FISHERIES BIOECOLOGY AT THE KHONE FALLS (MEKONG RIVER, SOUTHERN LAOS)

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WorldFish
CENTER

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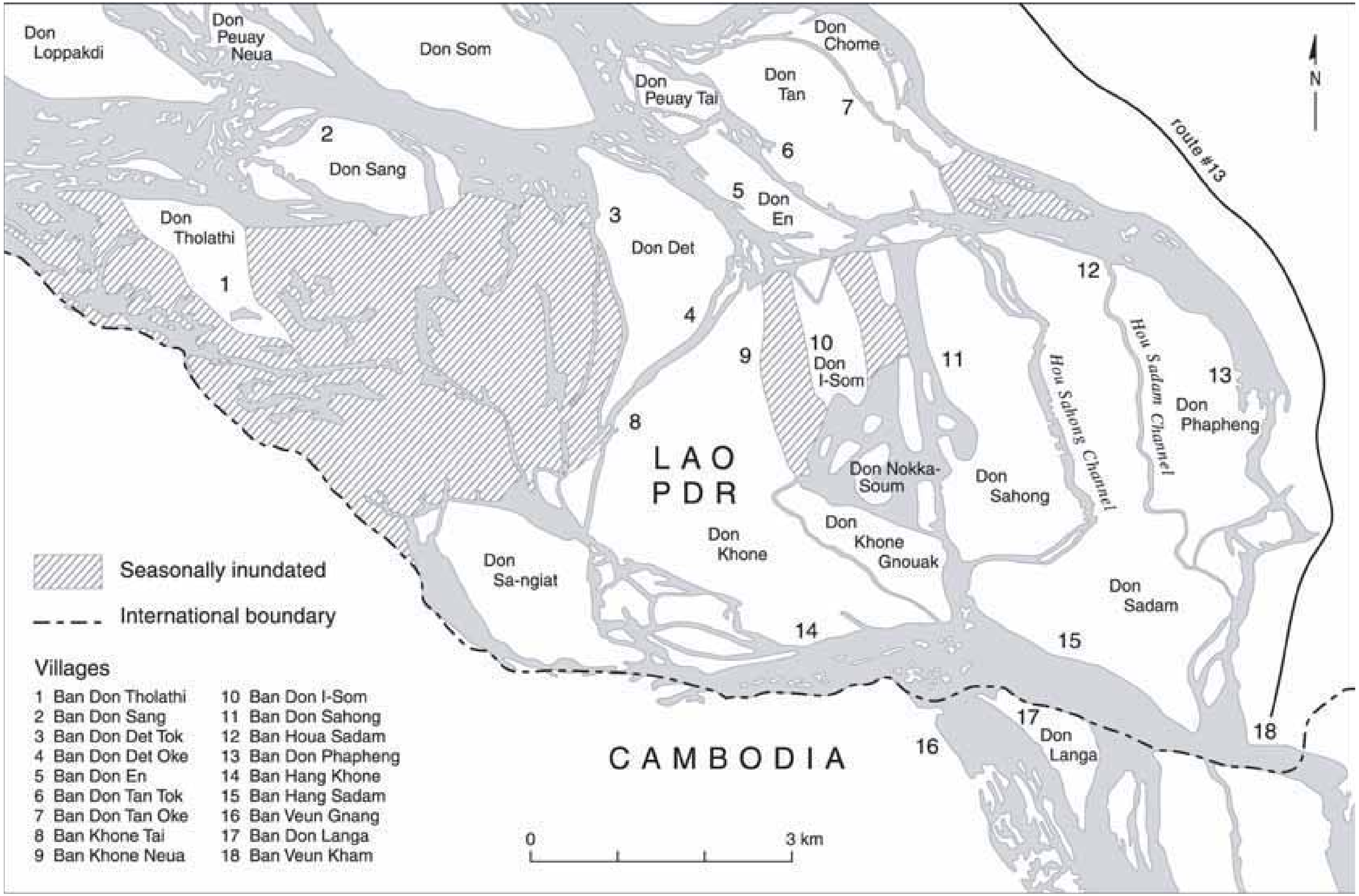

Figure 1: The Khone Falls area, including Hang Khone Village, Southern Laos Map prepared by Ole Heggen, Geography Department, University of Victoria, Canada. This map is a generalized illustration only. The representation of political boundaries is not to be used for reference purposes.

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EXECUTIVE SUMMARY

GENERAL DESCRIPTION OF THE FISHERY

- The database that this report is based upon covers six years of monitoring of artisanal fisheries (over 20 nuclear fishing families) in Hang Sadam and especially Hang Khone villages, just below the Khone Falls in Khong District, Champasak Province, Southern Laos.
- Forty-one fishing methods were monitored. Gill nets with various mesh sizes were the most frequently used gear; they make up to 73% of the number of fishing operations included in the database. A number of categories of gill nets, based on mesh sizes (from 2.5 to 30 cm), were monitored throughout the six years, and seven fishing methods were monitored consecutively for at least five years.
- There are two main peak periods in fishing activity: from November to March (most intense period), and in June. Fishing intensity is the least between August and October. This trend is driven by the frequent utilization of gill nets during these months.
- Four main groups of fishing gears can be identified: gears operating all year long; gears targeting migrating fish at the beginning of the rainy season (June-July); gears operating at the end of the rainy season (October to January) and gears operating in the dry season (January to May).

INTERANNUAL TRENDS: ISSUES AND CONSTRAINTS

Given the very particular context of these fisheries, which target more than one hundred species of fish, some migratory and others more or less sedentary, with a diversity of gears, an analysis of trends in annual overall catches would face multiple constraints and biases. We detail this point through taking the *Probarbus jullieni* fishery as an example, and show that such contexts challenge classical fishery science approaches.

COMPARISON OF CAMBODIAN BAG-NET *(DAI)* FISHERY AND LAO FENCE-FILTER TRAP *(TONE)* FISHERY

It was not possible to draw significant conclusions from an extensive analysis of available data about the correlation between the catch of the *tone* fishery in the Khone Falls area and the *dai* fishery in Cambodia. This was due to a limited number of points (n = 5 years).

ABUNDANCE PATTERNS OF 110 SPECIES

The abundance patterns of 110 fish taxa (i.e. fish identified at the species level or at least at the genus level) in catches have been analysed; they often indicate migration patterns. Three major groups of fish have been identified:

i) species present during the dry season (peak in January), some of them exhibiting a small secondary peak in catches at the beginning of the rainy season (May-June);

ii) species present during two equivalent periods (dry and wet season respectively) or being regularly distributed all year long (no evident migrations); and

iii) species showing a dominant or exclusive abundance at the beginning of the rainy season (May-June).

Among the 110 taxa studied, 90 exhibit strong patterns of sudden abundance in catches. Most of these species are migrating.

MIGRATION TRIGGER OF *PANGASIUS KREMPFI*

The catfish *Pangasius krempfi* provides a clear example of a migration triggered by a water level rise. The migration of this species occurs suddenly at the beginning of the wet season, and lasts in general 40-50 days. There are generally about a dozen days of intense migration peak each year. This points to the likely consequences of building dams that regulate the hydrology of the Mekong River and its tributaries on *P. krempfi* and on other species responding similarly to hydrological triggers.

DOMINANT SPECIES: LIFE HISTORY KEY FACTS, MIGRATIONS AND MIGRATION TRIGGERS

Dominant taxa in catches
There are forty-seven taxa for which at least 50 individuals have been caught on average per year over six years

Length of fish caught
- 61% of dominant taxa caught have a maximal size greater than 25 cm, but
- 85% of fishes actually caught (in terms of biomass) belong to taxa whose maximal size is less than 25 cm. This illustrates the abundance of small species in the catch, despite the diversity of a fish community in which large species are largely represented.

Species migrations
Ninety-six percent of dominant taxa are not present all year long, and thus undertake migrations or become impossible to catch at certain periods of time. This figure highlights the importance of migration behavior among dominant species of the Khone Falls fisheries.

Species, discharge and migration triggers
The highest biodiversity appears in catches for the lowest discharge levels. This underscores the importance of dry season water levels for fish and fishers, as well as that of rising waters at the end of the dry season.
1) at least 55% of taxa are sensitive to discharge among the dominant taxa of the Khone Falls.
2) Ninety six percent of the fish caught (expressed in terms of biomass) are highly sensitive to discharge in the Khone Falls fisheries.
Given this extremely high sensitivity of fishes to discharge and discharge variations, when flows are regularized, a very significant share of the fishery resource will be permanently impacted and might disappear from the catch.

DEEP POOLS AS DRY SEASON REFUGES

Catch-per-unit-effort (CPUE) of the gill nets set in deep-water pools in February and March is three to twelve times higher than CPUE of gill nets used in surface during the same period, and with the same mesh sizes.

Among the 30 dominant species caught during this monitoring, only two showed a preference for surface waters. Ten species showed a clear preference for deep-water pools in the dry season; they consisted of seven siluriforms (catfishes) and three cypriniforms (carps).

The average weights of 18 species caught at least five times in each environment were analysed. For ten species, the individuals caught in deep pools are 27 to 78% larger than those caught near the surface; for two species the individuals caught at the surface are larger than those caught in deep-water pools.

1 INTRODUCTION

This study results from a collaboration between the Global Association for People and the Environment (GAPE), which provided the data and the field knowledge used in this report, and the WorldFish Center (formerly ICLARM), which analysed data and developed an interactive interface for data display.

Figure 2: Indochina, Mekong River Basin and Khone falls

The data were collected as part of the Lao Community Fisheries and Dolphin Protection Project (LCFDPP) and the Environmental Protection and Community Development in Siphandone Wetlands Project (EPCDSWP), with the latter project being implemented by the Italian non-governmental organization CESVI Cooperation and Development, and funded by the European Union. At the WorldFish Center, data analysis and publication result from a project entitled "Conservation of Aquatic Biodiversity / Mekong Initiatives" also funded by the European Union.

In this study, over 20 fishers or fishing families using multiple seasonal gears on the southern end of Khone Island and the adjacent southern

end of Sadam Island (mainstream Mekong River, Southern Lao PDR) were monitored between 1993 and 1999. Both locations are just below the Khone Falls fault line, and just north of the border with Cambodia.

The use of the artisanal fishing gears in the Khone Falls are described, new information about the possible migration patterns of 110 Mekong fish taxa is provided, hydrological triggers of fish migrations are detailed, and the crucial role of deep-water pools in the mainstream Mekong River as refuges for fish in the dry season is demonstrated.

The overall objective of this study is to contribute to biodiversity conservation and the sustainable management of inland fisheries in the Khone Falls, a zone of major ecological and livelihood importance in Laos and in the Mekong River Basin.

2 FISHING GEARS, FISHING OPERATIONS AND FISH CAUGHT

The monitoring of the Khone Falls fisheries started on 4th March 1993, and continued until 30th May 1999. This represents monitoring of six full years and five full seasons of fishing (a fishing season is traditionally considered to start in October). Over 20 fishers and their immediate families were monitored in Hang Sadam Village and especially Hang Khone Village, along with a few others whose catches were only monitored periodically.

During these years:

- Forty-one gears were initially monitored; they were lumped for analyses into 32 categories (due to overlapping mesh sizes among initial gill net categories; Table 1);
- 20,222 fishing operations were analyzed (Table 2 and Figure 3);
- 138 species or taxa were caught;
- 666,000 individual fishes plus many bulk weighed fishes were caught. Overall, the database includes a biomass of 53 metric tons (Table 3).

Table 1: Names of the gears monitored

Lao gear name	Gear description
Bet khen siap mengkhinai	Set hook baited with mole cricket
Bet teuk siap khikadeuan	Pole and line baited with worm
Bet teuk siap koung	Pole and line baited with shrimp
Chan	Falling-door trap
Chap pa kap meu	Fish caught with hands
Chip	Cylindrical current trap
He po	Large meshed cast-net
He soi	Small meshed cast-net
Kha	Branch bundle fish attractant pull basket trap
Lai tao siap mak deua	Floating hook baited with *Ficus sp.* fruit
Lai tao siap mak houn	Floating hook baited with *Crayratia trifolia* fruit
Lan	Upright basket trap baited with bran
Li	Khone Falls wing trap (monsoon season)
Lope gnai	Large funnel basket trap
Lope none	Hang Sadam Village funnel basket trap
Lope tang	Hang Sadam Village standing funnel basket trap
Mong 12-18	Set gill net 12-18 cm
Mong 18-30	Set gill net 18-30 cm
Mong 2.5	Set gill net 2.5-3 cm
Mong 4-9	Set gill net 4-11 cm
Mong yone 12-18	Deep set gill net 12-18 cm
Mong yone 4-9	Deep set gill net 4-9 cm
Phiak siap khikadeuan	Longline baited with worm
Phiak siap mak deua	Longline baited with *Ficus sp.* Fruit
Phiak siap mak houn	Longline baited with *Crayratia trifolia* fruit
Phiak siap mengkhinai	Longline baited with mole cricket
Phiak siap pako	Longline baited with *Gyrinocheilus pennocki* fish
Phiak siap pasoi	Longline baited with cyprinid fish
Souang	Wedge cone trap
Tone	Khone Falls fence filter trap (dry season)
Tone houay	Hang Sadam Village stream fence filter trap
Tone na	Hang Sadam Village rice field fence filter trap

Table 2: Fishermen and their total effort in the database

Fisher code	1	3	4	2	5	10	6	7	8	9
Fishers names	Vilay; Bounpheng; Sounthone; Nouphai (family)	Songma	Sai	Keo	Sout	Bounheng	Mai	Tha	Sit	
# of fishing operations	3556	3196	1975	1871	1408	1329	1236	1011	849	704

Fisher code	13	22	11	15	12	16	23	20	14	17
# of fishing operations	308	261	255	152	102	92	40	36	23	22

Fisher code	18	21	30	24	19	25	26	40	50	0
# of fishing operations	22	20	10	6	5	5	5	5	5	1713

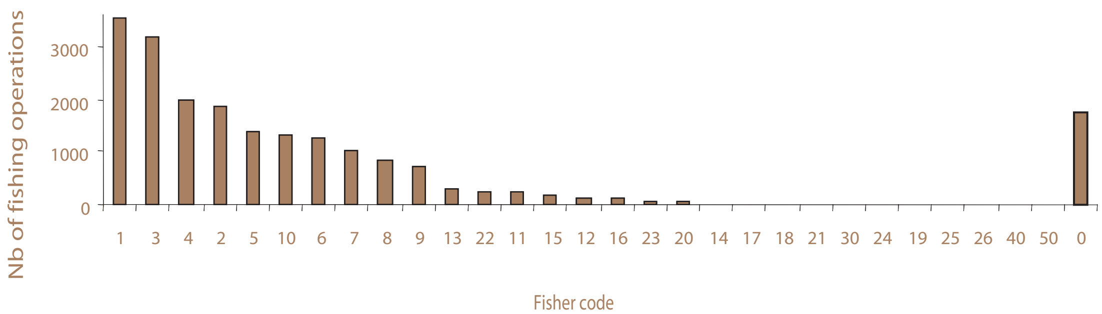


Figure 3: Fishers and their fishing effort during 6 years

Table 3: Abundance and biomass of fish caught

Fishing season		
1992-1993	Number	1846
	Biomass (kg)	9527
1993-1994	Number	15612
	Biomass (kg)	6956
1994-1995	Number	18403
	Biomass (kg)	8358
1995-1996	Number	8393
	Biomass (kg)	9757

Fishing season		
1996-1997	Number	600737
	Biomass (kg)	6668
1997-1998	Number	18640
	Biomass (kg)	6870
1998-1999	Number	3070
	Biomass (kg)	5318
Total Number	666701	
Total biomass (kg)	53455	

Note: In 1992-1993 and 1998-1999, only a fraction of the October-September fishing season was monitored; the fishing seasons fully monitored are highlighted above in italics.

3 TEMPORAL USE OF KHONE FALLS FISHING GEARS

3-1) Annual use of fishing gears

Gill nets were the most frequently sampled fishing gears; they made up to 73% of fishing observations (data and results are detailed in a companion technical report). Three categories of gill nets were mainly used and monitored throughout the six years: gill nets 4-11 cm; gill nets 12-16 cm; gill nets 18-30 cm. However, 2.5-3 cm meshed gill nets gained popularity during the latter years of the study, but were not intensively monitored over a long period, although some observations of catches were recorded.

Thirteen fishing methods have been monitored less than 70 times in seven years (arbitrary value representing less than 0.3% of the total fishing effort). The general use of the fishing gears or methods is illustrated in Figure 4.

It should be noted that these results reflect the gears monitored, and not the exact number of gears operating in the area. For example, 2.5 cm meshed gill nets are underrepresented; only limited numbers of small meshed gill nets were initially used and monitored, but their use by fishers rose dramatically over the course of monitoring, which is not illustrated well by the data.

Tone traps (fence-filter traps operated during the dry season) and *li* traps (wing traps operated during the monsoon season) are also quite underrepresented because, for logistical reasons, i) only one fishing site for each of the two gears was monitored, and ii) fishers who were sampled for other gears were not sampled for their *li* and *tone* traps, even though many had them. Thus *tone* and *li* traps are some of the most important gears in the Khone Falls area, but the data does not reflect this reality well.

Generally, the database is most useful for i) considering certain fisheries by themselves, and over a period of time; and ii) considering the presence and abundance of fish species at certain times of the year.

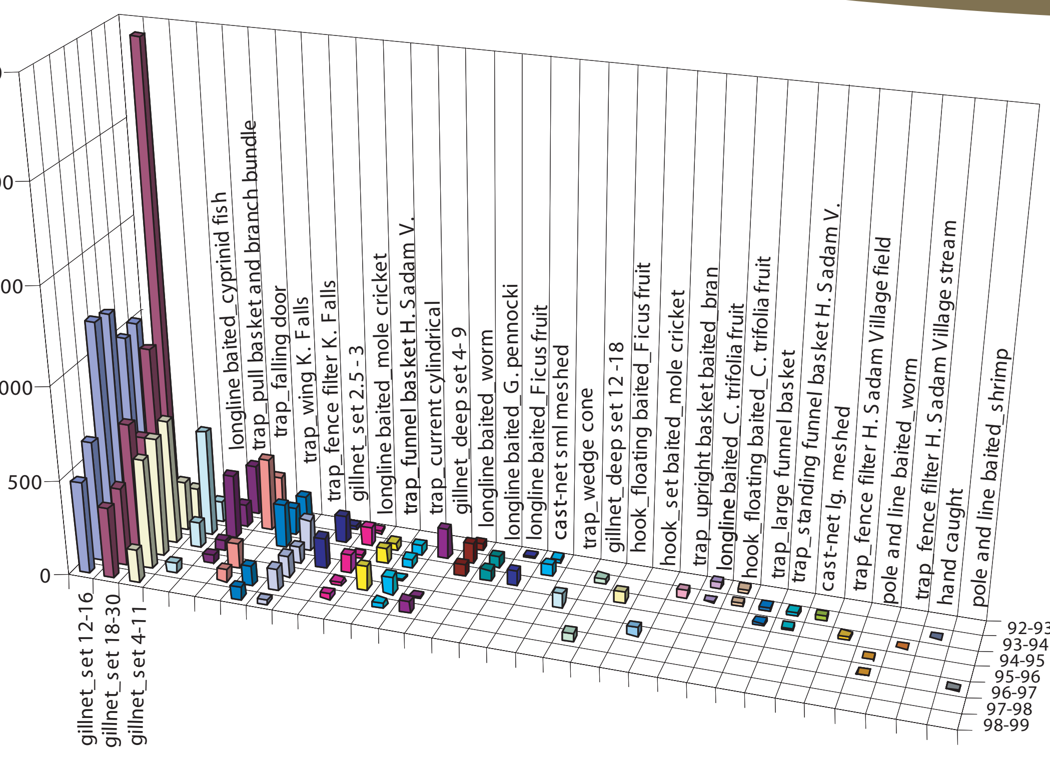


Figure 4: Annual number of operation for each fishing method monitored

3-2) Monthly use of fishing gears

It is not possible, due to sampling biases and other constraints, to use the database to determine the monthly variability in the use of fishing gears. For instance *li* traps are very active in May, but due to logistical constraints, only one set of these traps was monitored. Thus this database results from the monitoring during six years of 21 nuclear fishing families, but is not exactly representative of the overall fishing activity in the area.

In order to give an idea of the seasonal variation of fishing activity in the whole area, we propose below a qualitative estimate based on the extensive field experience of the second author. The monthly intensity of fishing for the 19 gears that represent 99.7% of the total fishing effort has been ranked according to the following scale:

0: gear not used or not set **1:** few gears set or little catch

2: moderate fishing **3:** intense fishing

The result is given in Table 4 and the global temporal pattern in Figure 5.

Table 4: Relative intensity of fishing per gear and per month at Ban Hang Khone

0: gear not used or not set 1: few gears set or little catch
2: moderate fishing 3: intense fishing

Gear name	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Gill net_set 12-16	1	2	2	2	1	1	1	3	3	2	1	1
Gill net_set 18-30	1	3	3	2	1	1	1	2	2	1	1	1
Gill net_set 4-11	1	2	3	3	2	2	1	1	2	1	1	1
Longline baited_cyprinid fish	0	1	0	2	2	2	1	1	3	3	1	0
Trap_pull basket and branch bundle	0	0	0	0	0	0	0	0	3	3	1	0
Trap_falling door	2	3	2	1	0	0	0	0	0	1	1	2
Trap_wing K. Falls	0	0	0	0	0	0	1	3	3	2	0	0
Trap_fence filter K. Falls	0	0	1	3	3	1	1	0	0	0	0	0
Gill net_set 2.5-3	1	1	1	3	2	2	2	3	2	1	1	1
Longline baited_mole cricket	2	3	2	0	0	0	0	0	0	1	1	1
Trap_funnel basket H. Sadam V.	1	3	3	1	0	0	0	0	0	0	1	1
Trap_current cylindrical	0	2	3	1	0	0	0	0	0	0	0	0
Gill net_deep set 4-9	0	0	0	1	2	3	2	0	0	0	0	0
long line baited_worm	2	3	1	1	1	0	0	0	1	1	1	1
long line baited_G. pennocki	0	0	0	1	2	3	3	1	0	0	0	0
long line baited_Ficus fruit	0	0	0	1	3	3	2	1	0	0	0	1
cast net sm. Meshed	1	1	1	2	3	3	3	2	1	1	1	1
Trap_wedge cone	0	1	3	1	0	0	0	0	0	0	0	0
Gill net_deep set 12-18	0	0	1	1	3	3	1	0	0	0	0	0

Overall, the months with the most intense fishing are November to March, whereas August to September is the period with the least fishing effort and catches.

