site, all trap construction costs and labor expenditures associated with the fishery are divided equally between the partners. Moreover, the fish catch is divided equally amongst all those participating in the fishery, regardless of their ownership status (ROBERTS & BAIRD, 1995).

Figure 3. Fence-filter trap at Nok Kasoum Island, Khong District Champasak Province, southern Lao PDR

Figure 4. (same as above)

Figure 5. (same as above)

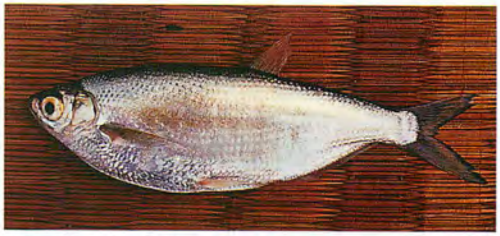

Figure 7. *Paralaubuca typus* (pa tep)

Figure 6. Removing the catch basket from the fence-filter trap at Nok Kasoum Island

Figure 8. The first author weighs catch from-filter trap at Nok Kasoum Island in the presence of fishers

Figure 9. Sun-dried *Paralaubuca typus* (*pa tep*) for sale in the Pakse market, Champasak Province, southern Lao PDR

Figure 10. Small cyprinids are laid out on rocks on Nok Kasoum Island to be sun-dried

Considering the egalitarian nature of such arrangements, which clearly indicates the value of labor in the production process, one might wonder what, if any, advantages trap owners receive over their non-owning partners. In fact, there appears to be no immediate material advantage for the owners. Owners do, however, have several important long-term advantages. The first is that they have the exclusive right to sell or rent out the *tone* trap site to others, and garner all the associated economic benefits. Secondly, owners have the right to decide whether they want partners and, if so, how many. If after one year of cooperating with one family the owner decides that he would rather work with someone else, he is under no obligation to renew the old agreement for the coming year. This provides the owners with more occupational security than their non-owning partners. Thirdly, it gives owners the opportunity to gain social influence in their villages, especially when they own a particularly good fishing site (see ROBERTS & BAIRD, 1995).

Historically, people in the Khone Falls area who do not have *tone* trap sites, or who were unable to catch enough fish to feed themselves, can obtain fish by asking the owners of good trap sites to give them small to moderate amounts of fish for free. Even today, villagers sometimes make requests when they arrive at trap sites during peak fishing periods. Although the growing commercialization of the fishery is making it increasingly difficult for people to ask for fish for free, the tradition of giving fish away still persists in the Khone Falls area (ROBERTS & BAIRD, 1995). However, those who get fish for free are, in turn, expected to give fish away when they have a lot of fish and others are in greater need. This has lead to the saying, *"kho pheng koua seu,"* which roughly translates into, "It is more expensive to ask for something for free than to pay for it."

METHODS

The *tone* tenure system in the Nok Kasoum Island area is well established, and in recent years, all of the fence-filter traps in the area have been built in essentially the same places and in the same ways. The same people have also operated the traps, and there have been no new entries into the fishery in the Nok Kasoum Island area for at least the last ten years. However, the fishery undoubtedly experienced a period of expansion a few decades ago. There are a dozen or so traps of various shapes, sizes and efficiency levels in the Nok Kasoum Island area, and probably more than 200 throughout the Khone Falls (ROBERTS & BAIRD, 1995).

Data collection at the *tone* site at Nok Kasoum Island was quite straightforward. One single immovable trap built in the same manner, and situated at the same location in the river each year was monitored. Each year about five or six families operate it, although there are only two owners. This facilitated obtaining yearly data for the fishery that are directly comparable. Since the vast majority of fish caught in this fishery are taken during daylight hours, project officers were stationed at the designated trap with notebooks and scales. They recorded the species and weights of all fish caught for entire seasons, which generally run from between late January and March or early April, depending on hydrological cycles.

On several occasions, the small size of individual fish and the large quantities caught over short periods necessitated lumping large numbers of fish together for weighing. When there was insufficient time to separate large quantities of fish by species, 1-kg random samples were taken from large batches and were treated as representative of the total catch. Because large quantities of fish are caught over short periods of time during peak seasons, it would have excessively inconvenienced fishers if we had insisted on weighing each fish. Once large quantities of fish are caught, villagers are generally anxious to lay the fish out on rocks to dry in the sun so that they do not spoil.

The *tone* fishery data collected have been entered into a relational database management system (RDMS) using the Microsoft programs EXCEL and ACCESS. The variables recorded were weights of individual fish species in grams, the fishing gear used to catch the fish, the number of gears used, the names of the fishers, the time periods fishing effort took place, and the number of hours of fishing.

RESULTS

Table 1 presents the total catch summaries by species and weight for each of the five fence-filter trap or *tone* fishing seasons monitored between 1995 and 1999. Table 2 combines the results of all five seasons. The results clearly indicate the dominance of the small cyprinids *Henicorhynchus lobatus (pa soi houa lem)* and *Paralaubuca typus (pa tep)* in the fishery. *H. lobatus* made up 45% of the combined catch for the five year period, while *P. typus* constituted 33%. Together they made up almost 79% of the total combined harvest for all years. Although *P. typus* catches exceeded those of *H. lobatus* in 1995 and 1996, between 1997 and 1999 *H. lobatus* was more abundant. Annual *H. lobatus* catches ranged from between 35 and 77%, while *P. typus* catches were between 11 and 48%.

The third most important species in the *tone* fishery was *Henicorynchus siamensis (pa soi houa po)*, which made up an average of 5.4% of the catch over the five years (annual range 2.6–11%). The fourth most abundant species was the cyprinid *Labiobarbus leptocheilus (pa lang khon)*, with 4.8% (annual range 0.6–12%). The cobitid loach *Botia modesta (pa mou man)* was fifth most abundant with 4.4% (range 0.4–14%). The small cyprinid *Crossocheilus reticulatus* (*pa tok thoi*) made up 1.2% (range 0.08–1.7%). The remaining 84 species recorded in catches all constituted less than 1% of the total catch for the combined five-year period. However, it is notable that *Cirrhinus microlepis (pa phone mak koke)* made up 4.1% of the catch in 1995, but were very rare or absent in catches for all other years. SINGHANOUVONG *ET AL.* (1996) also recorded relatively high catches of *Cirrhinus microlepis* in the Siphandone Wetland area upriver from the Khone Falls in early 1995.

Tables 1 and 2 include the minimum, maximum and mean individual weights, along with their standard deviations, for each of the species recorded in the *tone* fishery monitored. However, only part of the total catch could be used to derive these statistics, as it was not possible to include fish weighed in bulk.

From the five years of catch data available, it has not been possible to detect any significant trends in catch declines or increases for the *tone* fishery. However, since only one fishing site was monitored, albeit one of the most important single traps in the Falls, it is possible that the fish catch data collected may not have been representative of the overall fishery. However, we believe, from having observed many *tone* trap catches in other channels of the Khone Falls, that the relative differences between areas are generally not great, although there are exceptions.

Table 1. Summary of 1995–1999 fence-filter trap (*tone*) fish catches at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR. The top 8 species are listed, plus others having at least 0.5% of the catch for the years.

