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Abbreviations and acronyms

AMCF	Assessment of Mekong Capture Fisheries (Component of MRC Fisheries Programme)
BOD	Biological Oxygen Demand
DANIDA	Danish International Development Assistance
CA	Catchment area
CEO	Chief Executive Officer
CPOM	Coarse particulate organic matter
DoF	Department of Fisheries (Thailand)
DO	Dissolved Oxygen
EIA	Environmental Impact Assessment (EIA)
GH	Gauge height
IFReDI	Inland Fisheries Research and Development Institute (Cambodia)
IKMP	Information and Knowledge Management Programme (MRC)
ISH	Initiative for Sustainable Hydropower (MRC)
LARReC	Living Aquatic Resources Research Centre (Lao PDR)
LEK	Local Ecological Knowledge (knowledge of the environment, natural history and patterns of resource availability that has accumulated over many generations)
Lmat	Length at maturity (of a fish)
ML	Megalitre (million litres or thousand cubic metres)
LMB	Lower Mekong Basin (in Cambodia, Lao PDR, Thailand, and Viet Nam)
MASL	Metres above sea level
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat

PNPCA	Procedures for Notification, Prior Consultation and Agreement (MRC)
RIA2	Research Institute for Aquaculture No. 2 (Viet Nam)
SL	Standard length (of a fish)
SPM	Suspended particulate matter
TL	Total length (of a fish)
TSS	Total suspended solids (or sediment) (the material retained by filtering water through a 0.45-µm filter. An old term that is still commonly used; a more correct term is suspended particulate matter [SPM] because the retained material contains organic material and colloids).

Executive Summary

This pilot study aimed to provide some basic information on larval and juvenile fish in the Mekong River in northern Lao PDR, including species composition, general patterns of drift density and load, and possible spawning locations and timing, as well as providing information for planning future studies. Sampling was conducted during a period of 75 days in the early wet season (May-August) of 2010 at four sites. Two sites (Pakhao and Thadeua) are 40 and 20 km upstream of the Xayaburi dam site respectively and two sites (Nasak and Angnyai) are 176 km and 364 km downstream of the dam site respectively. Samples were collected four times per day (00:00, 06:00, 12:00, 18:00) with a plankton net suspended in the main current of the river one metre below the surface. For each sample, the net was set to filter water for 30 minutes.

The 1,180 samples collected in this study contained 7,096 fish in 87 species and 22 families. Combination of some congeneric species into groups (one group of two similar species and one group of three similar species) reduced the number of 'species' for analyses to 84. The dominant families were Cyprinidae, Pangasiidae and other catfishes, and other typical Mekong mainstream fish families. The fauna was rather similar at each site as judged by a ranking of species abundance, reflecting similarity of habitat and lack of barriers to dispersal between sites. However, after allowing for differences in total numbers of fish, Nasak appeared to be relatively poor in species whereas Angnyai and Thadeua were relatively rich. These differences may reflect variation in habitat. About 3/4 of the species and 90% of the fish were very small to medium-sized species (up to 50 cm maximum size) with relatively few large or very large species (> 50 cm maximum size), a group which includes many long-distance migratory fish.

The study samples included larvae (57 of 84 or 68% of species and about 80% of individuals), juveniles and adults (about 20% of all fish). As well as fish species which were present as larvae, 27 species were present only as juveniles or adults and in low numbers (about 4% of all fish). While the sampling nets were designed to catch drifting larvae, the presence of larger fish in samples may have represented incidental capture of fish swimming locally but in some cases appeared to indicate active dispersal of juvenile fish. Relatively few species dominated the samples, with ten species making up about 95% of all larvae in samples. The most common among these were the catfishes *Pangasius macronema* and *Glyptothorax lampris* and the carps *Henicorhynchus* spp. The 87 species collected ranged from very small to very large fishes. Over the course of a full year, it could be assumed that many more species would spawn in or upstream of this section of the river with adults, juveniles and larvae requiring passage, posing a major challenge for dam design. This is apart from the issue that fish at different stages have various and different habitat, flow and food requirements, which for many species will not be met once dams alter the environment in the vicinity.

Fish larvae were classified into three stages: yolk-sac (estimated as <1 day old), pre-larvae (estimated as about 1 – 5 days old) and post-larvae (estimated as about 5 – 43 days old); ages are

post-hatching, estimated from known growth rates from other studies. Numbers of fish were converted to density (numbers per megalitre of water filtered), which was multiplied by discharge to provide an estimated load (numbers per day). Overall, the abundance of larvae, particularly pre-larvae, increased between Pakhao and Angnyai (most upstream to most downstream), indicating net input of larvae along this section of the river, either from spawning in the Mekong or in tributaries. At the most downstream site (Angnyai), the mean drift rate was estimated as 5.9 million fish per day, including 5 million fish larvae, so over the 75 days of the study about 375 million fish larvae drifted past this point, and annually the total would be much more. This figure provides some indication of the difficulty of replacing lost recruitment by stocking, even if it were possible to breed in captivity the 200-plus species that inhabit this section of the river. The overall pattern of upstream-downstream accumulation of larvae was heavily influenced by the most abundant species, *Pangasius macronema*. For most other species, there was no clear pattern of accumulation of larvae. Rather, it appears that for most species a proportion moves out of the drift as the larvae develop, swimming to the bed and banks which would be favourable behaviour for fish seeking to access edge habitats during rising water. This interpretation is supported by three general features of the data: (1) generally poor correspondence between peaks of larval drift between sites, (2) some species were abundant at upstream sites but rarer or absent at downstream sites, and (3) for some species, pre- or yolk-sac larvae appeared at more downstream sites at the same time as drift rates did not increase or declined. A 2009 study (Cowx *et al.*, 2015) also showed variable densities of fish larvae down the length of the Mekong which, as in this study, can be attributed to newly hatched fish larvae drifting up to a few hundred kilometres before settling or moving to the edges. In another study in the Mekong River in Chiang Rai province about 335 km upstream of Pakhao, in sampling just prior to this study, Hanpongkittikul *et al.* (2010) found abundant larvae of two large pangasiid catfishes. But these were rare in this study, suggesting that larvae of these species move out of the drift as they develop so few reach the study area as larvae.

Diurnal variation was examined for abundant stages of abundant species. Three species (*Pangasius macronema*, *Glyptothorax lampris* and *Gobiopterus* cf. *chuno*) drifted in greatest densities at midnight and lowest densities at midday; such night-drifting behaviour is an advantage for avoiding predation and has also been found for Pangasiidae elsewhere. However, one species (*Ompok bimaculatus*) was more abundant at dawn and midday and other species showed variable patterns. To be representative, the study samples should be taken during the day and at night.

The results from this 2010 sampling were compared with results from local ecological knowledge (LEK) interviews in 1999, which for this section of the river covered 55 commonly caught species. The LEK study showed that most species migrate upstream and have eggs between March and July with a peak early in the flood (May-June). On a species-by-species basis, the results of this 2010 study are broadly consistent with the LEK findings for northern Lao PDR. Some of the species found in 2010 were not covered by the LEK study (which included only common basin-wide species) and some of the LEK study species were not recorded in the 2010 study, probably because they spawned earlier or later so their larvae were not present at the time of sampling or rare.

Comparison with data sets for fish larvae and juveniles sampling over an equivalent period near Phnom Penh and in the Mekong Delta in Viet Nam showed that the northern Lao samples contained relatively few fish, approximately 1% of the numbers found in Phnom Penh samples. The total load near Phnom Penh for June – August 2010 was estimated to be of the order of 20 billion fish larvae. Comparison with Mekong Delta monitoring samples showed that the total load of fish larvae at Angnyai was about 1/50 of the load in Viet Nam during the study period. Similarly, the 2009 regional study (Cowx *et al.*, 2015) found fish larvae in relatively low abundance in northern Lao PDR; Luang Prabang samples had about 1/50 as many larvae as samples from Phnom Penh, and an even smaller proportion compared with samples from Viet Nam Mekong Delta sites. Lower densities of fish larvae in northern Lao PDR would be consistent with the relatively limited extent and diversity of aquatic habitats in the upland Mekong and smaller fish stocks.

A possible limitation of this study is the validity of the assumption that sampling at a single point in the cross section provides a reasonable estimate of mean density of fish larvae in the water column. At the sampling locations the Mekong is a fast-flowing turbulent and well-mixed upland river, which would tend to distribute fish larvae evenly throughout the main water body. Future studies should include assessment of the pattern of fish larvae and drift across the profile of the river to determine how representative plankton net samples are of the total load of fish larvae.

As discussed in Section 5, there were some operational problems during the study, including flowmeter malfunction, drifting logs in the early flood which tangled nets, and excessive quantities of organic detritus in samples which hindered sorting. Section 5 also contains various recommendations for any future work of this kind based on the experiences of this study.

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1. Introduction

The Mekong River originates in China in the Upper Mekong Basin and flows through Myanmar, Lao PDR, Thailand, Cambodia and Viet Nam before discharging to the South China Sea. It is one of the world's largest river systems, with a catchment area of about 795,000 km^2 and a mean annual discharge of about 475 km^3 (MRC, 2010). The Mekong Basin supports one of the world's largest inland capture fisheries, a resource that provides food and livelihoods for millions of people (MRC, 2010).

Eleven hydroelectric dams are currently proposed to be built on the Mekong mainstream including six in northern Lao PDR (upstream of Vientiane) with one of these (Xayaburi) currently under construction. Each dam may cause various impacts on the aquatic environment and fisheries in its vicinity, as well as for considerable distances upstream and downstream. Many dams are also planned on tributaries.

Despite the importance of fisheries in the Mekong Basin and an ongoing debate over the impacts of proposed mainstream dams, there is relatively little quantitative information that can be used to objectively judge the likely impacts of any particular dam, especially those impacts that are distant from the dam site. Blockage of migration routes (the barrier effect) and alteration of flow patterns may cause many primary and higher-order effects on river systems and the fauna they support. Various other kinds of impacts often result from activities associated with development in the region of a new dam. Of particular concern are transboundary impacts, i.e. those which occur across national borders.

Under national legislation, dam proponents now prepare detailed Environmental Impact Assessments (EIAs). But the biological information they include is usually based on short-term sampling, which provides very limited information, typically a tabulation of the main species present. For EIAs, local people are also usually interviewed regarding the general patterns of fish migration and seasonality of effort and catch. Such local ecological knowledge (LEK) is useful but needs to be complemented by quantitative long-term studies to verify the opinions of respondents, quantify catches and their value, and answer any questions that are beyond the knowledge base of local people. For example, fishers may know that certain fish spawn in their area at certain times. But they will not know about all species and cannot know how many eggs are spawned or how many larvae hatch from them, nor the importance of their fishing areas for any species in the context of the entire Mekong Basin. EIAs may also include secondary data from other studies of fisheries in the Lower Mekong Basin (LMB) which cover Cambodia, Lao PDR, Thailand and Viet Nam. However, such studies either lack geographic coverage (intensive studies at one or a few sites) or have been carried out over limited periods (surveys or censuses), or are snapshots which suffer from both limitations. The Mekong and its tributaries in northern Lao PDR are particularly understudied because access is limited and most research has been directed at the large and valuable fisheries associated with floodplains further downstream in southern Lao PDR, northeastern Thailand and Cambodia.

As well as routine national project EIAs, recent broader catchment-scale assessments include the MRC Strategic Environmental Assessment and Basin Development Plan Scenario assessments. But these also suffer from a lack of the data needed to answer key questions about dam impacts on fisheries.

Of the Mekong mainstream dams that are planned or under consideration, the most advanced is at Xayaburi in northern Lao PDR. In 2010, this dam was the first to be assessed under the MRC's Procedures for Notification, Prior Consultation and Agreement (PNPCA) which raised many issues but provided few quantitative answers to the many questions about its impact on fisheries.

The fieldwork for the pilot study described in this report was carried out in 2010 in anticipation of some of the questions that would be raised during the debate over mainstream dams and, more specifically, to provide information that would be useful in assessing and mitigating the impact of the Xayaburi Dam and other dams proposed in northern Lao PDR. This study aimed to quantify the drift of fish larvae as a way of determining the relative importance of this section of the river for fish spawning and recruitment. Sampling was carried out in the same way as at sites further downstream in Cambodia and Viet Nam, where intensive sampling has been carried out for several years. The study also aimed to obtain information on the fish species that spawn at this time and to provide baseline information.

Sampling for this study (as for the routine studies mentioned above) was during the early wet season which is the period of greatest spawning activity for most of the important lowland fish species in this monsoonal system (e.g. Bao *et al.*, 2001). Early-flood spawning produces eggs which develop rapidly into larvae at a time when growing fish can take advantage of the great expansion of habitat and food availability associated with increased river flows and flooding. As a result of their exploitation of a greatly expanded area of habitat during the wet season, early-flood spawners contribute disproportionately to overall fisheries production. Moreover, they are more catchable and heavily fished while migrating in the early flood and during the flood recession as they migrate off flooded areas.

The approach for this study in northern Lao PDR was to sample intensively in a similar manner to long-term monitoring in Cambodia and Viet Nam to enable a direct comparison with these long-term data sets and also to gain some understanding of the relationship between fish larvae drift and environmental variables, such as river flow. The study was also a trial that would inform future work, particularly regarding the best frequency and duration of any future sampling, any particular issues or problems encountered during sampling, and the likely cost and time limitations. It also provided Lao scientists with field and laboratory experience.

An earlier study in 2009 collected samples using plankton and seine nets and interviewed fishers at 11 sites along the mainstream over one or two-day periods in February, April, May, July, September and November (Cowx *et al.,* 2015). That was a relatively extensive survey with limited coverage over time at a site; by contrast this 2010 study was intensive at four sites in northern Lao PDR using a single method (plankton netting).

In another study, larval and juvenile fish were sampled by Hanpongkittikul *et al.* (2010) over the period 8-28 May 2010, in the Mekong River at Pak Ing, which is 2,305 km from the sea and about 335 km upstream of Pakhao, the most upstream site sampled in this study (Table 1). The Pak Ing study overlapped with the starting date of this study (22 May 2010).

Table 1: Northern Lao PDR sampling sites and long-term monitoring sites in Cambodia and Viet Nam

Country	Sampling locations	Position	Elevation (masl)	Gradient (m/km)	Distance from sea (km)	Distance downstream (km)	Coordinates		Channel width at low flow (m)
							N	E	
Cambodia	Mekong River at Phnom Penh (Chroy Changvar)	2.5 km upstream of Chaktomuk	7	< 0.01	348	1,622	11º 34.732'	104º 56.376'	1,000–2,000
	Tonle Sap at Phnom Penh	1 km upstream of Chaktomuk	7	< 0.01	348	1,622	11º 34.549'	104º 55.969'	390–440
Lao PDR	Pakhao, Xayaburi Province	40 km upstream of Xayaburi dam site	263	1.04	1,970	0	19º 35.382'	101º 47.741'	100–300
	Thadeua, Xayaburi Province	20 km upstream of Xayaburi dam site	253	0.63	1,955	15	19º 25.695'	101º 50.731'	100–600
	Nasak, Xayaburi Province	14 km downstream of Paklai dam site	215	0.31	1,794	176	18º 09.697'	101º 23.207'	300–800
	Angnyai, Vientiane Capital	20 km upstream of Vientiane	166	0.23	1,606	364	18º 00.946'	102º 23.692'	200–800
Viet Nam	Mekong River at Quoc Thai	1.5 km downstream of the Cambodian border	1–2 m	< 0.01	230	1,740	10º 54.583'	105º 11.278'	900–1,700
	Bassac River at Vinh Xuong	1 km downstream of the Cambodian border	1–2 m	< 0.01	229	1,741	10º 57.316'	105º 5.614'	110–160

2. Study sites and background data

2.1 Site selection and basic description

Sites were selected on the Mekong River at two locations upstream and two locations downstream of the proposed Xayaburi Dam. Because sampling was carried out during the day and at night, it was necessary to sample near villages where fishers would be available full time. Road access along the river was very limited in this region, and sites were chosen where there was a road suitable for four-wheel drive vehicles. The main (unsealed) access road (Route 4) was from Luang Prabang inland to cross the river at Thadeua. A round-trip visiting all sites from Vientiane took several days.

Some of the basic features of the sites are shown in Table 1 and the site locations are shown in Figures 1 and 2, with Google Earth images (Figure 3) and photos (Figure 4) of each site. The upper three sites are within the northern uplands while the most downstream site, Angnyai, is in the transition zone to the flatter Korat Plateau (Claridge, 1996). In this region of the LMB, the Mekong River is confined between steep hills, so its level rises and falls within a relatively well-defined channel. There are no extensive floodplains as found in southern Lao PDR and Cambodia. The annual variation in river height is up to 18 metres at Luang Prabang and up to 15 metres at Chiang Khan (Section 2.2 and Table 2). Habitats include pools with muddy-sandy substrata alternating with fast-flowing rapids and runs where the substrate is mainly bedrock, boulders and cobbles. There is very little in-stream vegetation, although algae grow during the dry season and two types of filamentous green algae are harvested for food by local people.

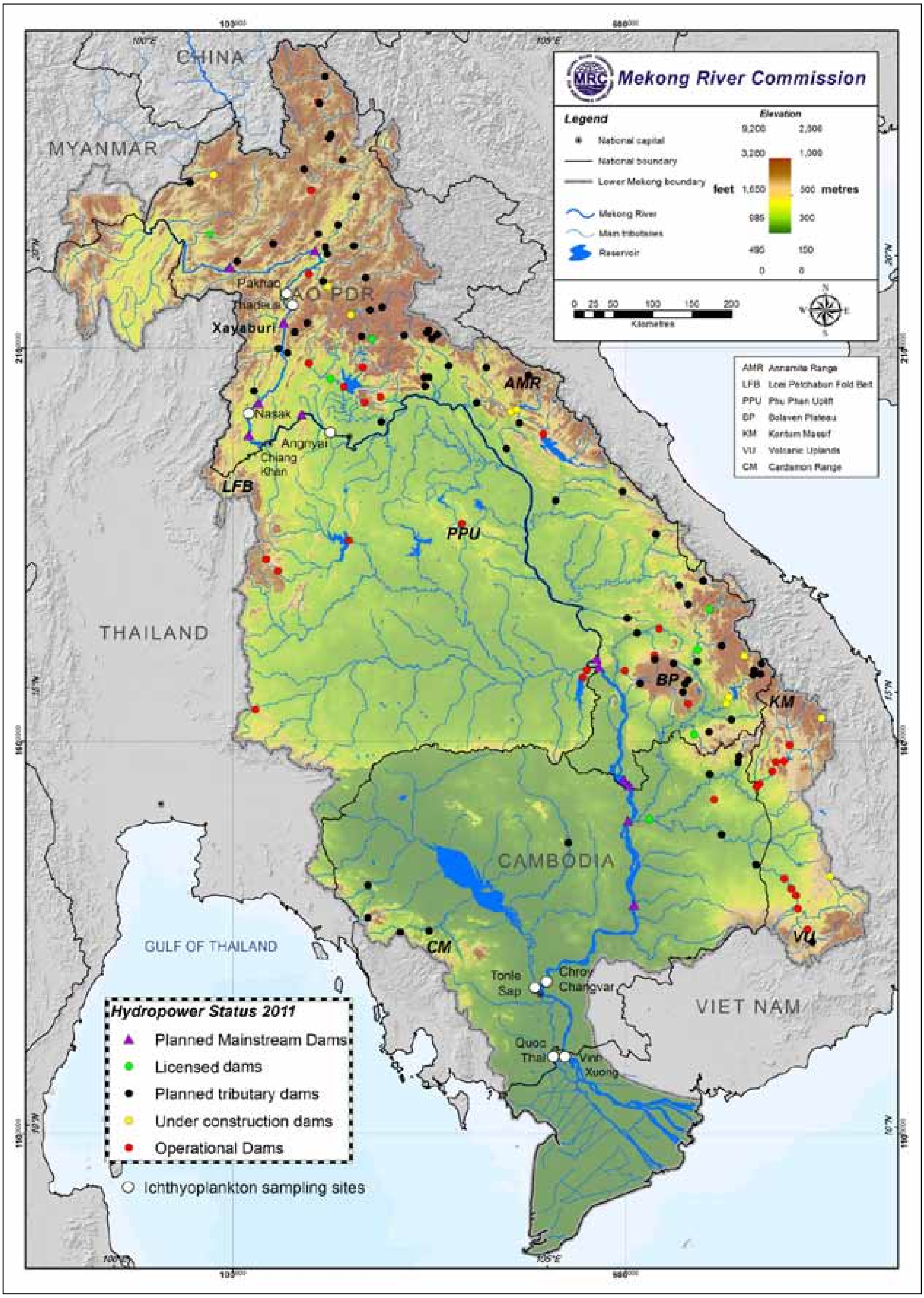


Figure 1: Location within the LMB of the sites discussed in this report

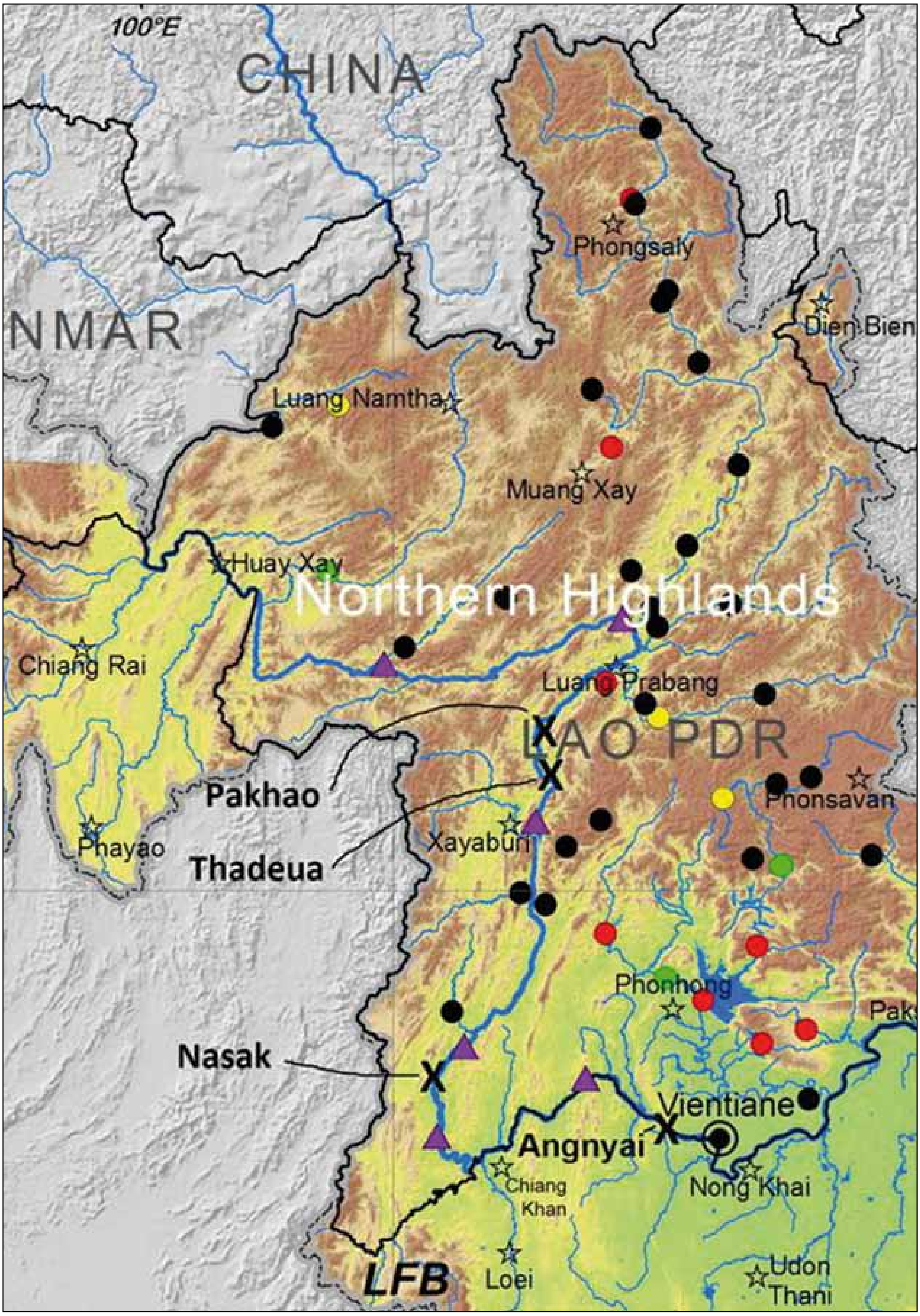


Figure 2: Detail of sampling sites in northern Lao PDR, labelled with X

Expanded from Figure 1. The six proposed mainstream dams are shown as purple triangles; from upstream, Pak Beng, Luang Prabang, Xayaburi, Pak Lai, Sanakham, Pak Chom.