Among the gears, four main groups of fishing gears can be identified (Figure 6):

- Gears operated mostly at the beginning of the dry season, between October and January; these gears are longlines baited with mole cricket; Hang Sadam Village funnel basket traps; cylindrical current traps; falling-door traps; and wedge cone traps;

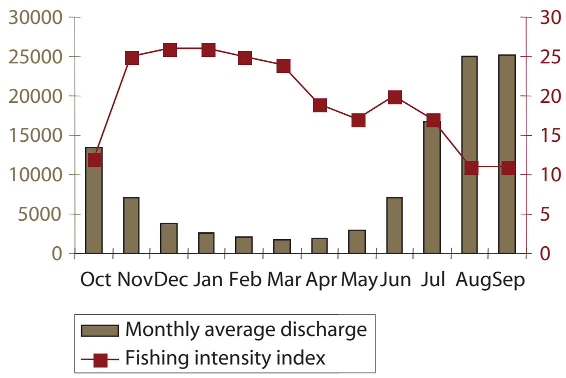


Figure 5: Monthly average intensity of fishing and discharge in Khone Falls area

- Gears targeting migrating fish in June and July (in particular, Khone Falls wing traps and branch bundle fish attractant pull basket traps);
- Gears operating all year long; these gears are gill nets of various sizes; and long lines baited with Cyprinid fish and cast nets;
- Gears operating in the dry season, mostly from January to May; these are Khone Falls fence- filter traps, deep-water gill nets; and long lines baited with *Ficus* fruit or *Gyrinocheilus pennocki* fish.

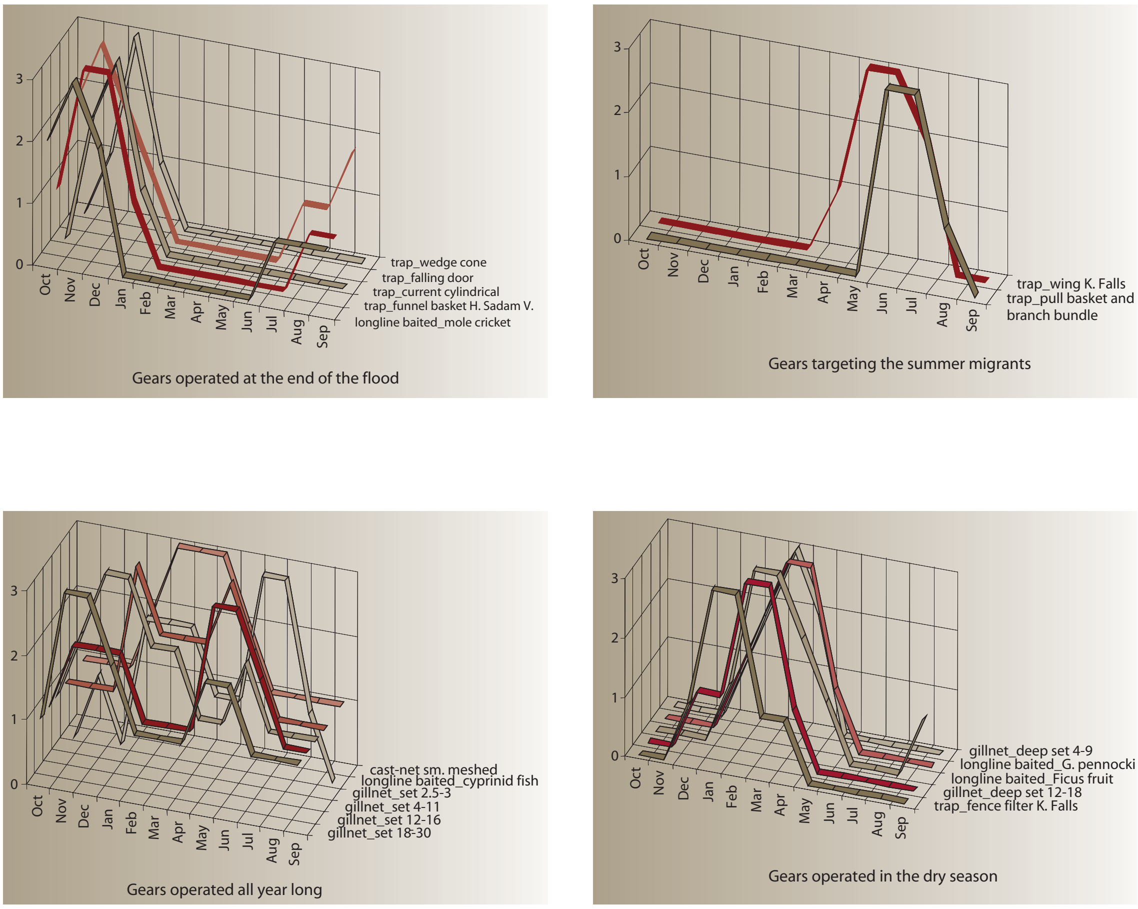


Figure 6: Khone Falls main fishing gears and their use in time

4 INTERANNUAL TRENDS: ISSUES AND CONSTRAINTS

4-1) Interannual trends in overall catches

Given the availability of catch data over six years, it is tempting to study the interannual variation of fish catches at the Khone Falls. However, analysing trends in overall catches over several years by lumping the catches of all gears would not be relevant for several reasons:

1) A good (hydrological) year for species A can be a bad one for species B, and given the species diversity in the fishery (138 species caught), lumping them all together would only blur the specific trends.

2) The annual abundance of some fish species is heavily influenced by the hydrological regime during the same year (e.g. small opportunists like *Henicorhynchus* spp.; Deap Loeung 1999, Baran *et al*. 2001a), while that of long-lived species (e.g. large catfishes) is buffered over several years. The abundance of such long-lived fishes seems to be declining, while changes in the catches of small opportunists are less evident (Van Zalinge & Nao Thouk 1999, Sverdrup-Jensen 2002, Baird 2005d). Therefore, the response of catches to environmental factors over six years might be blurred by changes in the structure of fish communities due to fishing itself.

3) Following previous remarks, interannual trends in abundance should be analysed for coherent groups of fish only (e.g. black/white fishes at least).

4) Given i) the very high selectivity of the different fishing gears; ii) the specific choice of fishing methods depending on the hydrology and on the corresponding migrating species, and iii) the shift from one target species to another for one given gear at different times of the year. Thus, lumping all gears together would certainly blur the detailed trends, as shown in Figure 7:

5) Comparisons between years should, as pointed out above, be done on the basis of a standardized effort; however standardization (i.e. calculations based on the smallest temporal sequence is common) might force the removal of some months/weeks during which migration peaks occur. Fish abundance and catches during peak periods can be 100 times as much as catches during other weeks/months. Therefore, such standardization would create a major bias.

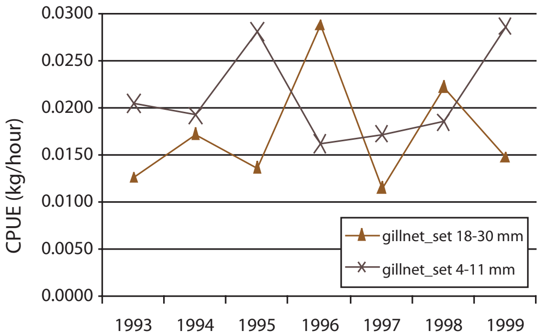


Figure 7: Interannual trends in CPUE for 2 types of gears

6) A quick overview of overall yearly trends (not detailed here) is not consistent with what fishers say about "good" and "bad" years. Fishers, for instance, mightconsider that a year is "good" when catches of a high-valued species like Probarbus are good, while catching the same biomass of small low value fish, such as *Henicorhynchus*, might not indicate "a good year".

Incidentally, these arguments outline the need for an in-depth and systematic analysis of the Khone Falls fisheries at the species level.

4-2) Interannual trends in catches of a migrating species

In the case of fisheries targeting migratory river species, classical approaches in fisheries science might be irrelevant due to very specific constraints and biases inherent to flooding rivers. The *Probarbus jullieni* fishery provides an example of such inadequacies.

Figure 8: *Probarbus jullieni*

Probarbus jullieni is a large Cyprinid found in the mainstreams of a number of large rivers in mainland Southeast Asia. In the Mekong River, it is believed to undertake short migrations (Singhanouvong *et al.* 1996a, Baird 2005d), although it has also been reported by some to conduct longer migrations (Pantulu 1986, Poulsen and Valbo-Jørgensen 2000). Observations of the species have resulted in the hypothesis that it might consist in a series discrete stocks that undertake migrations over relatively short distances (MFD 2002).

This excellent tasting and high-priced food fish can reach 150 cm and is mainly caught in large-meshed gill nets during its spawning season. Formerly abundant, it has been subject to serious long-term decline throughout its range and is now classified as endangered by IUCN (Baird 2005d). Its ecology and fishery has been extensively described in Baird (2005d). FishBase should also be consulted for details regarding this species (www.fishbase.org).

The database indicates the daily total catches of *P. jullieni* during six years at Hang Khone (Figure 9):

The data exhibit clear seasonal patterns, with sudden high abundance levels beginning in November-December every year. Over a period of years, data availability raises the following question: what is the long-term trend in catches of *Probarbus jullieni*? In other words, can a decline be identified in the catches of this endangered species?

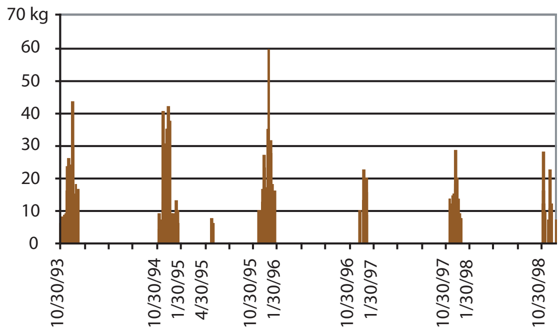


Figure 9: temporal pattern of *Probarbus jullieni* catches

Standard as well as revised fishery science approaches (e.g. Holden and Raitt 1974, Caddy and Mahon 1995) would support standardizing these data and expressing them in terms of CPUE levels prior to making interannual comparisons. In the case of gill nets, CPUE is expressed in terms of kilograms of fish per hour per square meter of net, or, if the surface area is not exactly known, in terms of kilograms of fish per hours of fishing with a standard net.

Before addressing the above issue, we examined data at a smaller time scale, on a daily basis, and it became apparent that fishing seasons significantly vary in terms of their beginnings, ends and durations, even when daily catches remain in the same range (Figure 10; details of data for the 1997-1998 and 1998-1999 fishing seasons).

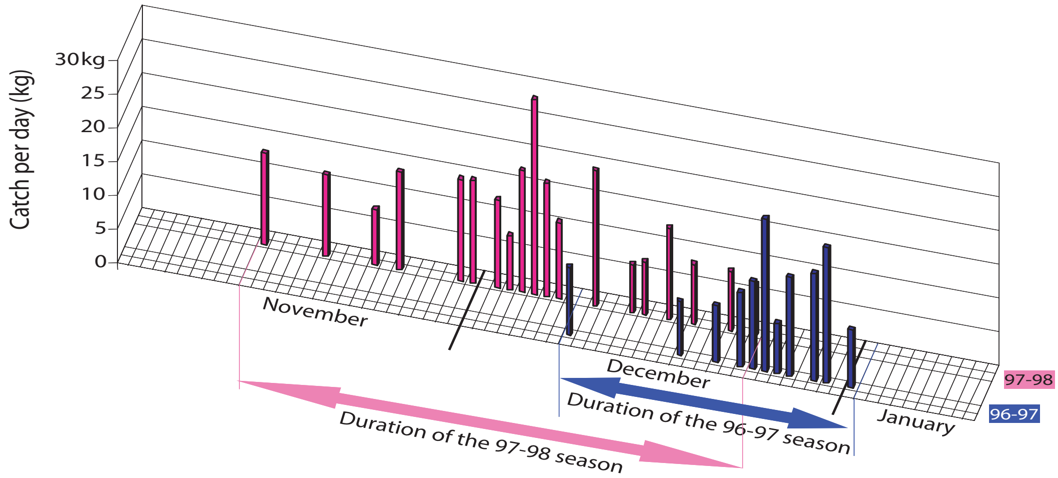


Figure 10: Comparison of 2 fishing seasons of *Probarbus jullieni*

The standardized comparison of CPUEs between 97-98 and 98-99 is included in Table 5. We have also integrated the number of days of catches (starting from the first day when Probarbus jullieni is caught in the season, to the last day).

Table 5: Catch of *Probarbus jullieni*, corresponding effort and CPUE

Season		93-94	94-95	95-96	96-97	97-98	98-99
A	Total catches (kg)	509.21	552.65	552	139.3	247.8	154.3
B	Total effort (hours of net)	1476	3420	1728	612	1392	672
A/B	CPUE (kg/hour of net)	0.345	0.162	0.319	0.228	0.178	0.230
C	Nb of days of peak abundance	65	74	61	24	40	48
(A/B)xC	CPUE integrating peak abundance duration	22.4	12.0	19.5	5.5	7.1	11.0

The conclusions are that:

1) Standard CPUE analysis leads to the conclusion that fish were scarcer in 97-98 than in 96-97, as less fish were caught per hour of fishing.

2) The fishing period was much shorter in 96-97 than in 97-98. During years with long fishing seasons, fish can be caught at the same rate (i.e. same CPUE) but over a longer period of time, which results in larger catches overall.

3) Fishes were available much longer in 97-98 than in 96-97, and therefore overall catches were greater in 97-98. This illustrates a higher abundance of *Probarbus jullieni* in 97-98 than in 96-97.

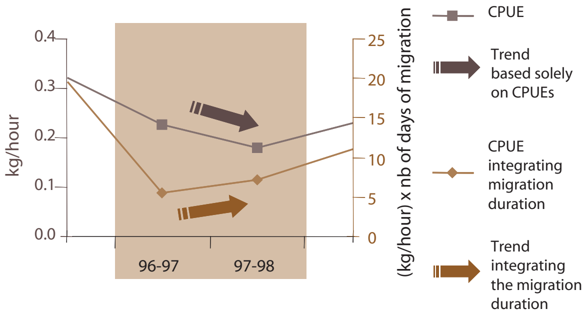


Figure 11: Interannual trends as concluded from 2 different approaches

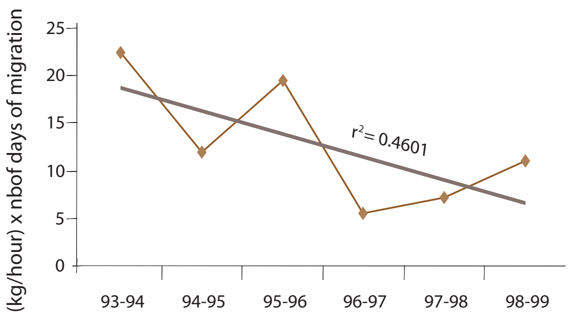


Figure 12: Interannual trend in the catch of *Probarbus jullieni* in Khone Falls

4) Conclusions drawn from standard CPUE analysis contradict conclusions that integrate peak catch duration data (Figure 11). However when tested versus facts (points 2 and 3 above), the approach based solely on CPUE is proven to be irrelevant, at least in this particular case

5) A possible way to partially overcome this problem is to multiply the CPUE by the number of days of fishing. This is possible under the assumption that fishers are skilled, and that they set their nets in space and time in a way that maximizes catches. This is the case of the Khone Falls fishers, who are particularly knowledgeable about the behavior of fishes (Roberts and Baird 1995, Baird *et al.* 1999a, Baird 2005a).

Thus the interannual trends in catches for the *Probarbus jullieni* fishery are illustrated in Table 5 and in Figure 12. These six years of monitoring show that the variability in catches is high. Despite the claims of fishers who probably focus on biomass caught, with less knowledge or consideration of variability in fishing effort, the data indicate that there was a decline in the catches of *P. jullieni* over time, but this trend is not very significant, with a regression coefficient of only 0.46.

An important lesson from this analysis is that in terms of ecology and interannual trends, a standardized analysis focusing on CPUEs only leads to erroneous conclusions. Conversely an analysis focusing on biomass only would also be biased, as illustrated below.

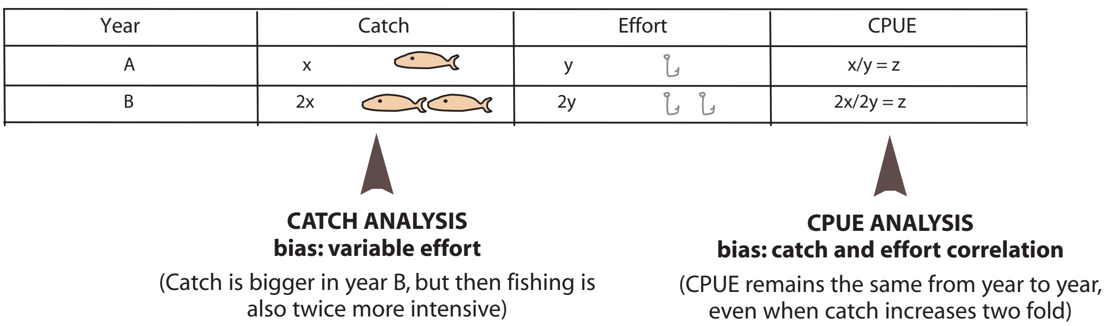


Figure 13: Possible biases in the analysis of interannual trends for migrant species

In the case of migrating river fishes harvested over a limited period of time every year, an assessment of production from year to year should result from a tri-dimensional approach encompassing CPUE, but also biomass and duration of the fishing season (Figure 14). In addition, as indicated by Baird (2005d), socio-economic issues must also be considered. For example, gill nets used in the later years of the study were generally older and less efficient than in earlier years. This was because the fishery was believed to be in decline, and fishers were less willing or able to invest in new gill nets in the latter years. There were also reportedly more filamentous algae in the water in later years, reducing the efficiency of individual gill nets. Also, due to increased gill net theft, fishers were less willing to leave gill nets in the water during marginal fishing periods in the latter years as compared to the earlier years of the study.

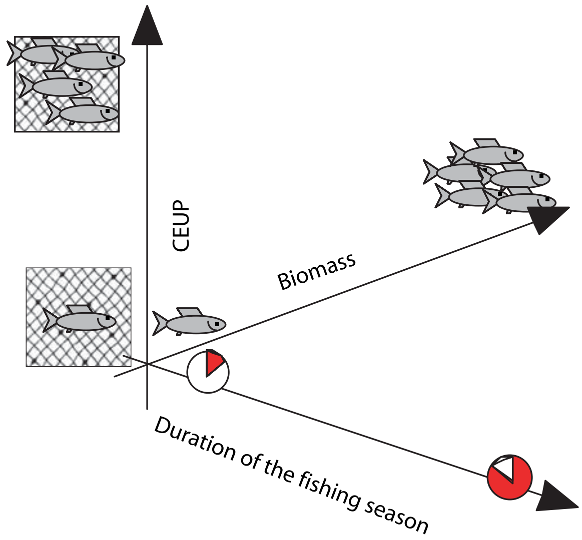


Figure 14: Parameters of importance in the monitoring of migrating species production

5 RELATIONSHIP BETWEEN A LAO AND A CAMBODIAN FISHERY

COMPARISON OF THE FENCE - FILTER TRAP (*TONE*) AND BAG-NET (*DAI*) FISHERIES

The *tone* (or fence-filter trap) fishery in Hang Khone Village consists of a variety of different types of weirs and basket traps set in and around the Khone Falls area, the only part of the lower mainstream Mekong River where the geography allows for the use of these traps. The fishery operates from December to March, with peaks strongly associated with new moon periods (Baird *et al*. 2003). The species that are dominant in catches are all small highly migratory Cyprinids such as *Henicorhynchus lobatus*[1], and *Paralaubuca typus* (51 and 33% of catches respectively; Baird *et al.* (2003). This fishery was monitored during five seasons from 94-95 to 98-99 and is extensively described in Roberts and Baird (1995), Baird (1998) and especially in Baird *et al.* (2003).

The *dai* (or bag-net) fishery in the Tonle Sap River (Cambodia) operates from October to March; it mainly targets small migrating Cyprinids such as *Henicorhynchus* spp. and *Paralaubuca typus* (37 and 12% respectively).

This fishery has been monitored from 94-95 up to now and is described in Lieng *et al*. (1995), Deap Loeung (1999), Hap Navy and Ngor Peng Bun (2000), Ngor Peng Bun and Hem Chanthoeun (2000), and Baran *et al.* (2001). The catches of the *dai* fishery in Cambodia and the *tone* fishery in the Khone Falls area in Southern Laos were compared by Baird *et al.* (2003).

---

[1] *Henicorhynchus lobatus* (Smith 1945) is referenced as *Cirrhinus lobatus* (Smith 1945) in FishBase 2004, based on Roberts (1997).

The difference of scale between these two fisheries is important:

- Limited unit size in Laos, large gear in Cambodia.
- Annual average yields of about 3 tonnes per year for one fishing gear in Laos, and about 200 tonnes per gear in Cambodia.
- 1 unit monitored in Laos (of about 200 in use throughout the Khone Falls area), 63 units monitored in Cambodia (all the units in use).