#	Latin name	T_weight (g)	% catch	Min (g)	Max (g)	Mean (g)	StDev (g)
	1995						
1	*Paralaubuca typus*	1,648,137	47.63	3	25	7	4
2	*Henicorhynchus lobatus*	1,163,126	33.62	2	11	5	2
3	*Cirrhinus microlepis*	142,780	4.13	60	200	124	27
4	*Henicorhynchus siamensis*	130,992	3.79	5	60	29	15
5	*Labiobarbus leptocheilus*	99,617	2.88	5	27	13	7
6	*Botia modesta*	62,938	1.82	4	20	10	4
7	*Crossocheilus reticulatus*	38,668	1.12	3	13	5	3
8	*Barbodes altus*	17,320	0.50	25	150	74	31
9	Others (68 species +)	156,469	4.52				
	Totals	3,460,047	100.00				
	1996						
1	*Paralaubuca typus*	2,053,534	48.39	3	5	4	1
2	*Henicorhynchus lobatus*	1,792,600	42.24	6	7	7	1
3	*Labiobarbus leptocheilus*	123,390	2.91	10	17	13	5
4	*Henicorhynchus siamensis*	111,819	2.63	8	8	8	
5	*Crossocheilus reticulatus*	55,055	1.30	3	5	4	1
6	*Botia modesta*	41,093	0.97	5	10	7	3
7	*Lobocheilos melanotaenia*	34,317	0.81	5	5	5	
8	*Garra fasciacauda*	7,882	0.19	3	5	4	1
9	Others (37 species +)	24,100	0.57				
	Totals	4,243,790	100.00				
	1997						
1	*Henicorhynchus lobatus*	1,745,148	44.95	1	19	6	2
2	*Paralaubuca typus*	806,310	20.77	3	21	6	2
3	*Botia modesta*	544,308	14.02	3	20	8	3
4	*Labiobarbus leptocheilus*	303,768	7.82	3	40	10	5
5	*Henicorhynchus siamensis*	145,187	3.74	5	56	14	8
6	*Thynnichthys thynnoides*	95,580	2.46	4	20	13	4
7	*Crossocheilus reticulatus*	65,772	1.69	2	10	4	1
8	*Garra fasciacauda*	34,703	0.89	2	7	4	1

Table 1 (continued).

#	Latin name	T_weight (g)	% catch	Min (g)	Max (g)	Mean (g)	StDev (g)
9	*Lobocheilos melanotaenia*	31,204	0.80	2	33	10	9
10	*Gyrinocheilus pennocki*	28,150	0.73	3	100	22	25
11	Others (52 species +)	82,494	2.13				
	Totals	3,882,624	100.00				
	1998						
1	*Henicorhynchus lobatus*	615,121	35.08	3	45	7	5
2	*Paralaubuca typus*	451,406	25.74	2	37	6	5
3	*Labiobarbus leptocheilus*	214,225	12.22	5	110	21	18
4	*Henicorhynchus siamensis*	196,396	11.20	7	220	39	43
5	*Scaphognathops bandanensis*	39,351	2.24	10	250	45	29
6	*Botia modesta*	30,197	1.72	3	150	18	26
7	*Barbodes altus*	24,175	1.38	20	310	89	48
8	*Crossocheilus reticulatus*	24,021	1.37	2	15	7	3
9	*Thynnichthys thynnoides*	20,070	1.14	12	33	20	10
10	*Sikukia gudgeri*	17,433	0.99	4	70	35	14
11	*Lobocheilos melanotaenia*	15,726	0.90	5	60	20	16
12	*Mekongina erythrospila*	12,582	0.72	5	402	128	101
13	*Garra fasciacauda*	12,555	0.72	4	160	11	28
14	*Gyrinocheilus pennocki*	8,937	0.51	10	138	37	37
15	Others (67 species +)	71,336	4.07				
	Totals	1,753,531	100.00				
	1999						
1	*Henicorhynchus lobatus*	1,818,947	76.93				
2	*Henicorhynchus siamensis*	257,700	10.90				
3	*Paralaubuca typus*	252,369	10.67				
4	*Labiobarbus leptocheilus*	13,065	0.55				
5	*Botia modesta*	9,170	0.39				
6	*Lobocheilos melanotaenia*	5,115	0.22				
7	*Garra fasciacauda*	3,292	0.14				
8	*Crossocheilus reticulatus*	1,962	0.08				
9	Others (6 species)	2,650	0.11				
	Totals	2,364,270	100.00				

Table 2. Summary of total combined 1995–1999 fence-filter trap (*tone*) fish catches at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR

#	Latin name	Lao name	T_weight (g)	%catch	Min (g)	Max (g)	Mean (g)	StDev (g)
1	*Henicorhynchus lobatus*	*pa soi houa lem*	7,134,942	45.44	1	45	6	3
2	*Paralaubuca typus*	*pa tep*	5,211,756	33.19	2	37	6	4
3	*Henicorhynchus siamensis*	*pa soi houa po*	842,094	5.36	5	220	27	32
4	*Labiobarbus leptocheilus*	*pa lang khon*	754,065	4.80	3	110	13	12
5	*Botia modesta*	*pa mou man*	687,706	4.38	3	150	11	14
6	*Crossocheilus reticulatus*	*pa toke thoi*	185,478	1.18	2	15	5	2
7	*Cirrhinus microlepis*	*pa phone mak koke*	148,135	0.94	20	210	106	39
8	*Thynnichthys thynnoides*	*pa koum*	117,820	0.75	4	33	14	5
9	*Lobocheilos melanotaenia*	*pa khiang*	101,996	0.65	2	60	13	12
10	*Scaphognathops bandanensis*	*pa pian*	65,354	0.42	10	250	42	25
11	*Garra fasciacauda*	*pa khiko*	61,841	0.39	2	160	7	17
12	*Barbodes altus*	*pa vian fai*	45,015	0.29	20	310	82	40
13	*Gyrinocheilus pennocki*	*pa ko*	43,620	0.28	3	138	26	27
14	*Sikukia gudgeri*	*pa khao na*	35,727	0.23	4	200	35	19
15	*Puntioplites falcifer*	*pa sakang*	30,047	0.19	3	165	64	30
16	*Hypsibarbus malcolmi*	*pa pak kom*	28,894	0.18	5	300	92	66
17	*Mekongina erythrospila*	*pa sa-i*	23,196	0.15	5	402	81	77
18	*Cyclocheilichthys enoplos*	*pa choke/pa chok*	19,670	0.13	5	1,530	320	327
19	*Himantura chaophraya*	*pa fa lai/pa fa hang*	14,800	0.09	1,300	1,300	1,300	
20	*Coius undecimradiatus*	*pa seua*	13,076	0.08	6	1,200	200	202
21	*Scaphognathops stejnegeri*	*pa pian*	11,045	0.07	12	300	93	56
22	*H. lobatus/L. leptocheilus*	*pa soi/pa lang khon*	11,040	0.07				
23	*Cosmochilus harmandi*	*pa mak ban*	9,854	0.06	3	950	66	159
24	*Botia caudipunctata/spp.*	*pa mou man*	8,199	0.05	3	15	7	3
25	*Bagarius yarrelli/spp.*	*pa khe*	7,885	0.05	10	800	254	240
26	*Bangana behri*	*pa va na no*	6,765	0.04	10	300	73	63
27	*Mystacoleucus marginatus*	*pa lang ko*	5,867	0.04	5	180	17	25
28	*Henicorhynchus lineatus*	*pa soi lai*	5,555	0.04	2	6	5	1
29	*Belodontichthys dinema*	*pa khop*	4,640	0.03	100	1,100	356	312
30	*Cirrhinus molitorella*	*pa keng*	4,600	0.03	5	400	46	74
31	*Botia helodes*	*pa kheo kai*	4,451	0.03	1	25	12	5
32	*Pangasius pleurotaenia*	*pa gnone thong khom*	3,760	0.02	22	150	77	41
33	*Crossocheilus siamensis*	*pa khang lai noi*	3,652	0.02	2	15	5	2
34	*Hemibagrus nemurus*	*pa kot leuang*	3,545	0.02	20	400	135	90
35	*Rasbora spp.*	*pa sieu ao*	3,451	0.02	3	15	6	3
36	*Cirrhinus mrigala*	*pa nang chan*	3,395	0.02	60	280	139	68

Table 2 (continued).