Pakhao

Thadeua

Nasak

Angnyai

Figure 3:
Google Earth images of
sampling sites in northern Lao PDR

Images are to approximately the same scale, in upstream-downstream order

Pakhao

Thadeua

Nasak

Angnyai

Figure 4:
Photos of the sampling sites in upstream-downstream order

2.2 Hydrology at the study sites

Hydrological data were obtained from MRC-IKMP for two gauging stations sites in northern Lao PDR: Luang Prabang upstream of all sampling sites and Chiang Khan, which is between Nasak and Angnyai (Figures 1 and 2). Data were also obtained for the two Cambodian long-term fish larvae monitoring sites and for two sites which are a few kilometres downstream of each of the two Vietnamese long-term fish larvae sites. Water level data were available for all sites, but discharge data for 2010 were only available for three of the sites.

As shown from the summary data in Tables 2 and 3, the annual hydrological variability in northern Lao PDR is much greater than further downstream, with a greater range in river height and discharge, as is typical for large river systems. Short-term variations are also greater in northern Lao PDR with relatively rapid changes in water level and discharge creating more extreme hydrological conditions which, coupled with the relative lack of habitat diversity and absence of floodplains, would tend to select for a more restricted suite of species compared with sites further downstream.

Table 2: Comparison of ranges of some basic hydrological variables for key gauging sites from northern Lao PDR to the Mekong Delta

GH = gauge height. All based on daily data from 1967 to 2010, except Tan Chau (1979-2010) and Chau Doc discharge (2001-2007)

Gauging Station	River	Min GH (m)	Max GH (m)	Difference in GH (m)	Min discharge (m3/s)	Max discharge (m3/s)	Ratio of Max/ Min discharge
Luang Prabang	Mekong	2.1	20.3	18.2	451	22,446	49.8
Chiang Khan	Mekong	1.8	17	15.2	531	22,800	42.9
Chroy Changvar	Mekong	1.5	11.2	9.8	1,331	35,599	26.7
Phnom Penh Port	Tonle Sap	0.4	10.1	9.7	No data	No data	-
Chau Doc	Bassac	-0.35	4.90	5.3	45	7,120	158.2*
Tan Chau	Mekong	0.0	5	5.1	No data	No data	-

* discharge at Chau Doc is affected by tidal fluctuations

Compared with long-term averages (1967-2010), 2010 was a dry year with below-average river levels and discharges of between 68 and 91% of long-term means at the three sites for which 2010 discharge data were available (Table 3).

Figure 5 shows the variation in daily discharges over the course of the year and the increase in discharge between northern Lao sites and Cambodia. At Chroy Changvar (near Phnom Penh), mean discharge is approximately 3.2 times that at Luang Prabang (long-term data) and in 2010 there was a 3.6-fold increase in discharge between these stations.

Table 3: Comparison of means of some basic hydrological variables for key gauging sites from northern Lao PDR to the Mekong Delta.

All based on daily data from 1967 to 2010, except Tan Chau (1979-2010).

Gauging Station	River	Long-term mean GH (m)	Mean GH in 2010 (m)	Long-term mean discharge (m^3/s)	Mean discharge in 2010 (m^3/s)	Ratio of 2010 to long-term mean discharge
Luang Prabang	Mekong	6.9	5.9	3,807	2,601	68.3%
Chiang Khan	Mekong	6.0	5.7	4,251	3,863	90.9%
Chroy Changvar	Mekong	5.0	4.0	12,240	9,275	75.8%
Phnom Penh Port	Tonle Sap	4.0	3.3	No data	No data	-
Chau Doc	Bassac	2.0	0.8	2,625	No data	-
Tan Chau	Mekong	2.0	1.1	No data	No data	-

Discharges for the Lao PDR sampling sites were synthesised based on catchment areas and

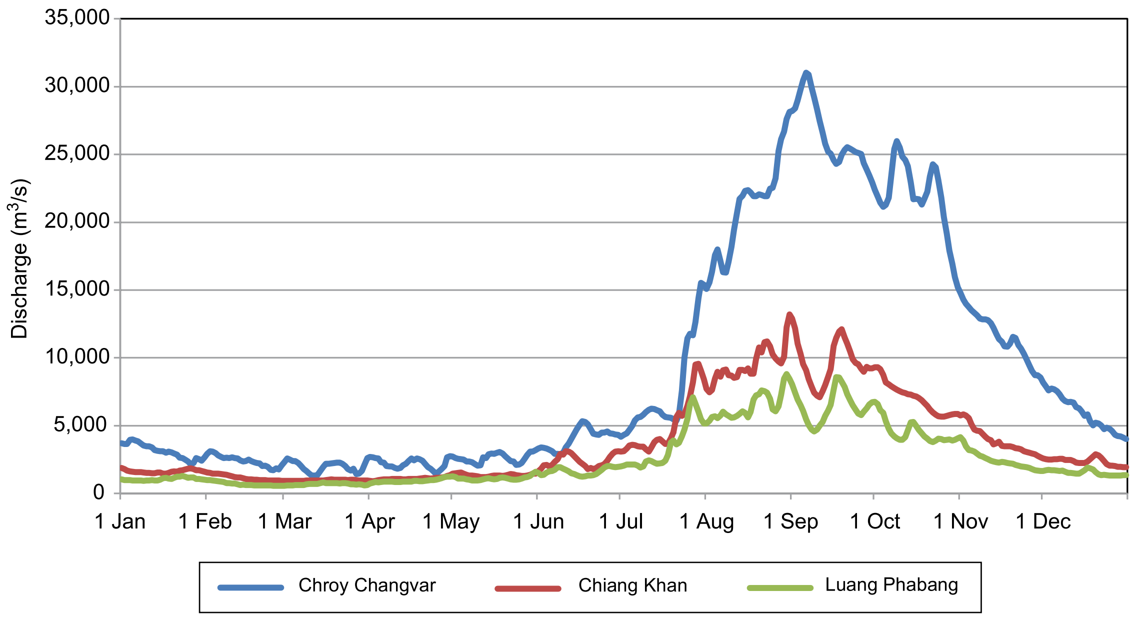


Figure 5: Daily discharges at key gauging stations in 2010

See Figures 1 and 2 for locations.

discharges at the northern Lao gauging sites as explained in Appendix 1, which also mentions some apparent anomalies in the discharge data. Discharge data were used in estimating the load of fish drifting downstream at a site. Figure 6 shows the synthesised values.

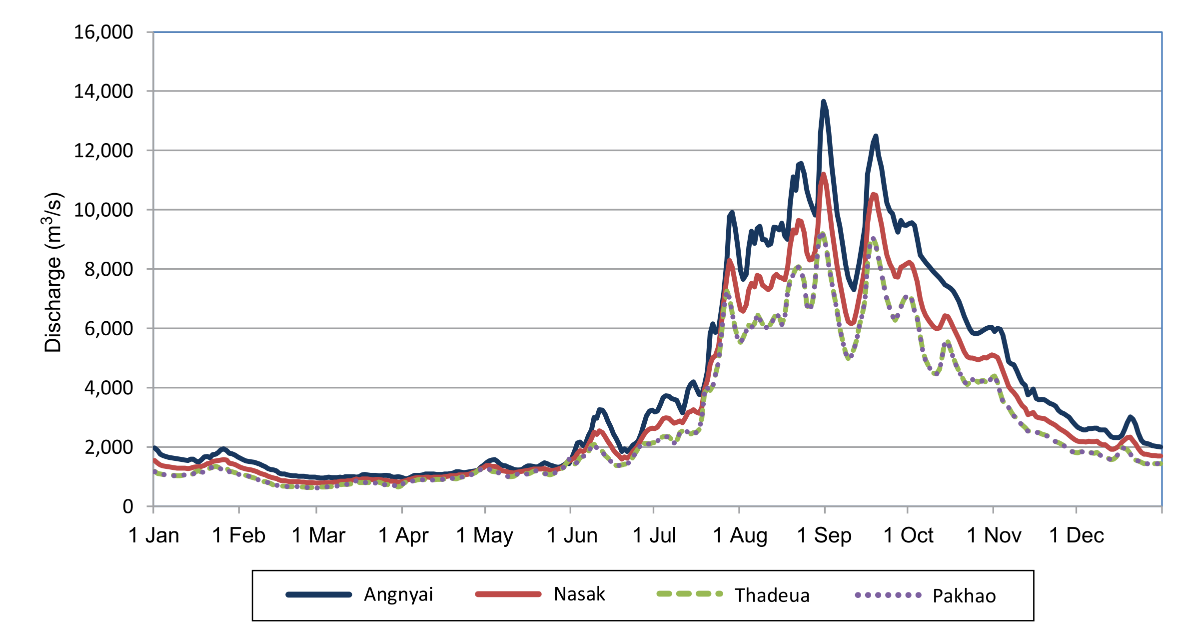


Figure 6: Synthesised daily discharges at sampling sites in northern Lao PDR in 2010
Thadeua and Pakhao are indistinguishable at this scale.

2.3 Water quality

Aquatic animals respond to habitat and hydrology as discussed briefly above, and are also influenced in many ways by water quality, which should also be taken into account in interpreting biological data, such as the data reported herein. MRC (2008) assessed long-term water quality data (1985-2005) to produce an index of suitability of sites on the Mekong for aquatic life. The index is based on selected parameters (dissolved oxygen, pH, ammonia, conductivity, nitrate-nitrite and total phosphorous), being within guideline values for aquatic life. Based on this index, almost all sites on the Mekong mainstream, including all those covered in this report, were considered to have high-quality water in terms of suitability for aquatic life. Statistics for key parameters are summarised in MRC (2008). Since the assessment, examination of MRC data showed that there had not been major changes in the selected parameters (note that these do not include TSS) with the exception that dissolved oxygen (DO) concentrations were very low for all six samples during 2009 at the two Cambodian sites and were also unusually low on some occasions in 2009 further downstream at the two Vietnamese sites. The results seem consistent with high BOD at the time, indicating unusually high organic loads in 2010. At the DO concentrations recorded in Cambodia (as low as 0.3 mg/L), there would be significant effects on sensitive fish and other aquatic organisms. Other parameters, which are important in terms of their impact on aquatic animals, include temperature and TSS. As would be expected, water in northern Lao PDR is generally colder (temperatures as low as 17 °C) than in Cambodia or Viet Nam, where temperatures up to 38 °C were recorded. A further significant difference between the sites is in TSS regime; the northern Lao sites have significantly higher median TSS concentrations and much higher peak TSS concentrations (up to 5,716 mg/L) than the downstream sites in Cambodia and Viet Nam.

While prevailing TSS concentrations up to 25 mg/L are generally tolerated by riverine organisms, species begin to disappear as concentrations increase because sediment has many negative direct and indirect effects on aquatic animals (Alabaster and Lloyd, 1982; Wood and Armitage, 1997; Harrison *et al.*, 2007). Unfortunately, there are no agreed criteria for TSS for aquatic life for tropical rivers and TSS was not used in the MRC (2008) assessment of suitability of the Mekong system for aquatic life. The differences in temperature, oxygen and sediment regime between sites, as briefly discussed above, would tend to select for organisms which are adapted to somewhat different conditions. In summary, at the more upstream sites (in Lao PDR) water is generally colder and well-oxygenated, but at times extremely turbid, whereas at the more downstream sites (in Cambodia and Viet Nam) water is generally warmer, at times anoxic and relatively clear.

It is worth noting that there have been some significant changes in recent years in water quality in northern Lao PDR. As shown in Figures 7 and 8, peak TSS concentrations were less than in previous years from 1997 until 2005 at Luang Prabang and until 2006 at Vientiane; this 8 – 9 year period followed the completion of the Manwan Dam in China and presumably is a result of trapping of sediments in the reservoir formed by that dam. The data indicate that at the time of sampling, the Mekong River in northern Lao PDR was not pristine but already affected by dams upstream with unknown effects on aquatic fauna including fish. Clearance of forests and conversion of land for agriculture in northern Lao PDR and China would also have altered inputs of water, sediment, nutrients and organic material to the Mekong River system (e.g. Moa *et al.,* 2002) but such effects have not been examined systematically.

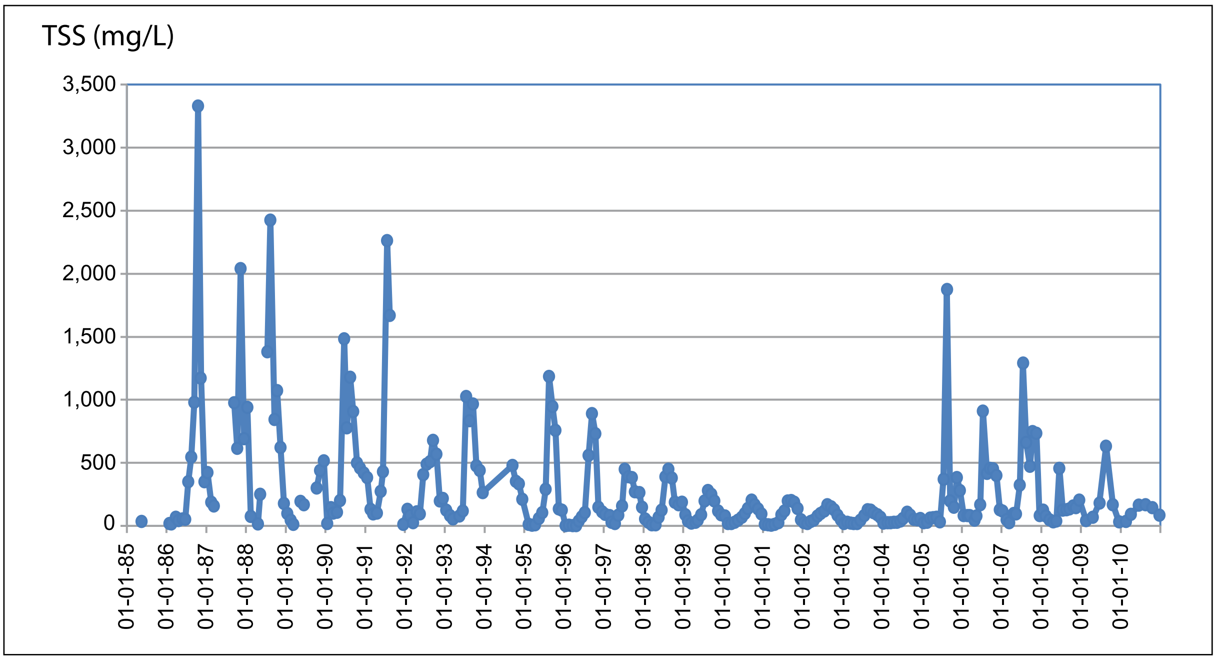


Figure 7: TSS concentrations in the Mekong River at Luang Prabang, 1985-2010

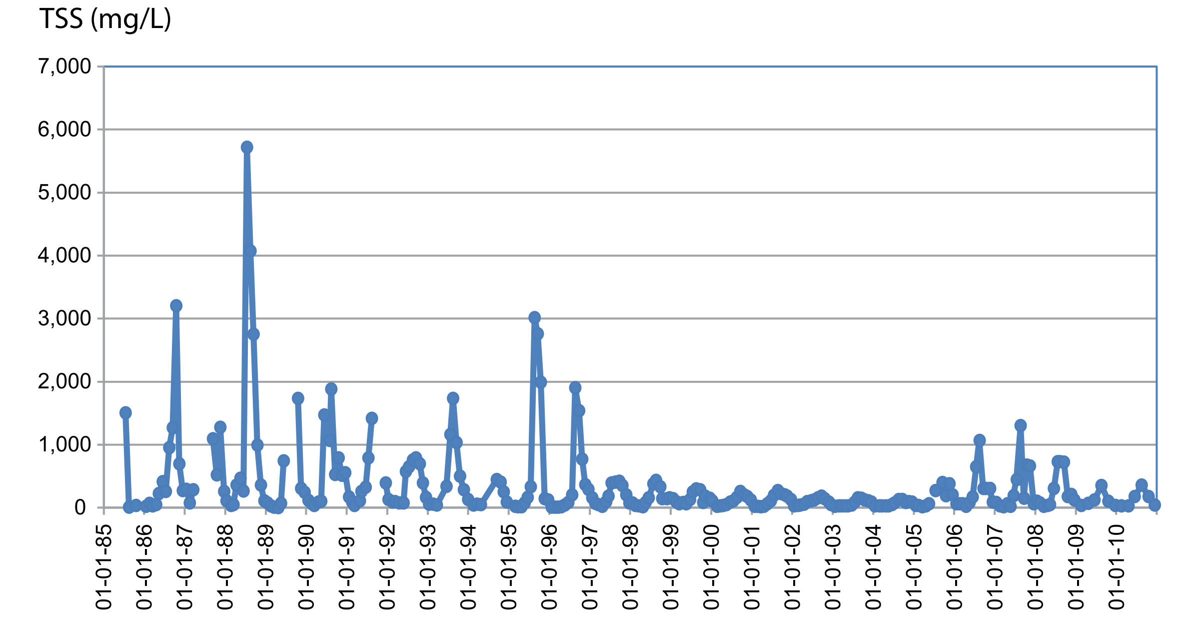


Figure 8: TSS concentrations in the Mekong River at Vientiane, 1985-2010

The dramatic changes in TSS were not evident further downstream at the sites in Cambodia or Viet Nam, as would be expected, given dilution and time lags in sediment transport

2.4 Local Ecological Knowledge (LEK) data

During fieldwork, fishers generally reported increased catches of fish at the beginning and the end of the flood season, which they believe are related to fish migrating upstream and downstream respectively, as has been noted by other authors such as Poulsen *et al.* (2002). Most fishing activity was said to be related to two upstream peaks in migration: April-May (late dry season – start of wet) comprising mainly small cyprinids and silurid catfish, and July-August (early – mid wet season) mainly consisting of larger fish including Pangasiids. These are apparently upstream spawning-related migrations. Local fisheries agency staff and some villagers also reported later September-November (end of wet season) downstream migrations.

As fishers were not systematically interviewed in this study, to get more detailed information, we reviewed the database from the 1999 AMCF Migration and Spawning study that has formed the basis for various subsequent papers and reports such as Bao *et al.* (2001) and Poulsen *et al.* (2002).

The AMCF Migration and Spawning database contains interview data from 449 fishers at 112 villages along the Lower Mekong from Chiang Rai in northern Thailand to Dong Thap in the Mekong Delta in Viet Nam and covers 190 common Mekong fish species. Questions covered (1) direct observations of spawning behaviour, (2) migration behaviour and timing and (3) presence of fish with eggs. Data for the Mekong in northern Lao PDR are based on interviews with 51 fishers in 14 villages along the Mekong in Loei, Xayaburi and Luang Prabang provinces, who provided 385 records on 55 species, of which 47 were considered migratory. As background information, the following summarises some key points from the survey for this section of the river. The LEK study is further referred to in interpreting migration patterns of individual species later in the report.

From the LEK study in this part of the river system, there were only five direct observations from three mainstream-based fishers of spawning, not surprisingly, as river waters are generally turbid in this region. Three records were from the Nam Loei River, a Thai tributary, one from the Huai Kid Reservoir in Thailand, and one from the Nam Hueng River, a Lao tributary. Although spawning is rarely observed, many fishers report upstream and/or downstream migrations (i.e. large-scale movements of fish over short time periods) with the direction usually deduced from the position of fish in nets and other gears. Fishers also observed developed eggs in fish, a good indication that fish are in pre-spawning or spawning condition. Fishers reported the months when migrations began and ended, or the months that eggs were observed (i.e. from first to last). These observations are summarised in Figures 9 to 11. Note that the average duration of the period of upstream migration, downstream migration and egg presence was about one month for each of these variables. For example, a fisher who reported that a particular fish species begins to move upstream in May would typically report that the migration period ended in May or in June.

Figure 9 shows that (according to reports) most fish (90%) begin to migrate upstream in the period March to July, and fish with eggs were reported mostly (80%) in the same period. Downstream migrations were reported mostly (93%) in November and December. These observations (Figures 9 to 11) provide strong evidence that the main period of upstream migration and spawning for the species covered is prior to and in the early wet season, with a downstream migration at the end of the wet season. There are far fewer reports of downstream migrations, perhaps because many fish are caught while migrating upstream (so they do not return) or because the downstream migrations are more attenuated or occur during the flood when fishing is more difficult. The LEK regarding early wet-season spawning supported the approach of sampling from late May to August.