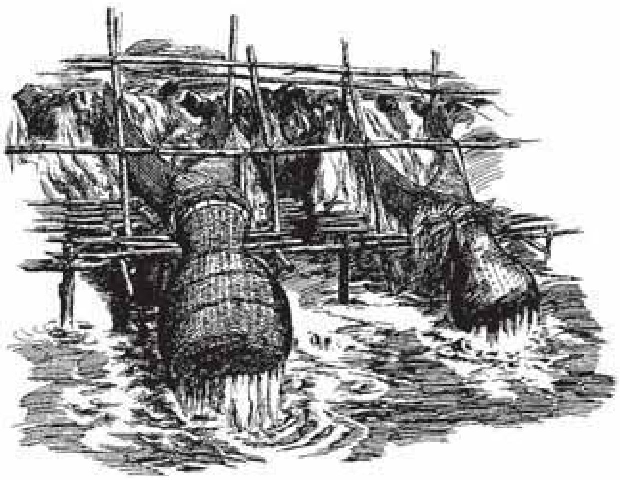

Drawing from Claridge et al. 1997

Figure 15: *"Tone"* fishing gear.

Despite their difference in scale, these two fisheries are very similar in nature, as they both target the same species at around the same time of the year. Baird *et al.* (2003) reported that both fisheries probably target many of the same fish, with those fish taking about 20 days on average tomigrate upstream from where they are targeted by the dai fishery to where they are targeted by the tone fishery *Henicorhynchus* spp. and *Paralaubuca typus*, the two dominant taxa in the catches of both fisheries, migrate between October and March from the Tonle Sap Great Lake (through the Tonle Sap River where the dai fishery operates) to the Khone Falls, where the tone fishery operates. When the water recedes in the Tonle Sap, *Henicorhynchus* spp. migrate down to the Mekong (Lieng *et al*. 1995) and from October to February the fish continue their journey up the Mekong, past the Khone Falls (Baird *et al*. 2003; Poulsen and Valbo-Jørgensen 2000).

(Photo E. Baran)

Figure 16: One *dai* unit in the Tonle Sap River

Lao fishers operating the *tone* fishery believe that at this time of year a good fishing season in Cambodia corresponds (in relative terms) to a poor fishing season in Laos. They also believe that catches of the *tone* fishery in Laos reached historical record highs in 1975-1979, when the Khmer Rouge interrupted large-scale fishing operations. These claims have never been substantiated, and call for a more detailed comparison of the two fisheries. Baird *et al*. (2003) show that between 1995 and 1999 good *dai* fishing years tend to result in relatively poor catches in the *tone* fishery, but there are not enough years of data to significantly represent this negative correlation statistically.

An extensive analysis of available data has been undertaken by the authors in order to determine if the tone fishery catches were positively or negatively correlated to those of the dai fishery and to the hydrological level in each zone. However, the limited number of points (n = 5 years) led to contradictory or spurious correlations (e.g. catch of year y with water level of year y+1). Subsequently, it was impossible to provide, based on existing monitoring data, clear-cut conclusions about the relationship between the two fisheries.

In both cases, catches are dominated by *Henicorhynchus* spp. and *Paralaubuca typus* (between 50 and 80%), whose similar migrating behavior is well known; however 30 to 50% of catches are due to other species exhibiting various migratory patterns (see section on migrations), and these species might blur a trend noticed by fishers, and due to only a few species. It is therefore recommended that, beyond the scope of this exploratory report, comparisons between *tone* and *dai* fisheries should be deepened at the species level. The following section standardizes taxonomic categories for such an analysis.

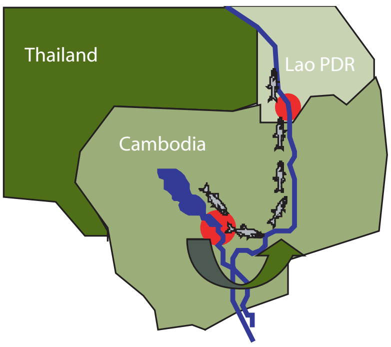


Figure 17: October-March migrations of dominant species caught in Tone and Dai fisheries

The analysis of the *tone* and *dai* data sets highlighted several discrepancies between the fish taxonomy used in Southern Laos and in Cambodia. The intricacies of the taxonomy of Mekong fishes have already been pointed out elsewhere (Rainboth 1996, MRC Mekong Fish Database), and the resulting confusions have been highlighted (Baird *et al*. 1999a, Baran *et al*. 2001b, Baran and Chheng 2003).

In view of a detailed comparison of catches in the two fisheries for which different Latin names were used, it was necessary to adopt a common taxonomic system, detailed in Table 6.

Table 6: Taxonomic standardization for species caught in *dai* and *tone* fisheries

Latin name (dai fishery database)	Lumped Latin name (Khone Falls fisheries database)	Latin name used	Reason
Acantopsis sp.	*Acantopsis* sp. or spp.	*Acantopsis* sp.	Species unknown OR uncertain identification
Achiroides leucorhynchos	*Achiroides* spp.	*Achiroides* spp.	Uncertain identification (2 close species)
Barbichthys thynnoides	*Thynnichthys thynnoides*	*Thynnichthys thynnoides*	*Barbichthys thynnoides* does not exist
Barbodes gonionotus	*Hypsibarbus lagleri/ Hypsibarbus wetmorei*	*Barbodes/Hypsibarbus* sp. or spp.	Dispute over identification
Botia sp.	*Botia modesta/Botia* spp	*Botia* spp.	Several possible species
Cyclocheilichthys spp. (non *enoplos*)	*Cyclocheilichthys spp.* non *enoplos*	*Cyclocheilichthys* spp. non *enoplos*	
Henicorhynchus siamensis	*Henicorhychus lobatus, H. siamensis and H. lineatus*	*Henicorhynchus* spp.	Lumping of closely related species
Morulius chrysophekadion	*Morulius chryso-phekadion*/spp.	*Labeo chrysophekadion*/spp.	Valid name (reference FishBase 2004)
Mystus nemurus	*Hemibagrus nemurus*	*Hemibagrus nemurus*	*H. nemurus* = valid name (reference FishBase 2004)
Mystus spp.	*Hemibagrus wycki/wyckioides/* + *Mystus multiradius/ mysticetus/ singaringan*/spp.	*Mystus* spp. non *nemurus*	Lumping of closely related species, except *H. nemurus*
Pangasius hypophthalmus/sp.	*Pangasianodon hypophthalmus*	*Pangasius hypophthalmus*	Pangasius = valid genus (reference FishBase 2004)
Parambassis wolffi	*Parambassis wolffi*/spp.	*Parambassis* spp.	
Polynemus multifilis	*Polynemus longipectoralis* (valid name = *P. dubius*)	*Polynemus* sp.	Dispute over identification
Probarbus jullieni	*Probarbus jullieni/ labeamajor*	*Probarbus* spp.	Lumping of two closely related species
Puntioplites proctozysron	*Puntioplites falcifer*	*Puntioplites* spp.	Dispute over identification
Xenentodon sp./ *Dermogenys* sp.	*Xenentodon cancila*	*Xenentodon cancila*	*Dermogenys (pusilla,* only species) is too small to be caught

6 TEMPORAL ABUNDANCE PATTERNS OF 110 FISH TAXA

Several authors have described the migration patterns of Mekong fishes (review in Baran *et al*. 2001b). In the past few years a considerable amount of progress has been made in the knowledge of Mekong River fish migrations. Among the most comprehensive publications on regional migrations are those of Poulsen and Valbo-Jørgensen (2000), Bao *et al*. (2001) and MRC (2001), all based at least partially on fishers' knowledge. In Cambodia, recent insights provided by Srun Phallavan and Ngor Peng Bun (2000), Chhuon Kim Chhea (2000), Chanh Sokheng (2000); Chanh Sokheng *et al*. (2000) and Heng Kong (2002) have been useful, and in Laos, Baird *et al*. (1999a), Baird and Flaherty (2005) and Baird (2005a) have relied heavily on local knowledge provided by fishers.

In Southern Laos, Singhanouvong *et al*. (1996a and b), Warren *et al*. (1998), Baird *et al*. (2001a, 2003, 2004), Hogan *et al*. (2004) and Baird and Flaherty (2004) have also detailed the migration patterns of small Cyprinidae carps and Pangasiidae catfishes based mainly on quantitative field data.

Here, we detail the seasonal appearance of fishes in catches for 110 taxa in Southern Laos, on the basis of Khone Falls fishery monitoring over six years. So far, 201 fish species, including 196 native species, have been recorded from the mainstream Mekong River just below the Khone Falls, but not all of those are important in fisheries (Baird 2001).

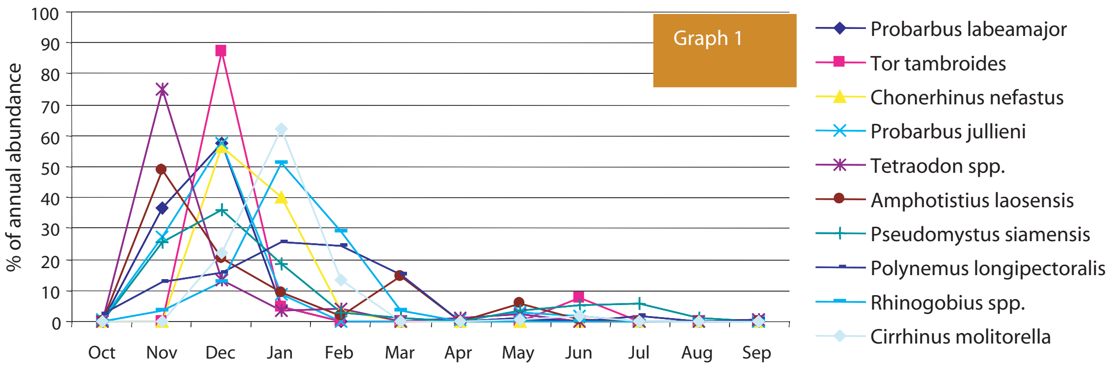
The analysis is based on the relative monthly abundance of species in catches; thus for each month, the fraction or percentage of the total annual catches for a given species is provided.

All fishing methods are indistinctly lumped, as this is considered to be a comprehensive multi-gear migration survey covering a diversity of species, of gear selectivity, and of hydrological fishing conditions (six annual cycles, 32 distinct fishing gears sampled; 666,000 fish caught). Analysis is performed on raw biomasses, as gears are generally chosen by fishers to be as efficient as possible, which implicitly follows at best the abundance of fish in the river. Analysis of CPUE data is not

possible i) because the diversity of gears, which were not all monitored consistently each year; and ii) because of the biases detailed in section 3-2-1).

The appearance of fish in catches often implies migratory behavior. Here, migrations are understood to constitute any kind of long-distance or short-distance systematic movement by a population of fish. The Khone Falls fisheries are dependent on both, as even fish migrating over short distances at certain times of the year become more easily catchable then (e.g. *Probarbus jullieni*, *Boesemania microlepis*, Baird *et al*. 2001b; Baird 2005d). Formally speaking, this study only reflects the abundance variation in Khone Falls catches, and is not a study of fish migrations between different locations. However, the studies cited above have largely demonstrated that migrations are a major feature of Mekong fishes, and field experience (e.g. Roberts and Baird 1995; Baird *et al*. 2003; 2004) confirms that the Khong fisheries are principally based on fish migratory behavior. In any case, the inference from site-specific catches to migrations is appropriate for most species.

Figure 18 and its 11 graphs detail the temporal distribution of fish species in the Khone Falls fisheries. For improved readability, species have been ordered in groups of ten following their scores in a Correspondence Analysis. Interactive distribution analyses for individual species can be performed on the CD-ROM companion to this document.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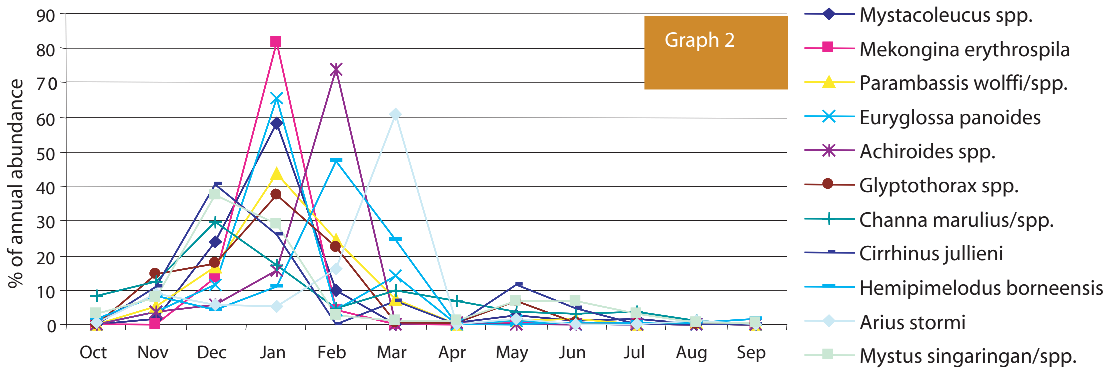
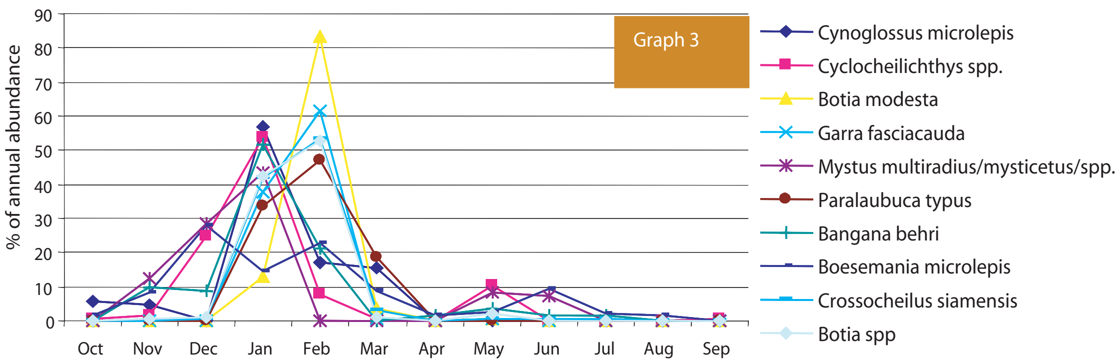
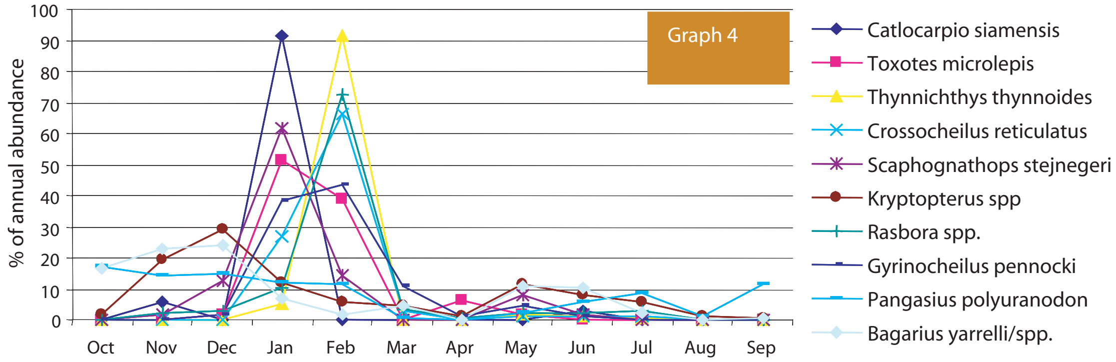
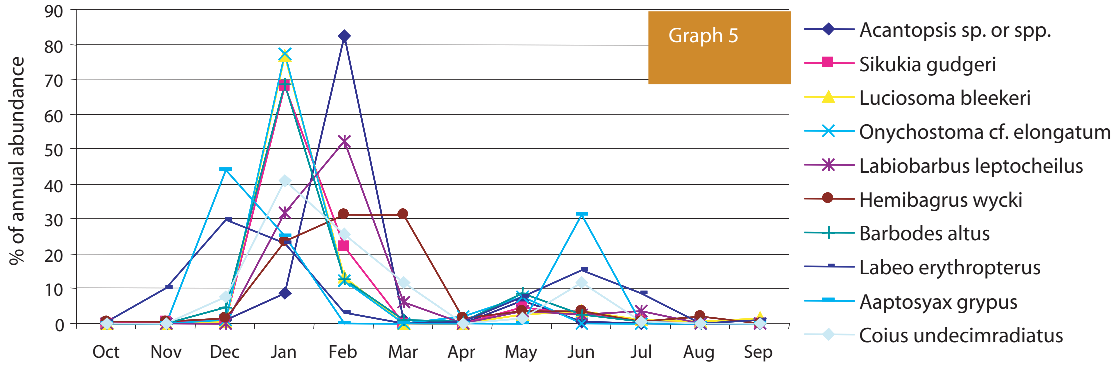
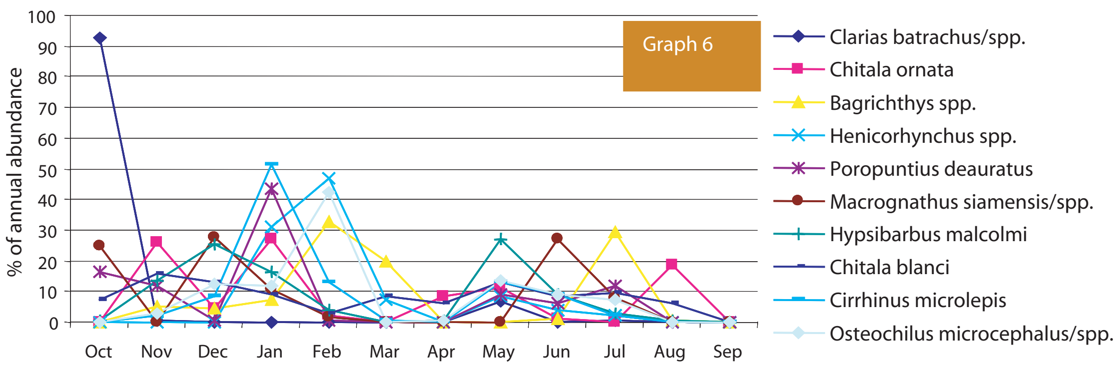
% of annual abundance
100
90
80
70
60
50
40
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Probarbus labeamajor
Tor tambroides
Chonerhinus nefastus
Probarbus jullieni
Tetraodon spp.
Amphotistius laosensis
Pseudomystus siamensis
Polynemus longipectoralis
Rhinogobius spp.
Cirrhinus molitorella

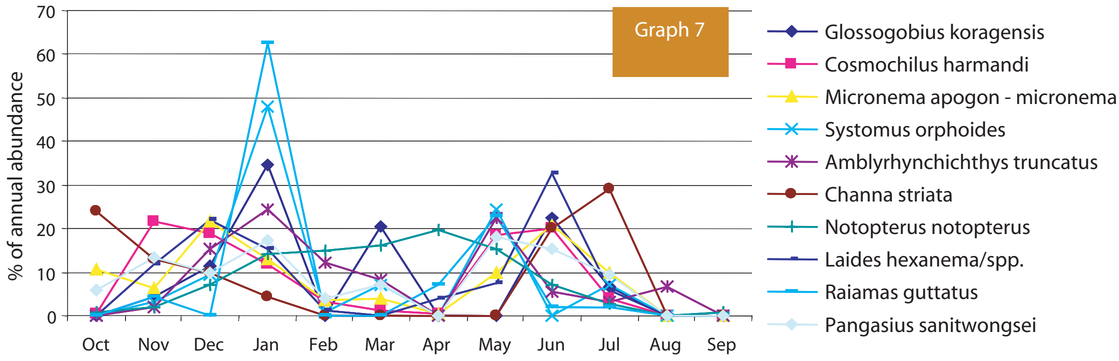

Graph 2
% of annual abundance
90
80
70
60
50
40
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Mystacoleucus spp.
Mekongina erythrospila
Parambassis wolffi/spp.
Euryglossa panoides
Achiroides spp.
Glyptothorax spp.
Channa marulius/spp.
Cirrhinus jullieni
Hemipimelodus borneensis
Arius stormi
Mystus singaringan/spp.

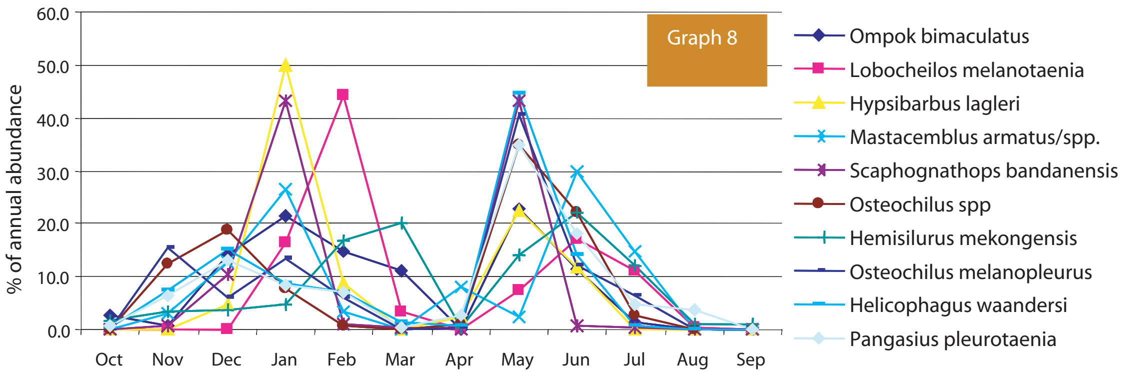

Graph 3
% of annual abundance
90
80
70
60
50
40
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Cynoglossus microlepis
Cyclocheilichthys spp.
Botia modesta
Garra fasciacauda
Mystus multiradius/mysticetus/spp.
Paralaubuca typus
Bangana behri
Boesemania microlepis
Crossocheilus siamensis
Botia spp

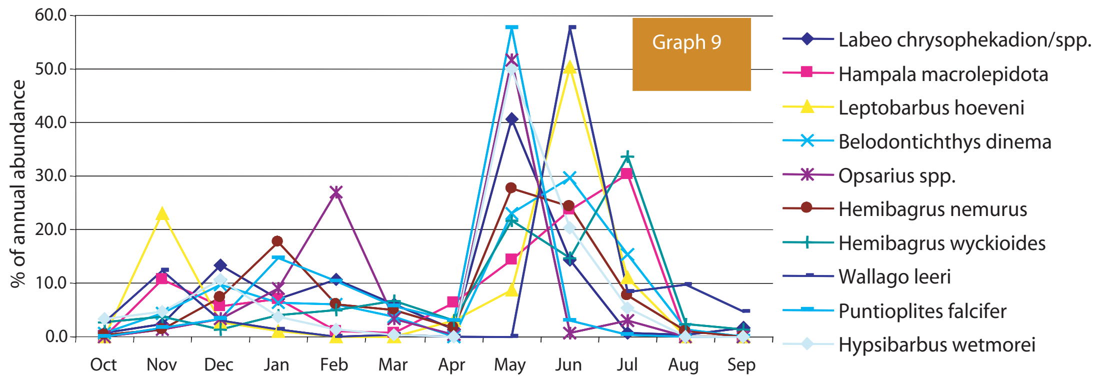

Graph 4
% of annual abundance
100
90
80
70
60
50
40
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Catlocarpio siamensis
Toxotes microlepis
Thynnichthys thynnoides
Crossocheilus reticulatus
Scaphognathops stejnegeri
Kryptopterus spp
Rasbora spp.
Gyrinocheilus pennocki
Pangasius polyuranodon
Bagarius yarrelli/spp.