#	Latin name	Lao name	T_weight (g)	%catch	Min (g)	Max (g)	Mean (g)	StDev (g)
37	*Luciosoma bleekeri*	*pa mak vai*	3,258	0.02	20	180	47	39
38	*Acantopsis sp. or spp.*	*pa hak kouay*	2,866	0.02	3	10	7	3
39	*Hypsibarbus lagleri*	*pa pak pay*	2,605	0.02	20	435	165	120
40	*Osteochilus microcephalus/waandersii*	*pa khang lai gnai*	2,354	0.01	2	22	8	6
41	*Opsarius pulchellus*	*pa lai khouang*	2,183	0.01	1	10	4	2
42	*Glyptothorax spp.*	*pa kon*	1,711	0.01	2	10	5	2
43	*Morulius chrysophekadion/spp.*	*pa phia*	1,685	0.01	5	1,000	209	333
44	*Chitala blanci*	*pa tong kai*	1,620	0.01	80	900	540	419
45	*Osteochilus melanopleurus*	*pa khang lai gnai*	1,605	0.01	10	100	44	28
46	*Boesemania microlepis*	*pa kouang*	1,600	0.01	1,600	1,600	1,600	
47	*Hemisilurus mekongensis*	*pa nang deng*	1,530	0.01	10	480	121	162
48	*Hypsibarbus wetmorei*	*pa pak thong leuang/pa pak kham*	1,480	0.01	1,480	1,480	1,480	
49	*Cyclocheilichthys armatus*	*pa doke ngieu*	1,408	0.01	5	230	72	61
50	*Tenualosa thibaudeaui*	*pa mak phang*	1,245	0.01	10	90	39	17
51	*Kryptopterus spp.*	*pa pik kai*	1,230	0.01	5	150	32	29
52	*Wallago attu*	*pa khao*	1,200	0.01	1,200	1,200	1,200	
53	*Pangasius bocourti*	*pa houa mouam*	1,150	0.01	267	350	308	59
54	*Pangasius conchophilus*	*pa pho/pa ke*	995	0.01	100	300	199	89
55	*Toxotes microlepis*	*pa mong*	905	0.01	20	100	50	24
56	*Helicophagus waandersi*	*pa nou/pa hoi*	825	0.01	15	240	123	91
57	*Pangasius macronema*	*pa gnone thamada*	815	0.01	10	100	41	28
58	*Henicorhynchus/Paralaubuca spp.*	*pa soi/pa tep*	790	0.01				
59	*Notopterus notopterus*	*pa tong na*	760	0.00	20	200	117	70
60	*Micronema apogon/micronema*	*pa nang khao/pa sangoua*	575	0.00	5	240	73	93
61	*Hemibagrus wyckioides*	*pa kheung*	511	0.00	10	501	256	347
62	*Lycothrissa crocodilus*	*pa mak chan*	500	0.00	38	38	38	
63	*Labeo erythropterus*	*pa va souang*	420	0.00	10	100	49	30
64	*Laides hexanema/spp.*	*pa gnone thong*	405	0.00	5	50	19	14
65	*Parambassis wolffi/spp.*	*pa khap khong*	404	0.00	1	54	28	37
66	*Ompok bimaculatus*	*pa seuam*	390	0.00	20	120	78	41
67	*Hampala macrolepidota*	*pa sout*	300	0.00	300	300	300	
68	*Mystus singaringan/spp.*	*pa kha gneng*	300	0.00	10	55	33	16
69	*Onychostoma cf. elongatum*	*pa khiang fai*	295	0.00	10	40	20	10
70	*Probarbus labeamajor*	*pa eun khao*	250	0.00	250	250	250	
71	*Mastacemblus armatus/spp.*	*pa lat*	214	0.00	2	40	24	15
72	*Tetraodon leiurus/spp.*	*pa pao*	205	0.00	10	65	24	19

Table 2 (continued).

#	Latin name	Lao name	T_weight (g)	%catch	Min (g)	Max (g)	Mean (g)	StDev (g)
73	*Rhinogobius spp.*	*pa bou*	183	0.00	3	5	4	1
74	*Osphronemus exodon*	*pa men*	150	0.00	20	50	35	21
75	*Amblyrhynchichthys truncatus*	*pa ta po*	150	0.00	25	100	63	53
76	*Raiamas guttatus*	*pa sanak*	120	0.00	50	70	60	14
77	*Xenentodon cancila*	*pa kathong*	100	0.00	5	20	13	6
78	*Opsarius koratensis*	*pa sieu*	100	0.00				
79	*Poropuntius deauratus*	*pa chat*	100	0.00	5	30	14	11
80	*Pristolepis fasciata*	*pa ka*	80	0.00	20	20	20	0
81	*Epalzeorhynchos frenatum*	*pa dout hin*	80	0.00	5	5	5	0
82	*Systomus orphoides*	*pa pok*	65	0.00	5	50	22	25
83	*Glossogobius koragensis*	*pa bou khao*	45	0.00	5	10	6	2
84	*Bagrichthys macracanthus*	*pa kouay souk*	40	0.00	10	30	20	14
85	*Euryglossa panoides*	*pa pan gnai*	40	0.00	20	20	20	
86	*Hemimyzon sp.*	*pa tit hin*	35	0.00	5	5	5	0
87	*Pseudomystus siamensis*	*pa khi hia*	30	0.00	10	20	15	7
88	*Macrognathus siamensis/spp.*	*pa lot*	30	0.00	10	20	15	7
89	*Hypsibarbus malcolmi (juv.)*	*pa khao lan*	30	0.00	30	30	30	
90	*Chonerhinus nefastus*	*pa pao louang*	25	0.00	5	15	10	7
91	*Kryptopterus cryptopterus*	*pa pik kai*	20	0.00				
92	*Achiroides spp.*	*pa pan*	15	0.00	5	10	8	4
93	*Mystacoleucus atridorsalis*	*pa lang ko*	15	0.00	5	5	5	0
94	*Oxyeleotris marmorata*	*pa bou*	10	0.00	5	5	5	0
	Totals		15,703,525	100.00				

Table 3. Fish species believed to migrate from the Tonle Sap River to Khone Falls at the beginning of each dry season. Fish species listed as being caught in the *tone* fishery by ROBERTS & BAIRD (1995) but not included here are presently not believed to migrate from the Tonle Sap River to the Khone Falls.

#	Latin name	Listed by Roberts & Baird (1995)	Listed by Lieng et al. (1995)
1	*Henicorhynchus lobatus*	yes, as *Cirrhinus lobatus*	yes, as *Henicorhynchus* spp.
2	*Henicorhynchus siamensis*	yes, as *Cirrhinus siamensis*	yes, as *Henicorhynchus* spp.
3	*Henicorhynchus lineatus*	yes, as *Cirrhinus lineatus*	yes?, as *Henicorhynchus* spp.
4	*Cirrhinus microlepis*	yes	yes
5	*Paralaubuca typus*	yes	yes
6	*Labiobarbus leptocheilus*	yes	yes, as *Dangila* spp.
7	*Thynnichthys thynnoids*	yes	yes
8	*Lobocheilus melanotaenia*	yes	no, possibly mixed with other spp.?
9	*Garra fasciacauda*	yes	no, small size - overlooked?
10	*Barbodes altus*	yes	yes
11	*Gyrinocheilus pennocki**	yes	no
12	*Sikukia gudgeri**	yes, incorrectly as *S. stejnegeri*	no
13	*Puntioplites falcifer*	yes, incorrectly as *P. proctozysron*	yes, incorrectly as *P. proctozysron*
14	*Cyclocheilichthys enoplos*	yes	yes
15	*Cyclocheilichthys sp./spp.*	no	yes, as *C. apogon*/spp.
16	*Cosmochilus harmandi**	no	yes
17	*Epalzeorhychus frenatum*	yes, incorrectly as *E. frenatus*	no
18	*Crossocheilus reticulatus*	yes	no, small size - overlooked?
19	*Crossocheilus siamensis*	yes, as *Epalzeorhychus siamensis*	no, small size - overlooked?
20	*Osteochilus melanopleurus*	no	yes, incorrectly as *O. melanopleura*
21	*Osteochilus microcephalus*	yes	no
22	*Amblyrhychichthys truncatus*	no	yes
23	*Luciosoma bleekeri*	yes	no
24	*Leptobarbus hoeveni*	no, large size, not caught in *tone*	yes
25	*Rasbora sp.**	no	no
26	*Tenualosa thibaudeaui*	yes	yes
27	*Schistura sp.*	no	no, small size - overlooked?
28	*Acantopsis sp.*	yes	no
29	*Botia modesta*	yes	yes, as *Botia* spp.
30	*Botia helodes*	yes	yes, listed as *Botia* spp.
31	*Botia caudipunctata*	no	yes?, as *Botia* spp.
32	*Parambassis wolffi*	no	yes
	*** Origins of migrations unclear**		