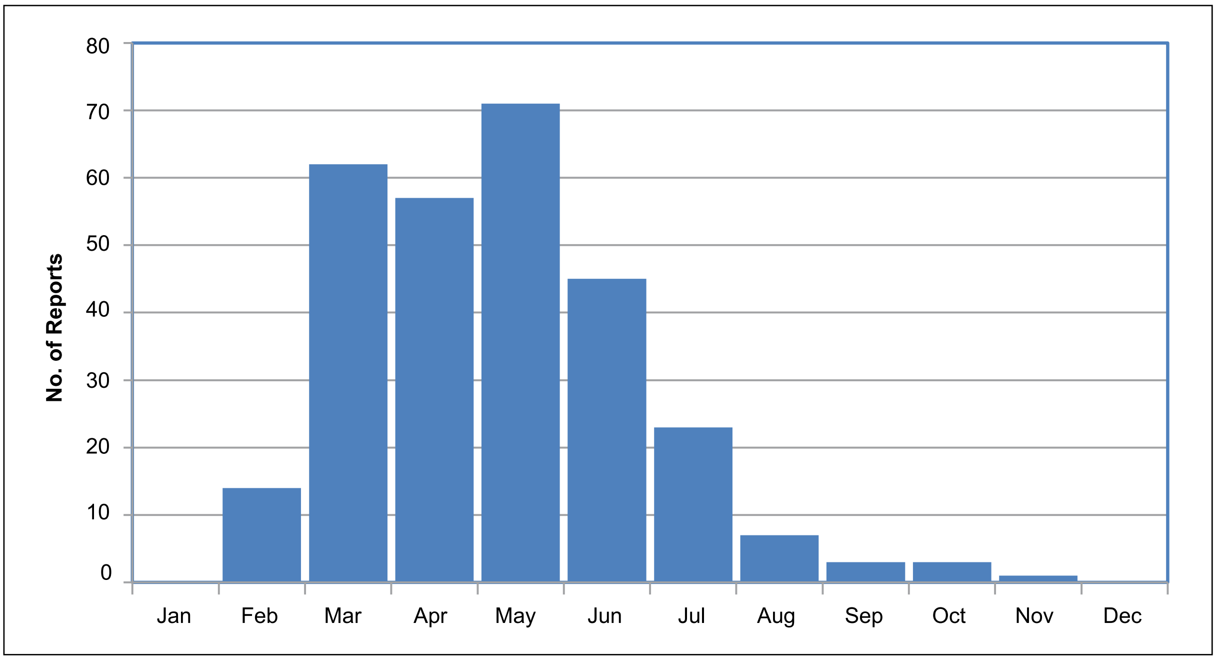


Figure 9: Number of reports of a fish species beginning to migrate upstream each month in the Mekong River from Loei to Luang Prabang

Total = 286 reports for 47 species. AMCF LEK survey 1999

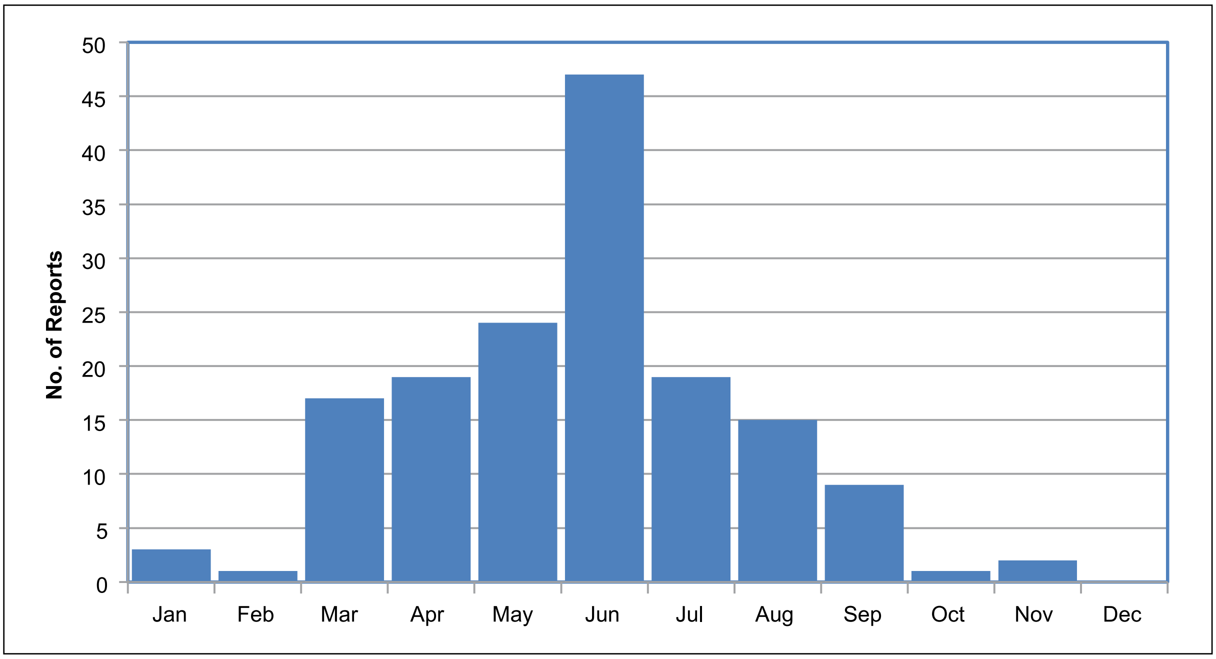


Figure 10: Number of reports of ripe eggs in fish in each month in the Mekong River from Loei to Luang Prabang

Total = 157 reports for 46 species. AMCF LEK survey, 1999

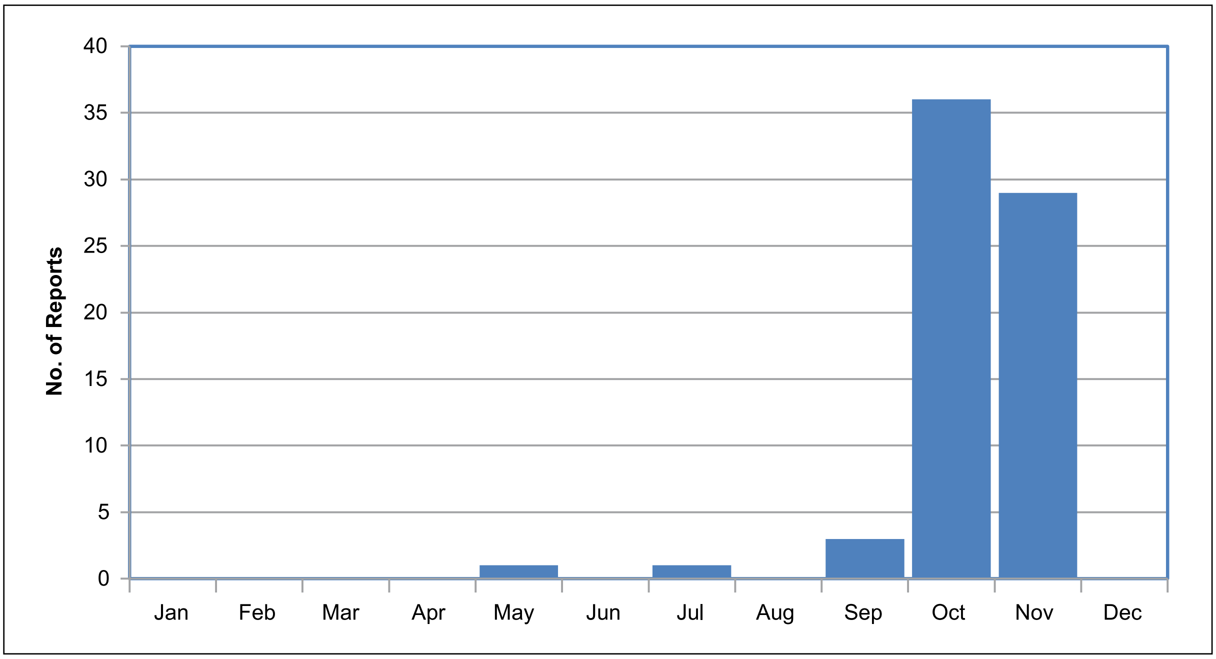


Figure 11: Number of reports of a fish species beginning to migrate downstream each month in the Mekong River from Loei to Luang Prabang

Total = 70 reports for 33 species. AMCF LEK survey, 1999

3 Methods

3.1 Field sampling

At each site, two fishers were hired to sample fish larvae and to record data on forms every day. Local provincial and district government and LARReC staff were responsible for supervising the fieldwork. Fishers were trained in using plankton nets, handling formaldehyde, labelling containers and recording data (Figures 12 – 13).

Samples were taken with a plankton net which had a mouth of one metre internal diameter, a net length of 5 m and mesh aperture of 0.9 mm (checked under a microscope). The net comprised a cylindrical section of about 4 metres, which was attached to a steel hoop, followed by a conical section about 1 metre long, tapering to a collecting jar; such a net is usually termed a 'conical-cylindrical plankton net'[1]. Plankton nets are usually towed behind boats at a constant speed for a fixed time interval to ensure that they filter approximately the same volume of water with the same efficiency for each sample. It should be noted that the efficiency of a plankton net (like any filtering device) varies with speed or flow rate of water passing through. At slower speeds, nets tend to clog with detritus and animals, and faster-swimming species or larger animals are more likely to avoid the net or swim out of it. At faster speeds, more animals enter the net, but smaller animals tend to be forced through the mesh, rather than being slowly swept along the sides of the net into the sampling jar. However, given the need to sample at night and with the large number of samples to be taken (i.e. for safety and cost considerations), the net was suspended by ropes in the current to filter the water rather than towing.

Each site was chosen where the river was well-mixed and nets were set 20 – 30 m from the water's edge within the main flow of the river and way from backwaters and eddies. The depth at each sampling point was 3 – 6 metres. The net was moved periodically as the river rose to maintain approximately the same position relative to the water's edge and to position the net within the main flow of the river. It is not known to what extent selecting this relative position provides a representative picture of fish larvae drift and juvenile across the entire river at any site. But it was assumed that results from each location would be comparable and that the main patterns of diurnal and daily variation would be evident. It should also be noted that the same approach has been followed for sampling fish larvae under MRC-sponsored studies in Cambodia and Viet Nam for many years, so those results should also be comparable.

The net was held in position with anchors as shown in Figure 15, with the ropes adjusted to maintain the upper edge of the net about one metre below the surface. Particles drifting in the water (including fish) were retained by the net and collected in the sampling jar. The net was set four times each day, at 00:00, 06:00, 12:00 and 18:00, and retrieved after 30 minutes each time. Upon retrieval,

[1] In comparison to a net which simply tapers from the hoop to the collecting jar, the cylindrical section in this design enhances flushing of the net by the flow of water.

the sides of the net were washed down to sweep all animals and detritus into the sample jar which was then removed. Samples were preserved by adding 4% formaldehyde and then each sample bottle was labelled with location, date and time of sampling.

Figure 12:
Project staff training fishers at Thadeua Village, Xayaburi Province

Figure 13:
Project staff show how to handle formaldehyde and label bottles at Thadeua

Figure 14:
General Oceanics 2030R flowmeter and recorder

The plankton net was equipped with a General Oceanics 2030R Digital Mechanical Flowmeter fitted with a standard rotor. This meter has a flow threshold of approximately 0.1 metres per second and can measure flow accurately over a range of 0.1 to 7.9 metres per second. The meter has a mechanical counter that records up to 999,999 rotations of the propeller. One rotation of the propeller indicates that 2.6854 cm of water has flowed past it. Each time a plankton net was set and retrieved, the reading on the counter was recorded and the difference in counts indicated the number of rotations of the propeller over the period of setting. This difference was converted to mean flow rate by the formula:

$$\boxed{\text{Flow rate (m s}^{-1}\text{) = No. of rotations x 0.026854 (m) / time of setting (seconds)}}$$

The total volume of water flowing through the net during the period of setting was obtained by multiplying the flow rate by the area of the mouth of the net (0.7857 m^2):

$$\boxed{\text{Volume passing through net (m}^3\text{) = Flow rate (m s}^{-1}\text{) x area of mouth of net (m}^2\text{) x time of setting (s)}}$$

Because the flowmeter was hung in the centre of the net's mouth where flow rates are highest, the formula may slightly overestimate flow rate and volumes. However, this is a standard procedure and any errors should be systematic (i.e. causing a similar bias in all samples) and therefore not affect comparisons.

Samples were stored for up to one month in the field and then collected and transported to Vientiane in a four-wheel drive vehicle.

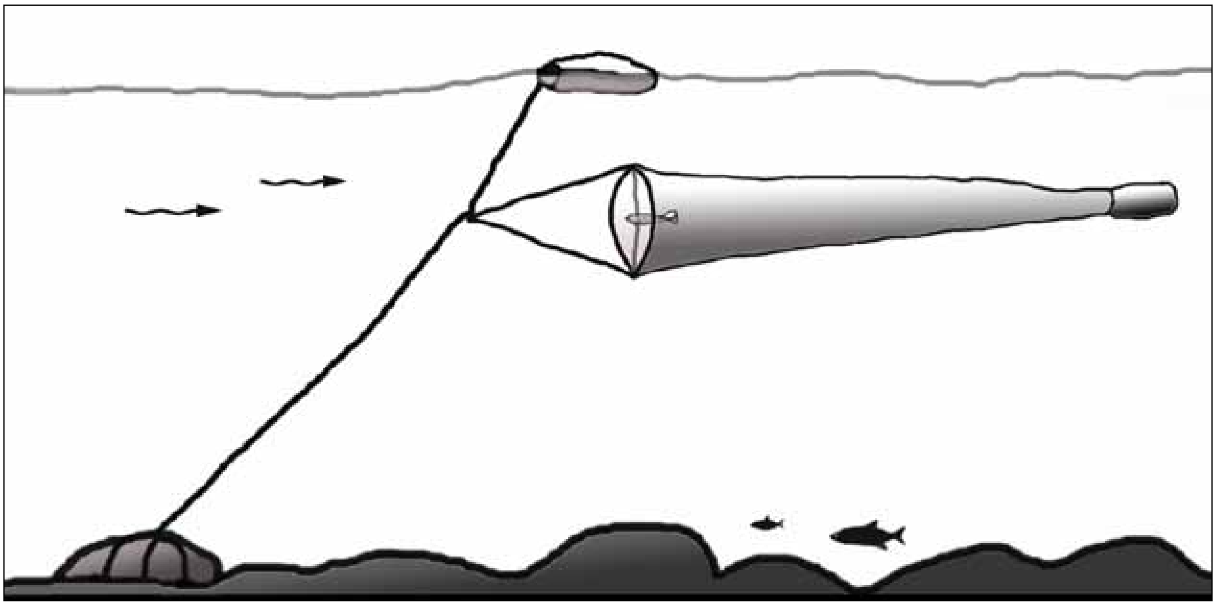


Figure 15: Schematic view of the method of setting the plankton net, using an anchor and a float

The flowmeter is in the mouth of the net

Figure 16:
Checking a plankton net at Angnyai prior to setting

Figure 17:
Retrieving a plankton net sample from the Mekong at Thadeua

Figure 18:
Project staff and fishers with a plankton net and retrieved sample at Thadeua

Figure 19: Field storage of samples at Angnyai

Figure 20: Sorting animals from detritus, and preliminary identification at LARReC

Figure 21: The most common fish in samples, *Pangasius macronema*, pre-larvae and some post-larvae

Figure 22: A common catfish, *Hemibagrus spilopterus*, larvae and juveniles

Figure 23: *Parambassis siamensis*, a very small species for which mostly adults and juveniles were caught

3.2 Sampling dates

Samples were collected over the period 22-May-10 to 21-August-10 (Table 4). Sampling was planned at approximately equivalent periods at each site to allow for drift, by assuming a mean flow rate of about 1 m s^{-1}. Sampling at Pakhao and Thadeua began on the same day, Nasak two days later, and Angnyai a further 3 days later, as shown in Table 4. At two of the four locations, Pakhao (18 – 29 July 2010) and Nasak (21 July – 2 August 2010), logs tangled the plankton nets during the rising flood, dragging them onto the river bed where they remained until retrieved or replaced during visits by the project staff. Because of the need to compare coincident samples, these incidents created a 12-day gap in the data across all sites. There was also a 3-day gap in data at Nasak on 17 – 19 June 2010 which was ignored for comparisons.

Table 4: Summary of sample dates, days and number of samples collected (4 samples per day)

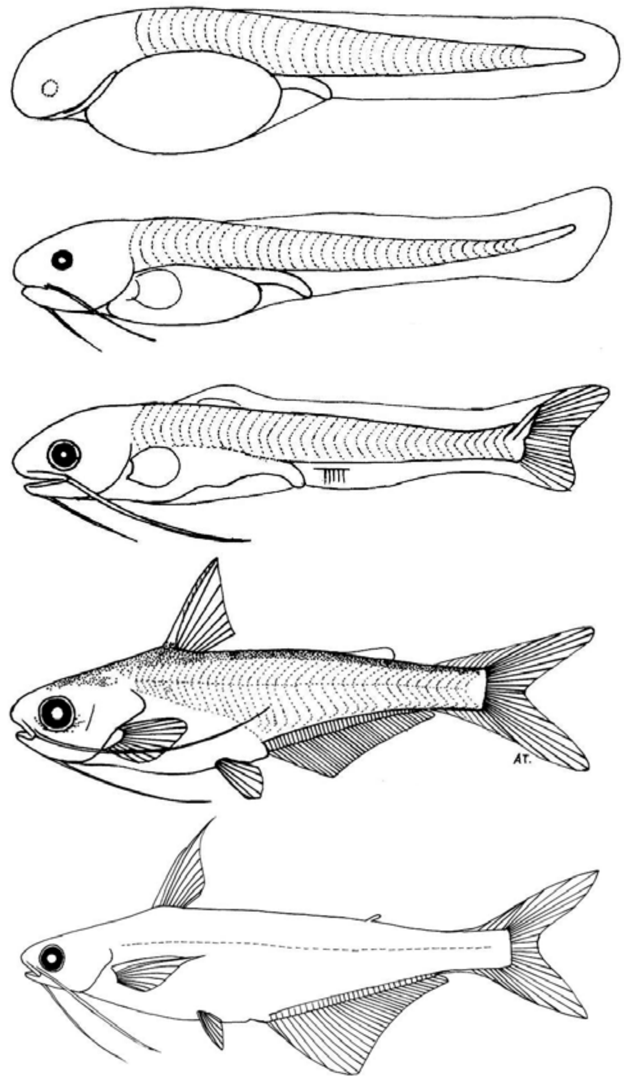
Site	Sampling Dates			Sampling Days	No. of Samples
	Start	Finish	Gap		
Pakhao	22-May-10	16-Aug-10	18 – 29 July 12 days	75	300
Thadeua	22-May-10	16-Aug-10	18 – 29 July 12 days	75	300
Nasak	24-May-10	18-Aug-10	20 July – 2 August 12 days & 17 – 19 July 3 days	70	280
Angnyai	27-May-10	21-Aug-10	23 July – 3 August 12 days	75	300
Total				**295**	**1,180**

* **Note:** discharge at Chau Doc is affected by tidal fluctuations

3.3 Sample processing

In the laboratory, the contents of each sample were washed over a 0.9 mm sieve, then spread in a tray where animals were removed by visual inspection under a magnifying lamp, with some further checking under a dissecting microscope. Animals that were removed were stored in 70% ethanol and fish were later identified by technicians, based on keys and descriptions in texts prepared by Thai DoF (Termvidchakorn and Hortle, 2013 and references cited therein). Representative individuals of each fish species were later rechecked by Dr Apichart Termvidchakorn, the regional fish larvae expert from DoF Thailand.

Fish in each sample were grouped by species and stage of development. The length range (total length) and the stage of development of representative fish in each group were recorded based on reference to the descriptions from Apichart and Hortle (2013). An example of the stages is shown in Figure 24.



Larva - stage: yolk-sac
Age 12 hours, 4.2 mm TL

Larva - stage: pre-lavae
Age 2 days, 5.4 mm TL

Larva - stage: post-lavae
Age 7 days, 9.2 mm TL

Juvenile
Age 45 days, 50.3 mm TL

Adult
Age 1 year, 180 mm TL

Figure 24: Example of developmental stages for *Pangasius macronema*, the most common fish in the northern Lao PDR samples in 2010

From Apichart and Hortle (2013). Drawings by Apichart Termvidchakorn not to scale.

Larval fish:

- **Yolk-sac larva**: After hatching, a fish larva has a yolk sac which can be seen attached to the anterio-ventral part of its body. During this phase, the fish is nourished by yolk and the main body parts and sensory systems develop; these include the mouth, gut, anus, eyes and primordial fins, known as anlages. By the end of this stage, the fish can feed on external prey.

- **Pre-larva:** This stage begins when the eye is fully pigmented and the mouth and anus are open and the fish begins to feed on external prey. In pre-larvae, the vertebral column terminates in a urostyle, a long unsegmented rod-shaped bone which represents a number of fused vertebrae. Late in this stage, the urostyle flexes upwards and the caudal fin rays start to develop. This stage corresponds to pre-flexion larva combined with flexion larvae as applied in some other classification systems.

- **Post-larva:** By this stage, the small fish begins to resemble a juvenile with development of caudal, dorsal and anal fins. This stage ends when the larva has undergone metamorphosis (some species) or when its pelvic fins have developed. This stage corresponds to post-flexion larva in some other classification systems.

Juvenile fish:

A juvenile fish has all organs (except the gonads) functional. The fish gradually assumes the full adult shape as it grows. Certain parts of the fish, such as the number of scales or gill rakers, may increase in number as the fish grows.

Adult fish:

An adult fish has all organs functional, including mature or maturing gonads. In this study, larger fish were classed as adults based on estimated mean size at first maturity (Lmat, in cm) which is related to length (TL, in cm) by the equation: Log_{10} (Lmat) = 0.8776 x Log_{10}(TL) – 0.038. This is the equation for the best fit regression line for 647 fish species[2]. Although approximate, it was adequate to classify fish as juveniles or adults for the purpose of this study.

The **maximum** recorded size for each species was obtained from MRC (2003) and FishBase. Some lengths were recorded in literature as standard length; these were converted to total length by multiplying by an approximate factor of 1.15.

For Mekong fishes, the typical lengths of each stage and typical ages (post-hatching) during early development are known from studies in fish hatcheries, as shown in Appendix 2. These data were used to estimate approximate ages of fish from the recorded lengths based on interpolation of a best-fit line of age versus length. Where there were no data for a species, data from the most similar species or group of species (pooled) was used, similarity being based on taxonomy (same genus or family), size (maximum adult size, Lmax) and trophic guild (carnivore/omnivore/herbivore). The basis for age estimation for each species is shown in Appendix 3. Given that these data are only indicative (individual growth rates can vary greatly and growth rates of wild fish may differ from hatchery fish), the fish were categorised into very broad age groups (post-hatching) as follows:

< 5 days old	Yolk-sac larvae, pre-larvae and for most species early post-larvae
5.1 – 15 days old	Late post-larvae and for some species early juveniles
15.1 – 30 days old	Early post larvae
> 30 days old	Mostly juveniles and adults of small species

[2] http://www.fishbase.org/manual/FishbaseThe_MATURITY_Table.htm

This categorisation meant that some groups of fish had to be re-examined and re-split for measurement of minimum and maximum lengths within an age group.

The maximum distance that fish larvae could have drifted prior to sampling can be estimated approximately based on an assumed current speed in the river and the approximate age of the fish. Fish larvae may move in the water column and accumulate in backwaters, and it cannot be assumed that they have drifted downstream in a linear manner with the main water flow since hatching.

As well as fish, other animals were removed and preserved. These included aquatic insects, terrestrial insects and shrimps. Adult shrimps carrying eggs were common in samples and larval shrimp were extremely abundant and in greater numbers than fish but the results have not been analysed or presented in this report.