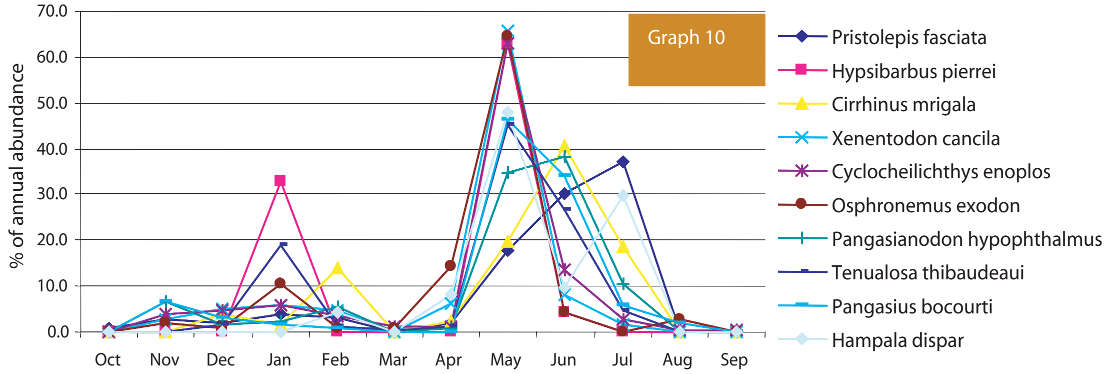

Graph 5
% of annual abundance
90
80
70
60
50
40
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Acantopsis sp. or spp.
Sikukia gudgeri
Luciosoma bleekeri
Onychostoma cf. elongatum
Labiobarbus leptocheilus
Hemibagrus wycki
Barbodes altus
Labeo erythropterus
Aaptosyax grypus
Coius undecimradiatus


Graph 6
% of annual abundance
100
90
80
70
60
50
40
30
20
10
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Clarias batrachus/spp.
Chitala ornata
Bagrichthys spp.
Henicorhynchus spp.
Poropuntius deauratus
Macrognathus siamensis/spp.
Hypsibarbus malcolmi
Chitala blanci
Cirrhinus microlepis
Osteochilus microcephalus/spp.


Graph 7
% of annual abundance
0
10
20
30
40
50
60
70
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Glossogobius koragensis
Cosmochilus harmandi
Micronema apogon - micronema
Systomus orphoides
Amblyrhynchichthys truncatus
Channa striata
Notopterus notopterus
Laides hexanema/spp.
Raiamas guttatus
Pangasius sanitwongsei


Graph 8
% of annual abundance
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Ompok bimaculatus
Lobocheilos melanotaenia
Hypsibarbus lagleri
Mastacemblus armatus/spp.
Scaphognathops bandanensis
Osteochilus spp
Hemisilurus mekongensis
Osteochilus melanopleurus
Helicophagus waandersi
Pangasius pleurotaenia


Graph 9
% of annual abundance
0.0
10.0
20.0
30.0
40.0
50.0
60.0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Labeo chrysophekadion/spp.
Hampala macrolepidota
Leptobarbus hoeveni
Belodontichthys dinema
Opsarius spp.
Hemibagrus nemurus
Hemibagrus wyckioides
Wallago leeri
Puntioplites falcifer
Hypsibarbus wetmorei



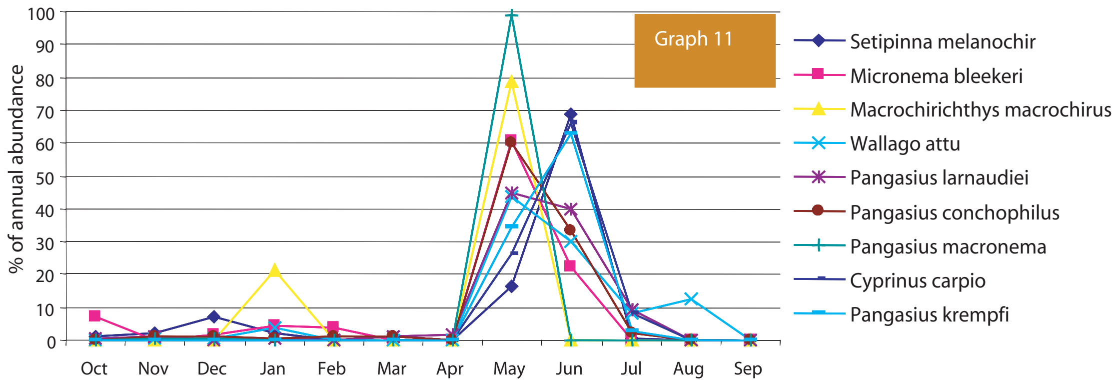


Figure 18: Temporal distribution of fish species in the Khone Falls fisheries

Conclusions:

Four clear patterns can be isolated:

Graph 1: precocious species arriving at the beginning of the new hydrological year (Oct-Nov).

Probarbus labeamajor, Tor tambroides, Chonerhinus nefastus, Probarbus jullieni, Tetraodon spp., Amphotistius laosensis, Pseudomystus siamensis, Polynemus longipectoralis, Rhinogobius spp., Cirrhinus molitorella.

Graph 2 to 5: having a dominant presence during the dry season (peak in January); with some of them exhibiting a small secondary peak at the beginning of the rainy season (May-June).

Mystacoleucus spp., Mekongina erythrospila, Parambassis wolffi/spp., Euryglossa panoides, Achiroides spp., Glyptothorax spp., Channa marulius/spp., Cirrhinus jullieni, Hemipimelodus borneensis, Arius stormi, Mystus singaringan/spp., Cynoglossus microlepis, Cyclocheilichthys spp., Botia modesta, Garra fasciacauda, Mystus multiradius/mysticetus/spp., Paralaubuca *typus, Bangana behri, Boesemania microlepis, Crossocheilus siamensis, Botia spp, Catlocarpio siamensis, Toxotes microlepis, Thynnichthys thynnoides, Crossocheilus reticulatus, Scaphognathops stejnegeri, Kryptopterus spp., Rasbora spp., Gyrinocheilus pennocki, Pangasius polyuranodon, Bagarius yarrelli/spp., Acantopsis sp. or spp., Sikukia gudgeri, Luciosoma bleekeri, Onychostoma cf. elongatum, Labiobarbus leptocheilus, Hemibagrus wycki, Barbodes altus, Labeo erythropterus, Aaptosyax grypus, Coius undecimradiatus.*

Graph 6 to 8: species having two equivalent abundance periods (dry and wet season respectively) or being regularly distributed all year long.

Clarias batrachus/spp., Chitala ornata, Bagrichthys spp., Henicorhynchus spp., Poropuntius deauratus, Macrognathus siamensis/spp., Hypsibarbus malcolmi, Chitala blanci, Cirrhinus microlepis, Osteochilus microcephalus/spp., Glossogobius koragensis, Cosmochilus harmandi, Micronema apogon - micronema, Systomus orphoides, Amblyrhynchichthys truncatus, Channa striata, Notopterus notopterus, Laides hexanema/spp., Raiamas guttatus, Pangasius sanitwongsei, Ompok bimaculatus, Lobocheilos melanotaenia, Hypsibarbus lagleri, Mastacemblus armatus/spp., Scaphognathops bandanensis, Osteochilus spp., Hemisilurus mekongensis, Osteochilus melanopleurus, Helicophagus waandersi, Pangasius pleurotaenia.

Graph 9 to 11: species showing a dominant or exclusive peak at the beginning of the rainy season (May-June).

Labeo chrysophekadion/spp., Hampala macrolepidota, Leptobarbus hoeveni, Belodontichthys dinema, Opsarius spp., Hemibagrus nemurus, Hemibagrus wyckioides, Wallago leeri, Puntioplites falcifer, Hypsibarbus wetmorei, Pristolepis fasciata, Hypsibarbus pierrei, Cirrhinus mrigala, Xenentodon cancila, Cyclocheilichthys enoplos, Osphronemus exodon, Pangasianodon hypophthalmus, Tenualosa thibaudeaui, Pangasius bocourti, Hampala dispar, Setipinna melanochir, Micronema bleekeri, Macrochirichthys macrochirus, Wallago attu, Pangasius larnaudiei, Pangasius conchophilus, Pangasius macronema, Cyprinus carpio, Pangasius krempfi.

These patterns are in general agreement with the interviews of fishers along the Mekong River conducted by the Mekong River Commission (MRC), although there are some differences (Bouakhamvongsa and Poulsen 2000). These patterns can largely be explained by the fact that a large number of species migrate from tributaries into the mainstream Mekong River at the end of the rainy season, when water levels drop. They enter the tributaries again when water levels rise during the rainy season. Moreover, fish are generally easier to catch when water levels are low, and fishers often have more free time for fishing during the dry season.

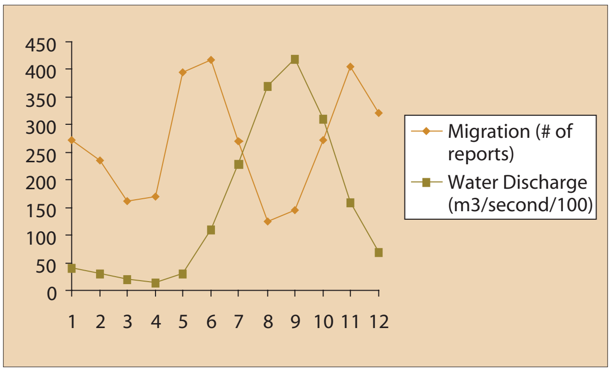


Figure 19: Major migration patterns in the Mekong mainstream, after Bouakhamvongsea and Poulsen (2000)

Furthermore, a detailed comparison of the above results with the MRC "Fish migrations and spawning habits" survey (Poulsen and Valbo-Jørgensen 2001) gives the following results for 28 species considered in both studies:

- 18 species having essentially the same results
- 7 cases with minimal variation:

Migration pattern	Poulsen and Valbo-Jørgensen (2001)	Present study
Paralaubuca typus	Two migrations per year	Second migration non-visible
Pangasius polyuranodon	Onset of the flood season	Unclear pattern
Aaptosyax grypus	No mention of a second migration	Second migration in June
Cirrhinus microlepis	Unclear pattern above Khone falls	Peak in January
Hypsibarbus malcolmi	Unclear patterns	Two peaks in December and May
Wallago attu	Peak in June	Peak in May
Pangasius krempfi	Peak in July	Peak in June

- 3 disagreements:

Migration pattern	Poulsen and Valbo-Jørgensen (2001)	Present study
Mekongina erythrospilla	March-May	Clear peak in January
Botia modesta	Peak in June-July in Khong	Peak in February
Pangasius hypophthalmus	Nov.-Dec. peak in Khong	Peak in May-June

The two studies compared here are highly complementary, as:

- The present study is based on actual catch data over a six-year period, while the study reported on by Poulsen and Valbo-Jørgensen (2001) is based on interviews of fishers (the drawbacks of this latter method are detailed in Poizat and Baran 1997).
- The present study provides the details of migration patterns over all the months of the year and above all encompasses 110 taxa, when that of Poulsen and Valbo-Jørgensen (2001) provides information for only 50 species. The latter study failed to study some of the most important fish species, including *Scaphognathops bandenensis*.
- As opposed to Poulsen and Valbo-Jørgensen (2001), the present study does not provide any indication of the direction, amplitude or purpose of migrations, but Baird *et al.* (1999a) does provide much information of this nature for all the species recorded in the Khone Falls fisheries database, as does Baird *et al.* (2001a; 2003; 2004), and Roberts and Baird (1995).

7 HYDROLOGICAL TRIGGERS OF MIGRATIONS: THE EXAMPLE OF THE CATFISH *PANGASIUS KREMPFI*

Various factors are known to trigger fish migrations, including rises in water levels and changes in discharge, and this study confirms the relationship between migrations and hydrological changes. The catfish *Pangasius krempfi* provides a remarkable example of the sensitivity of a highly migratory species to water level rises, and warns us of how changes in water levels caused by large dam construction could negatively impact fish populations through changing hydrological conditions necessary for triggering migrations (see, also, Hogan *et al*. 2005).

The analysis of the daily catches of *Pangasius krempfi* in 12-16 cm gill nets vs. water level as recorded in Pakse (Figure 20) shows the close relationship between the migrations of this species and rising water levels. The migration occurs suddenly at Khone, and lasts around 40-50 days. However there are in general a dozen days each year when migrations peak, just when the water starts rising after the driest period of the year (e.g. evolution of the catch from 0 to 270 kg per day within 10 days in 1993). This phenomenon is well known by fishers who believe that migrations of *P. krempfi* are triggered by the first seasonal increases in current speeds. Graphs also show that should the water recede after a first rise, the migration correspondingly slows down. It re-starts as soon as water levels rise again (examples in 1997 and 1998).

These results indicate that dams regulating the downstream hydrology of the Mekong River or one its tributaries would likely have very serious negative impacts on the behavior and migrations of this species, as well as on other species responding similarly to hydrological triggers. One serious example of a large dam that has had a massive impact on the downstream hydrology of a large river is the Yali Falls dam on the Sesan River in the Central Highlands of Viet Nam, which has affected downstream hydrology for hundreds of kilometres in Cambodia (Baird and Dearden 2003).

The statistical quantification of the relationships between fish abundance and water levels is not detailed here because:

1) The relationship is graphically clear and does not require further testing;

2) The day-to-day variability of catches is a major impediment to calculating the correlation between catches (which vary a lot) and water levels (which vary a little), unless catch data is normalized by a disputable Ln(x+1) transformation;

3) The catches on day D might depend on water levels on day D-n, but n remains undetermined;

4) Beyond that particular case it can be considered that the rise of water levels is a trigger that initiates migrations, but that once initiated, the migrations occur relatively independently from water levels. In that sense these would be events of stochastic nature for which a classical statistical approach based on correlations would be irrelevant.

The impossibility of addressing the migration triggers with standard statistical methods led to prefer a graphic approach, as detailed in the following section.

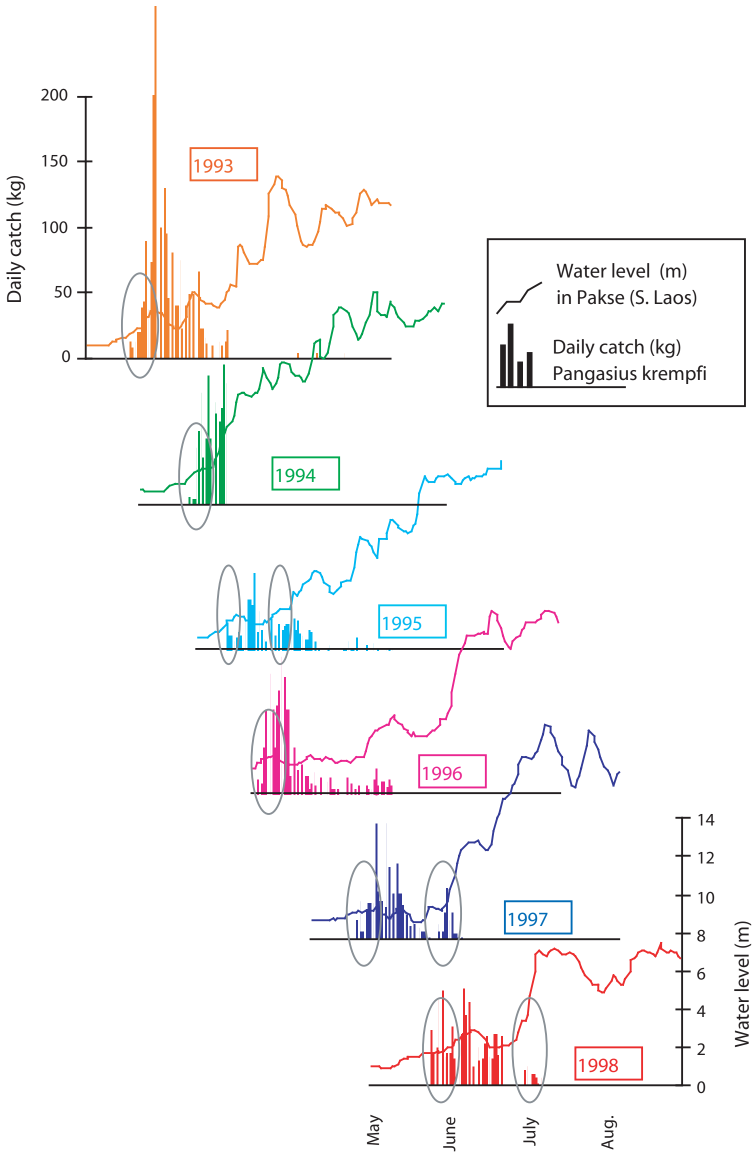
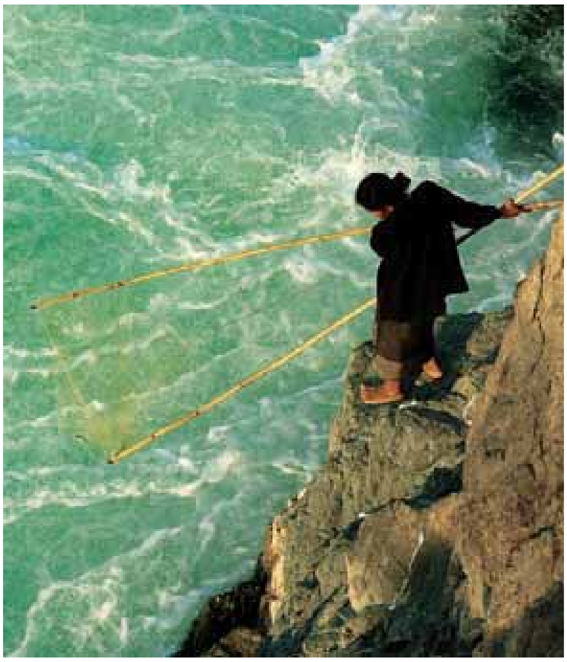


Figure 20: Relationships between water level increases and *Pangasius krempfi* catches in Khone Falls fisheries



8 DOMINANT SPECIES: LIFE HISTORY KEY FACTS, MIGRATIONS AND TRIGGERS

This section combines biological information originating i) from the Khone Falls fisheries database and ii) from FishBase with hydrological data from the MRC. The objective is to provide an overview of the ecological traits of the dominant species, including major life history key facts (e.g. maximum length, size at maturity, approximate life span, main food, etc), seasonal abundance patterns, in particular in relation to river discharge, and sensitivity to flow modifications.

Method

Dominant species

This analysis has been performed on taxa for which more than 750 individuals were caught in Khong between 1993 and 1999 (i.e. at least 50 individuals per year on average); this corresponds to 47 taxa. When only the genus was known, all possible species of this genus present in Laos according to FishBase 2004 have been listed. The original taxonomy used comes from the Khone Falls database, but updated valid names according to FishBase 2004 are also given.

Life history facts

FishBase gives life history facts for each species. Here we used a new procedure developed upon our request by the FishBase team to automatically produce a "Species ecology matrix", i.e. a table of all ecological key facts for a given list of species (matrix Species x Key facts). This matrix combines original values from the literature (in particular maximum length) and values calculated from other existing parameters (details are given below). In the Khone Falls fisheries database,

when fishes were not known at the species level but only at the genus level, we gave the range of values found for the Lao species of the genus.

Maximum length: The default value used here is the maximum length ever reported in the literature for the species in question.

Approximate life span: This is the maximum age that a fish of the species would reach. It is calculated from the length at infinity, that is itself calculated from growth studies, or when no growth studies are available, from maximum length using an empirical relationship between length at infinity and maximum length (Froese and Binohlan 2000).

Length for maximum yield: This is the size of fish that would result in the maximum possible yield given their size and abundance. This parameter is estimated from growth studies or from length at infinity The matrix of species and corresponding life history key facts is detailed in Annex A.

Main food items: from the literature reviewed in FishBase.

This matrix is supplemented, for each taxon, by a brief description of the seasonal abundance pattern based on figures from section III-3.

Abundance patterns and discharge

Daily overall catches have been calculated for each taxon, based on the sum of all gear-specific data. Daily water discharge data in Pakse originating from the MRC have been juxtaposed to daily catch data. Graphs showing abundance vs. discharge have been generated for each taxon (with details for species of a given genus whenever available); these graphs are detailed in Annex B. Based on these graphs, the sensitivity to discharge of 47 taxa to hydrological triggers has been coded as nil, medium or high.