Figures 11 to 15 compare daily total fish catches for each year against lunar phases (the tops of the darkened triangles represent full moon periods while the bottoms represent new moon periods). Figure 16 includes summaries of daily total catches for all five seasons. It is evident that fish catches are closely associated with lunar cycles. Peak catches always occur around the new moon, when nights are the darkest. The main peak catches for each year occurred during a new moon phase in late January or early to mid-February, followed by a second smaller peak almost exactly one lunar month later, again around the time of the new moon. However, in 1997 there was a deviation from this pattern in that a small peak in catches occurred around the time of the full moon, about half a lunar month after the first main peak in catches. It is unclear why this occurred, but the fish may have been delayed for some reason, or they may have lost a number of days trying to ascend other channels in the Khone Falls area before reaching Nok Kasoum Island. Another small peak occurred during the new moon a month after the first main peak, half a month after the unexpected small peak around the full moon. In 1999, only a first peak in catches was recorded. The second smaller peak was probably not recorded because water levels dropped more rapidly in 1999 than in previous years. By the time a full lunar month had passed since the main peak in catches, water levels had already dropped too much for *tone* fishing to take place. In other words, fish may have been migrating at the time, but the *tone* trap being monitoring at Nok Kasoum Island could not catch them.

Figure 17 depicts monthly total fish catches for the bag-net fishery in the Tonle Sap River in central Cambodia for each of the five years between 1995 and 1999. It also includes the monthly total catches for the fence-filter trap at Nok Kasoum Island over the same five-year period. The weights for both fisheries are not directly comparable, however, because the bag-net fishery catches are recorded in metric tons, and have been extrapolated to represent the total catch for all bag-net operations (LIENG *ET AL.*, 1995). The fence-filter trap catches are recorded in grams and are only available for a single trap. Due to the wide range of efficiency for different traps, no attempt has been made to extrapolate results for the whole fishery. For example, some small traps in minor channels catch less than 100 kg a season, while the traps at Nok Kasoum Island generally catch over 3,000 kg per season. Even if a large sample of traps in different channels could have been monitored with a large amount of labor, it still would be difficult to extrapolate the results because even traps in the same channels often have quite different catches.

Peak bag-net fish catches generally occur about three-quarters of a lunar month before the peak fence-filter trap seasons. It appears that years of particularly high bag-net catches, such as 1995 and 1998 (18,410 and 14,671 tons, respectively (VAN ZALINGE *ET AL.*, 1999; LIENG *ET AL.*, 1995), are associated with low to moderate fence-filter trap catches (3.5 and 1.8 tons, respectively). In 1996 and 1997 when *tone* catches were highest (4.2 and 3.9 tons), *dai* catches were moderate (14,429 and 15,488 tons) (VAN ZALINGE *ET AL.*, 1999). In 1999, *dai* catches were the lowest in five years (8,894 tons) (VAN ZALINGE *ET AL.*, 1999), and while *tone* catches were also low, they were nevertheless higher than in 1998 (2.4 tons in 1999 compared to 1.8 tons in 1998). The above data are not strong enough to make any definitive conclusions about the relationship between the *dai* fishery and the *tone* fishery. However, the possible implication is that the success of the *tone* fishery is strongly influenced by how many fish are caught in the *dai* fishery.

The 1993–1997 water discharges in the mainstream Mekong River at Pakse (approximately 130 km upriver from the Khone Falls; Fig. 18) indicate that peak small

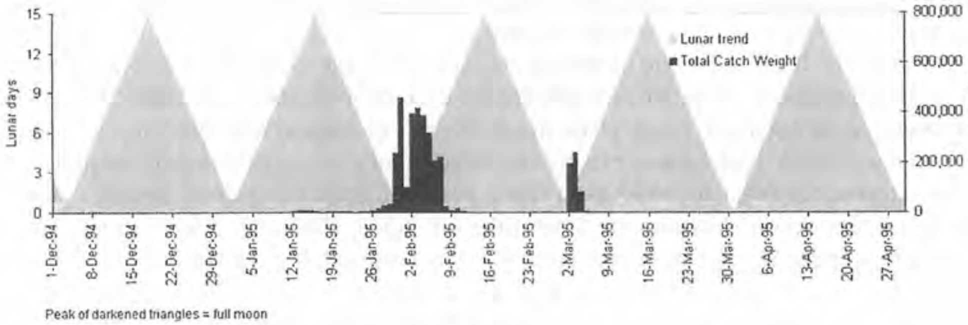

Figure 11. Total 1995 fish catches for the fence-filter trap (*tone*) fishery at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR against lunar phases

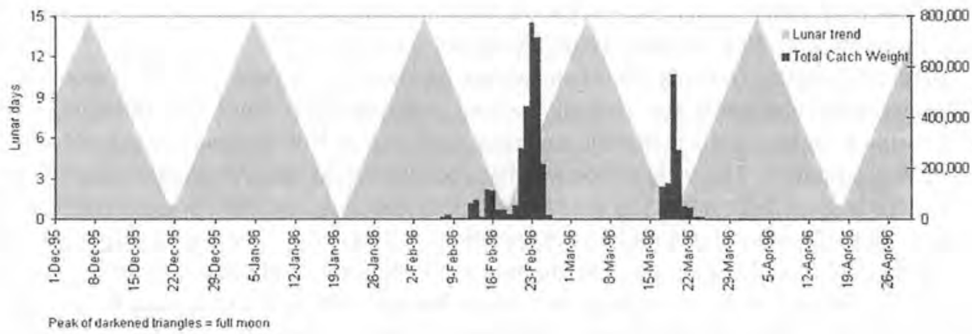

Figure 12. Total 1996 fish catches for the fence-filter trap (*tone*) fishery at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR against lunar phases

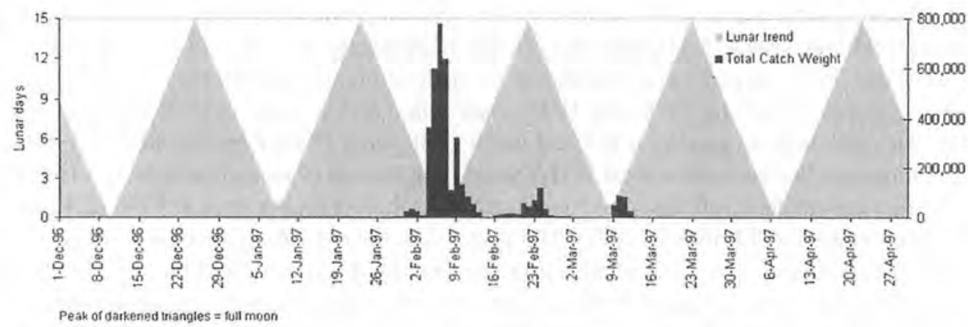

Figure 13. Total 1997 fish catches for the fence-filter trap (*tone*) fishery at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR against lunar phases