Units used for fish abundance

The abundance of fish as sampled in this study can be expressed in several ways:

(1) **Numbers of fish (per net) per unit time:** the number of fish drifting into the sampling net over a standard time interval (30 minutes in this study). This unit is sensitive to an increased density of fish as well as an increased flow or discharge of water. However, because each net was periodically moved to maintain a constant position relative to the edge, the volume sampled does not increase linearly with discharge. Therefore the number of fish in the net should be affected mostly by fish density. This unit is likely to indicate the general pattern of movement past a point, but is not accurate as a measure of density or load.

(2) **Density of fish:** the number of fish caught during the sampling interval divided by the volume of water that was filtered and adjusted to number of fish per thousand cubic metres (or megalitres) of water (no. ML^{-1}). This unit is preferable to numbers (per net) per unit time (1). But if flow information is missing or inaccurate, values cannot be calculated. This unit may be misleading because discharge varies over time and between locations. So different fish densities may be a result of varying discharge (i.e. more or less dilution) rather than differences in the load (3), the total number of fish drifting past the sample location.

(3) **Load of fish:** the number of fish drifting past the sampling location in the entire river per unit time (fish per day). To calculate loads accurately, it is necessary to account for variation in fish density across the river section and at various depths. In the absence of cross-sectional sampling, loads cannot be estimated with certainty. However, to examine variation over time or between locations, taking account of discharge variation is essential. It was assumed that the water was well-mixed at the sampling sites where the river is turbulent and fast. An estimated load (no. of fish day^{-1}) was calculated by

multiplying the density of fish (no. m^{-3}) by the discharge (m^3 s^{-1}) in each of four daily samples, then averaging the load estimates to obtain a daily estimate. Discharge data were obtained from the IKMP-MRC hydrological database as discussed in Section 2.1.2.

3.4 Ancillary data

Data of sampling of fish larvae from Cambodia and Viet Nam were obtained from line agency staff who had been responsible for these long-term data sets.

4 Results

4.1 Operational issues and basic sample data

As well as drifting logs tangling nets as mentioned above, there were some errors in flowmeter readings which required minor adjustments to data at three of the four sites, where the data were generally of good quality. Because of problems with flowmeter readings, the density and load estimates for Nasak should be considered less reliable than at the other three sites as discussed fully in Appendix 6.

Excessive detritus was present in some samples during the rising flood. So it might also be desirable to reduce sample duration to avoid nets clogging, an adjustment that is usually made in drift-sampling studies. This would be feasible only if technical staff were on-site full-time to supervise.

4.2 Overview of fish composition and abundance in drift

The 1,180 samples collected during this study contained a total of 7,096 fish in 84 species or species groups in 22 families. The species groups were *Henicorhynchus* spp., which include *H. siamensis* and *H. lobatus,* and *Kryptopterus* spp. which include *K. cheveyi, K, geminus* and *K. schilbeides*. Smaller larvae within these groups are very similar and cannot be identified to species. The total species count is therefore 87, but for simplicity, the two species groups are also referred to and counted as 'species'.

The fauna at each site was rather similar in terms of the proportions and ranking of each species. A simple way of judging similarity is by rank correlation based on the total numbers of individuals of each species recorded at each site; Spearman's Rho varied from 0.51 to 0.77 for comparisons between all pairs of sites and all correlations were highly significant ($\rho < 0.001$). Similarity in the fauna would be expected as the habitat was similar at all sites, and because fish movement between sites was unobstructed by barriers.

Of the 84 species (or groups) of fish collected, 57 species or 68% were present as larvae and most of these (36 species) were also present as juveniles. However, a significant number of species were present only as juveniles and/or adults (27 species); i.e. at the time of the sampling, they were not contributing to larval drift. The number of species recorded from each site varied as shown in Table 5. As a general rule, as more fish are collected more species are also recorded, which needs to be taken into account in comparisons between sites. Allowing for the variation in numbers of fish collected at each site, it appears that there were fewer species present as larvae at Nasak which might indicate a lower abundance of some species, perhaps an unfavourable habitat for spawning for some species or some difference in relative position of setting the plankton net at that site. For the 27 species recorded only as juveniles and/or adults (i.e. not as larvae), there were fewer species at Nasak and Pakhao, which may reflect higher abundance of small and very small species at some sites or differences in sampling efficiency for these larger fish between sites.

Table 5: Total numbers and species of fish recorded from each site

Group	Parameter	Pakhao	Thadeua	Nasak	Angnyai	Table
All fish	Number of species	34	49	37	60	84
	Number of fish	810	2,127	1,496	2,663	7,096
Species which had larvae	Number of species	23	34	19	38	57
	Number of larvae	512	1,529	1,333	2,304	5,678
	Number of juveniles/adults	246	507	94	290	1137
	Total number	**758**	**2,036**	**1,427**	**2,594**	**6,815**
Species without larvae	Number of species	11	15	18	22	27
	Number of juveniles/adults	52	91	69	69	281

Table 6: Summary of fish in samples grouped by families

Family	No. of species in samples	Percent	No. of fish in samples	Percent
Bagridae	3	3.6%	181	2.6%
Pangasiidae	7	8.3%	3,365	47.4%
Salangidae	2	2.4%	140	2.0%
Schilbeidae	2	2.4%	49	0.7%
Siluridae	8	9.5%	259	3.6%
Sisoridae	4	4.8%	491	6.9%
All catfish (subtotal)	**26**	**31.0%**	**4,485**	**63.2%**
Ambassidae	1	1.2%	151	2.1%
Anabantidae	1	1.2%	1	0.01%
Balitoridae	1	1.2%	1	0.01%
Channidae	2	2.4%	16	0.2%
Cichlidae	1	1.2%	2	0.03%
Clupeidae	3	3.6%	63	0.9%
Cobitidae	1	1.2%	1	0.01%
Cyprinidae	34	40.5%	2,023	28.5%
Eleotridae	1	1.2%	3	0.04%
Gobiidae	3	3.6%	301	4.2%
Loricariidae	1	1.2%	5	0.1%
Mastacembelidae	1	1.2%	6	0.1%
Nandidae	2	2.4%	6	0.1%
Notopteridae	2	2.4%	23	0.3%
Osphronemidae	3	3.6%	7	0.1%
Soleidae	1	1.2%	2	0.03%
Total	**84**	**100.0%**	**7,096**	**100.0%**

Most of the fish and most species collected were either Pangasiid catfish (47% of numbers and 8% of species) or Cyprinidae (29% of numbers and 41% of species); some other catfish families as well as some very small fishes such as gobies (Gobiidae) and glass perch (Ambassidae) were also relatively abundant (Table 6). The dominance of catfishes and cyprinids is typical for fish samples from the Mekong mainstream.

Most of the fish in samples were larvae of medium-sized species, but 60% of the species and about 37% of the fish in samples were either small or very small species (Table 7). In general, long-distance migratory fishes tend to be larger species. Few very small or small species are likely to be active long-distance migrants as maximum swimming speed and endurance of fish depend partly upon their size.

Table 7: Summary of fish in samples classified by maximum size recorded in literature
From FishBase – refer to the text; TL = total length

Category	Maximum recorded size in literature (TL cm)	No. of species in samples	Percent	No. of fish in samples	Percent
Very Small	0 – 12.5	25	30%	1,266	17.8%
Small	12.6 – 25	25	30%	1,384	19.5%
Medium	25.1 – 50	14	17%	3,617	51.0%
Large	51 – 100	10	12%	239	3.4%
Very Large	> 100	10	12%	590	8.3%
Total		**84**	**100%**	**7,096**	**100.0%**

Table 8: For all fish (larvae, juveniles and adults), the most abundant species in samples, mean values for all fish at all sites
Species that comprised > 1% of total numbers in terms of mean density or mean load across all sites
* species that did not comprise >1% of larvae across all sites
Maximum lengths from literature (FishBase – refer to the text)
TL = total length
Unshaded species had few larvae

Species	Mean No. day^{-1} all sites		Mean No. ML^{-1}		Max length (cm TL)	Category
	Percent	Cumulative Percent	Percent	Cumulative Percent		
Pangasius macronema	39.8%	39.8%	52.2%	52.2%	40	Medium
Henicorhynchus spp.	16.9%	56.7%	10.0%	62.2%	20	Small
Cosmochilus harmandi	7.7%	64.4%	6.9%	69.1%	100	Large
Hemibagrus spilopterus	4.8%	69.2%	2.6%	71.7%	75	Large
Glyptothorax lampris	4.5%	73.7%	5.0%	76.7%	7	Very small
Paralaubuca barroni	2.6%	76.3%	2.8%	79.4%	15	Small
Cyclocheilichthys armatus	2.3%	78.6%	1.7%	81.1%	26	Medium
*Parambassis siamensis**	2.2%	80.9%	2.0%	83.0%	7	Very small
*Puntioplites proctozystron**	2.1%	83.0%	1.2%	84.2%	25	Small
Gobiopterus sp.	1.8%	84.8%	2.4%	86.6%	5	Very small
*Mystacoleucus marginatus**	1.8%	86.6%	1.4%	88.0%	20	Small
Neosalanx sp. cf. jordani*	1.4%	88.0%	1.6%	89.6%	8.5	Very small
Ompok bimaculatus	1.2%	89.2%	1.3%	91.0%	50	Medium
Kryptopterus spp.	1.0%	90.2%	0.9%	91.9%	20	Small
Phalacronotus apogon	1.0%	91.2%	0.7%	92.6%	77	Large
Other (69 spp.)	8.8%	100.0%	7.4%	100.0%		

Of the 84 species of fish recorded, 15 species made up about 90% of the total abundance, judged as mean load or mean density across all sites (Table 8). Of these 15 species, 4 species were present mainly or wholly as juveniles or adults (not highlighted in Table 8) and did not contribute more than 1% of total larval abundance. The other 11 common species each made up more than 1% of larval abundance, and cumulatively made up about 96% of larvae sampled (Table 9), judged as mean density or load, so the drift of these species was examined in most detail. However, the total numbers of larvae of each species collected were also taken into account. Only species which comprised more than 1% of all larval fish in samples (i.e. 1% of 5,678) were plotted; *Phalacronotus apogon* (36 larvae), ranked 10th by mean density was not plotted, in favour of *Paralaubuca barroni* (81 larvae, but ranked 11th by mean density - Appendix 4 shows raw counts for all fish).

Table 9: For fish larvae, the most abundant species in samples, mean values for all fish larvae at all sites

Species that comprised > 1% of total numbers of larvae in terms of mean density or mean load across all sites
Maximum lengths from literature (FishBase – refer to the text; TL = total length)
Note that 27 species were present only as juveniles and/or adults so total numbers re less than in Table 10

Species	Mean No. day^{-1} all sites		Mean No. ML^{-1}		Max length (cm TL)	Category
	Percent	Cumulative Percent	Percent	Cumulative Percent		
Pangasius macronema	51.8%	51.80%	63.7%	63.7%	40	Medium
Henicorhynchus spp.	22.0%	73.8%	12.2%	75.9%	20	Small
Glyptothorax lampris	5.5%	79.3%	5.9%	81.7%	7	Very small
Cosmochilus harmandi	5.2%	84.5%	4.5%	86.2%	100	Large
Gobiopterus sp.	1.7%	86.2%	2.2%	88.4%	5	Very small
Hemibagrus spilopterus	2.7%	89.0%	2.0%	90.4%	75	Large
Cyclocheilichthys armatus	2.2%	91.1%	1.6%	92.0%	26	Medium
Ompok bimaculatus	1.4%	92.5%	1.5%	93.5%	50	Medium
Kryptopterus spp.	1.3%	93.8%	1.1%	94.6%	20	Small
Phalacronotus apogon	1.2%	95.0%	0.8%	95.4%	77	Large
Paralaubuca barroni	0.8%	95.8%	1.1%	96.5%	15	Small
Other species (46)	4.2%	100.0%	3.5%	100.0%		

As shown in Tables 10 and 11 and Figures 25 and 26, most of the fish were pre-larvae and post-larvae, but a significant proportion (about one fifth) were juveniles; adults of 13 very small species were also collected in the plankton nets. Overall, about 82% of fish by density or 77% of fish by load were larvae, of which approximately equal proportions were pre-larvae and post-larvae with very few (<1%) yolk-sac larvae. While it can be assumed that larvae drifted into the nets, juvenile and adult fish may have been caught while swimming locally in the vicinity of the nets so cannot be assumed to have been passively drifting or actively migrating downstream.

Table 10: Mean abundance of fish of each stage at all sites 1,180 samples and 7,096 fish

Statistic	Yolk-sac larvae	Pre-larvae	Post-larvae	Juveniles	Adults	Total
No./30-minute sample	0.04	2.20	2.55	1.14	0.05	5.98
Density (No./ML of filtered water)	0.1	4.8	4.8	2.1	0.1	11.8
Load (No./second)	0.3	12.8	10.4	6.7	0.4	30.5
No. of Species	5	13	56	61	13	84

As shown in Table 11, larval fish varied between an estimated age of 2 hours and 43 days. Yolk-sac larvae were all estimated to be less than two days old and all pre-larvae were estimated to be less than 5 days old. Post-larvae were up to 43 days old. The youngest juvenile fish present were estimated as being approximately 16 days old but about 85% of juvenile fish were estimated as older than 30 days. The wide range in estimated ages across all fish and within larval stages (i.e. the three sub-stages combined) makes it difficult to draw inferences about precise spawning locations, and more detailed examination is required to attempt to track development species by species. Assuming passive drift and a mean current speed of 1 m s^{-1}, fish larvae could drift up to 86.4 km day^{-1}. Even if spawning events are localised and of short duration, fish are likely to drift variable distances as a result of random transport into slower or faster areas of the river which would cause attenuation of any peaks with transport downstream. Fish larvae can also swim actively as they develop swim bladders within a few days of hatching, enabling them to move vertically or laterally in the water column, so a simple upstream-downstream pattern in larval drift should not be assumed.

Table 11: Estimated ages post-hatching and proportions within age categories for all fish

Stage	No.	Length (TL mm)		Estimated age (days)		Age category			
		Min	Max	Min	Max	< 5 days	5.1 – 15 days	15.1 – 30 days	> 30 days
Yolk-sac larvae	50	3	7	0.1	1.8	100%			
Pre-larvae	2,603	5	8	1.0	4.9	100%			
Post-larvae	3,025	6	36	3	43	22%	60%	12%	6%
Juvenile	1,355	15	113	16	164			12%	88%
Adult	63	32	84	54	148				100%
All fish	**7,096**	**3**	**113**	**0.1**	**164**	**47%**	**25%**	**8%**	**20%**

Figure 25 shows that there were relatively minor differences in the mean density of juvenile and adult fish with downstream progression. But the density of fish larvae generally increased from upstream to downstream. The increase was more pronounced for loads (Figure 26) than density because discharge increases downstream. The increase indicates an addition of larvae between the sites as a result of fish spawning either in the Mekong mainstream or in tributaries which flow into the Mekong between the sampling sites. The load of pre-larvae (up to 5 days old) increased most between Thadeua and Nasak and between Nasak and Angnyai with increasing loads of post-larvae also a likely result of development of pre-larvae.

At the most downstream site (Angnyai), the mean load estimate of about 5.9 million fish per day included 5 million fish larvae drifting downstream per day, or about 375 million fish larvae over the 75 days of the study. Most of the increase in load of larvae between sites comprised a few abundant species, especially the catfish *Pangasius macronema*. Drift of some other species did not increase between sites, as discussed below. While the estimated total load seems large, it should be noted that many Mekong fishes may spawn tens or hundreds of thousands of eggs so the estimates are in fact quite low relative to the possible load and much lower than further downstream as explained in Section 5.

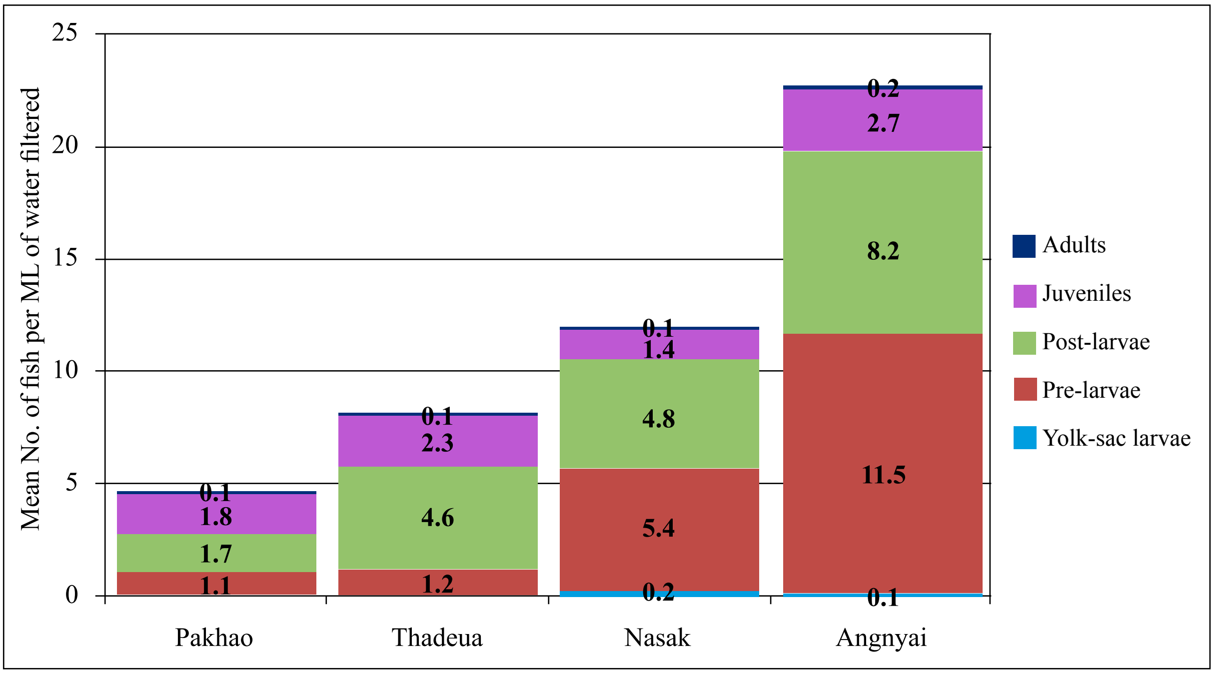


Figure 25: Mean density of fish of each stage at each site

Units are no. of fish per ML or 000 m³ of filtered water. All fish species combined, N = 75 at each site except N = 70 at Nasak.

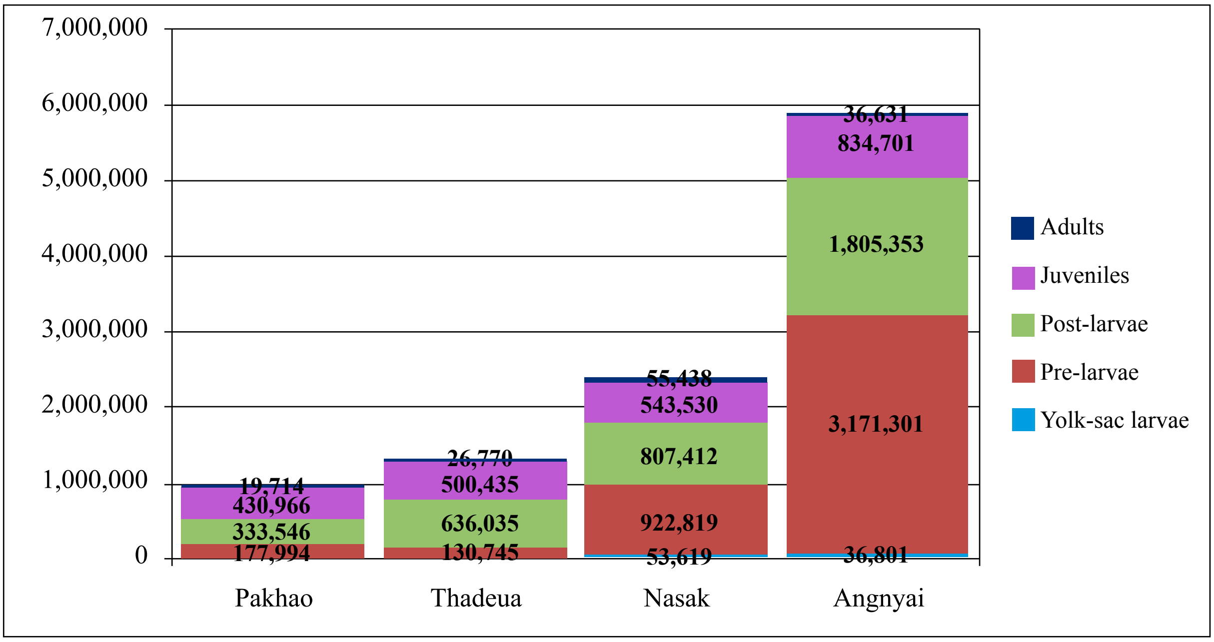


Figure 26: Mean load of fish at each stage at each site (mean number of fish per day)

All fish species combined, N = 75 at each site except N = 70 at Nasak

Variation over the period of sampling

As shown in Figure 27, there was considerable variation in fish abundance over the period of sampling with a general decrease in fish density (numbers/ML) while discharge increased, with these two variables negatively correlated (Spearman's Rho (ρ) = – 0.26 to – 0.75), which can be attributed mainly to dilution. The relationship for individual species varied, but overall there appeared to be a strong effect of dilution by rising floodwaters. This result shows that comparison of fish density may lead to quite erroneous conclusions regarding differences between sites and times, which may simply reflect varying degrees of dilution.

The relationship of fish load with discharge was highly variable and inconsistent between sites. It was significantly positive at Pakhao ($\rho = 0.33$) and negative at Thadeua ($\rho = -0.22$) and Angnyai ($\rho = -0.47$). At Nasak, there was no relationship ($\rho = 0.06$). The variability is shown for the most common species below.

There was a strong correlation between daily mean raw counts (fish/30 minute sample) and daily mean fish density (fish/ML) at all four sites ($\rho = 0.85 – 0.98$, all $p < 0.001$) showing that the main determinant of fish density was number of fish per sample rather than variation in volume filtered which was relatively minor.