Results

1) Dominant taxa in catches

The forty-seven taxa for which at least 50 individuals have been caught on average per year over six years are:

> *Bagarius* spp.; *Bagrichthys* spp.; *Bangana behri; Barbodes altus; Botia modesta; Botia spp; Cirrhinus microlepis; Cosmochilus harmandi; Crossocheilus reticulatus; Crossocheilus siamensis; Cyclocheilichthys enoplos; Garra fasciacauda; Glyptothorax* spp.; *Gyrinocheilus pennocki; Hemibagrus nemurus; Hemipimelodus borneensis; Hemisilurus mekongensis; Henicorhynchus* spp.; *Hypsibarbus malcolmi; Kryptopterus* spp.; *Labeo erythropterus; Labiobarbus leptocheilus; Laides hexanema/spp.; Lobocheilos melanotaenia; Mekongina erythrospila; Labeo chrysophekadion*/spp.; *Mystacoleucus* spp.; *Opsarius* spp.; *Osteochilus* spp.; *Pangasius bocourti; Pangasius conchophilus; Pangasius krempfi; Pangasius larnaudii; Pangasius macronema; Pangasius pleurotaenia; Pangasius polyuranodon; Paralaubuca typus; Parambassis wolffi*/spp.; *Pristolepis fasciata; Probarbus jullieni; Pseudomystus siamensis; Puntioplites falcifer; Rasbora* spp.; *Scaphognathops bandanensis; Sikukia gudgeri; Tenualosa thibaudeaui; Thynnichthys thynnoides.*

2) Length of fish caught

For each of the dominant taxa, the FishBase matrix gives the maximal length known; this consists of a unique value for each species, or a range of values for a genus. This analysis highlights the kind of fish caught (either large or small species), which is an indicator of the health of the fishery: the higher the percentage of large species, the healthier the fishery is assumed to be.

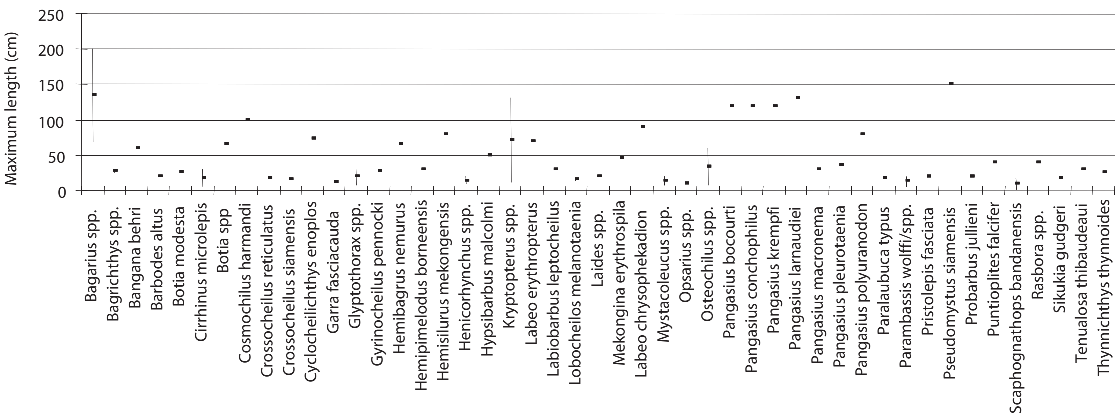


Figure 21: Maximum size per taxon

The distribution of maximum sizes per taxon is given in Figure 21.

The number of taxa and the biomass caught per class of maximum size are expressed below in terms of relative frequencies (this analysis is based on 43 species *sensu stricto* for which the maximum length range is well defined):

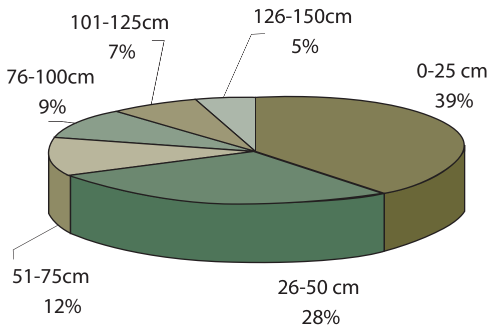


Figure 22: Maximum size distribution among the dominant taxa

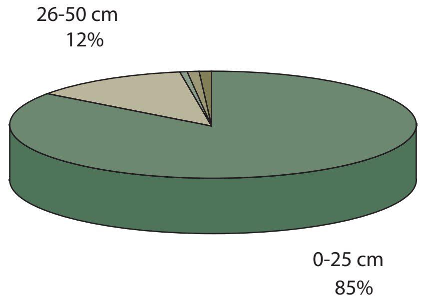


Figure 23: Maximum size distributionin the total biomass caught

These figures show that:

- 61% of dominant taxa caught have a maximum size superior to 25 cm, but
- 85% of fishes actually caught (in terms of biomass) belong to taxa whose maximum sizes are inferior to 25 cm.

This illustrates the abundance of small species in the catch, despite the diversity of a fish community in which large species are largely represented.

3) Species migrations

Each of the 47 dominant taxa is characterized by its relative abundance during a year (see section 3). This abundance pattern has been coded according to five possible classes:

i) caught all year long; **ii)** dominant in dry season; **iii)** dominant between the rainy and dry seasons; **iv)** dominant in rainy season; **v)** peaks during both dry and in rainy seasons.

The figure below shows the relative distribution of dominant taxa in terms of temporal abundance.

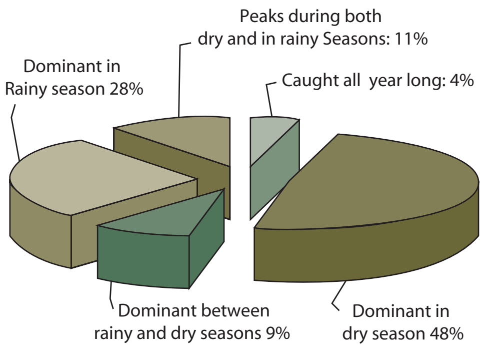


Figure 24: Temporal abundance patterns of 47 dominant species

These figures lead to the conclusion that 96% of dominant taxa are not present all year long, and thus undertake migrations or become impossible to catch at certain periods of time (selectivity and operation mode of a gear depending upon hydrology). Given the diversity of fishing methods in the Khone Falls area (see section 2 and 3) aimed at catching fishes whenever they are present, this figure mostly highlights the importance of migrating behavior among dominant species of the Khone Falls fisheries.

4) Species, discharge and migration triggers

The relationship between discharge and abundance is illustrated for each of the 47 dominant taxa in Annex B. Figure 25, resulting from an analysis based on all catches over six years and including all the 110 taxa, shows clearly that the highest biodiversity appears in catches during times with the lowest discharge levels. This underscores the importance of dry season water levels for fish and fishers, as well as the importance of rising waters at the end of the dry season. These rising water levels actually act as triggers for several taxa, as illustrated by *Pangasius krempfi* in section III-4.

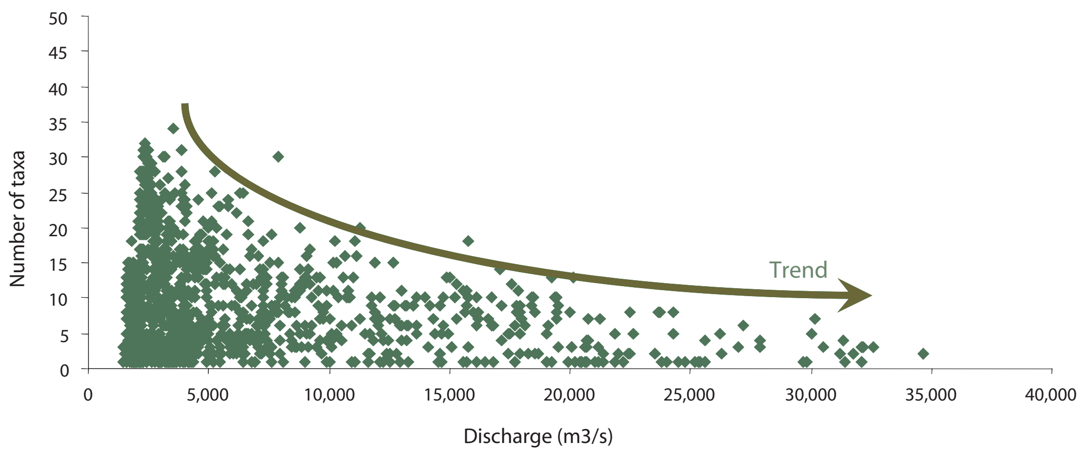


Figure 25: Number of taxa caught versus Discharge

The sensitivity of taxa, to discharge variations has been analysed further with the 47 dominant taxa of the Khone Falls database. For each taxon, the sensitivity to discharge has been coded; this sensitivity is expressed by the nature of the relationship between abundance and discharge in the figures of Appendix B, and is coded as nil, medium, high or unknown. The abundance of each taxon in overall catches has also been integrated.

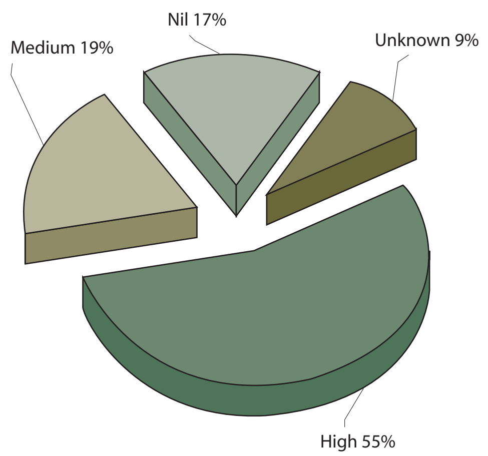


Figure 26: Percentage of each class of sensitivity to discharge among the dominant taxa.

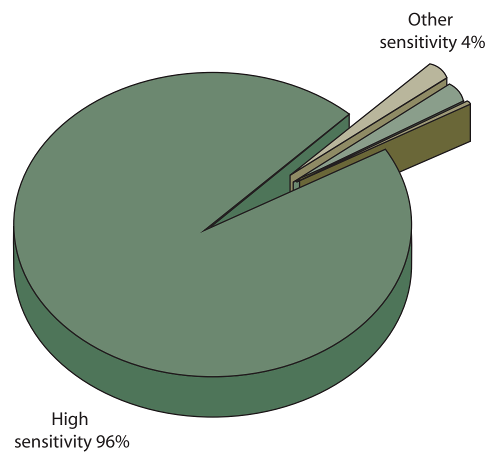


Figure 27: Percentage of taxa sensitive to discharge in the total biomass caught

These results show:

1) The high percentage of taxa sensitive to discharge among the dominant taxa of the Khone Falls

2) The extremely high percentage of species highly sensitive to discharge in the overall catch of the Khone Falls fisheries.

As a conclusion, one can note that when flows vary naturally, the diversity of specific responses to flooding makes some hydrological years good for certain fish species and bad for others; overall a certain catch, made of variable species, is likely year after year. But when flows are regularized, a range of species are permanently impacted and disappear from the catch, which in the long term results in an overall loss. This loss can be very significant when the river concerned is home to the most intensive inland fishery worldwide.

9 DEEP-WATER POOLS AS FISH REFUGES

The importance of deep-water pools in the mainstream to the ecology of Mekong fishes has been outlined in several studies or publications (Blanc 1959, Nguyen Xuan Tan and Nguyen Van Hao 1991, Roberts and Baird 1995). Baird *et al.* (1999a), Chea Vannaren and Sien Kin (2000), Baird *et al.* (2001a and b), Poulsen and Valbo-Jørgensen (2001), Poulsen *et al.* (2002), Kolding *et al.* (2002), Baird and Flaherty (2005) and Baird (2005a and c) have recently addressed this topic again.

It appears that deep pools shelter many species during the dry season; they are also thought to be spawning areas for several species (see, for example, Baird *et al*. 2001b; Baird and Flaherty 2005). Poulsen *et al*. (2002) give a list of 39 species reported to use deep pools as a dry season habitat; and Baird (2005c) wrote that fishers from mainstream Mekong River villages in Khong District (Champasak Province, Southern Laos) reported that 51 species had directly benefited from the establishment of Fish Conservation Zones for protecting deep-water pools from being fished. However, beyond fishers' reports, there is no biological data to confirm these hypotheses in the Mekong Basin, although Kolding *et al*. (2002) reported that hydro-acoustic methods piloted in Khong District have indicated that deep-water pools in the mainstream Mekong River are in fact inhabited by large numbers of fish, albeit, without being able to identify species.

In part of the mainstream Mekong River in Khong District, several deep-water pools have been identified (Baird *et al*. 1999a and b; Baird *et al*. 2001b, Baird and Flaherty 2005, Baird 2005a and c), and more specifically, some important deep-water water pools have been monitored in front of Hang Khone Village, Khong District, just below the Khone Falls, right on the border with Northeastern Cambodia (Roberts and Baird, 1995; Baird *et al*., 2001b; Baird 2005c).

Our objective in this study is to compare the catches of the same gear set either at the surface or in relatively shallow areas outside of deep-water pools or near the bottom of deep-water pools (approximately 20 m deep) in front of Hang Khone Village, and to assess if there is a significant difference between in CPUEs and catch compositions for both fisheries.

The gears studied are monofilament gill nets with mesh sizes ranging from 4 to 9 cm (see section 2 for details about this gear). Surface gill nets were monitored, as a dominant gear, every year from 1993 to 1998, but deep-set gill nets were monitored only in 1994, 1997 and 1998. Surface gill nets are used all year long (with a peak between December and February) while deep-set gill nets are used almost exclusively in February and March (98% of annual use), as these are the dry season months during which fish concentrate in deep pools.

Subsequently bottom and surface catches were compared in February and March 1994, 1997 and 1998. During these months 150 deep fishing operations and 218 surface fishing operations were monitored, time spent fishing was recorded, and 2153 fish belonging to 68 species were caught. The exact surface of each individual gill net was unknown, so the fishing unit was "one net", under the assumption (confirmed by field observations) that the average surface areas of depth gill nets are very similar to those of surface gill nets.

9-1) Comparison between deep-water pools and surface CPUEs

Deep-water and surface 4-9 cm meshed gill nets are compared below during the same period and in the same general areas, in order to determine whether the CPUE of gill nets used in deep-water pools is different from those of the same gear used near the surface or in relatively shallow areas. The CPUE for surface and depth gill nets are given in Table 7.

Table 7: Catches per unit effort (CPUE) of surface and deep gill nets at Hang Khone village

	Hours spent fishing		Catch (kg)		CPUE (grams per hour per net)	
	Depth gill net set 4-9 mm	Surface gill net set 4-9mm	Depth gill net set 4-9 mm	Surface gill net set 4-9 mm	Depth gill net set 4-9 mm	Surface gill net set 4-9 mm
March 1994	1284	660	193.7	7.9	**151**	**12**
February 1997	12	1665	2.5	60.4	**206**	**36**
February 1998	504	948	66.4	34.0	**132**	**36**

This analysis shows that the CPUEs of gill nets set in deep-water pools in February and March are three to twelve times higher than the CPUEs of surface nets during the same months (see, also, Baird 2005c). This demonstrates the concentration of fishes in deep-water pools during the dry season. Fishers are well aware of this high concentration of fishes, but their fishing effort is tempered by the frequent loss of gears and reduced lifespan of nylon gill nets in rocky deep-water areas.

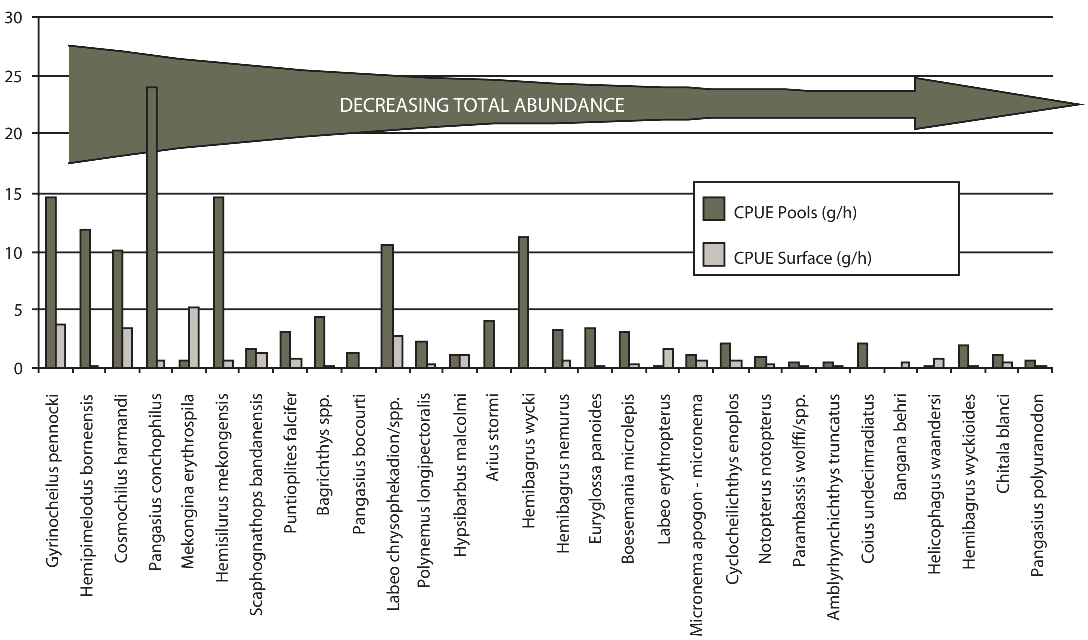


Figure 28: Biomass in surface and pools of the 30 most abundant species

9-2) Deep-water pool species versus surface species

The following analysis, based on the same data set used above, focuses on the species composition in the catches of 4-9 cm meshed deep-water and surface gill nets.

The catch of each species in February and March has been divided by the unit effort, and species ordered according to their decreasing abundance. Results are presented in Figure 28 for the thirty dominant species.

The most abundant species in catches (number of individuals caught) are *Gyrinocheilus pennocki* (a suctorial algae feeder), *Hemipimelodus borneensis* (an Aridae catfish), *Cosmochilus harmandi* (a relatively common upper Mekong Cyprinid), *Pangasius conchophilus* (a large catfish reaching 1.2 m), and *Mekongina erythrospila* (a Mekong endemic Cyprinid). However in terms of total biomass, the dominant species are *Pangasius conchophilus, Gyrinocheilus pennocki, Hemisilurus mekongensis* (a Mekong endemic catfish), *Cosmochilus harmandi* and *Morulius* spp. (or *Labeo* spp., including *Labeo chrysophekadion*, a large Cyprinid). This latter list gives prominence to species abundant but also of large sizes.

For all these species, CPUE is higher in deep pools than at the surface, with the only exceptions being *Mekongina erythrospila* and *Labeo erythropterus*, for which CPUE is higher at the surface.

In order to make these results more readable and integrative, we calculated for each of the 30 species the difference between abundance in depth and at the surface, as well as the difference between biomass in depth and at the surface. Then a bi-plot of species was created (Figure 29).

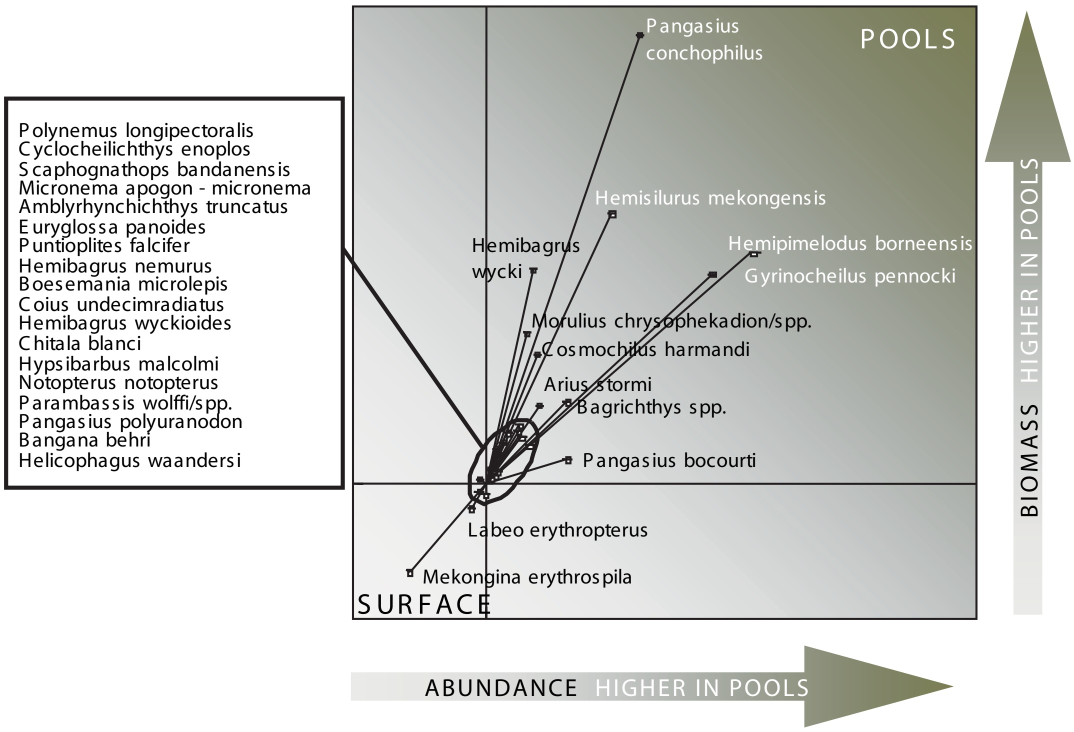


Figure 29: Dominance of biomass and abundance in each habitat, for the 30 dominant species

This analysis shows that:

- *Gyrinocheilus pennocki, Hemipimelodus borneensis, Cosmochilus harmandi, Pangasius conchophilus* and *Mekongina erythrospila* are the five dominant species in the 4-9 mm gill net peak dry season fishery; they make up to 46% of the catch (with 16% for *Gyrinocheilus pennocki* alone).
- Ten species among the thirty dominant species caught during this monitoring express a clear preference for the bottoms of deep-water pools in the dry season; they are *Pangasius conchophilus, Hemisilurus mekongensis, Hemipimelodus borneensis, Hemibagrus wycki, Gyrinocheilus pennocki; Labeo chrysophekadion/spp; Cosmochilus harmandi; Arius stormii; Bagrichthys spp.* and *Pangasius bocourti*.
- At the bottom of deep-water pools *Pangasius conchophilus, Hemibagrus wycki* or *Labeo chrysophekadion* spp. are dominant in terms of biomass, whereas *Gyrinocheilus pennocki* and *Pangasius bocourti* are dominant in terms of abundance.
- *Mekongina erythrospila* and *Labeo erythropterus* are among the few species dominant at the surface;

Some species listed here have not been identified by Poulsen *et al*. (2002) as making use of deep pools: *Hemisilurus mekongensis, Hemipimelodus borneensis, Hemibagrus wyckii, Gyrinocheilus pennocki, Cosmochilus harmandi, Arius stormii,* and *Bagrichthys* spp. Two of these species, *Hemipimelodus borneensis* and *Arius stormi*, are Ariidae catfishes not found above the Khone Falls (Roberts, 1993; Roberts and Baird 1995). Baird and Flaherty (2005) wrote that fishers in Khong reported *Hemisilurus mekongensis, Hemibagrus wyckii,* and *Cosmocheilus harmandi* as inhabitants of certain types of deep-water habitats. In fact, G. *pennocki* are found in rocky areas, and are generally not found in the deepest areas but at mid-depth. It is possible that G. *pennocki* was particularly caught because there are steep cliffs in the fishing area, and these algae eating fish are probably staying inside holes and around the edges of the rocks adjacent to the deep areas.