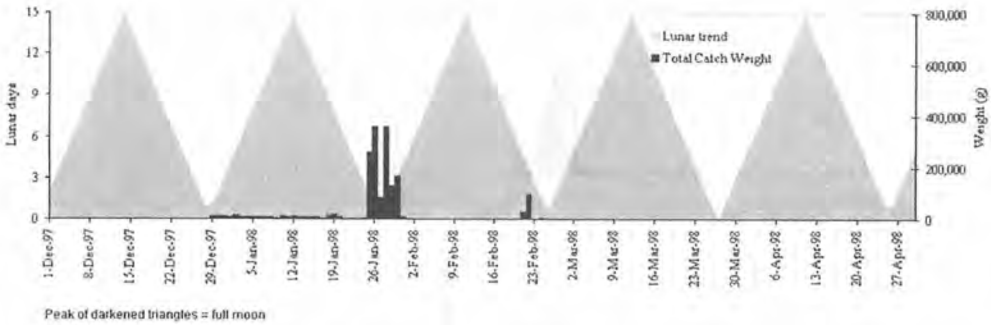

Figure 14. Total 1998 fish catches for the fence-filter trap (*tone*) fishery at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR against lunar phases

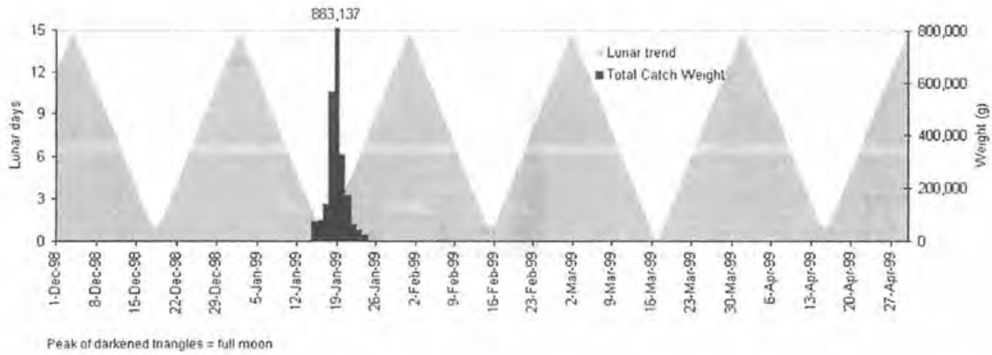

Figure 15. Total 1999 fish catches for the fence-filter trap (*tone*) fishery at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR against lunar phases

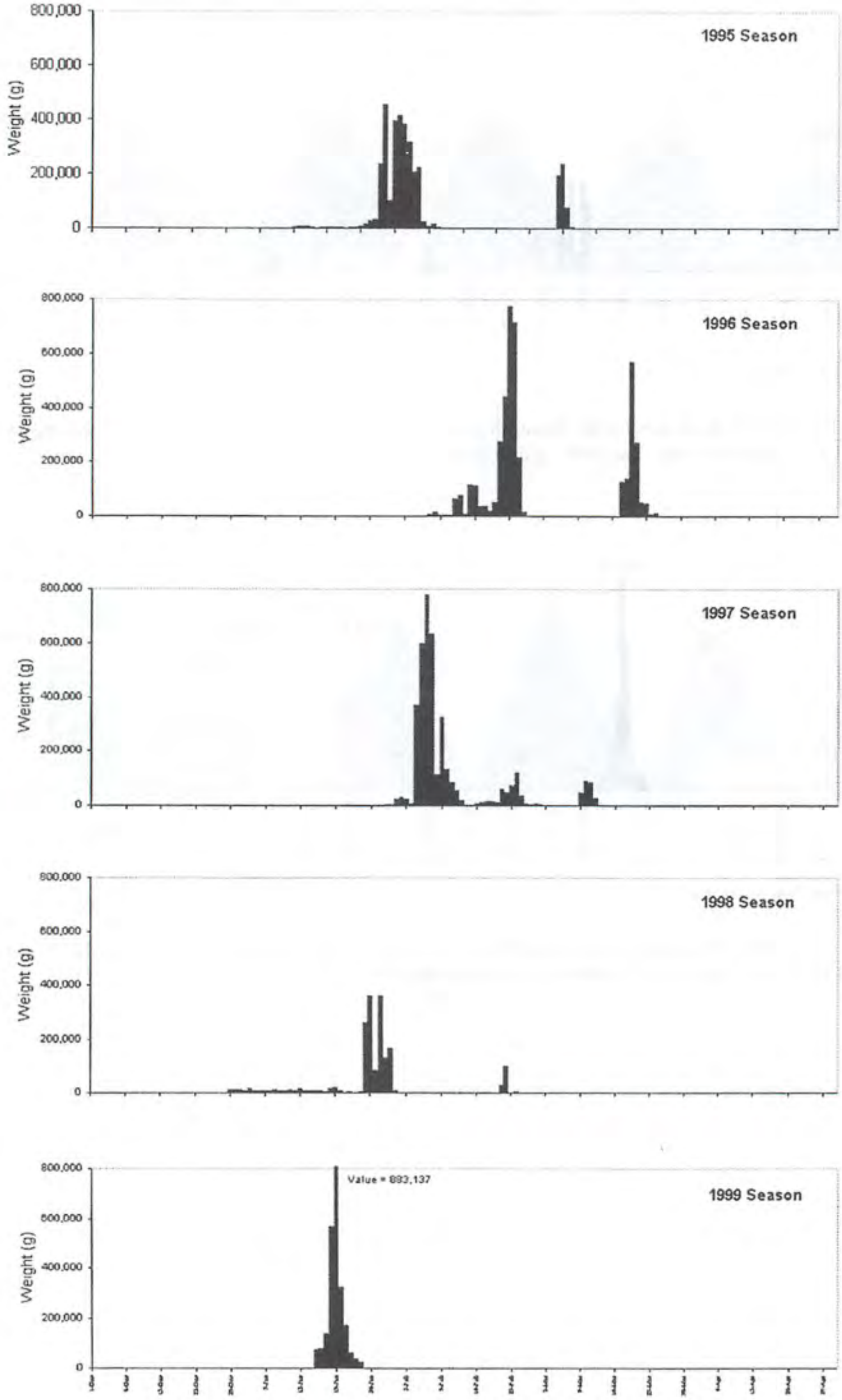

Figure 16. Peak 1995–1999 fish catches for the fence-filter trap (*tone*) fishery at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR against lunar phases