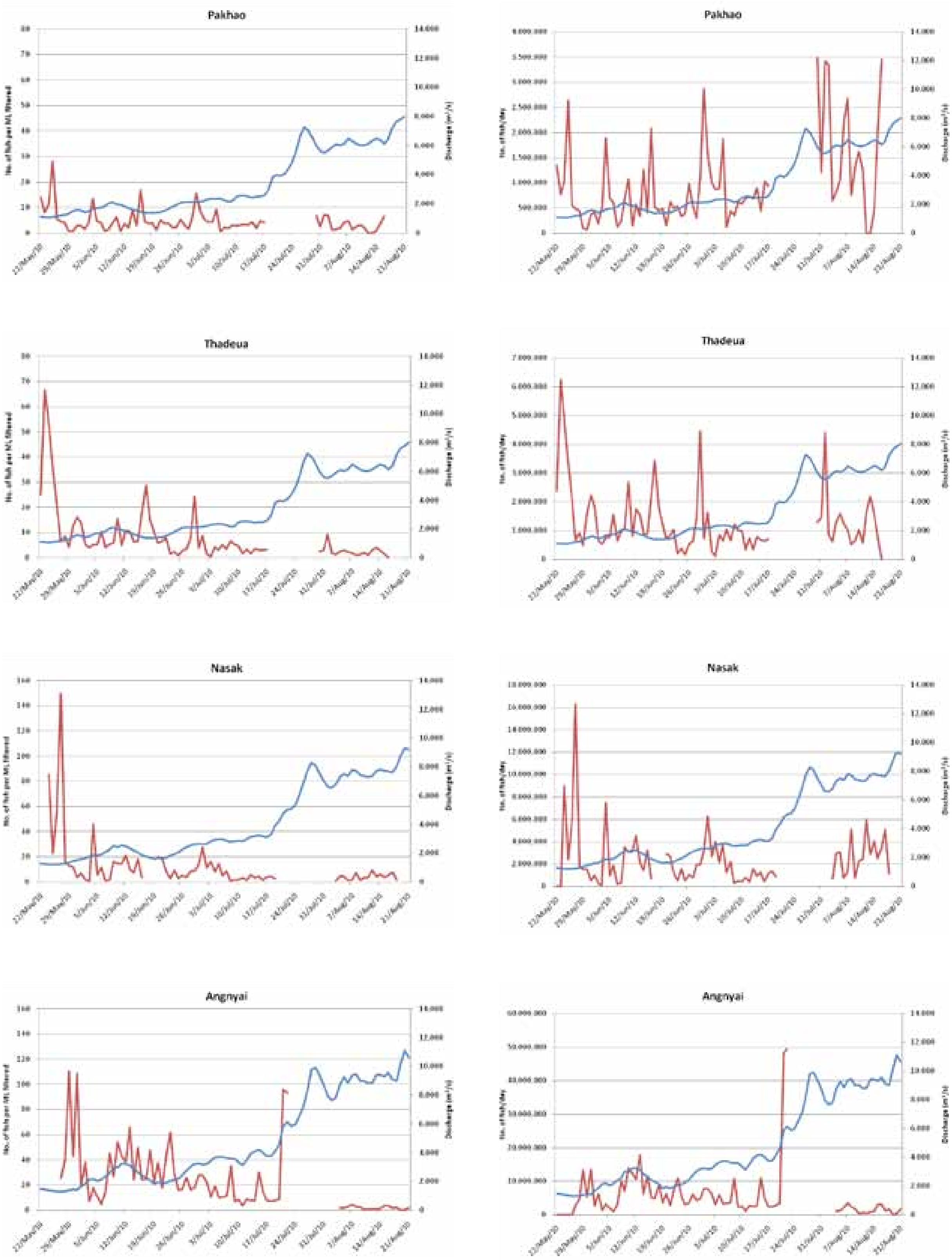


Figure 27: Daily abundance of fish (all species and stages) in samples (red line) and discharge (blue line)

Units are density [fish per ML (000 m^3) of filtered water] left side, and load – [fish per day] right side

4.3 Species composition and trends over time

To compare patterns in species abundance between sites and over time two approaches were taken:

1. The patterns in drift for the ten most abundant species (> 1% contribution to the total 5,678 total larvae collected) were plotted for each station and examined (Figures 28-37).

2. The raw counts for each species were also examined, as summarised in Appendix 4.

As mentioned above, most species were uncommon, making up less than 1% of total abundance by any measure. For these fishes, counts and dates of larvae were itemised by sites and the pattern summarised (Appendix 4).

General patterns in drift for common species

Figures 28 to 37 show the patterns in drift for the 10 most common species, showing load of larvae at each stage and also juvenile fish where there were significant numbers relative to larval numbers. Sites are shown in an upstream-downstream direction. The graphs provide an indication of the change in fish load over time and also the relationship between peaks at each site. The presence of yolk-sac larvae (< 2 days old) and pre-larvae (1 – 5 days old) indicates recent spawning at or upstream of the study sites, which aids interpretation of the graphs. If such early-stage larvae were present at a particular site but not at the sites upstream in the preceding few days, it is likely that spawning occurred at or upstream of the particular site but not as far upstream as the next site. The discussion for each species also mentions information from LEK survey data for this part of the Mekong River, as discussed below.

All ten common species showed evidence of spawning throughout the study period and also at multiple locations along the river. Two of the ten most common species (*Pangasius macronema* and *Cyclocheilichthys armatus*) showed a pattern of upstream-downstream accumulation of larvae in the drift, with a large proportion of larvae being transported past Angnyai. For all other common species, however, drift appears to be a more complex phenomenon with variable load between sites and some larvae probably exiting the drift by moving to the bed and banks along this section of the river, while younger larvae (especially yolk-sac or pre-larvae) continue to enter the drift from other spawning events. The drift pattern for the ten most common species is discussed below with reference to Figures 28 to 37.

Pangasius macronema**,** the most abundant fish in the samples, is a common medium-sized catfish along the entire lower Mekong River. Pre-larvae were present at all sites and yolk-sac larvae were also present at Nasak and Angnyai so some larvae enter the drift immediately post-hatching. Drift of post-larvae increased also with downstream progression, consistent with development through from pre-larvae. The graphs show that *Pangasius macronema* spawns over an extended period, producing multiple peaks of larval drift. While a few peaks correspond in an upstream-downstream direction, there is generally a poor match between peaks at each site which may indicate that fish larvae settle in some parts of the river early in development, e.g. between Pakhao and Thadeua. There were very few advanced post-larvae or juveniles collected and, with the high load of fish at Angnyai, it is likely that this section of river contributes a large quantity of larvae to downstream reaches. The total estimated drift of this species at Angnyai was 179 million larvae over 75 days of the study. Fisher reports from LEK survey data (discussed below and summarised in Appendix 5) indicate that this species migrates upstream in this part of the system, typically between April and July, and also has eggs in those months, which is consistent with the pattern observed in this study.

***Henicorhynchus* spp.** are among the most common fishes found along the Mekong and in tributaries and are very important in river fisheries. The load of *Henicorhynchus* spp. did not increase with downstream progression (averaged over the duration of the study) at the upper three sites but was much higher at Angnyai because of a strong peak (pre-larvae) indicating spawning in late July. Several peaks of pre-larvae were evident at each site, with yolk-sac larvae also drifting at Nasak and Angnyai. There was, however, little or no evident correspondence of peaks even allowing for delayed movement between sites, and no evidence of progressive development of fish through to post-larvae with upstream-downstream progression. The pattern suggests spawning along the entire section of river; spawning also occurs upstream of all study sites as evidenced by the late peaks in post-larvae at Pakhao, the most upstream site. The relative lack of post-larvae and non-correspondence between peaks could be explained if developing larvae move to the edges of the river soon after the pre-larvae stage, a behaviour which would benefit fish seeking to move into any newly flooded margins. Fisher reports from LEK survey data in this part of the river system indicate that this species migrates upstream typically between March and September and has eggs from May to September, indicating an extended breeding season which is consistent with the pattern observed in this study.

Glyptothorax lampris is a very small benthic catfish species that is common in rocky streams and rivers. Its larval drift pattern indicates an extended spawning season along this section of the river, with possible correspondence of some peaks that may indicate drift between sites; e.g. the large peak in pre-larvae at Pakhao in early August matched later peaks in post-larvae at Nasak. However, there are gaps, particularly at Nasak, and generally the data do not support sustained and accumulative drift through the study area as mean load was highest at Thadeua. It seems more likely that input of larvae from fish spawning through the area is matched by fish developing and moving to the bed and edges.

Cosmochilus harmandi is a very large cyprinid that is common along the Mekong and in tributaries. The drift data indicate an extended spawning season with multiple peaks in drift, including several peaks of pre-larvae at three sites. Highest abundance was at Angnyai with relatively very low abundance at Nasak, indicating significant inputs of larvae between these sites. There is some correspondence in drift peaks between stations but there are apparent gaps at Nasak. LEK surveys reported upstream migration in April and eggs present in May and June, which is consistent with the findings of this study.

Gobiopterus* cf. *chuno is a very small goby that appears to be common and widespread in the Mekong. Only post-larvae were present in samples as like other gobies its larvae hatch at an advanced stage. Its drift pattern showed multiple peaks of post-larvae with some site-to-site correspondence but no clear downstream progression or accumulation of fish, suggesting possible movements of fish to the bed or banks as they develop. As well as larval drift, there was an apparent strong dispersion of juveniles on 1 July at Thadeua, which was also evident as a smaller peak upstream at Pakhao on 26 June. There were no LEK data for this very small species and little information on its life history.

Hemibagrus spilopterus is a common large catfish, formerly known as *Hemibagrus* aff. *nemurus* in Kottelat (2001). Its drift pattern indicates an extended spawning season with several peaks in larval drift with pre-larvae found at Nasak and Angnyai indicating recent spawning. There was little correspondence in peaks between sites, except that juveniles appeared at all sites in August. These fish would have grown from the larvae observed earlier in the sampling period, and their appearance indicates that there may be a period of active dispersion of juvenile fish, i.e. after the larval phase. LEK data indicate this species migrates upstream in this part of the Mekong from May to August, mostly from May to June. Eggs have been observed from April to November, with most reports in June and July. The LEK data suggest an extended spawning season centred on the early flood;

migration upstream is in May and June and eggs are present from April to October, consistent with the data from this study.

Paralaubuca barroni is a common small cyprinid that was most abundant at Pakhao and Thadeua, suggesting spawning at or upstream of these sites, with movement out of the drift upstream of Nasak. Multiple peaks of larvae were evident with some upstream-downstream correspondence. Significant numbers of juvenile fish were also present, with peaks in August perhaps indicating a juvenile migration, which could be developing fish migrating. In LEK surveys, this species may have been lumped with its very similar congener *P. typus*, which was reported to move upstream from March to June and have eggs for an extended period from January to September. The LEK data are consistent with the presence of larvae in this study.

Ompok bimaculatus is a medium-sized sheatfish, common basin-wide. Its abundance was much higher at Thadeua than elsewhere with a large peak on 29 June at Thadeua not matched upstream or downstream, suggesting local movement into and out of the drift. A peak in drift matched from Pakhao (16 June) through Thadeua (17 June) to Nasak (22 June) but was absent at Angnyai, suggesting larvae move out of the drift downstream of Nasak. Multiple drift peaks were evident but its overall abundance was low.

***Kryptopterus* spp.** includes three small and similar species which are all widespread in the Mekong. The drift data are difficult to interpret because they include three species. As for other common fishes, there were multiple peaks in drift with early-stage larvae found at two sites. There were no LEK data for the 3 species in this group.

Cyclocheilichthys armatus is a medium-sized cyprinid which is common along the Mekong. The abundance of its larvae increased consistently downstream. The largest increase (approximately sevenfold) was between Thadeua and Nasak, indicating a large input of larvae in that section of the river in August, with several peaks also at Angnyai. Peaks appear to occur at different times at Pakhao and Thadeua. At this abundance, however, there were only 1 or 2 fish per sample so it is unlikely that peaks would match where numbers per sample are so low. Small juveniles were also relatively common in the drift samples. There was no information for this species recorded in LEK surveys, but its congener *Cyclocheilichthys enoplos* was noted as migrating upstream from April to November and having eggs from April to September. To the extent that similar species may have similar life histories, this extended period of spawning is consistent with the pattern observed in this study.

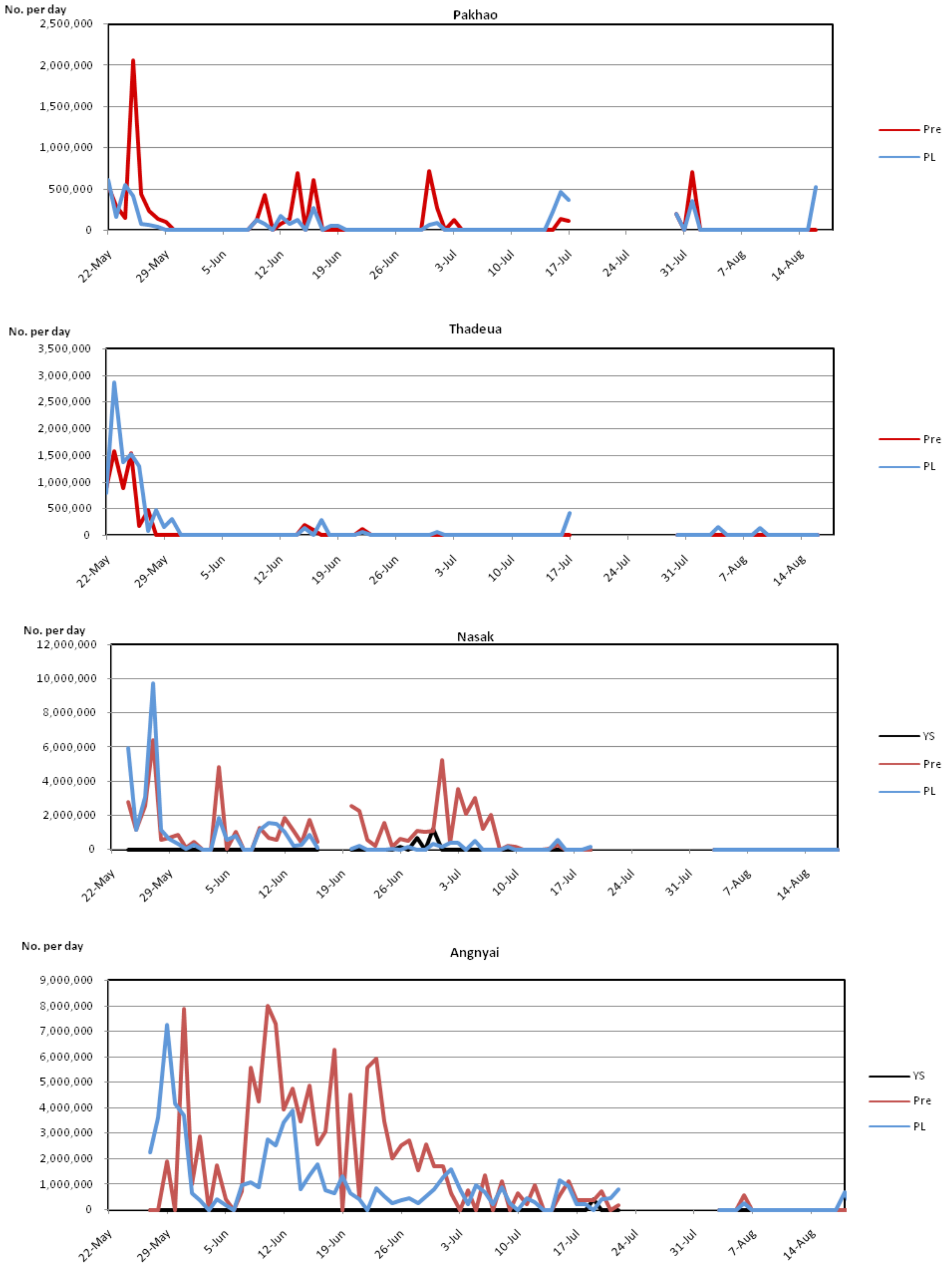


Figure 28: Drift of *Pangasius macronema* larvae over the course of the study at each site

YS = yolk-sac larvae, Pre = pre-larvae, PL = post-larvae

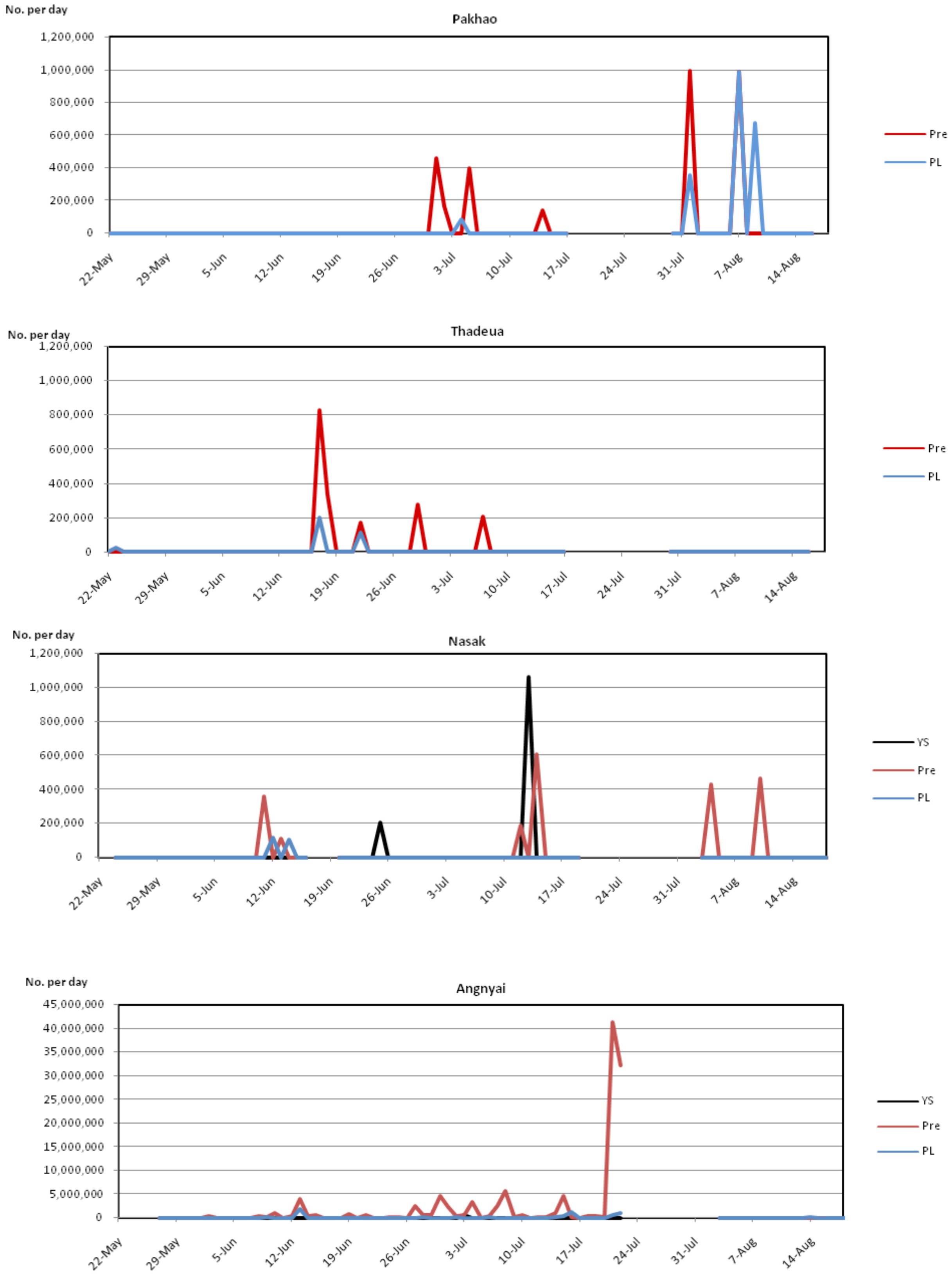


Figure 29: Drift of *Henicorhynchus* spp. larvae over the course of the study at each site

YS = yolk-sac larvae, Pre = pre-larvae, PL = post-larvae

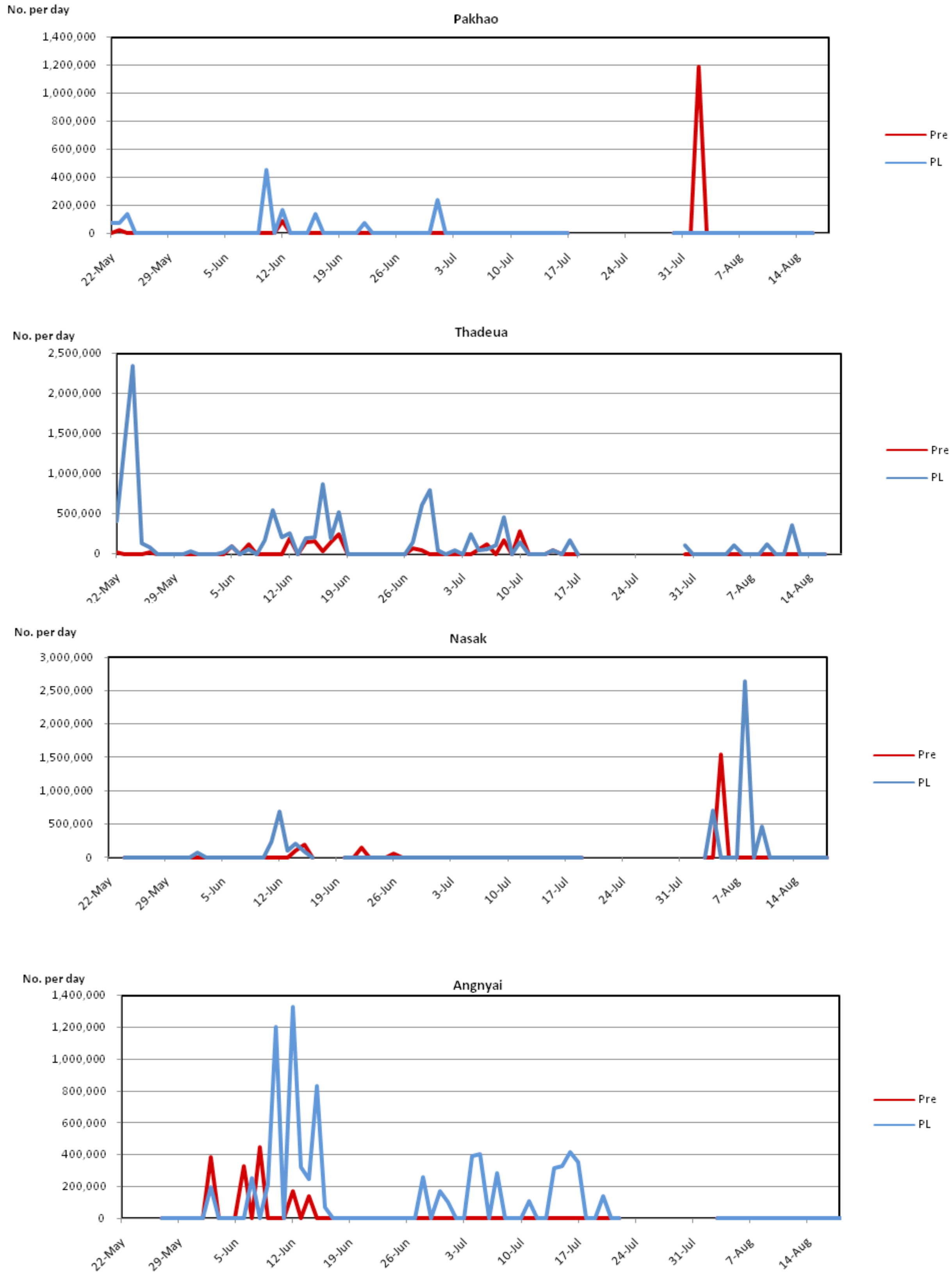


Figure 30: Drift of *Glyptothorax lampris* larvae over the course of the study at each site