It is important, however, to recognize that deep-water pools in the mainstream Mekong River certainly do not represent a single habitat, but rather a multitude of habitats that support different communities of fish, even in a relatively restricted area, such as throughout Khong District. Therefore, studies in other deep-water pools, even within Khong District, and especially above the Khone Falls, will certainly result in different catch compositions (Baird and Flaherty 2005, Baird 2005c).

9-3) Size of fishes in deep-water pools

Fishers claim that deep-water pools are places where large fishes are often caught, especially in the dry season; it is assumed that these "large fishes" (large individuals of common species) are old adults that contribute significantly to spawning, hence the importance of protecting deep-water pools from overfishing (Baird *et al*. 1999a; Baird and Flaherty 2005; Baird 2005c). Below, we analyze the differences in the weights of individuals caught in deep-water pools and at the surface.

For this analysis, the same dataset as above was used, but we selected 18 species, for which at least 10 individuals were caught, and at least 5 individuals were caught by each fishing method (deep-water and surface gill nets). This analysis was performed on gill nets with the same mesh sizes, and they therefore had the same selectivity (no sampling bias). However, the use of a restricted mesh size range (here, 4 to 9 cm) cannot be considered as suitable for length frequency or cohort analysis, since the smallest, and in particular the largest, individuals cannot be caught. The comparison of average individual weight of fish at the surface and in the bottom of deep pools is given in Table 8.

Table 8: Comparison of average individual weight in surface and in deep-water pools

<table>
<tr><th>Species name</th><th>Sample: nb in pools vs. nb in surface</th><th>% heavier in pools</th><th></th></tr>
<tr><td>Parambassis wolffi/spp.</td><td>9/11</td><td>78</td><td></td></tr>
<tr><td>Amblyrhynchichthys truncatus</td><td>8/8</td><td>63</td><td rowspan="10">Individuals larger in pools</td></tr>
<tr><td>Pangasius conchophilus</td><td>147/11</td><td>53</td></tr>
<tr><td>Chitala blanci</td><td>5/5</td><td>50</td></tr>
<tr><td>Scaphognathops bandanensis</td><td>29/66</td><td>48</td></tr>
<tr><td>Hemibagrus nemurus</td><td>26/14</td><td>48</td></tr>
<tr><td>Hemipimelodus borneensis</td><td>167/6</td><td>43</td></tr>
<tr><td>Mekongina erythrospila</td><td>7/144</td><td>42</td></tr>
<tr><td>Cosmochilus harmandi</td><td>87/75</td><td>42</td></tr>
<tr><td>Puntioplites falcifer</td><td>49/32</td><td>41</td></tr>
<tr><td>Cyclocheilichthys enoplos</td><td>15/9</td><td>27</td></tr>
<tr><td>Euryglossa panoides</td><td>32/5</td><td>0</td><td></td></tr>
<tr><td>Notopterus notopterus</td><td>14/8</td><td>-4</td><td></td></tr>
<tr><td>Hypsibarbus malcolmi</td><td>20/32</td><td>-5</td><td></td></tr>
<tr><td>Labeo chrysophekadion/spp.</td><td>48/21</td><td>-7</td><td></td></tr>
<tr><td>Polynemus longipectoralis</td><td>45/11</td><td>-8</td><td></td></tr>
<tr><td>Micronema apogon - micronema</td><td>14/14</td><td>-16</td><td rowspan="2">Individuals larger at surface</td></tr>
<tr><td>Gyrinocheilus pennocki</td><td>256/89</td><td>-25</td></tr>
</table>

Thus, among the 18 species caught at least five times in each environment:

- For eleven species the individuals caught in deep-water pools are 27 to 78% larger than those caught at the surface; these species are *Parambassis wolffi/spp.; Amblyrhynchichthys truncatus; Pangasius conchophilus, Chilata blanci; Scaphognathops bandanensis; Hemibagrus nemurus; Hemipimelodus borneensis; Mekongina erythrospila; Cosmochilus harmandi; Puntioplites falcifer; and Cyclocheilichthys enoplos.*
- For two species *(Micronema apogon/micronema* and *Gyrinocheilus pennocki)* the individuals caught at the surface were larger than those caught in deep-water pools. However, it is important to recognize that only juvenile *Micronema* spp. appeared in those results due to the relatively small mesh-size of the gill nets used. It is very rare to catch large individuals of these species in shallow waters, and adults are widely associated with deep-water pools (Baird *et al.* 1999a and b). No analysis could be made on the reproductive status of these species.

This brief analysis of fish catches at the surface and at the bottom of deep-water pools confirms the important role of these habitats as refuges in the dry season. During those months:

- CPUEs from the bottom of deep-water pools are three to twelve times higher than at the surface.
- Species exhibit various degrees of preference for deep-water pools; however among 30 dominant species, ten are clearly more abundant at the bottom, while two only are more abundant at the surface.
- Within a species, among 18 species studied, individuals of 11 are much larger (27 to 78% larger) at the bottom, while only two have larger individuals at the surface. This indirectly confirms the hypothesis according to which deep-water pools play a refuge role for large old individuals, i.e. breeders contributing largely to stock replenishment.
- Overall these results highlight the importance of developing measures so that Mekong deep-water pools become actual freshwater protected areas. It also shows the reason why fishers living along the mainstream Mekong River in Khong District, Champasak Province (both above and below the Khone Falls), have created a large number of Fish Conservation Zones (FCZs) in deep-water pools. Fishers living along the Mekong River in Southern Laos have long recognized the ecological importance of deep-water pools to fish, and have used this knowledge to both assist them in fishing and to protect fisheries resources (see, also, Baird et al. 2001b, Baird and Flaherty 2005, Baird 2005c).

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ANNEX 1: DOMINANT SPECIES, LIFE HISTORY KEY FACTS, ABUNDANCE PATTERNS AND RESPONSE TO DISCHARGE

Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Bagarius spp.	0.06	*Bagarius bagarius*	Sisoridae	70-200	2.2-8.3	46.1-135.3	mainly animals	Abundant in Oct.-Dec. + secondary peak in rainy season (May-June)	Species caught between 1,000 and 13,000 $m^3.s^{-1}$, rather around 5,000 $m^3.s^{-1}$	Medium
		Bagarius rutilus								
		Bagarius suchus					mainly animals			
		Bagarius yarrelli					mainly animals			
Bagrichthys spp.	0.07	*Bagrichthys macracanthus*	Bagridae	24.9-30	6-6.2	16-19.4	plants/detritus + animals	Dry season + rainy season peaks	Sharp and dense peak between 1,500 and 3,000 $m^3.s^{-1}$	High
		Bagrichthys macropterus					zoobenthos mainly animals			
		Bagrichthys obscurus								
Bangana behri	0.06	*Bangana behri*	Cyprinidae	60	20.4	39.4	mainly plants/detritus	Dry season peak + small secondary peak at first rains	Peak between 2,000 and 4,500 $m^3.s^{-1}$	High
Barbodes altus	0.17	*Barbonymus altus*	Cyprinidae	20	8.8	12.8	plants mainly plants/detritus	Dry season peak + small secondary peak at first rains	Species caught between 2,000 and 8,000 $m^3.s^{-1}$, with a peak between 2,000 and 3,000 $m^3.s^{-1}$	High
Botia spp.	0.17	*Botia caudipunctata*	Cobitidae	5.5-30	3.2-15.7	3.4-19.4		Dry season peak + small secondary peak at first rains	Very sharp and dense peak between 2,000 and 3,000 $m^3.s^{-1}$	High
		Botia eos					mainly animals			
		Botia helodes					zoobenthos mainly animals			
		Botia lecontei					zoobenthos mainly animals			
		Botia longidorsalis								
		Botia longiventralis					plants plants/ detritus + animals			
		Botia morleti					mainly animals			
		Botia nigrolineata								
		Botia sidthimunki					zoobenthos mainly animals			
		Botia splendida								

Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Botia modesta	14.55	*Botia modesta*	Cobitidae	25	13.5	16.1	zoobenthos mainly animals	Dry season peak	Very sharp and dense peak between 2,000 and 3,000 $m^3.s^{-1}$	High
Cirrhinus microlepis	0.13	*Cirrhinus microlepis*	Cyprinidae	65	26	42.7	plants mainly plants/detritus	Dry season peak + small secondary peak at first rains	Species caught between 1,500 and 7,000 $m^3.s^{-1}$, concentrated between 2,000 and 4,000 $m^3.s^{-1}$	High
Cosmochilus harmandi	0.40	*Cosmochilus harmandi*	Cyprinidae	100	32	66.5	plants mainly plants/detritus	Two peaks, one at decreasing flows (November-December) and one at first rains (May-June)	Species caught between 1,500 and 13,000 $m^3.s^{-1}$, concentrated between 1,500 and 6,000 $m^3.s^{-1}$	Medium
Crossocheilus reticulatus	3.47	*Crossocheilus reticulatus*	Cyprinidae	17	7.6	10.8	plants/detritus + animals	Dry season peak	Species caught between 1,500 and 19,000 $m^3.s^{-1}$, with a sharp peak between 1,500 and 2,500 $m^3.s^{-1}$	High
Crossocheilus siamensis	0.07	*Crossocheilus siamensis*	Cyprinidae	16	7.2	10.1	mainly plants/detritus	Dry season peak	Species caught between 1,500 and 10,000 $m^3.s^{-1}$, with a sharp and intense peak between 1,500 and 2,500 $m^3.s^{-1}$ (but 10 data points only)	High
Cyclocheilichthys enoplos	0.10	*Cyclocheilichthys enoplos*	Cyprinidae	74	28.7	48.8	zooplankton mainly animals	Dominant peak at first rains, but also caught in the dry season	Species caught between 1,500 and 20,000 $m^3.s^{-1}$, with a sharp peak around 3,000 $m^3.s^{-1}$	High
Garra fasciacauda	1.62	*Garra fasciacauda*	Cyprinidae	11	5	6.9	plants/detritus + animals	Dry season peak	Sharp peak between 2,000 and 3,000 $m^3.s^{-1}$, but few data points	High

Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Glyptothorax spp.	0.13	*Glyptothorax fuscus*	Sisoridae	8.8-30	2.9-12.4	0.6-19.4	mainly animals	Dry season peak + small secondary peak at first rains	Species caught between 2,000 and 5,000 $m^3.s^{-1}$, but few data points	Unknown
		Glyptothorax honghensis								
		Glyptothorax interspinalum								
		Glyptothorax lampris					mainly animals			
		Glyptothorax laosensis					mainly animals			
		Glyptothorax macromaculatus								
		Glyptothorax major					mainly animals			
		Glyptothorax trilineatus								
		Glyptothorax zanaensis								
Gyrinocheilus pennocki	0.73	*Gyrinocheilus pennocki*	Gyrinocheili-dae	28	3.8	18	plants/detritus + animals	Dry season peak + small secondary peak at first rains	Sharp and dense peak between 1,500 and 3,500 $m^3.s^{-1}$	High
Hemibagrus nemurus	0.22	*Hemibagrus nemurus*	Bagridae	65	15.1	42.7	zoobenthos mainly animals	Dominant peak at first rains, secondary peak in the dry season	No clear pattern but concentration around 1,500 - 9,000 $m^3.s^{-1}$	Medium
Hemipimelodus borneensis	0.10	*Hemipimelodus borneensis*	Ariidae	30	10.1	19.4	plants/detritus + animals	Appears in November, but major peak in the dry season	No clear pattern	Nil
Hemisilurus mekongensis	0.08	*Hemisilurus mekongensis*	Siluridae	80	2.6	52.9	plants/detritus + animals	Two peaks, one in dry season, one in wet season	No pattern	Nil
Henicorhynchus spp.[3]	47.26	*Henicorhynchus cryptopogon*	Cyprinidae	9.5-20	4.3-8.8	5.9-12.8	plants mainly plants/detritus	Dry season peak + small secondary peak at first rains	Pattern species-specific	High
		Henicorhynchus lineatus								
		Henicorhynchus ornatipinnis								
		Henicorhynchus siamensis					plants mainly plants/detritus			

[3] *Complex group of poorly identified species and controversial taxonomy, including also Cirrhinus spp., in particular Henicorhynchus/Cirrhinus lobatus, dominant in catches and coming from Cambodia where it is not recorded.*

Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Hypsibarbus malcolmi	0.37	*Poropuntius malcolmi*	Cyprinidae	50	20.4	32.7	mainly animals	2 equal peaks, in dry season and wet season	Species caught between 1,500 and 11,000 $m^3.s^{-1}$, with a peak between 3,000 and 5,000 $m^3.s^{-1}$	High
Kryptopterus spp.	0.18	*Kryptopterus apogon*	Siluridae	12-130	2.9-7.6	7.6-87	nekton mainly animals	Peak in December + small secondary peak at first rains (May)	No pattern	Nil
		Kryptopterus bicirrhis					mainly animals			
		Kryptopterus cheveyi					mainly animals			
		Kryptopterus cryptopterus					nekton mainly animals			
		Kryptopterus dissitus								
		Kryptopterus geminus								
		Kryptopterus hexapterus					mainly animals			
		Kryptopterus limpok					mainly animals			
		Kryptopterus micronema					mainly animals			
		Kryptopterus moorei					mainly animals			
		Kryptopterus schilbeides					mainly animals			
Labeo erythropterus	0.09	*Labeo erythropterus*	Cyprinidae	70	28.6	46.1	mainly plants/detritus	Peak in December + secondary peak at first rains (June)	Species caught between 1,500 and 33,000 $m^3.s^{-1}$, concentrated between 2,000 and 4,500 $m^3.s^{-1}$	High
Labiobarbus leptocheilus	6.35	*Labiobarbus leptocheila*	Cyprinidae	30	12.9	19.4	plants mainly plants/detritus	Dry season dominant peak + small secondary peak in rainy season	Species caught between 1,500 and 21,000 $m^3.s^{-1}$, with a concentration between 1,500 and 3,000 $m^3.s^{-1}$	High
Laides hexanema/spp.	0.06	*Laides hexanema*	Schilbeidae	14.2-16.5	4.5-4.8	9-10.5		Almost two equal peaks in dry and early rainy season	Species caught between 2,000 and 5,500 $m^3.s^{-1}$	High
		Laides longibarbis					mainly animals			

Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Lobocheilos melanotaenia	1.25	*Lobocheilos melanotaenia*	Cyprinidae	20	8.8	12.8	plants mainly plants/detritus	Dry season peak + small secondary peak in early rainy season	Species caught between 1,500 and 24,000 $m^3.s^{-1}$; no clear pattern	Nil
Mekongina erythrospila	0.57	*Mekongina erythrospila*	Cyprinidae	45	19	29.3	mainly plants/detritus	Dry season peak (January)	Very sharp and dense peak between 1,500 and 3,500 $m^3.s^{-1}$, in particular around 2,000 $m^3.s^{-1}$	High
Labeo chrysophekadion/spp.	0.06	*Labeo chrysophekadion*	Cyprinidae	90	28.7	59.7	plants mainly plants/detritus	Dominant peak at first rains, secondary peak in the dry season	Species caught between 1,500 and 26,000 $m^3.s^{-1}$, concentrated between 1,500 and 5,000 $m^3.s^{-1}$	Medium
Mystacoleucus spp.	0.11	*Mystacoleucus atridorsalis*	Cyprinidae	7.3-20	3.4-7.4	4.5-12.8	plants/detritus + animals	Dominant dry season peak + small secondary peak at first rains	Peak between 2,000 and 5,000 $m^3.s^{-1}$	High
		Mystacoleucus chilopterus								
		Mystacoleucus ectypus								
		Mystacoleucus greenwayi								
		Mystacoleucus lepturus								
		Mystacoleucus marginatus					plants/detritus + animals			
Opsarius spp.	0.06	*Opsarius koratensis*	Cyprinidae	10	4.6	6.3	zoobenthos mainly animals	Dominant peak at first rains, secondary peak in the dry season	Insufficient data	Unknown

Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Osteochilus spp.	0.08	*Osteochilus enn eaporus*	Cyprinidae	8.2-60	2.5-23.8	5.1-39.4	mainly plants/detritus	Caught almost all year long (except in April and Sept.) but species-specific variability	Pattern species-specific	Unknown
		Osteochilus hasseltii					zoobenthos plants/detritus + animals			
		Osteochilus lini					mainly plants/detritus			
		Osteochilus melanopleurus					plants mainly plants/detritus			
		Osteochilus microcephalus					mainly plants/detritus			
		Osteochilus salsburyi								
		Osteochilus striatus								
		Osteochilus vittatus								
		Osteochilus waandersii					mainly plants/detritus			
Pangasius bocourti	0.14	*Pangasius bocourti*	Pangasiidae	120	17.5	80.2	plants/detritus + animals	Dominant peak in early rainy season, secondary peak in Nov.	Species caught between 2,00 and 31,000 $m^3.s^{-1}$; no clear pattern	Medium
Pangasius conchophilus	0.59	*Pangasius conchophilus*	Pangasiidae	120	24	80.2	mainly animals	Exclusive peak in early rainy season	Species caught between 1,500 and 25,000 $m^3.s^{-1}$, concentrated between 3,000 and 6,000 $m^3.s^{-1}$	Medium
Pangasius krempfi	0.25	*Pangasius krempfi*	Pangasiidae	120	2.6	80.2		Exclusive peak in early rainy season	Species caught between 1,500 and 20,000 $m^3.s^{-1}$, concentrated between 2,000 and 9,500 $m^3.s^{-1}$	High
Pangasius larnaudiei	0.07	*Pangasius larnaudii*	Pangasiidae	130	2.7	87	zoobenthos mainly animals	Exclusive peak in early rainy season	Species caught between 1,500 and 22,000 $m^3.s^{-1}$, concentrated between 2,500 and 10,000 $m^3.s^{-1}$	Medium
Pangasius macronema	0.26	*Pangasius macronema*	Pangasiidae	30	2.6	19.4	zoobenthos mainly animals	Exclusive peak at first rains	Species caught between 1,500 and 26,000 $m^3.s^{-1}$, with a sharp and intense peak between 3,000 and 4,000 $m^3.s^{-1}$	High
Pangasius pleurotaenia	0.17	*Pangasius pleurotaenia*	Pangasiidae	35	2.4	22.7	plants/detritus + animals	Dominant peak at first rains, secondary peak in the dry season	No pattern	Nil

Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Pangasius polyuranodon [4]	0.15	*Pangasius polyuranodon*	Pangasiidae	80	80	80	plants/detritus + animals	Present all year long (mainly in Oct.) except in April	No pattern	Nil
Paralaubuca typus	14.63	*Paralaubuca typus*	Cyprinidae	18	8	11.4	zooplankton mainly animals	Exclusive dry season peak	Species caught between 1,500 and 5,500 $m^3.s^{-1}$, with a sharp and intense peak around 2,000 $m^3.s^{-1}$	High
Parambassis spp.	0.07	*Parambassis apogonoides*	Ambassidae	6-20	1.7-5.3	3.7-12.8	zoobenthos mainly animals	Exclusive dry season peak	Peak between 1,500 and 4,000 $m^3.s^{-1}$	High
		Parambassis siamensis								
		Parambassis wolffii					zoobenthos mainly animals			
Pristolepis fasciata	0.06	*Pristolepis fasciata*	Nandidae	20	4.4	12.8	zoobenthos mainly animals	Dominant peak in the rainy season (July)	No pattern	Nil
Probarbus jullieni	0.13	*Probarbus jullieni*	Cyprinidae	150	57.7	100.8	plants/detritus + animals	Dominant peak in Dec. + secondary peak in May	Species caught between 1,500 and 8,000 $m^3.s^{-1}$, with a peak between 3,000 and 5,000 $m^3.s^{-1}$	Medium
Pseudomystus siamensis	0.10	*Pseudomystus siamensis*	Bagridae	20	4.2	12.8	zoobenthos mainly animals	Dominant peak in Dec. + secondary peak in July	No pattern	Nil
Puntioplites falcifer	0.40	*Puntioplites falcifer*	Cyprinidae	40	13.6	26	mainly plants/detritus	Dominant peak at first rains, secondary peak in the dry season	Species caught between 1,500 and 7,000 $m^3.s^{-1}$, with a concentration between 2,000 and 5,000 $m^3.s^{-1}$	High