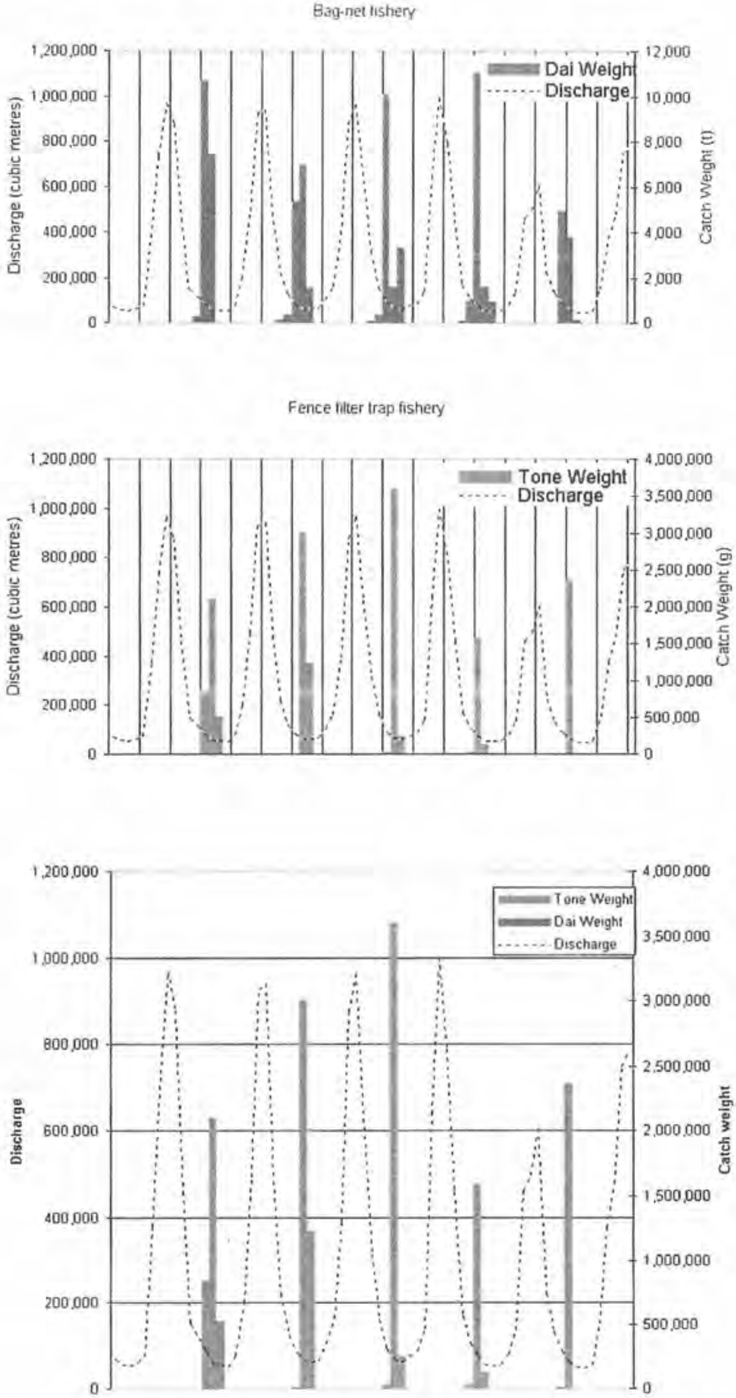

Figure 17. Monthly total fish catches for the bag-net fishery in the Tonle Sap River in Central Cambodia and the fence-filter trap fishery at the Khone Falls in Southern Laos between 1995–1999

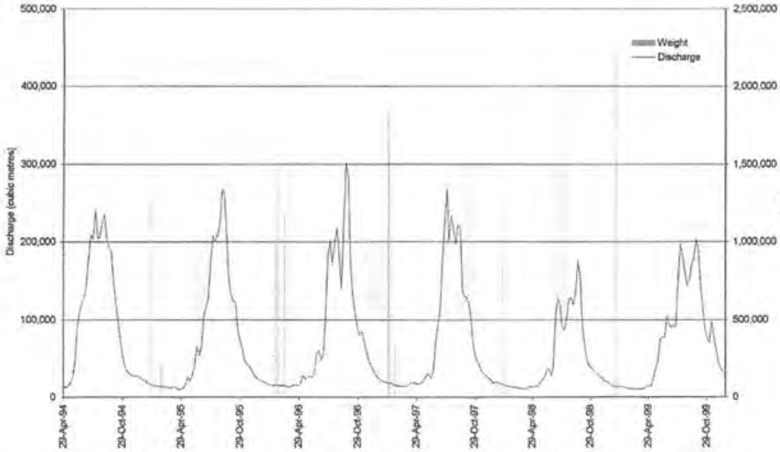

Figure 18. Total 1995 to 1999 fish catches for the fence-filter trap (*tone*) fishery at Nok Kasoum Island, Khong District, Champasak Province, Lao PDR against mainstream Mekong River water discharge at Pakse

cyprinid catches at the Khone Falls occurred when water levels were dropping. However, peak catches do not occur when water levels are at their lowest. They occur when water levels are only marginally above the lowest discharge levels.

DISCUSSION

Small cyprinids apparently migrate long distances from Cambodia to Laos and Thailand. Phnom Penh, the Capital of Cambodia, is situated adjacent to the Quatre Bras, where the Tonle Sap River flows into the Mekong River, and the Mekong River splits into two on her way to the Mekong Delta in Vietnam. The Cambodian Capital is situated approximately 335 km up the Mekong River from the sea, and *dai* fishing operations are an average of about 15 km up the Tonle Sap River from Phnom Penh (N. van Zalinge, pers. comm.). The Khone Falls, on the other hand, are approximately 719 km from the sea (Mekong Secretariat, 1994). Therefore, it is approximately 400 km from the *dai* fishery to the *tone* fishery.

If one compares the catch make-up of the *dai* fishery and that of the *tone* fishery, it becomes immediately evident that they are very similar. For example, in 1995, *Henicorhynchus* spp. made up 67.5% of the *dai* catch, compared to 37.4% for the *tone* fishery. Although *Paraluabuca typus* was more abundant in the 1995 *tone* catches, *Henicorhynchus lobatus* is generally the most abundant species in the *tone* fishery. Not surprisingly, *P. typus* was the second most abundant species in both fisheries. In 1995, *Cirrhinus microlepis* made up 4.1% of the *tone* fishery and 2.2% of the *dai* fishery. *Labiobarbus leptocheilus* made up 2.9% of the *tone* fishery in 1995, compared to 5.3% for the same genus, plus some *Osteochilus hasselti* (?), in the *dai* fishery. *Botia modesta* accounted for 1.8% of the 1995 *tone* catch compared to 1.5% for *Botia* spp. in the *dai* fishery (LIENG *ET AL.*, 1995). The catch distributions are apparently somewhat different, but still strongly suggest that fish migrating from the Tonle Sap River move up to the Khone Falls.

ROBERTS & BAIRD (1995) recorded 27 species of fish as being caught regularly in the *tone* fishery in the Khone Falls. We believe that 32 fish species migrate from the Tonle Sap River to the Khone Falls each dry season (Table 3). Species listings in ROBERTS & BAIRD (1995) and LIENG *ET AL.* (1995) are also included. Fish species added to the list of long distance migrators since ROBERTS & BAIRD (1995) include: (1) *Botia caudipunctata* (a newly described cobitid loach); (2) *Schistura* sp. (a mysterious small loach that shows up in peak *tone* catches—but due to the fact that *Schisturas* are not known to migrate in other places, this species is only tentatively included); (3) *Leptobarbus hoeveni* (a carp too large to be caught in *tone* fisheries but believed by villagers to migrate from the Great Lake in Cambodia); (4) the minnow *Rasbora* sp. (a species found in peak *tone* catches and of mysterious origin); and (5) *Osteochilus melanopleurus* (a carp believed by villagers to be highly migratory). Future research should be directed towards confirming the migration patterns of these species (Table 3).

The Great Lake and other large wetlands in Central Cambodia shrink vastly in size during the dry season (VAN ZALINGE *ET AL.*, 1998; RAINBOTH, 1996; LIENG *ET AL.*, 1995). This necessitates many of the fish inhabiting these areas during the monsoon season to look for other places to survive during the harsh low-water season. Peak *dai* catch periods in the Tonle Sap River occur between one and six days before the full moon (LIENG *ET AL.* 1995; N. van Zalinge, pers. comm., 1999), while peak *tone* catches at the Khone Falls occur approximately at the new moon, or slightly before or after it.

To determine the approximate swimming speed of the small cyprinids, we have assumed that peak *dai* fishing periods occurred each month four days before the full moon. We have counted the days between those peak catches and peak catch days for the *tone* fishery at the Khone Falls, based on our daily catch data from Nok Kasoum Island. It took between 15 and 25 days for the small cyprinids to migrate between the *dai* fishery and the *tone* fishery. The mean traveling time was 19.8 days (SD = 2.99). Nine lunar month periods over five years were used to estimate the traveling time for peak runs of small cyprinids. That translates to average swimming speeds of between 16 and 27 km per day, with a mean of about 20 km. The Project for Management of the Freshwater Capture Fisheries of Cambodia conducted a year-long sampling program at six landing sites along the Mekong River in Cambodia and found a swimming speed for the small cyprinids of 17 km/day between the *dai* traps and Stung Treng Province (N. van Zalinge, pers. comm., 1999).