Pre = pre-larvae,   PL = post-larvae

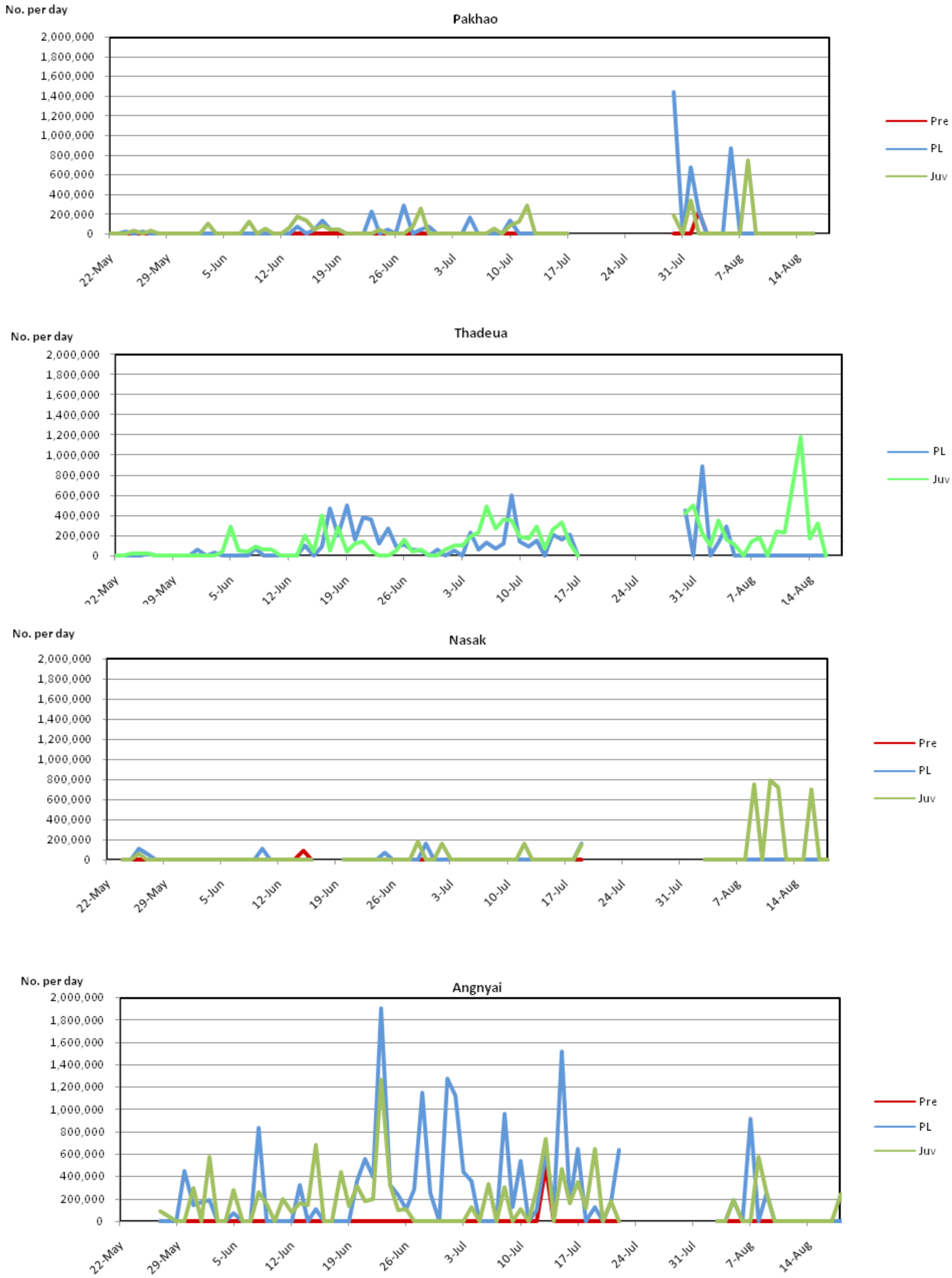


Figure 31: Drift of *Cosmochilus harmandi* larvae and juvenile fish over the course of the study at each site

Pre = pre-larvae, PL = post-larvae, J = juveniles

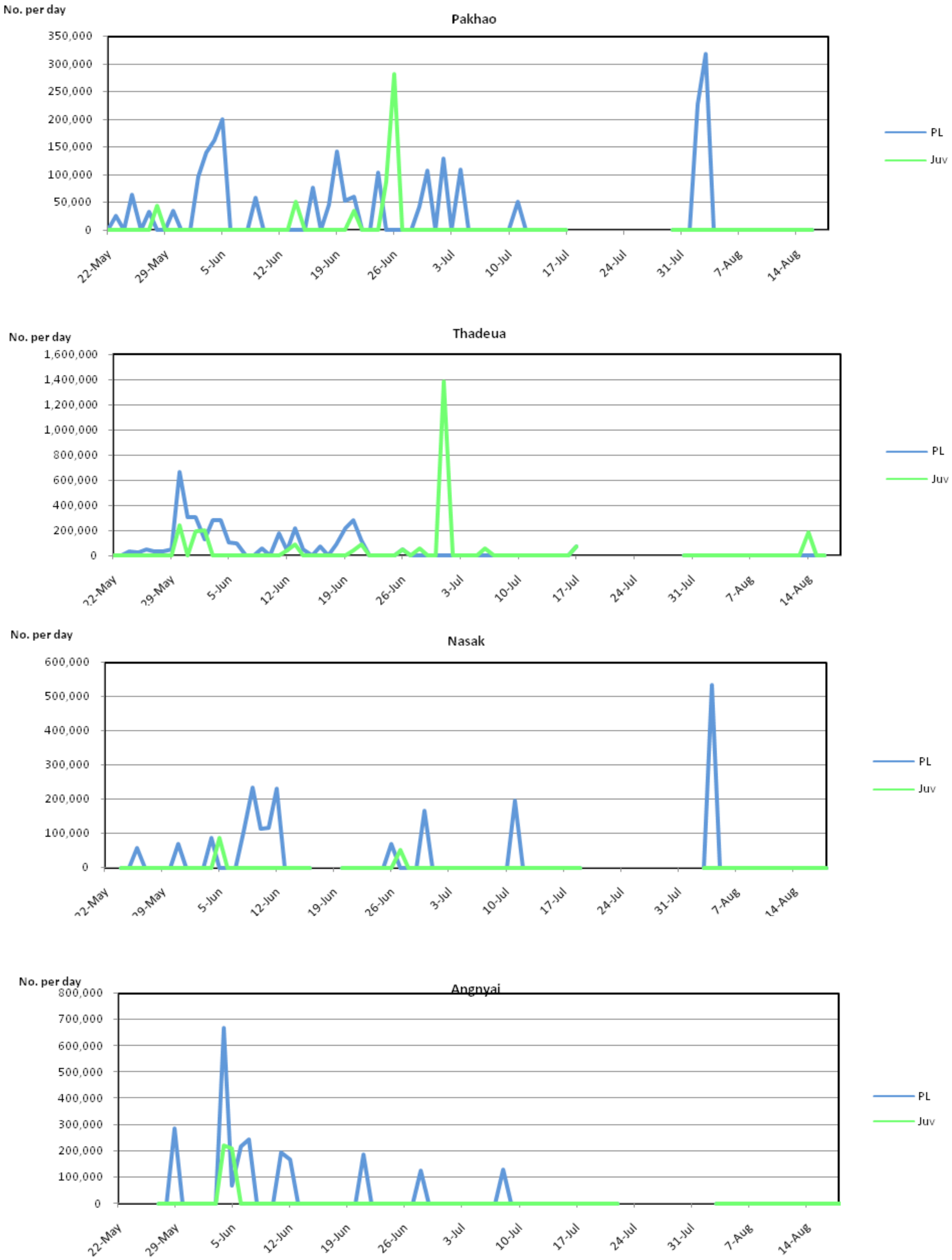


Figure 32: Drift of *Gobiopterus* cf. *chuno* larvae and juvenile fish over the course of the study at each site

Pre = pre-larvae, PL = post-larvae, J = juveniles

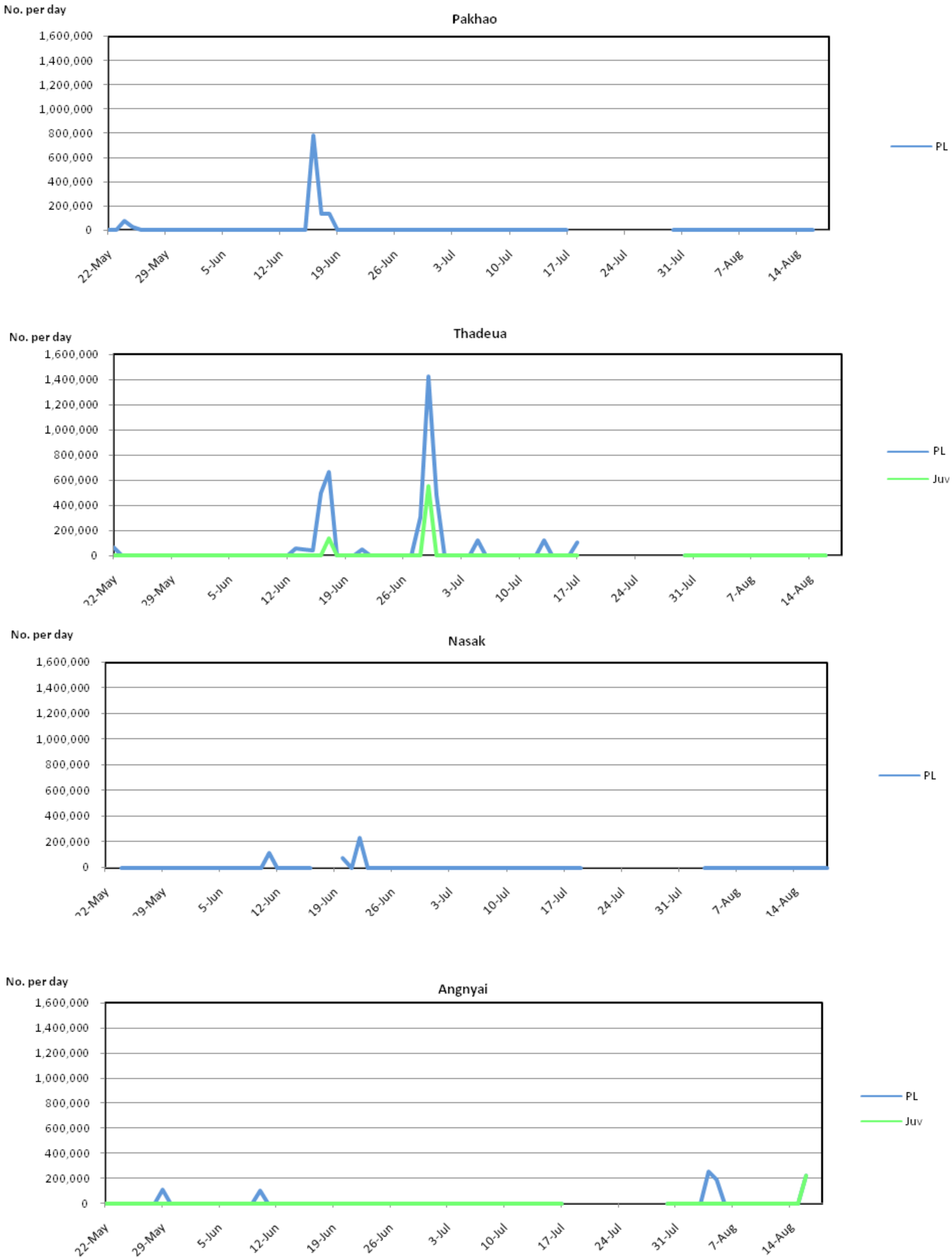


Figure 33: Drift of *Ompok bimaculatus* larvae and juvenile fish over the course of the study at each site

PL= post-larvae, J = juveniles

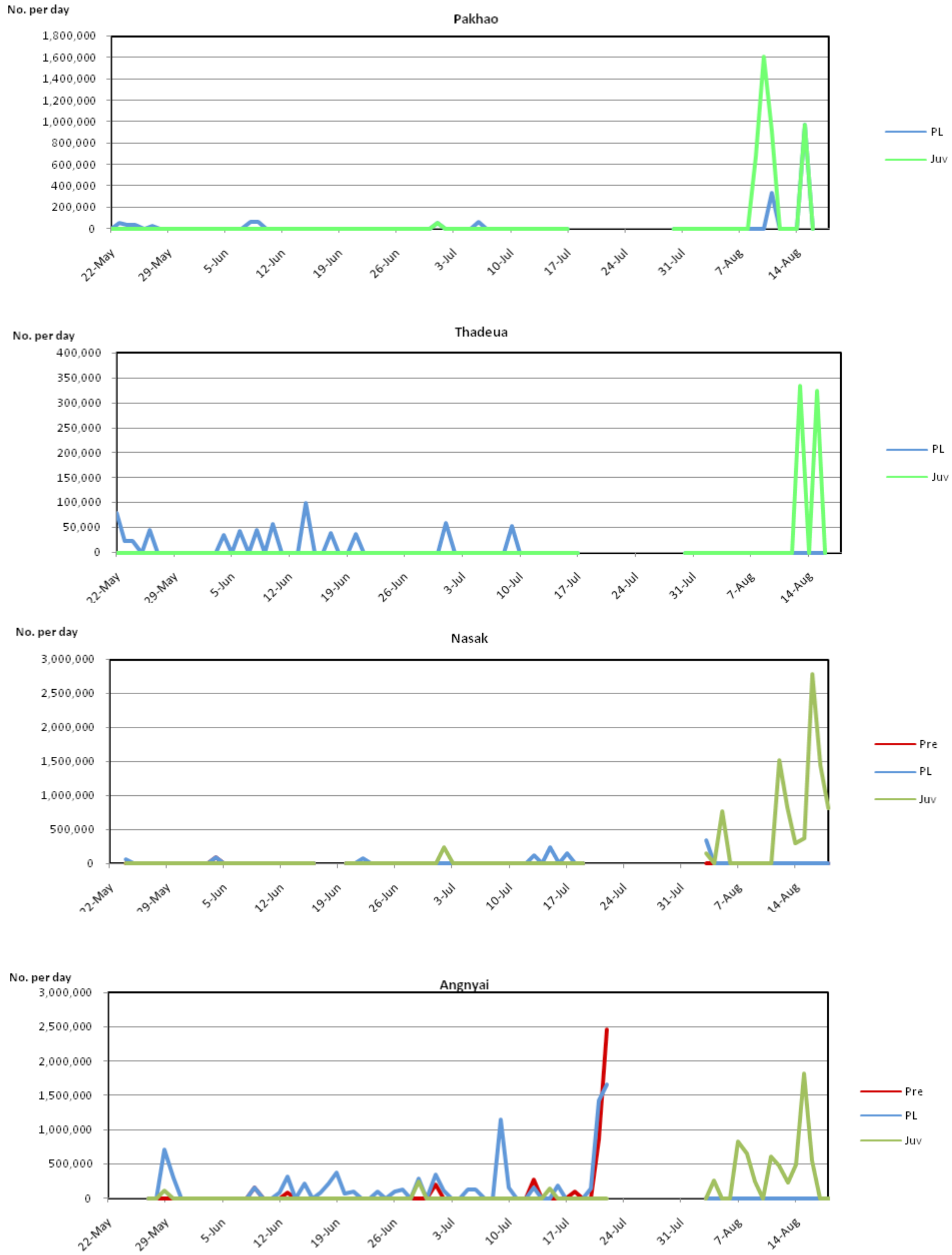


Figure 34: Drift of *Hemibagrus spilopterus* larvae and juvenile fish over the course of the study at each site

Pre = pre-larvae, PL= post-larvae, J = juveniles

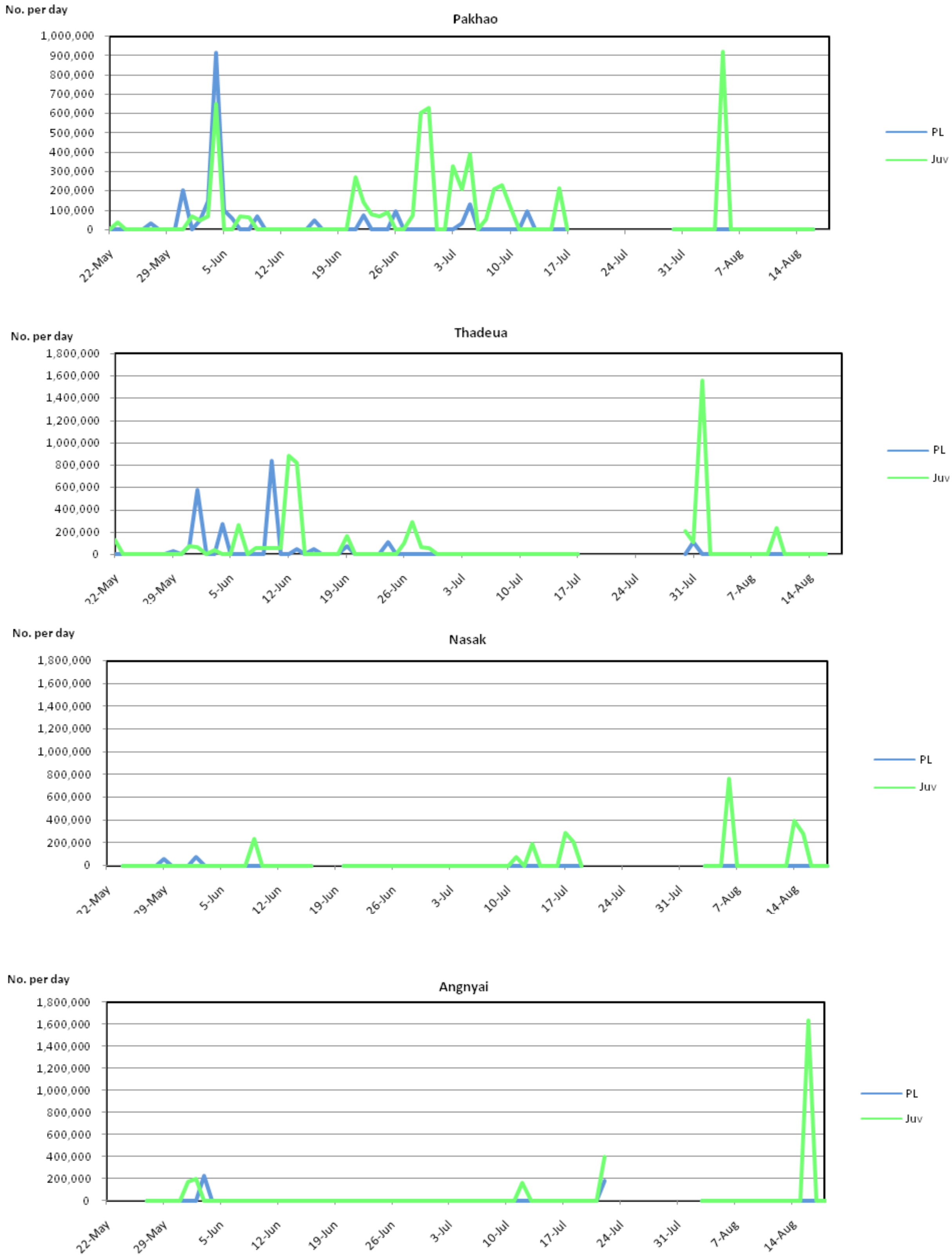


Figure 35: Drift of *Paralaubuca barroni* larvae and juvenile fish over the course of the study at each site

PL = post-larvae, J = juveniles

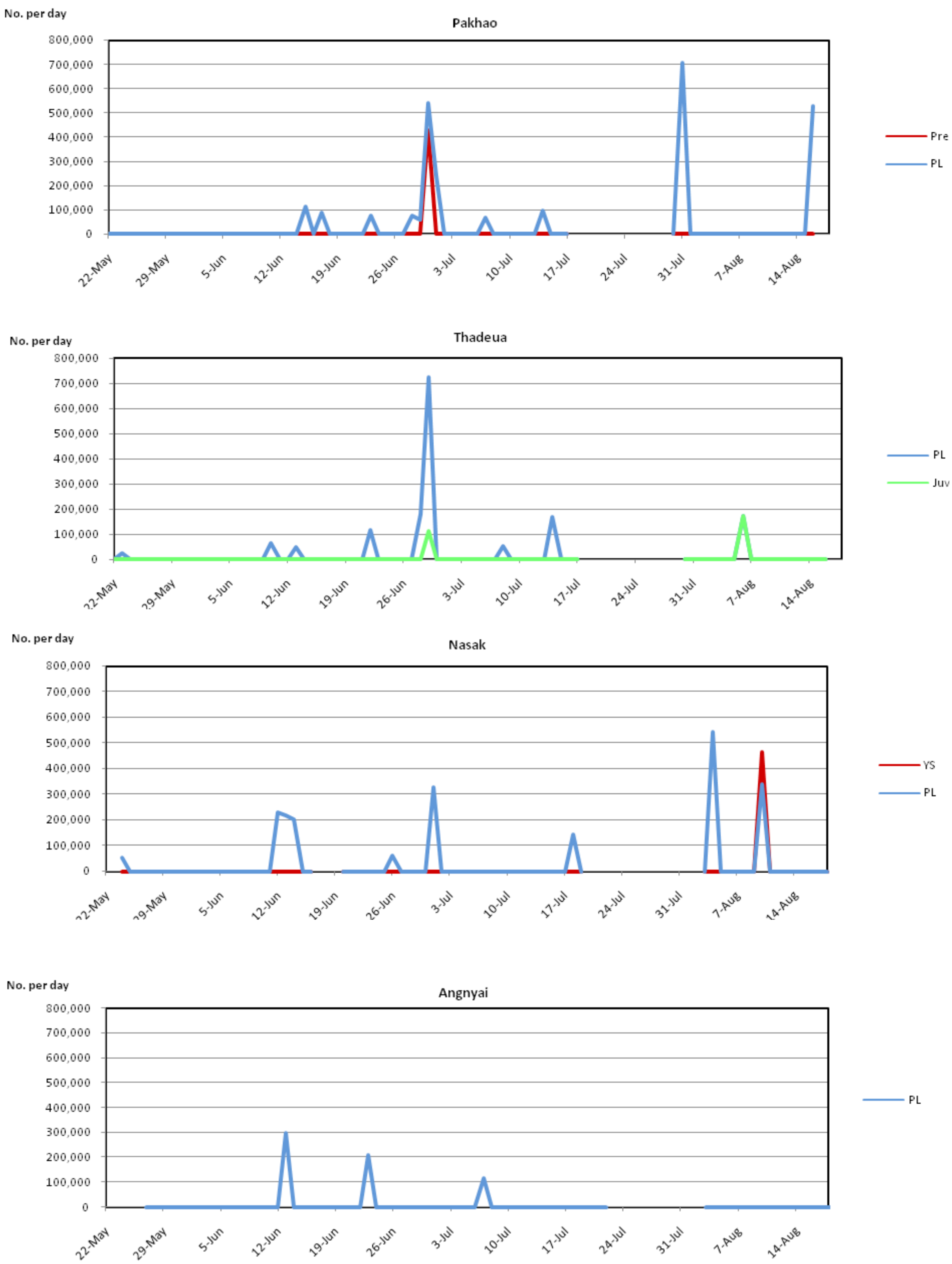


Figure 36: Drift of *Kryptopterus* spp. larvae and juvenile fish over the course of the study at each site

Pre = pre-larvae, PL = post-larvae, J = juveniles

Figure 37: Drift of *Cyclocheilichthys armatus* larvae over the course of the study at each site

YS = yolk-sac larvae, Pre = pre-larvae, PL = post-larvae

4.4 Drift patterns for uncommon species

Patterns for the 10 common species discussed above and another 47 species for which larvae were recorded are summarised in Appendices 3 and 4. These 47 uncommon species had between one and 37 larvae collected in total across all 295 samples, with many daily records for a single fish only and 16 species represented in total by a single fish only. The mean density of fish was therefore very low for most species so the presence of a fish in a particular sample was heavily influenced by chance. Therefore, the absence of larvae of other species may not indicate absence from the river. Rather, their density may have been low. In general, as the total number of larvae collected increased, so did the total number of sites at which the fish was recorded, as would be expected if most fish were present at all sites but not recorded at some sites due to low abundance. It is noteworthy that 13 species were recorded only at Thadeua and 15 were recorded only at Nasak, whereas there was only one species restricted to Nasak and two species restricted to Pakhao, which indicates a richer fauna at Nasak and Thadeua, as suggested also by Table 5. Two species that were caught in moderate numbers appear to have restricted distributions. *Rhinogobius* sp., a very small goby, was found only at Pakhao and Thadeua (22 larvae in samples); this fish is probably an upland species with limited downstream drift of larvae. Larvae provisionally identified as *Aaptosyax grypus*, a very large rare cyprinid, were found only at Angnyai over a short period in July; 17 larvae were collected and all were estimated as about one day old post-hatching, indicating spawning at or upstream of the site.