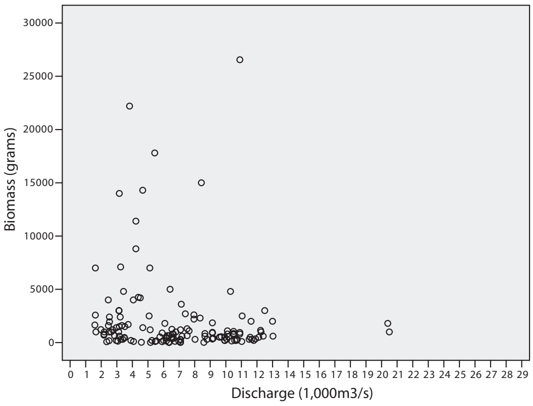
[4] *Present in the Khone species list, but not in Laos according to FishBase 2004*

Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Rasbora spp.	0.16	*Rasbora amplistriga*	Cyprinidae	2.6-17	1.3-7.6	1.6-10.8		Almost exclusive peak in the dry season	Unclear response, probably species-specific	Unknown
		Rasbora atridorsalis								
		Rasbora aurotaenia					zoobenthos plants/detritus + animals			
		Rasbora borapetensis					zoobenthos mainly animals			
		Rasbora daniconius					zoobenthos mainly animals			
		Rasbora dorsinotata								
		Rasbora dusonensis					zoobenthos mainly animals			
		Rasbora hobelmani					zoobenthos mainly animals			
		Rasbora myersi					plants/detritus + animals			
		Rasbora paucisqualis					zoobenthos mainly animals			
		Rasbora paviei					zoobenthos mainly animals			
		Rasbora rubrodorsalis								
		Rasbora septentrionalis								
		Rasbora spilocerca					zooplankton mainly animals			
		Rasbora steineri								
		Rasbora sumatrana								
		Rasbora tornieri					zoobenthos mainly animals			
		Rasbora trilineata					zoobenthos mainly animals			

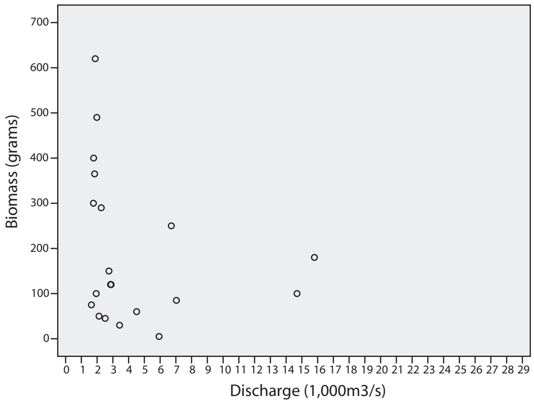
Taxon in the Khone Falls fisheries database	% of total catch	List of possible species and valid names	Family	Max. length (cm)	Approx. life span (years)	Length for max. yield (cm)	Main food	Seasonal abundance patterns	Abundance in relation to discharge	Sensitivity to discharge
Scaphognathops bandanensis	1.65	*Scaphognathops bandanensis*	Cyprinidae	40	16.7	26	plants/detritus + animals	2 equal peaks, in dry season and wet season	Species caught between 1,500 and 21,000 $m^3.s^{-1}$, with a peak around 3,500 $m^3.s^{-1}$	High
Sikukia gudgeri	0.18	*Sikukia gudgeri*	Cyprinidae	18	8	11.4	plants/detritus + animals	Almost exclusive peak in the dry season	Species caught between 2,000 and 22,500 $m^3.s^{-1}$, with a sharp peak between 2,000 and 3,000 $m^3.s^{-1}$	Medium
Tenualosa thibaudeaui	0.16	*Tenualosa thibaudeaui*	Clupeidae	30	7.3	19.4	plants mainly plants/detritus	Dominant peak at first rains, secondary peak in the dry season	Species caught between 2,000 and 5,000 $m^3.s^{-1}$	High
Thynnichthys thynnoides	1.22	*Thynnichthys thynnoides*	Cyprinidae	25	9.1	16.1	plants mainly plants/detritus	Almost exclusive peak in the dry season	Species caught between 2,500 and 12,500 $m^3.s^{-1}$, with a sharp peak between 2,000 and 3,000 $m^3.s^{-1}$	High

ANNEX 2: RELATIONSHIP BETWEEN ABUNDANCE AND

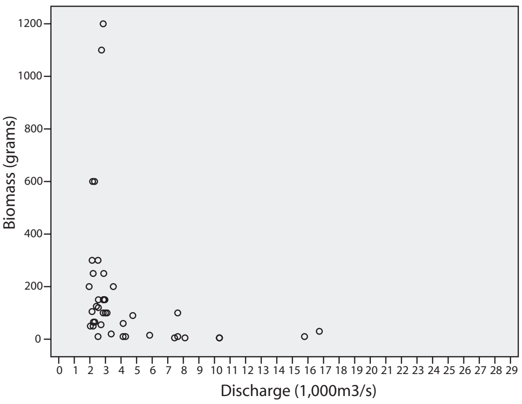
Species: Bagarius yarrelli/spp.



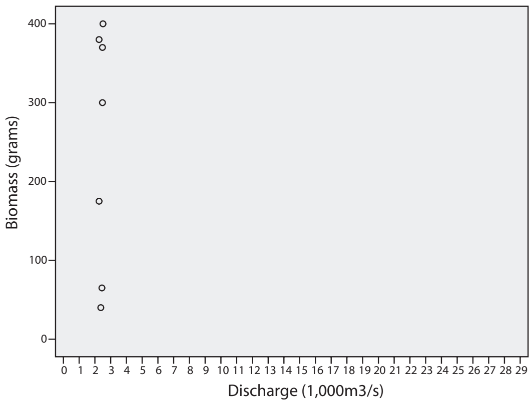
Species: Bagrichthys macracanthus



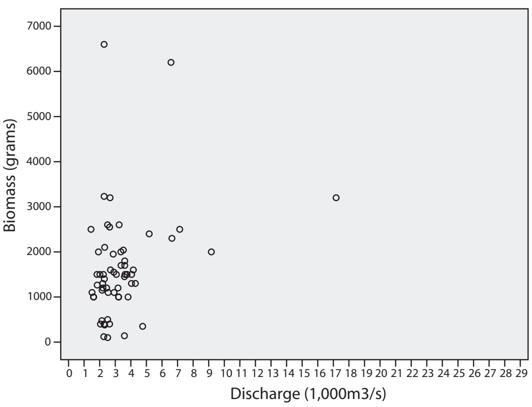
Species: Barbodes altus



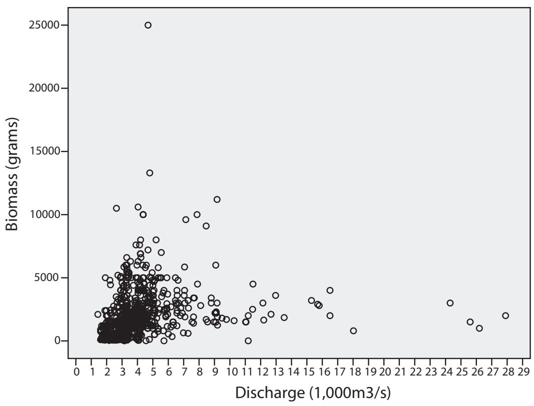
Species: Botia caudipunctata/spp.



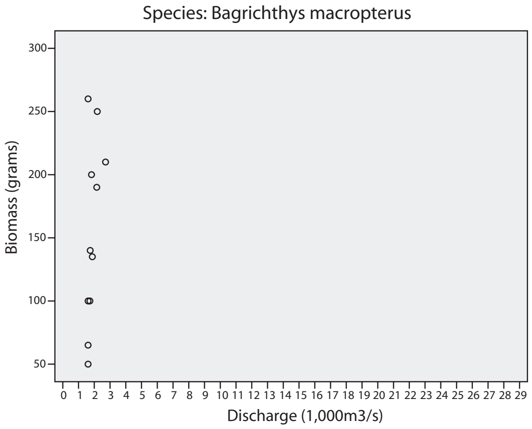
Species: Cirrhinus microlepis

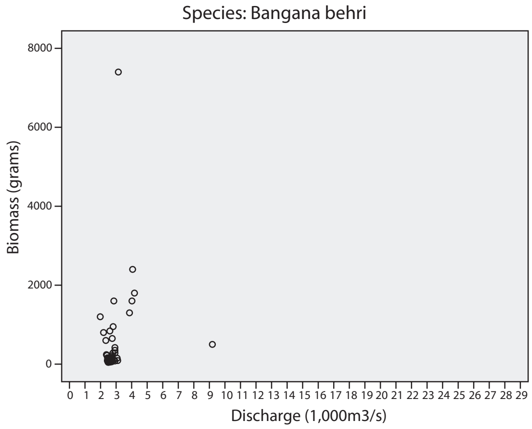


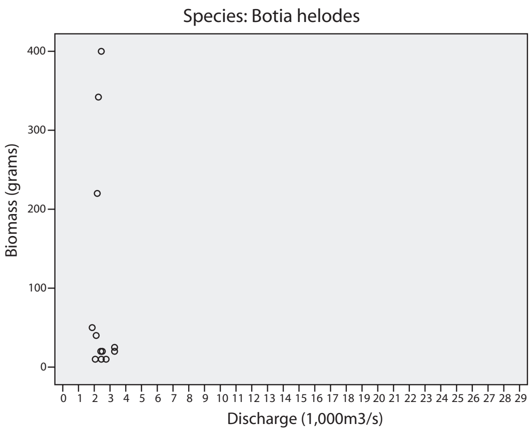
Species: Cosmochilus harmandi

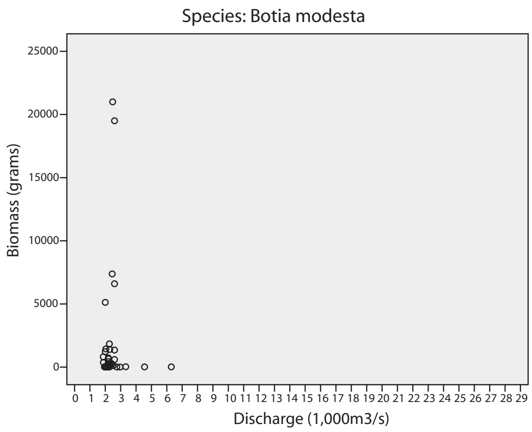


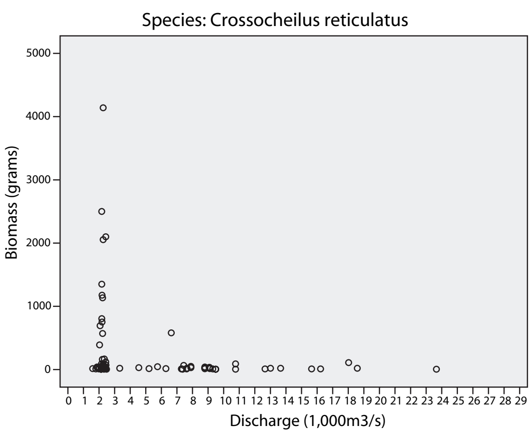
RIVER DISCHARGE FOR DOMINANT SPECIES

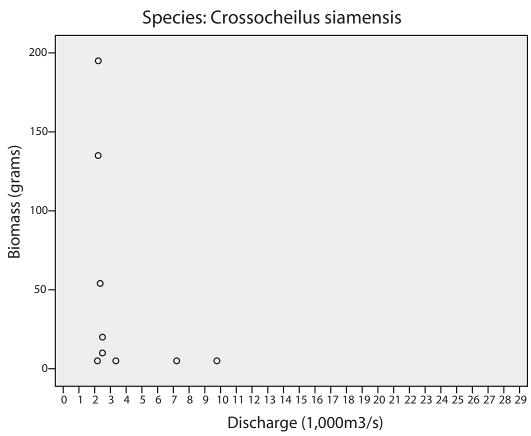


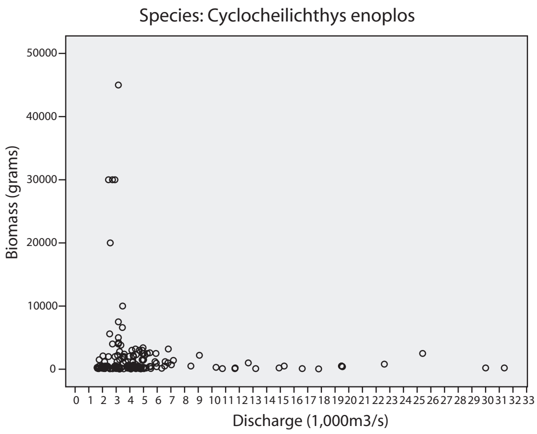


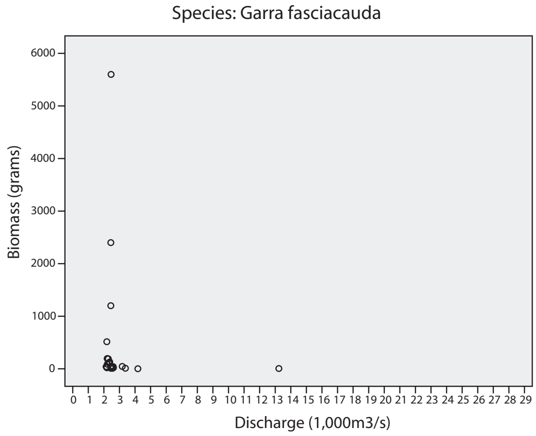


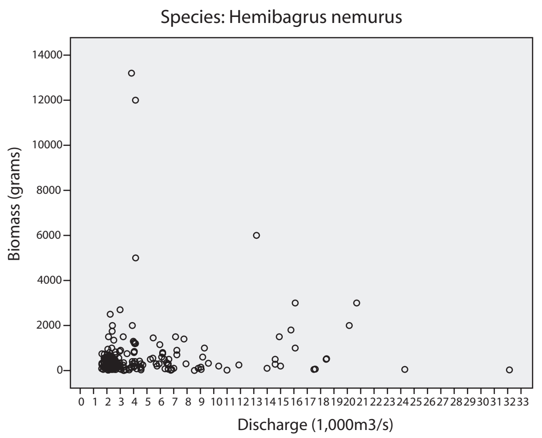


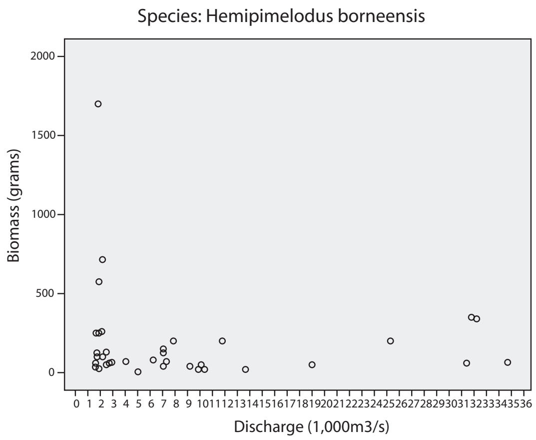


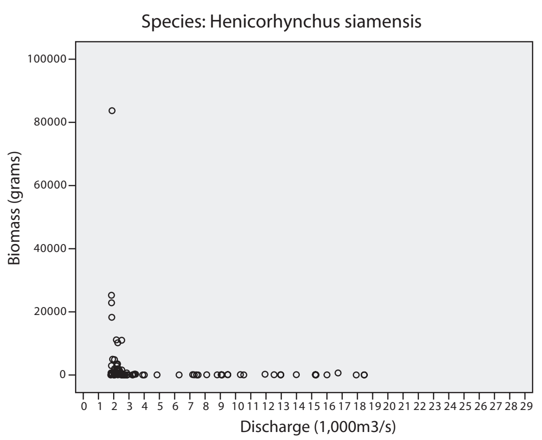


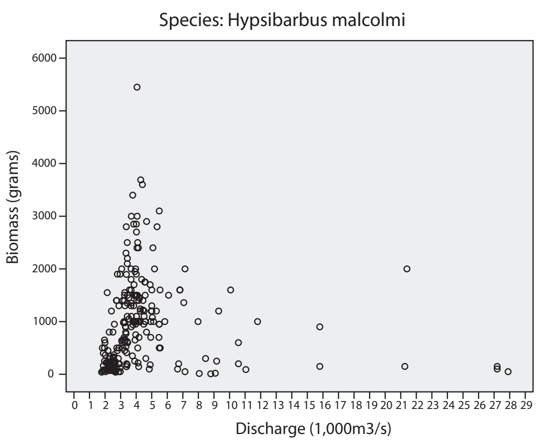

Species: Cyclocheilichthys enoplos
Biomass (grams)
50000
40000
30000
20000
10000
0
Discharge (1,000m3/s)


Species: Garra fasciacauda
Biomass (grams)
6000
5000
4000
3000
2000
1000
0
Discharge (1,000m3/s)

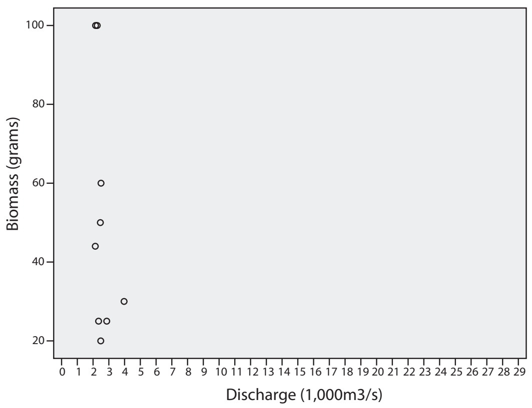

Species: Hemibagrus nemurus
Biomass (grams)
14000
12000
10000
8000
6000
4000
2000
0
Discharge (1,000m3/s)


Species: Hemipimelodus borneensis
Biomass (grams)
2000
1500
1000
500
0
Discharge (1,000m3/s)

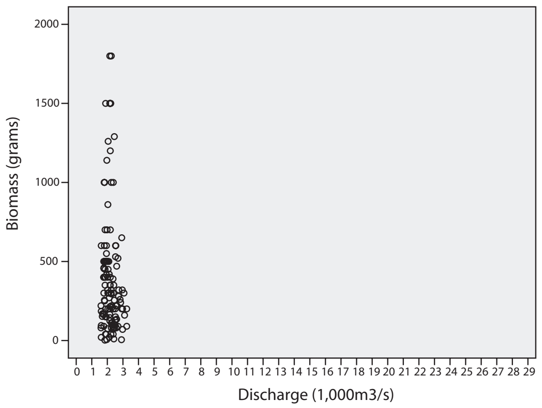

Species: Henicorhynchus siamensis
Biomass (grams)
100000
80000
60000
40000
20000
0
Discharge (1,000m3/s)


Species: Hypsibarbus malcolmi
Biomass (grams)
6000
5000
4000
3000
2000
1000
0
Discharge (1,000m3/s)

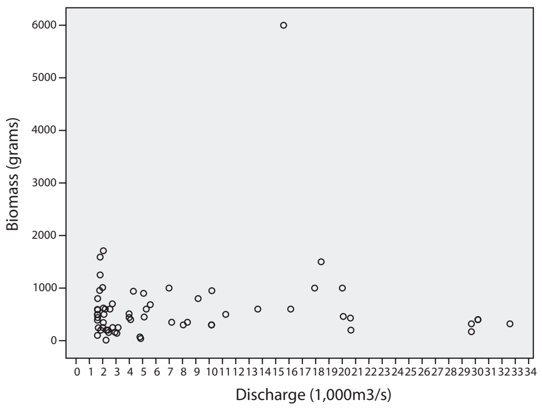
Species: Glyptothorax spp.



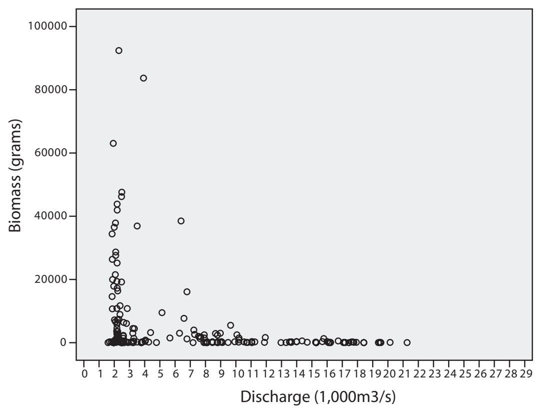
Species: Gyrinocheilus pennocki



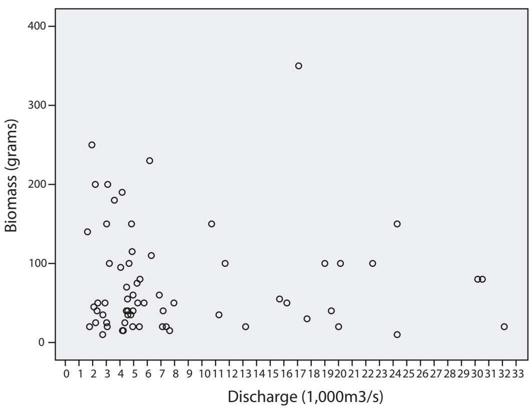
Species: Hemisilurus mekongensis



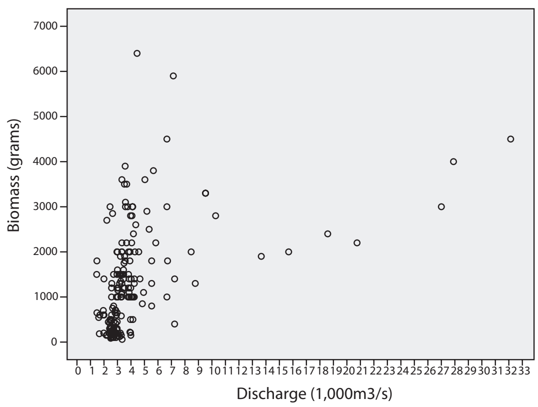
Species: Henicorhynchus lobatus



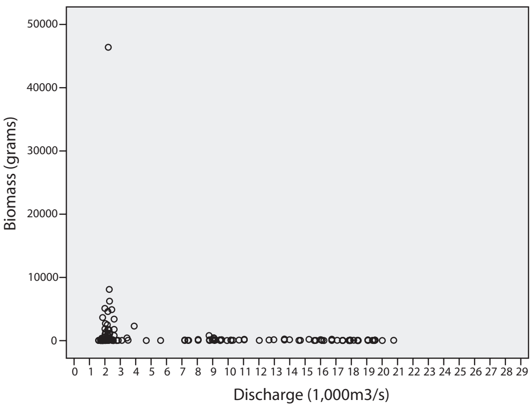
Species: Kryptopterus spp.