Experienced Lao fishers from the Khone Falls area believe that the main peak fishing period for the *tone* fishery occurs each year around the 3rd day of the rising moon during the 3rd Lao lunar month, which coincides with Chinese New Year (SINGHANOUVONG *ET AL.*, 1996; ROBERTS & BAIRD, 1995; ROBERTS & WARREN, 1994; ROBERTS, 1993). Data collected at Nok Kasoum Island indicate that villagers are correct in assuming this to be the case, although the time of peak catches can vary by a few days either way (Figs. 11 to 15).

In 1996 the first main peak *tone* catches were recorded during the new moon of the fourth Lao lunar month, rather than the third. Another smaller peak occurred during the new moon at the beginning of the fifth lunar month during the same year. These data suggest that the fish arrived at the Khone Falls one lunar month late. However, after comparing the peak *dai* fishing periods with the peak *tone* fishing periods, it became apparent that the fish were not a month late after all. On around January 1, 1996 (four days before the full moon), large *dai* catches were recorded (these catches were only slightly surpassed the next lunar month—5,644 compared to 5,282 tons) (N. van Zalinge, pers. comm., 1999). However, the first peak period for the *tone* fishery was not until around February 23, 1996, 54 days after the first *dai* peak. Considering what we already know about swimming speed, this is much longer than the average 20-day time period apparently required for the fish to reach the Khone Falls from the Tonle Sap River. However, if a 29.5-day lunar month is subtracted from the 54 days, an approximately 25 day traveling time remains, which sounds much more plausible. Therefore, our conclusion is that a run of fish probably did arrive at the Khone Falls at the end of January, 1996, but because water levels dropped particularly slowly that year, the water was too high for *tone* fishing to occur, and no fish were caught. The fish probably passed the Khone Falls relatively unimpeded, and this may explain why 1996 was considered a good year for small cyprinid fishing upriver from the Khone Falls (BAIRD *ET AL.*, 1998). Particularly high water levels in 1996 may also explain why it took 25 days for the fish to reach the Khone Falls, compared to the 20 days on average that the journey takes. It is possible that the swimming speed of the fish was reduced because the fish had to swim against stronger currents than are normal.

Conclusions based on our estimate for the swimming speed of the small cyprinids should be viewed with some caution. To begin with, the assumption that peak *dai* catches took place four days before the full moon may not hold in all years. Moreover, it is difficult to pin-point clear peaks in the *tone* catch data. Sometimes fish reach the Khone Falls and travel up one or more impassible channels before turning back and finally trying to go up the widest channel leading to Nok Kasoum Island (Fig. 2) (ROBERTS & BAIRD, 1995). Nok Kasoum Island is ideally sited in the largest channel in the Khone Falls area, just upriver from Hou Sahong, the main migration path for fishes moving above the Khone Falls (BAIRD *ET AL.*, 2001a; BAIRD, 1996; ROBERTS & BAIRD, 1995) (Fig. 2). Therefore, there is less risk of the *tone* fishery at Nok Kasoum Island missing major migrations of small cyprinids compared to other *tone* fisheries in the Khone Falls that are situated in smaller and less centrally located channels. Nevertheless, a few days may be lost in some months by fish that unsuccessfully try to ascend impassible waterfalls. They have to double-back before moving up into the Hou Sahong channel and Nok Kasoum Island area (see ROBERTS & BAIRD, 1995, for a detailed explanation of the channels of the Khone Falls).

Another factor that influences when migrating small cyprinids are caught in *tone* traps is the lapse of time between when they pass the trap moving upstream, and when they return after encountering an impassible obstacle. They generally move past the traps without being caught in significant numbers, and then hours later they are caught in large numbers as they return. These hours can, however, separate days with a night and influence swimming speed calculations. Considering all the above, it is probable that swimming speeds will exhibit considerable variation around the mean.

An apparently small run of small cyprinids passes the Khone Falls around the beginning of the 2nd Lao lunar month each year. The *tone* fishery at Nok Kasoum Island does not target these migrators because water levels are too high at that time of year. However, we have recorded small runs of *Henicorhynchus lobatus* caught in cylindrical current traps *(chip)* near Ban Hang Khone in the Khone Falls area around the beginning of the 2nd Lao lunar month during various years. These migrators are called *"pa soi houa pi"* in Lao, which translates as "the first *Henicorhynchus* of the year" (ROBERTS & BAIRD, 1995).

There is apparently at least a weak link between relatively large *dai* catches and low *tone* catches, although our data are far from conclusive. One of the possible implications of these results are that neither *dai* nor *tone* fish catches alone are a good indicator of the size of migrating small cyprinid populations in the Mekong basin during particular years. Instead it may be necessary to monitor more than one fishery in order to estimate population sizes. It is possible that in some years large numbers of small cyprinids are able to escape capture in the Tonle Sap River *dai* fishery due to hydrological or other reasons. However, small cyprinids also certainly migrate out of other wetlands in central Cambodia. Yet it is still unclear how much these fish contribute to small cyprinid migrations in the Mekong basin. For now we do not have enough information to answer these questions, which have important management implications.

While it is quite clear that small cyprinids arrive at the Khone Falls each year at the beginning of the rising moon during the 3rd Lao lunar month, as villagers claim, it is not clear whether individual species move at different speeds. Nevertheless, so far we have no data to indicate that they do. In fact, it is common to see large quantities of many species in catches during peak *tone* fishing periods. It is also unclear whether the small cyprinids travel at different speeds throughout their long journeys. They apparently only migrate during daylight hours, as small cyprinids are never caught in *tone* traps in large quantities during the night. Their daytime swimming patterns, however, are not well understood. *Henicorhynchus lobatus* appear to migrate in lines near the edge of channel while *Paralaubuca typus* frequently travel closer to the surface and in deeper water (personal observations., I. G. Baird).

One question comes to mind. Is it by design that masses of small cyprinids pass the Khone Falls during the darkest part of the month, and is this why they time their departure from the Great Lake as they do? On the one hand, it is plausible that it is coincidental that the small cyprinids reach Khone Falls during new moon periods, and that the time they arrive is simply a function of the number of days it takes for migrating masses of fish to swim from the Tonle Sap River or other wetlands up to the Khone Falls. Nevertheless, the Khone Falls represents the only major 'bottleneck' for the migrating fish over the course of their long journey (it is the only major waterfalls on the Lower Mekong River) (RAINBOTH, 1996). It seems possible that it could be advantageous for the fish to pass the Khone Falls during dark periods, in order to reduce the risk of predation during the nights when they are not migrating and retreat into small refuges around the Falls. During peak migration periods, the small cyprinids are sometimes forced to congregate in large numbers in relatively small shallow pools in the Khone Falls area where they could be easy prey if night visibility was good at that time, which it is not. This could be the evolutionary reason why they have come to pass the Khone Falls when they do.

This scenario makes even more sense when the geological history of the Mekong basin is considered. The Great Lake was only created during the most recent subsidence event of the Cambodian platform between 5,590 and 5,850 years ago (RAINBOTH, 1996), and during relatively recent history, much of the lower Mekong basin in southern Cambodia and Vietnam was under the sea. Therefore, it is likely that the small cyprinids had a much greater period of time to evolve their migration timing for passing the Khone Falls than for adapting to conditions in the Great Lake or other parts of southern and central Cambodia and southern Vietnam. Furthermore, before the Great Lake and other seasonally inundated wetlands in southern and central Cambodia and southern Vietnam were formed, it is possible that populations of small cyprinids were considerably smaller than they are now due to not having such vast wetlands available to reproduce and nurse. It is also true that when the small cyprinids reach the Khone Falls they are generally split up into smaller groups that try to ascend different channels. Therefore, their collective strategy of reducing the potential impact of predation by traveling in large groups is compromised more at the Khone Falls than anywhere else along their migration route. All of the above helps to explain why it would be advantageous for the small cyprinids to pass the Khone Falls at the darkest time of the lunar month.