4.5 Comparison with 1999 LEK data

This study recorded 57 species with larvae in this period, but for 37 of these there was no LEK data. This is not particularly surprising, given that the habitat of the Mekong in northern Lao PDR is quite different to that of most of the Mekong mainstream (Section 2.1) and that the LEK study covered only common Mekong species found basin-wide. The LEK survey in this part of the river reported migration and egg data for 52 species but for 32 of these no larvae were recorded in this study. Of these, juveniles were recorded for six species, which would indicate late dry-season spawning to produce juveniles by the time of this study consistent with the LEK data.

There are various reasons why 26 LEK species for which migration and egg data were provided might not be recorded in this 2010 study:

- 15 species are early spawners, with migration upstream beginning February to April. For these species, larval drift may have ceased by late May when this 2010 study started.
- 2 species are later spawners, migrating upstream beginning in July; their larvae may have drifted after this study ended in early August.
- 9 species which appear to spawn mainly in the early flood may be relatively rare.

There may be other explanations; fishers might err to some extent when recalling months of migration or egg presence and species are sometimes misidentified.

For the 20 LEK species for which larvae were also found in this study, reports for 18 species were considered consistent with larval presence in the early flood as found in this study, as summarised in Appendix 5 and discussed above. For two non-migratory species, 2010 data appeared somewhat inconsistent with LEK data. *Chitala ornata* (a grey fish) was reported to have eggs in August-September (i.e. probable later spawning) and *Pristolepis fasciata* to have eggs in April (i.e. possible earlier spawning). But there were few reports for both these species and also few larvae recorded.

For those species that could be compared, the 2010 study data were generally quite consistent with the LEK data which indicated many species migrating upstream and spawning in the early flood in this part of the Mekong.

As well as LEK data, the results from this study can be compared with the study of Hanpongkittikul *et al.* (2010) who sampled over the period 8 – 28 May 2010 in the Mekong River at Pak Ing Village, 2,305 km from the sea and about 335 km upstream of Pakhao, the most upstream site sampled in this study (Table 1). The Pak Ing study overlapped with the start of this study (22 May 2010) and aimed (unsuccessfully) to find larvae of the Mekong giant catfish (*Pangasianodon gigas*). They did, however, record many of the same species as found in this study. A significant difference between their results and results from this study was the capture of some pangasiid catfishes in significant numbers. Of a total of 1,529 larvae, their samples included *Pangasius bocourti* (290 larvae) and *P. conchophilus* (506 larvae) which together comprised about half of all the larvae they collected. If fish larvae drift passively with the current for several days, then fish drifting from the Pak Ing area should have been common at our study sites. But these two species were uncommon (total of 3 and 12 larvae respectively). Discounting other causes such as high mortality in transit, it seems likely that larvae must move out of the drift to develop further, perhaps migrating downstream later as juveniles.

4.6 Some notes on individual fishes

Introduced species

Of the 84 fish species collected, only two introduced species were present – *Oreochromis niloticus* (Nile tilapia), a common aquaculture species for which a single post-larvae was collected at Pakhao, and *Pterygoplichthys disjunctivus,* (vermiculated sailfin catfish), an aquarium escapee for which five juveniles were present in samples from Thadeua in August. The fauna in this part of the Mekong is still overwhelmingly indigenous, in part because the habitat and annual flow patterns are not greatly modified.

Black fish – grey fish

The samples contained larvae or juveniles of 8 black fish species and 6 grey fish species. These fishes are generally considered to be floodplain species or inhabitants of pools and slow-flowing reaches. Black fishes are considered non-migratory and grey fishes to migrate laterally (to tributaries and floodplains) with these species spawning adherent eggs in nests or on substrates. Their larvae or juveniles were recorded at low abundance in the drift. Nevertheless, their presence demonstrates that at least part of their population is dispersed downstream in drift in the same way as more migratory white fishes.

4.7 Diurnal variation in samples

Where there were more than 100 fish of any stage in total in samples, data were graphed to examine diurnal variation after adjustment to a 30-minute standard period. As discussed below with reference to Figure 38, peak drift appears to be at midnight and dusk for three species; these fishes can be termed night-drifting species. One species was most abundant at dawn and midday, apparently a day-drifting species. For three species, there was no clear diurnal pattern. Pooling all larvae data (not shown) produces a pattern of night-drifting, simply reflecting the contribution of the most abundant fish in samples, *Pangasius macronema*.

For *Pangasius macronema*, post-larvae were most abundant in midnight samples at three sites and overall, and least abundant in midday samples overall and at three sites. Pakhao had relatively few fish so sampling error (i.e. random variation) is likely to account for the different pattern evident there. *P. macronema* pre-larvae were also most abundant at midnight at two sites and overall, and least abundant at midday at three sites and overall, with Pakhao and Thadeua having relatively low densities. Hortle *et al.* (2005) found night-drift density of *Pangasius macronema*[3] near Phnom Penh was more than ten times day-drift density, and night-drift densities of three other pangasiids were also higher at night than in the day[4]. Hanpongkittikul *et al.* (2010) at Pak Ing sampled morning, midday and evening and found drift of the abundant Pangasiid species to be mainly in the early morning. These observations show that Pangasiids are generally night-drifting species.

Glyptothorax lampris post-larvae were apparently more abundant at midnight and dusk at the only site where they were abundant.

Gobiopterus* cf. *chuno post-larvae appeared to be most abundant at midnight and dusk, based on the two sites where they were most common.

Ompok bimaculatus post-larvae were most abundant at dawn and midday; apparently this is a day-drifting species.

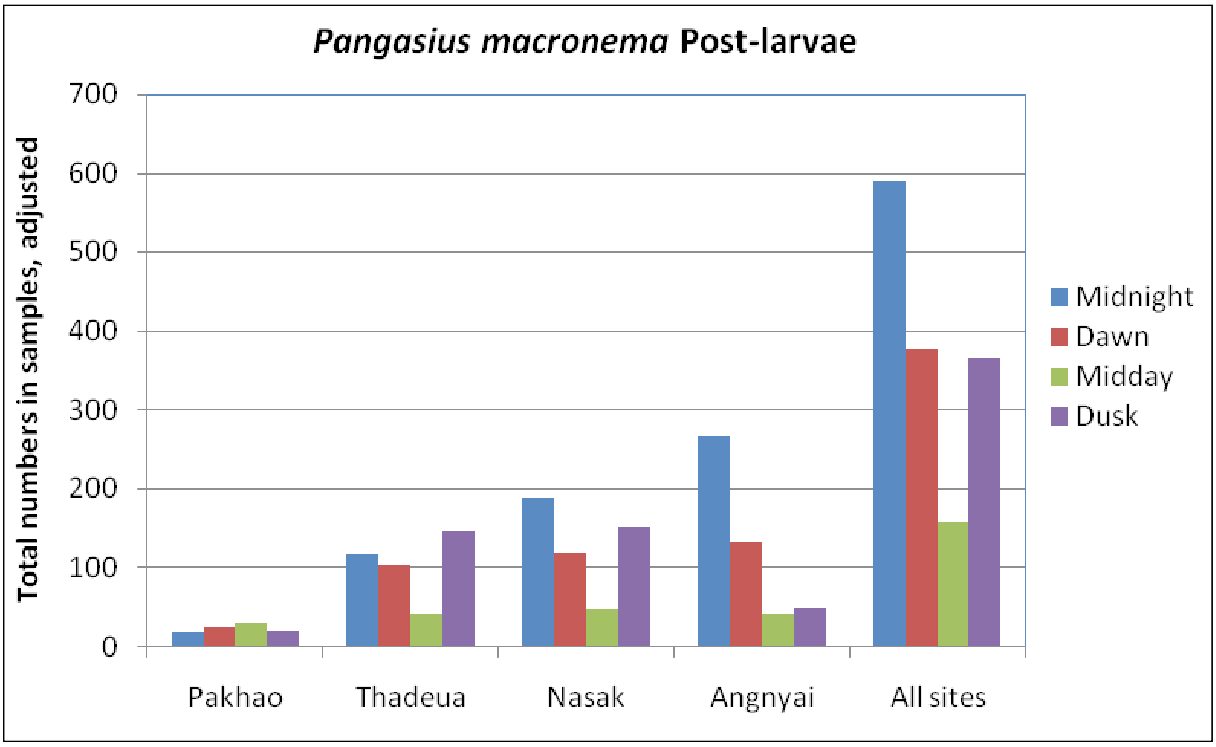
***Henicorhynchus* spp**. pre-larvae were significantly abundant at Angnyai where there appears to be a depression of drift at dawn.

Cosmochilus harmandi post-larvae and juveniles did not exhibit a consistent diurnal pattern.

Paralaubuca barroni juveniles did not show a consistent diurnal pattern.

[3] identified as *P. siamensis* in that study

[4] referring to plankton netting at 1 m depth as in this study



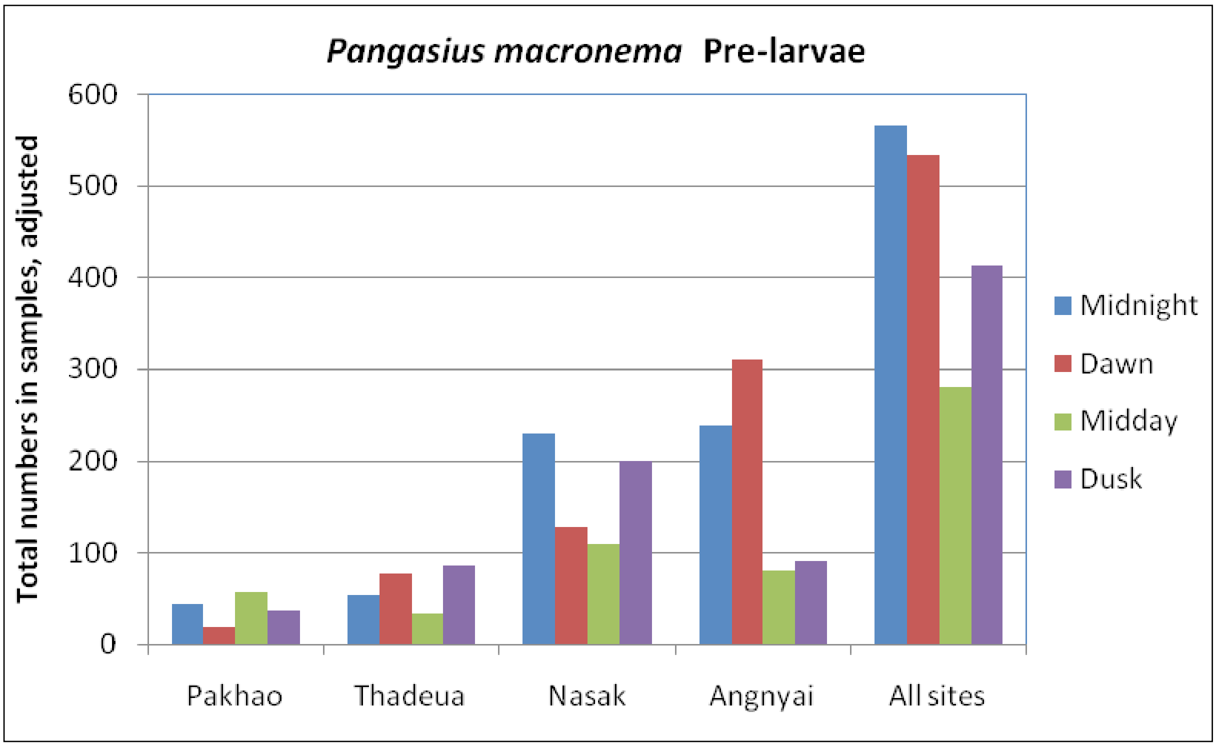


Figure 38.1: Diurnal variation in abundance of fish at all sites

Units are total number of fish adjusted to 30-minute sample time. Only species and stages are shown where there were more than 100 fish.

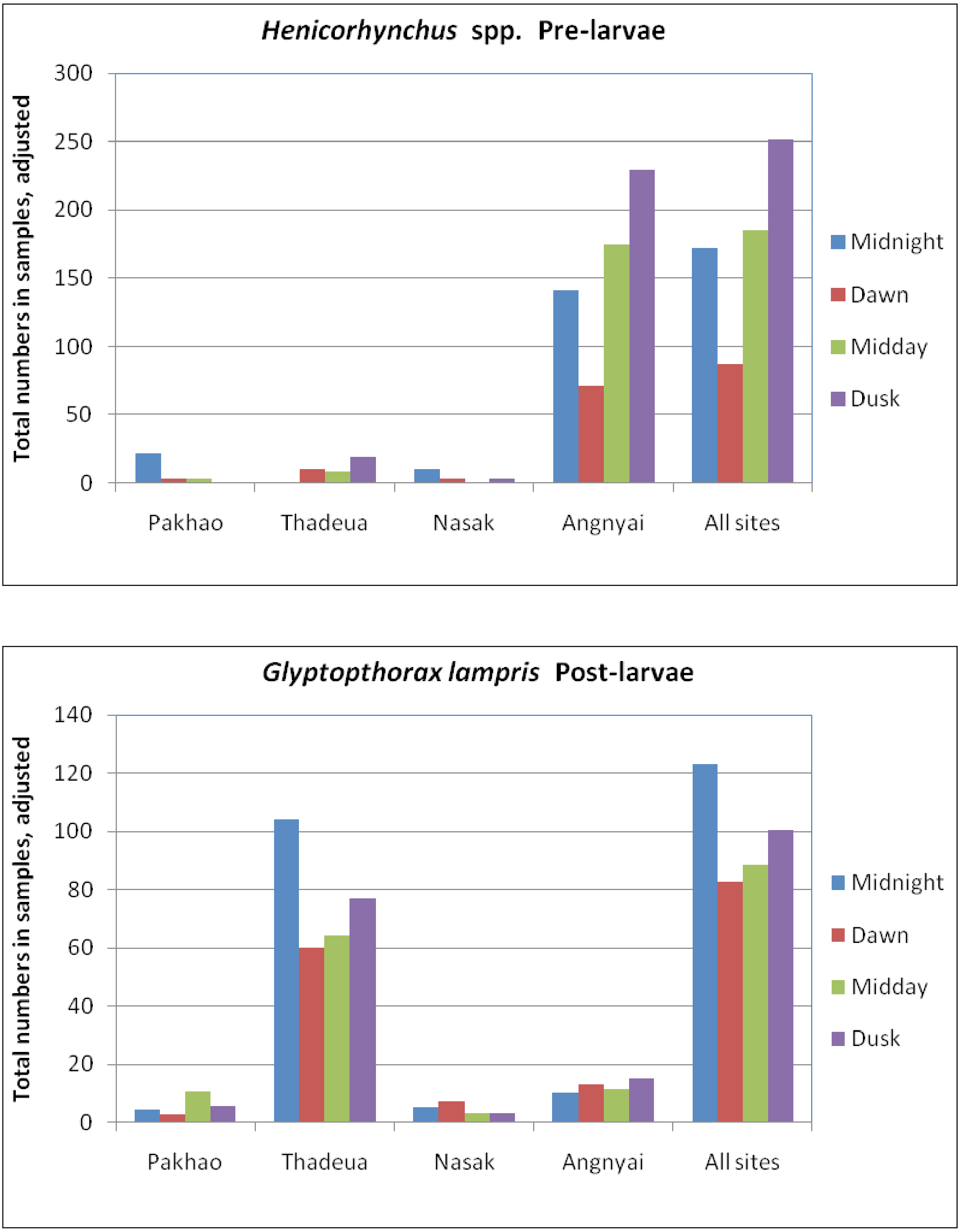
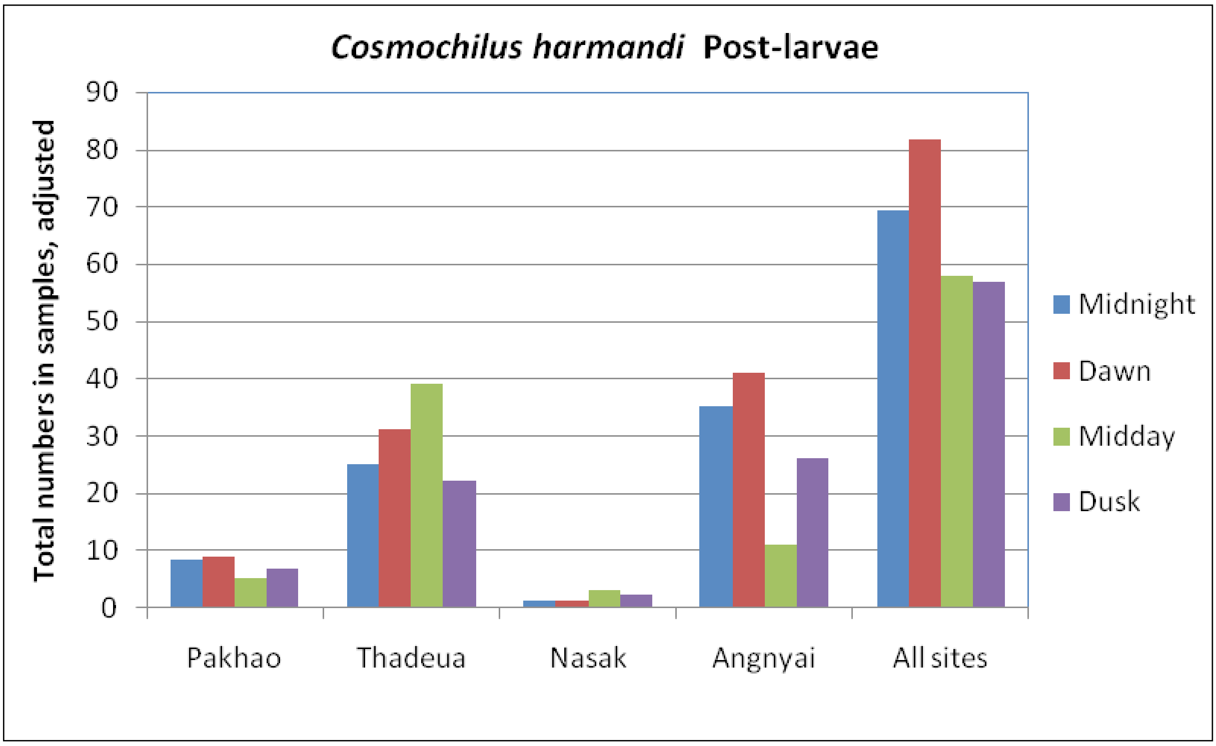


Figure 38.2: Diurnal variation in abundance of fish at all sites

Units are total number of fish adjusted to 30-minute sample time. Only species and stages are shown where there were more than 100 fish.