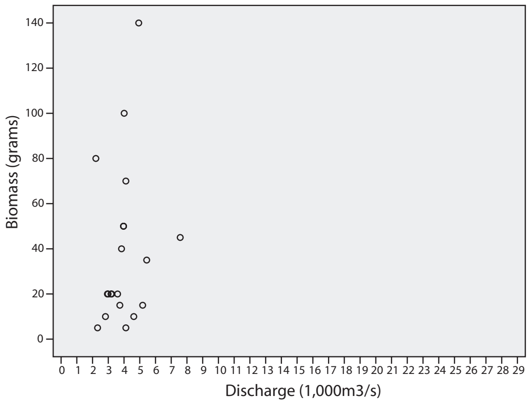
Species: Labeo erythropterus



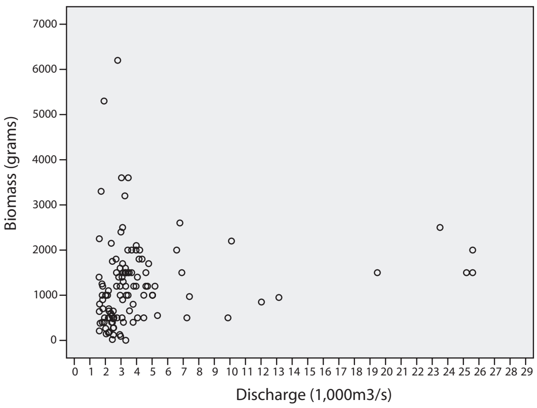
Species: Labiobarbus leptocheilus



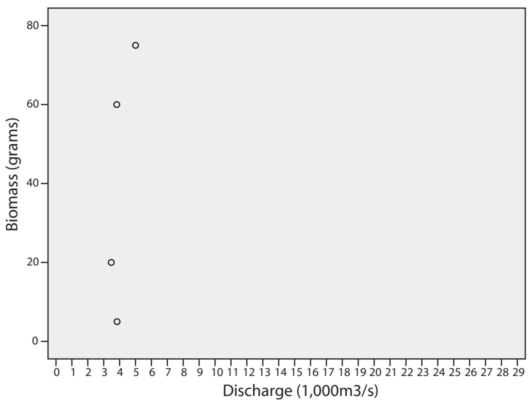
Species: Laides hexanema/spp.



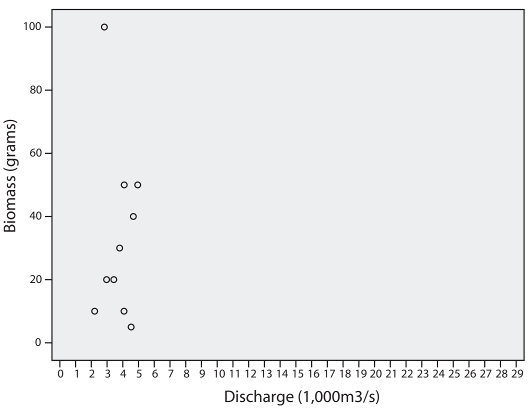
Species: Labeo chrysophekadion/spp.



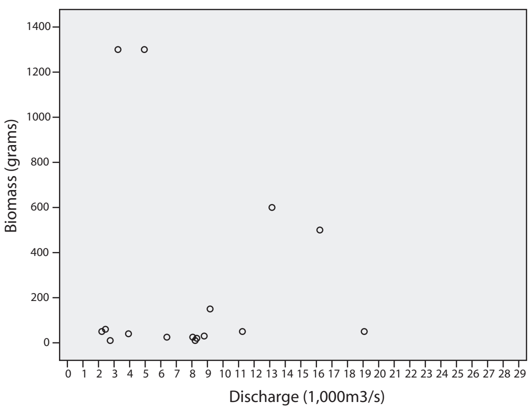
Species: Mystacoleucus atridorsalis



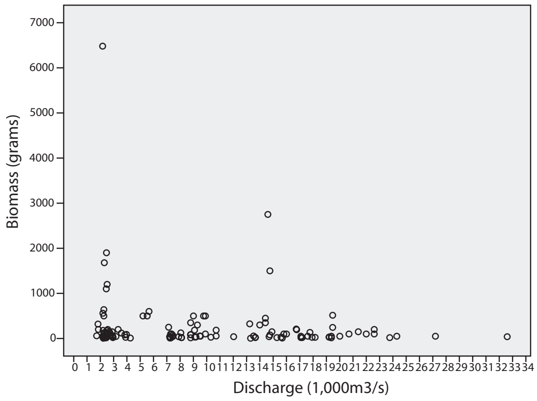
Species: Osteochilus hasselti



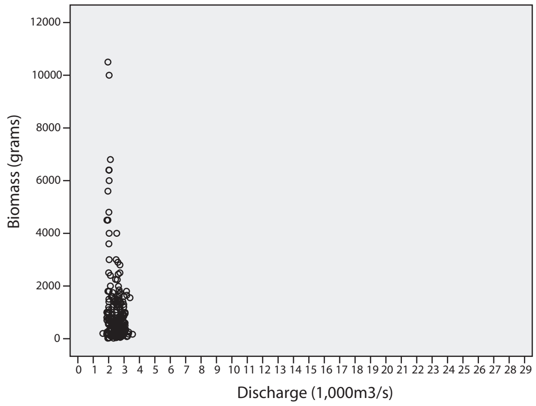
Species: Osteochilus melanopleurus



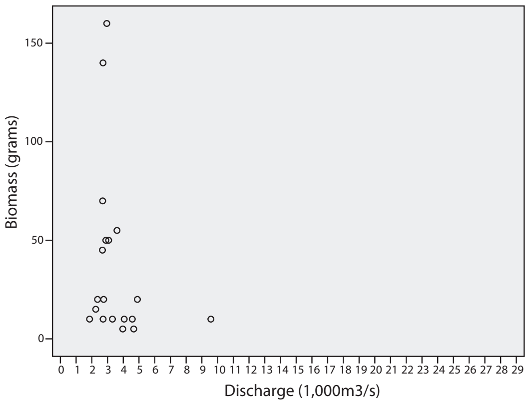
Species: Lobocheilos melanotaenia



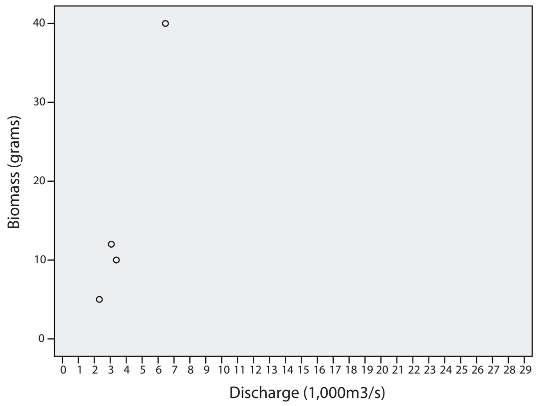
Species: Mekongina erythrospila



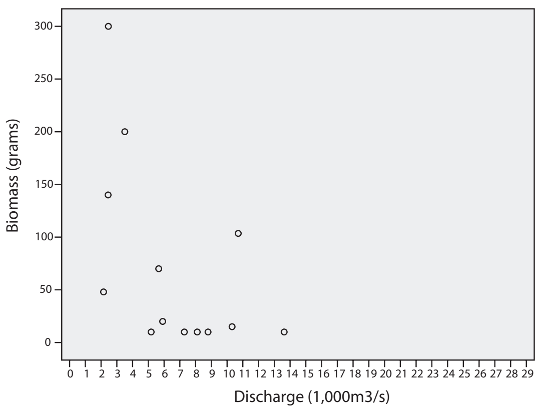
Species: Mystacoleucus marginatus



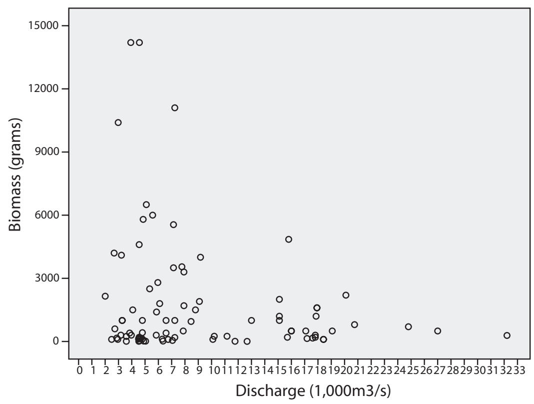
Species: Opsarius pulchellus



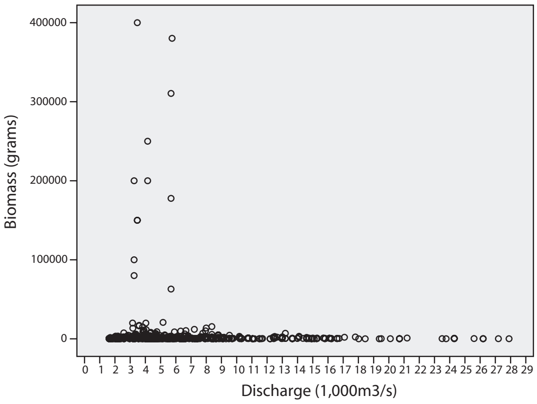
Species: Osteochilus microcephalus/waandersii



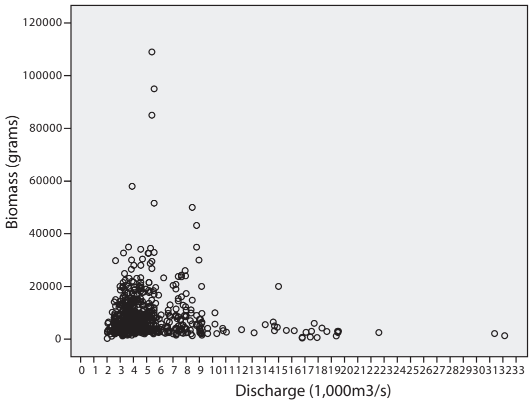
Species: Pangasius bocourti



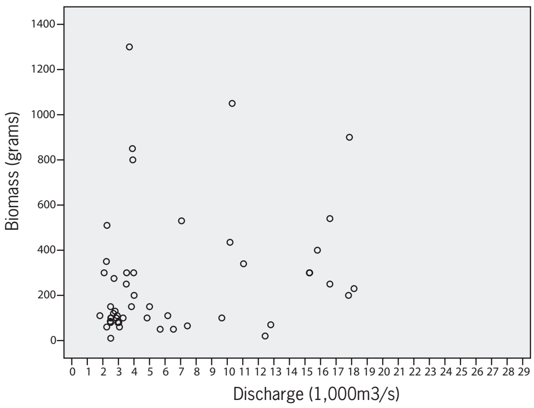
Species: Pangasius conchophilus



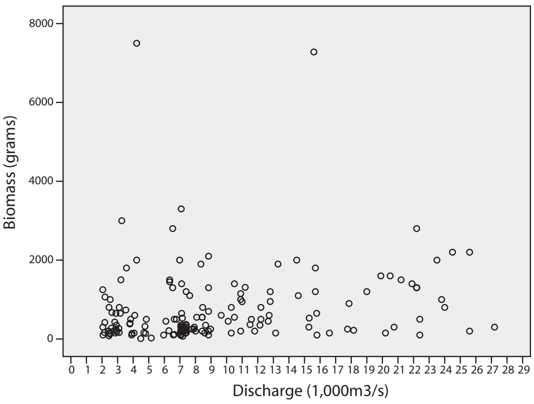
Species: Pangasius krempfi



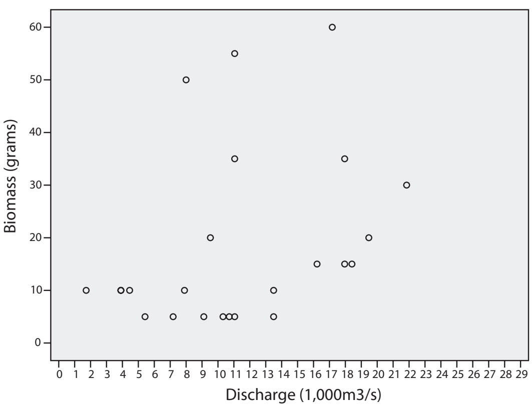
Species: Pangasius pleurotaenia



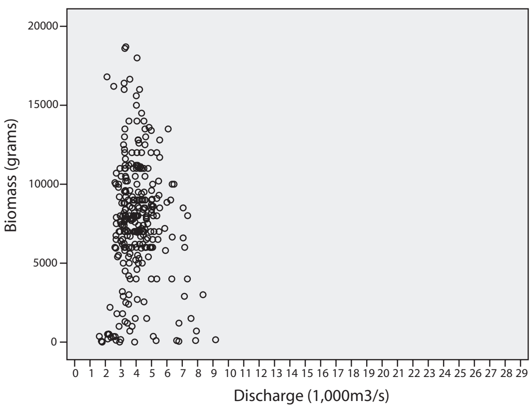
Species: Pangasius polyuranodon

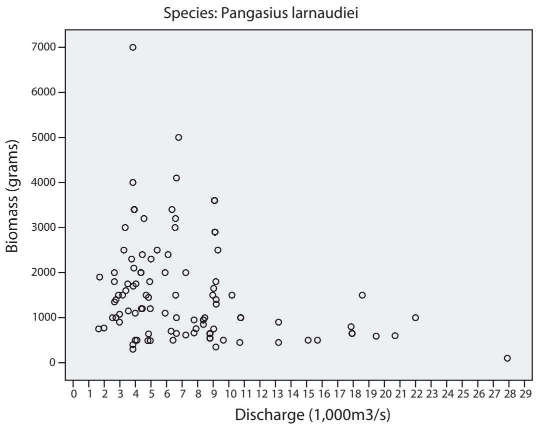


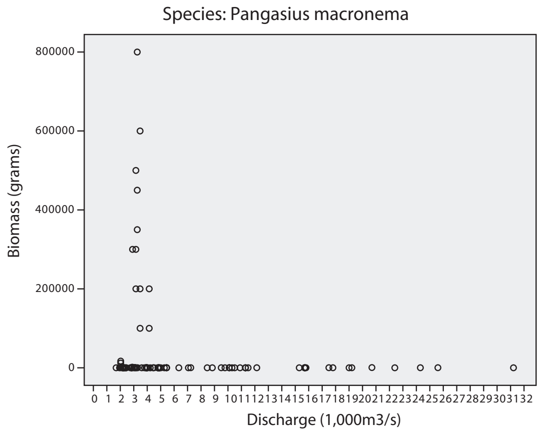
Species: Pristolepis fasciata

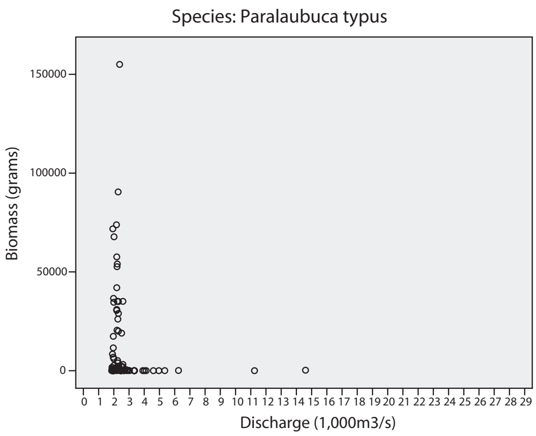


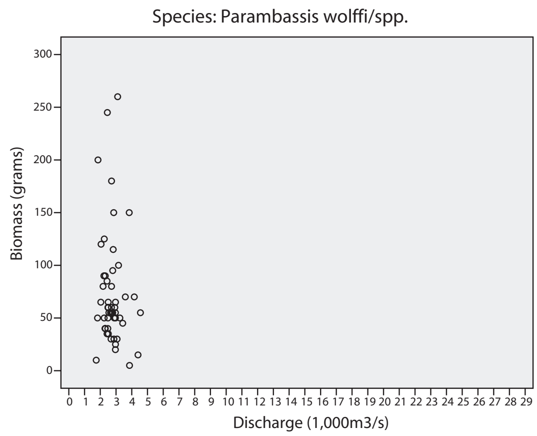
Species: Probarbus jullieni

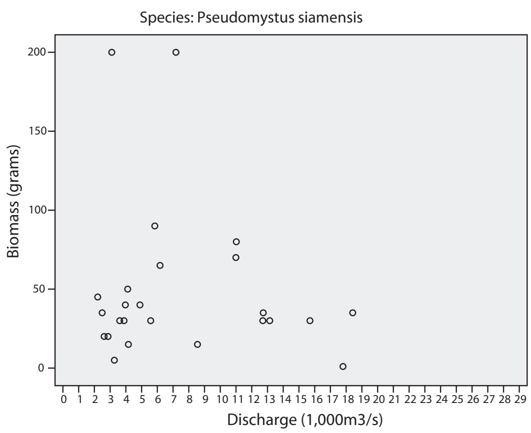


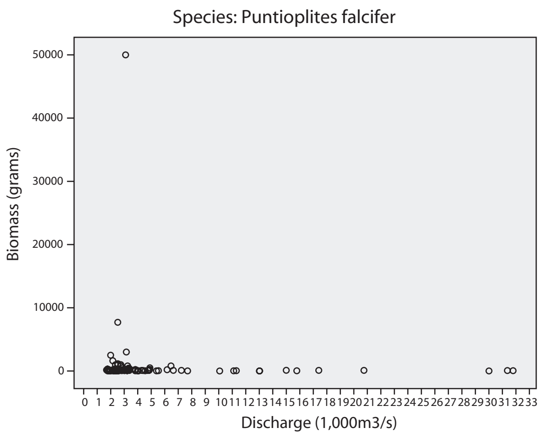

Species: Pangasius larnaudiei
Biomass (grams)
Discharge (1,000m3/s)


Species: Pangasius macronema
Biomass (grams)
Discharge (1,000m3/s)

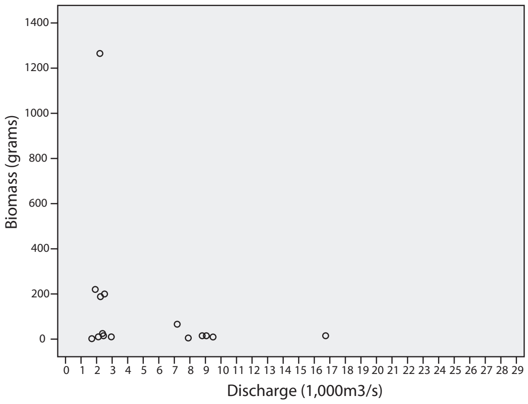

Species: Paralaubuca typus
Biomass (grams)
Discharge (1,000m3/s)


Species: Parambassis wolffi/spp.
Biomass (grams)
Discharge (1,000m3/s)

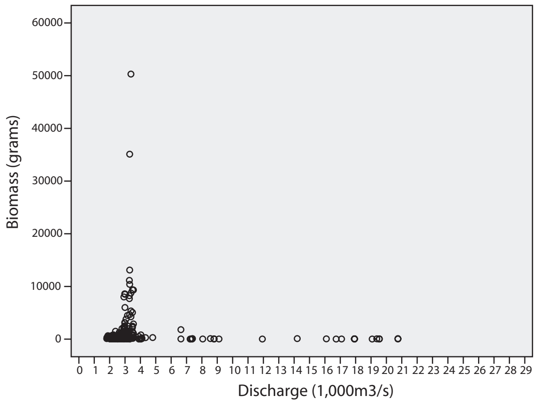

Species: Pseudomystus siamensis
Biomass (grams)
Discharge (1,000m3/s)


Species: Puntioplites falcifer
Biomass (grams)
Discharge (1,000m3/s)

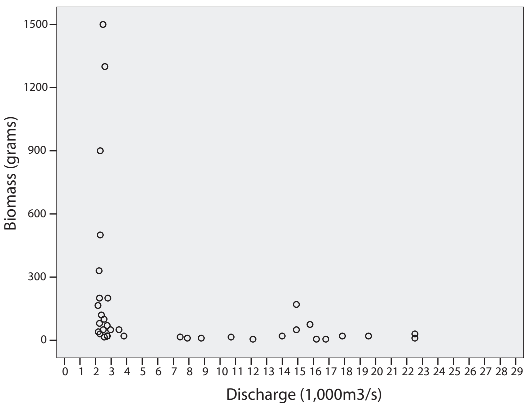
Species: Rasbora spp.



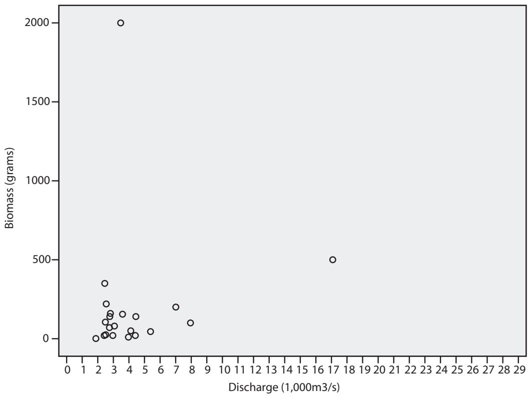
Species: Scaphognathops bandanensis



Species: Sikukia gudgeri



Species: Tenualosa thibaudeaui



Species: Thynnichthys thynnoides