There is still another reasonable explanation of why the small cyprinids time their migrations as they do. At first, it is not easy to recognize why they pass the Tonle Sap River from the Great Lake one to six days before the full moon. Why would they want to move a number of days before the full moon? However, if the recent geological history is again considered in a different light, a possible explanation becomes apparent. While the Great Lake and Tonle Sap Rivers are no longer directly affected by the tides, the spawning and nursing grounds of the small cyprinids were possibly significantly affected by tidal influences before the Great Lake was formed, and during the period when much of southern Cambodia and Vietnam were under the sea. The largest tides of the month, called spring tides, generally occur shortly after full moons (Wayne Gum and Bernard O'Callaghan, pers. comm., 1999). Therefore, salt-water intrusion into the Mekong River is likely to be greatest during that period, especially at the end of the rainy season when Mekong River downstream discharge declines. Assuming that the small cyprinids evolved in freshwater environments and would want to avoid particularly saline tidal influenced salt-water intrusions from the sea, it makes sense that they would have evolved to leave the wetlands before the high tides and during low neap tide periods, which occur before the full moon. Another factor that adds support to the second hypothesis is that migrations of other medium-sized cyprinids that annually migrate from the Sekong, Sesan and Srepok basins in Cambodia up to the Khone Falls at around the same time of year (including *Scaphognathops bandanensis, Mekongina erythrospila, Labeo erythropterus*, etc.) are not correlated with lunar cycles (BAIRD & FLAHERTY, 2001). If the Khone Falls had been the major influence on the lunar migratory patterns of the small cyprinids, one might expect the same to be the case for other fishes migrating past the Khone Falls at about the same time of year. In any case, it appears that the timing of the small cyprinid migrations can be evolutionarily explained by both factors related to conditions at the Khone Falls, and by historical tidal influences in lower parts of the basin. For now, we are not able to suggest which of the above two scenarios is likely to have influenced the evolution of migratory patterns of the small cyprinids more. Perhaps a combination of both resulted in the present circumstances.

It is likely that fishers catch many of the small cyprinids that pass the Tonle Sap River before they reach Khone Falls. Non-human predators, including fish, birds and mammals probably also feed heavily on the cyprinids. Dry season cyprinid migrations are not associated with spawning behaviour (most small cyprinid species spawn during the monsoon season) (WARREN *ET AL.*, 1998; SINGANOUVONG *ET AL.*, 1996; ROBERTS & BAIRD, 1995; ROBERTS & WARREN, 1994; ROBERTS, 1993). The migrations appear to be conducted by the small cyprinids in order to use the available feeding areas along all the large lowland rivers of the basin. This enables them to feed on algae that grow as the Mekong becomes less turbulent at the beginning of the dry season (see WARREN *ET AL.*, 1998; SINGANOUVONG *ET AL.*, 1996; ROBERTS & BAIRD, 1995). Some fish probably distribute themselves for feeding purposes in lower sections of the Mekong, below the Khone Falls. We do not know whether the distribution pattern changes from year to year, depending on environmental or other conditions. Many small cyprinids migrate up the Sekong, Sesan and Srepok Rivers in northeastern Cambodia, thus not reaching the Khone Falls. Villagers from Khong District have long believed that the health of the cyprinid fishery at the Khone Falls is largely dependent on what happens downriver in Cambodia. For example, villagers claim that migrating fish at the Khone Falls were extraordinarily abundant between 1975 and 1978, when the Khmer Rouge banned all commercial fishing operations and also severely limited subsistence fishing (ROBERTS, 1993).

Cambodian fishers seemly have the advantage in terms of having the first crack at the small cyprinids. In terms of other large-river management issues, such as those related to hydroelectric dam construction and water pollution emissions, however, being downstream is not necessarily advantageous. What is needed is joint-cooperation between all countries in the region so that each country does not negatively impact on fisheries of other countries. The goal should be to maximize benefits to the environment and ultimately local people. Cambodia needs to make sure that Laos and Thailand get their fair share of migrating small cyprinids. On the other hand, the Lao, and the Thais need to avoid impacting on hydrological cycles that influence natural processes downriver, or extracting too much water, or emitting too much pollution into the river system. If all the countries in the basin do not cooperate to prevent and solve these critical problems, everyone is likely to suffer. Sustainable fisheries based on highly migratory species depend on not over-harvesting fish throughout their migration routes as well as maintaining riverine conditions suitable for the successful reproduction and survival of fish populations.

CONCLUSIONS

Several conclusions can be made based on the analysis of the *tone* fishery data from Nok Kasoum Island in the Khone Falls area in southern Laos, and the fish catch data from the *dai* fishery in the Tonle Sap River in Central Cambodia. The first is that the small cyprinid migrations up the Khone Falls and the fence-filter trap fishery are highly correlated with lunar cycles, with peak catches always occurring during the new moon, followed by a second smaller peak in catches one lunar month later. This makes sense considering that peak *dai* fishery catches are already known to be associated with lunar phases (LIENG *ET AL.*, 1995). There is considerable evidence to show that fish caught in the *dai* fishery are from the same populations as those targeted by the *tone* fishery (BAIRD, 1998).

The small cyprinid migrations from the Great Lake to the Mekong River are triggered by lunar cycles. However, it is evident from catch data from the *dai* fishery that hydrological conditions play a significant role in determining when fish migrate. For example, in 1996, when water levels drop slowly, significant amounts of fish were caught in early January, but many more were caught in February and March (N. van Zalinge, pers. comm., 1999). In contrast, in 1999 when water levels dropped their quickest, the bulk of the small cyprinids had migrated past the Tonle Sap River by early January (N. van Zalinge, pers. comm., 1999). Therefore, it is reasonable to believe that the combined effects of lunar and hydrological cycles determine the nature of small cyprinid migrations from the Great Lake.

The most significant findings of our investigations are that small cyprinids, which are of great social and economic importance to local people in southern Laos and other parts of the Mekong River basin, pass at least 400 km, and probably over 1,000 km, between Cambodia, Laos and Thailand. Although lunar phases greatly influence their movements, any significant alterations of the hydrological regime are likely to greatly impact their migration patterns. Moreover, if even one of the ten large dams envisioned for the mainstream Mekong River between the Great Lake in Cambodia and the upper reaches of the Mekong River in Laos and Thailand is built (Mekong Secretariat, 1994), small cyprinid migrations could be totally blocked. This could result in extremely serious impacts to fish populations, the overall ecology of the Mekong River basin, and the millions of small-scale fishers and farmers who depend on fisheries for subsistence and income. Because of the great importance of the Hou Sahong channel for migrating fish (BAIRD *ET AL.*, 2001a; ROBERTS, 1997; BAIRD, 1996; ROBERTS & BAIRD, 1995), it would be a grave mistake to assume that damming that channel would have little impact on migrating fish. That is because other channels in the Khone Falls area are generally impassible by fish, especially in the low-water season (BAIRD *ET AL.*, 2001a; BAIRD, 1996; ROBERTS & BAIRD, 1995).

It is critical that a regional approach to research and fisheries management be developed so as to encourage the long-term maintenance of local fisheries throughout the lower Mekong basin. We need to think regionally while at the same time being sensitive to local conditions along the Mekong River and her tributaries. Striking a suitable balance between regional objectives and local priorities is critical, and remains one of the major future challenges for the peoples of the Mekong River basin. However, governments have often made development decisions that are deleterious to both fish populations and the people who depend on them (IRN, 1999; Fisheries Department, Ratanakiri Province and NTFP Project, 2000). It is our hope that this destructive pattern will not continue to be replicated in the Mekong River basin. We firmly believe that sustainable fisheries, which are irreplaceable resources, must be the ultimate goal, not the sacrifice of fisheries and livelihoods to achieve short-term replaceable resources that do not adequately take the overall picture and welfare of the region and its people into account.

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