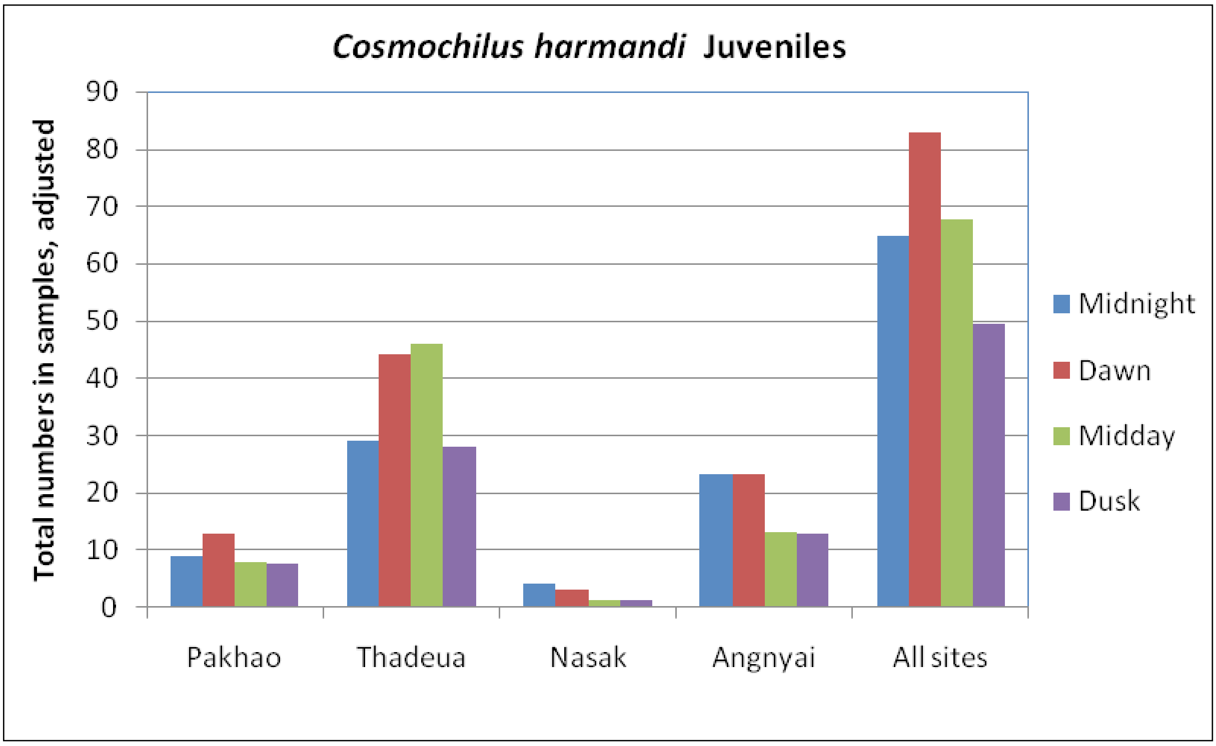
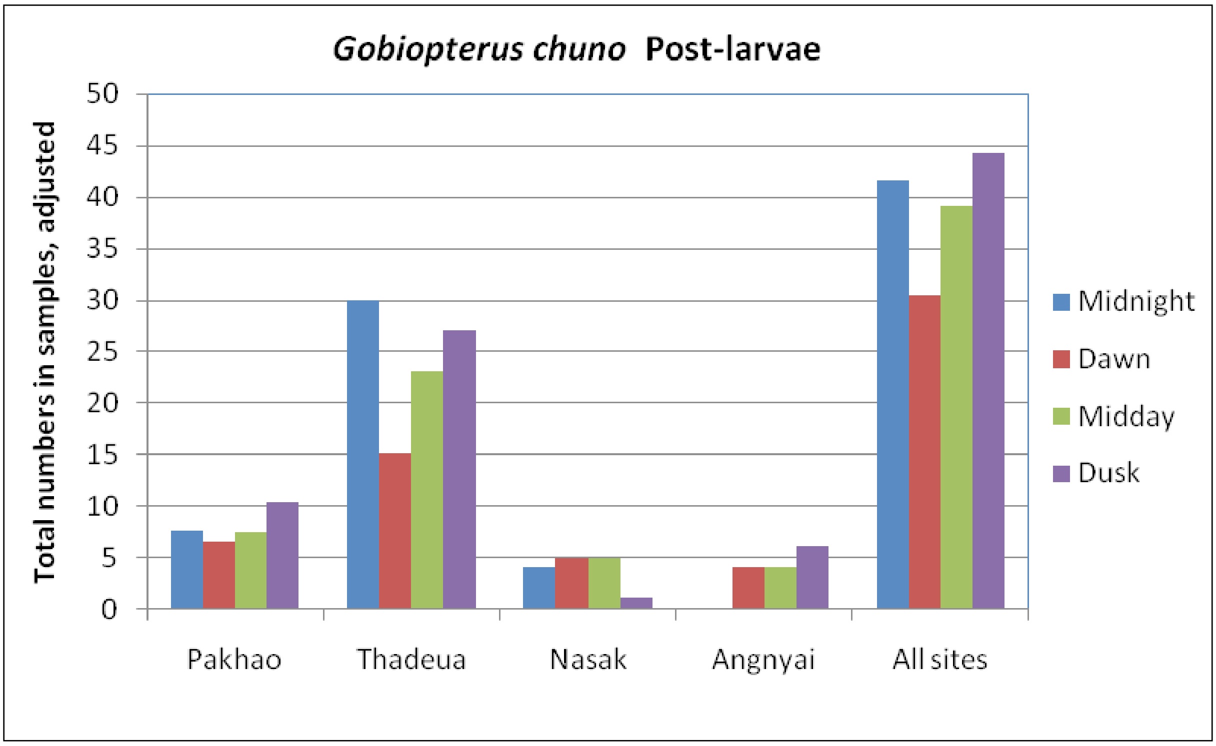


Figure 38.3: Diurnal variation in abundance of fish at all sites

Units are total number of fish adjusted to 30-minute sample time. Only species and stages are shown where there were more than 100 fish.



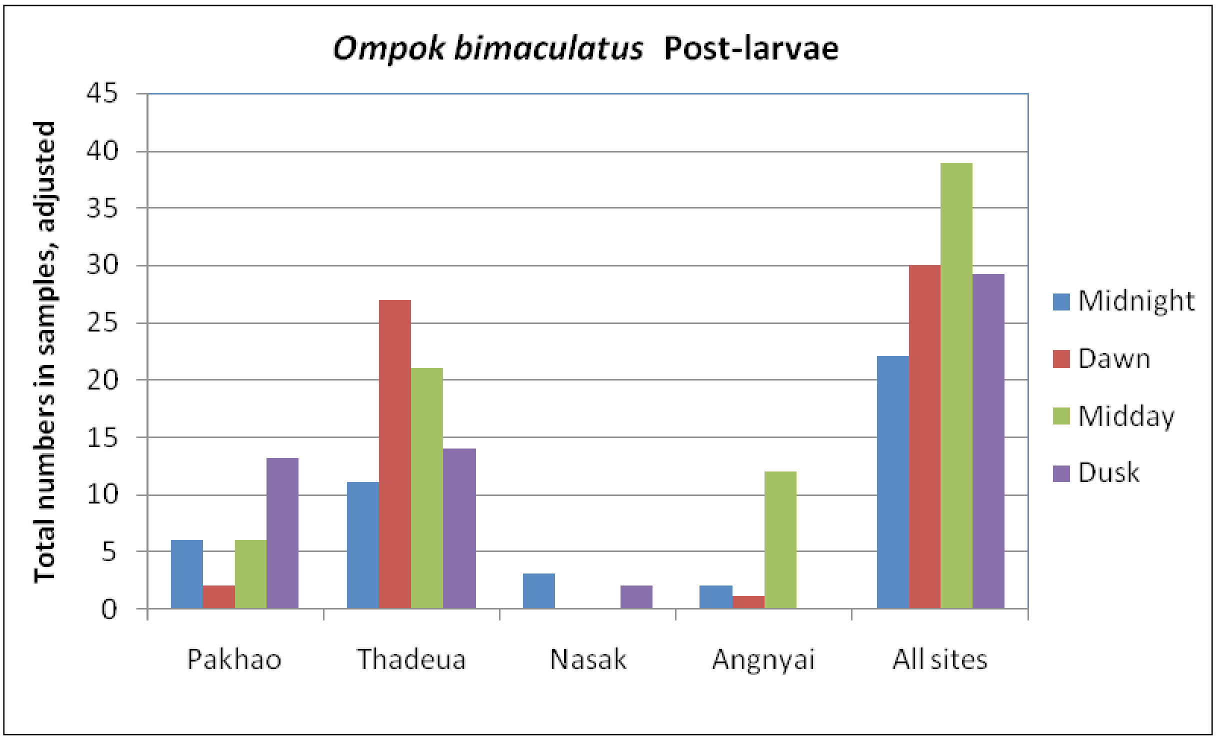


Figure 38.4: Diurnal variation in abundance of fish at all sites

Units are total number of fish adjusted to 30-minute sample time. Only species and stages are shown where there were more than 100 fish.

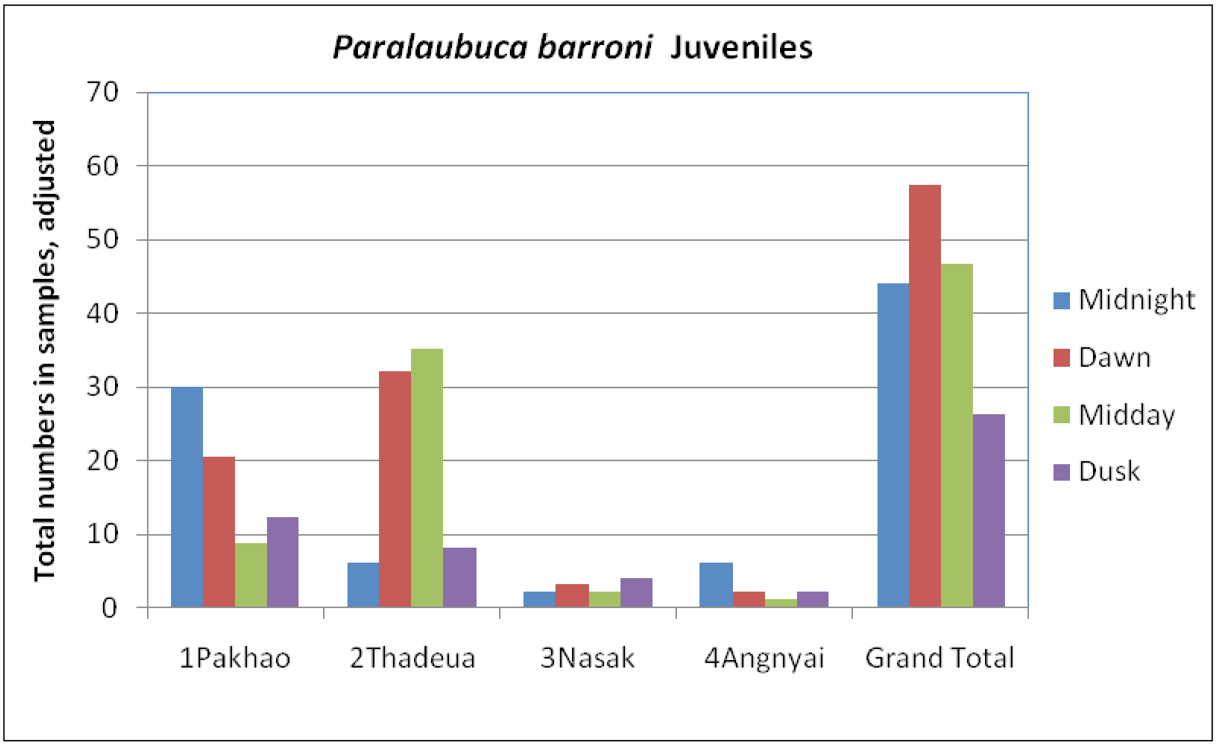


Figure 38.5: Diurnal variation in abundance of fish at all sites

Units are total number of fish adjusted to 30-minute sample time. Only species and stages are shown where there were more than 100 fish.

5 Discussion and recommendations

This study has shown that at least 54 fish species[5] spawn in the early flood in the Mekong or its tributaries between Angnyai and Pakhao. A further 27 species were represented by juveniles and/or adults (the latter of very small species), also indicating likely spawning in or near this section of the river. The fish represent a broad range of species, from very small to very large and including some grey fish and black fish. Only two introduced species were present, both in low abundance, so the fauna is still largely indigenous. At least 200 species are found in this section of the river (based on MRC monitoring data). So over the course of a full year, it could be assumed that many more species would spawn in or upstream of this section of the river, with adults, juveniles and larvae requiring passage, posing a major challenge for dam design. This is apart from the issue that fish at different stages have various and different habitat, flow and food requirements which for many species will not be met once dams alter the environment in their vicinity.

The majority of larvae were the result of spawning by a relatively few species at this time, in particular *Pangasius macronema*, a common medium-sized catfish. Where sufficient numbers of larvae were collected, the data indicated that spawning probably occurs at various places along this part of the river, with larvae drifting downstream for variable distances and some proportion moving out of the drift to the bed or edges within a few days of hatching. A few upland species appear to be restricted to the upper reaches of the study area, as their larvae did not appear in drift at the downstream sites.

Diurnal variation was evident for some species including several night-drifting fishes, as has been observed in other studies, and at least one day-drifting species. This finding shows the need to take samples through a 24-hour period to get representative data.

The results of this study are broadly consistent with LEK data from 1999 for this part of the Mekong; i.e. many species migrate upstream and spawn in the early wet season. Some LEK species also spawn earlier or later, so any long-term studies of fish larvae need to trade off intensity of sampling (at least 4 times per day every day) against duration (ideally over the entire year) and site coverage.

The total number of larvae caught in northern Lao PDR equates to about 375 million fish drifting past Angnyai over the 75 days of the study, which indicates something of the order of a billion fish could be drifting at this location annually, assuming that larval drift peaks in the early flood and that the plankton-net samples were representative of load. The natural recruitment derived from these larvae would be very difficult to replace by stocking and it would certainly be impossible to breed and stock most of the 200+ species present. Loss of this source of recruitment will likely have greatest effects on fisheries in northern Lao PDR, with progressively less effect downstream, consistent with the hypothesis that fish in this section of the river are within the 'upper Mekong migration system'. This system extends upstream from the Loei River confluence, and includes fish stocks which are largely distinct from the more downstream migration systems (Poulsen *et al.,* 2004).

[5] includes two species groups; total is 57 species, see Section 4.2

Comparison with Cambodian and Vietnamese data

Fish larvae and juveniles have been sampled for several years in Cambodia and Viet Nam using the same methods as in the 2010 Lao study. Ideally, these data should be compared as densities and loads of fish, but there are some data quality issues for volumes and discharges to be resolved. Comparisons would also ideally be between fish identified to the same taxonomic level; again, there are some issues to be resolved as data for species groups are combined in different ways, particularly in Viet Nam where there are many very early stage larvae, which indicate spawning within at most a few hundred kilometres upstream. Cambodian and Vietnamese data do not separate the stages of fish (i.e. larval-juvenile-adult) but it is understood that the vast majority of fish are larvae; in the Lao samples approximately 80% of fish were larvae.

To compare approximately the same period, summary data were prepared for the period 1-June-10 to 31-August-10 (Table 12).

Table 12: Comparison of data from this study with 2010 June-August data from Cambodia and Viet Nam
All studies used the same plankton-net method

Country	Site	No. of samples	No. of fish	No. of taxa
Northern Lao PDR	Pakhao	300	810	34
	Thadeua	300	2,127	49
	Nasak	280	1,496	37
	Angnyai	300	2,663	60
	Sum of northern Lao PDR samples	1,180	7,096	84
Country	**Site**	**No. of samples**	**No. of fish**	**No. of taxa**
Cambodia	Mekong at Chroy Changvar	369	404,633	54
	Tonle Sap at Phnom Penh	369	239,358	50
	Sum of Cambodia Samples	738	643,991	69
Country	**Site**	**No. of samples**	**No. of fish**	**No. of taxa**
Viet Nam	Quoc Thai (Bassac)	339	4,477	41
	Vinh Xuong (Mekong)	246	30,881	38
	Sum of Viet Nam samples	585	35,358	53

In this simple comparison, total fish (i.e. mostly larvae) abundance in Cambodia is approximately 90 times the abundance of fish in all Lao samples; this comparison is conservative as more samples and sites are included for Lao PDR. A site-to-site comparison shows that samples from the Mekong site in Cambodia (Chroy Changvar) had in total about 150 times as many fish as the most downstream site in Lao PDR (Angnyai). Taking discharge into account and assuming that the samples are representative, this difference would increase by a factor of 3.6 (Section 2.1) so the load of larvae passing Phnom Penh would have been approximately 500 times that at Angnyai, i.e. of the order of 20 billion fish larvae from June to August. This simple comparison shows there is little direct connection between larval drift in northern Lao PDR and near Phnom Penh, which is hardly surprising given transit times, the likelihood that developing northern Lao fish would settle out and taking into account the input of larvae from fish spawning in northern Cambodia. Larval numbers in Viet Nam are also much higher than in northern Lao PDR. The downstream drift of larvae in the Mekong Delta in Viet Nam is the sum of the two main channels (Bassac plus Mekong) as well as other minor distributaries which are not monitored. Larval abundance in the delta is about 13 times that in northern Lao PDR; taking discharge into account would raise the difference in load of fish to about 50 times, assuming that the samples are representative.

The RIS study in 2009 also found low density of fish at the northern Lao site (Luang Prabang) where the total number of fish in plankton nets was about 1/50 of that found at Phnom Penh and even less relative to Vietnamese sites (Cowx *et al.,* 2015 Table 3.1). That study also found relatively high densities of fish larvae between Nakhon Phanom and Ubon Ratchathani, as well as between Kratie and the delta. To the extent that the RIS study is representative, gaps in larval distribution along the river can be most readily accounted for by fish larvae drifting up to a few hundred kilometres before settling or moving to the edges.

Overall, these comparisons indicate that larval drift density in northern Lao PDR in the early flood is very low compared to that in Cambodia and Viet Nam, a finding that would be expected considering the relative extent and diversity of favourable aquatic habitats at and upstream of the sites, and the likely size of fish stocks. Many of the larval fish drifting in northern Lao PDR probably settle in northern Lao PDR and those that continue to drift downstream likely settle along the river or are transported onto flooded areas within a few hundred kilometres downstream by rising waters, as is considered part of a typical whitefish life-cycle. Unfortunately, with attention focused on the likely barrier effects of mainstream dams, there has been little recognition that fish larvae after drifting downstream require access to floodplain habitats which have been blocked by low-level water gates on most Thai tributaries and many of the smaller Lao tributaries.

Some larger species of fish that migrate long distances may migrate from Cambodia to northern Lao PDR, but to successfully reach the upper Mekong they would have to pass many thousands of gill nets and other gears which are barriers to migration. Older fishers interviewed in Lao PDR and Thailand reported that when large-mesh cheap monofilament gill nets first became available from the late 1980s, individual fishers could make daily catches of 50 or more of large catfish species such as *Pangasianodon hypophthalmus, Pangasius bocourti* and others. But in recent years, these fishes have been caught only occasionally and in low numbers; not surprisingly, their larvae were uncommon or absent in this study.

Operational problems with the study

At Pakhao and Nasak, the plankton nets during the early period of sampling became tangled in drifting logs and forced to the bed of the river so samples could not be collected, creating a gap in the data. In any future studies of this type, spare nets should be stored at study sites.

At Nasak, the flowmeter malfunctioned during the first half of the study. While this probably did not materially affect the study findings, any future studies should provide duplicate meters for cross-checking and backup.

Many samples contained large quantities of organic detritus, which made pre-sorting much more time consuming than at routine sampling locations well downstream (near Phnom Penh and in Viet Nam), where suspended organic material is much finer so that most passes through the 0.9 mm mesh of the net. Therefore, sorting samples in this part of the river requires a much larger time allowance than at sites downstream.

Samples were transported to Vientiane in a four-wheel drive vehicle. Shaking during the long trip caused some damage to animals in the samples so some were not in good condition on arrival, which made identification more difficult. It would be preferable to arrange boat transport for any future samples from such sites to Vientiane.

The identification of fish and invertebrates had to be carried out by specialists from Cambodia because LARREC staff either lacked capacity or were employed on other projects. Any future studies of this type should allow for training of Lao staff at the outset and for a reasonable daily remuneration for their work.

The resources and budget required for the study were underestimated, for various reasons including those mentioned above, leading to delays in its finalisation.

Long-term monitoring of fish larvae and juveniles in Lao PDR

This study of early wet-season of fish larvae and juveniles in northern Lao PDR and the longer-term sampling near Phnom Penh and in Viet Nam have produced much useful information about spawning and recruitment of Mekong fish. However, the number of samples collected during monitoring was onerous and should be reduced in any future studies. In northern Lao PDR, the early wet-season spawning periods appear to be quite extended for the common species and not to be very location-specific. Therefore, to monitor drift of larval and juvenile fish over the long term in northern Lao PDR, fewer sites could be sampled – possibly Thadeua and Angnyai – and monitoring could be spread over the entire year with weekly samples (four per day) at two sites. This would produce 416 samples, or about one third of the number collected in this study. Such monitoring would provide a clear picture of the annual pattern of recruitment and the quantity of downstream drift. Two further weekly monitoring sites could be added, in central and southern Lao PDR, to provide a reasonable picture of downstream fish larvae drift and juvenile. Annual sampling under this outline would collect 832 samples, less than collected in the 2010 study. Such sampling would also be a cost-effective way of monitoring invertebrate drift and would provide very useful information for understanding the relative contribution of spawning in Lao PDR to recruitment in Cambodia and Viet Nam, as well as the relative importance of drift of fish food organisms downstream. It is assumed that current monitoring continues for comparative purposes downstream in Cambodia and Viet Nam.

Invertebrates

Invertebrates including shrimps and insects were removed from samples and identified. The resulting data should be analysed and reported.

Comparative data

The 2010 dataset on larval and juvenile fish could be compared with data from routine MRC fisheries monitoring at nearby sites to compare species abundance and deduce migration patterns. The simple comparison with Cambodian and Vietnamese data should be improved by standardising taxonomy, adjusting for sample volumes and discharge, and comparing taxa composition statistically.

Sampling methods

Several issues with this kind of sampling need to be addressed.

A possible limitation of this study is the validity of the assumption that sampling at a single point in the cross section provides a reasonable estimate of mean density of fish larvae in the water column. At the sampling locations, the Mekong is a fast-flowing turbulent and well-mixed upland river, which would tend to distribute fish larvae evenly throughout the main water body. This assumption of an even distribution of fish larvae should be tested in future studies of fish larvae drift. Moderate violations of this assumption (e.g. some clumping of fish larvae along the edges) would not materially alter this report's conclusions, because variation over time is likely to be much more significant than variation within the water column as the data show strong peaks of drift over short periods. Moreover, all samples were taken in the same way at each site and, as in other MRC-sponsored studies, comparisons are valid if sampling bias is consistent. Nevertheless, future studies should include assessment of the pattern of abundance and drift of larval and juvenile fish across the profile of the river to determine how representative samples are of total load.

The patterns of larval movement should be elucidated by hand-netting in various habitats at various times, in particular to determine at what stages larvae move into or out of the main flow of the river. The study should include manual collection of larval and juvenile fish that may not be drifting but are ear the bank.

Dry-season sampling (not carried out in this study) is problematic because current speeds are usually too slow, for efficient sampling of larval and juvenile fish, as observed during the RIS study. During low-flow periods it would be preferable to tow the plankton net behind a boat parallel to the shore at a constant speed. This method samples a 'cylinder' of water actively (by moving) rather than passively (with a fixed net). Comparative sampling during normal flows should be carried out initially to test whether fixed and boat-towed sampling produce comparable results.

The efficiency of the plankton nets should be tested systematically to determine if there is any bias caused by flow speed variations during fixed sampling. An approach commonly taken is to tow a net at different speeds behind a boat at a time and place where fish larvae are abundant.

Any larval sampling should be complemented by properly structured LEK surveys and complementary sampling for other life stages using other methods.

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Appendix 1: Discharge data

Daily manual gauge height records (average of 2 readings per day) and daily discharge estimates for Luang Prabang (upstream of all the sampling sites) and Chiang Khan (between Nasak and Angnyai sampling site) were kindly supplied by MRC - IKMP (Table A1 and Figure A1).

The record for Luang Prabang gauging station was provided from 1960-2011 for gauge height and discharge, whereas the Chiang Khan record was provided for gauge height and discharge from 1967 to 2010, except that discharge data were not available for 2008. For 2008, Chiang Khan discharge was calculated based on 2007 rating data (GH < 5 m up to 22 May 2010) and 2009 rating data (> 5 m after 22 May 2008). All Lao and Thai daily manual gauge height data and discharge data were unavailable for the period 5-31 October 2010. For that period, discharge was estimated from daily mean water levels from 15-minute readings from automatic recorders which were converted to discharge by rating equations for that year; the automatic readings differ slightly from the daily manual readings.

The catchment area (CA) at Chiang Khan is 9.9% larger than the CA at Luang Prabang. The daily discharge data are well correlated between the two stations ($r^2 = 0.96$ for all data, 1967-2010). Over the period 1967-2010, the annual discharge at Chiang Khan was on average 12.4% higher or 13.7 km^3 more than at Luang Prabang (arithmetic average of annual totals). Between 2003 and 2009 Luang Prabang flows appeared to be relatively low, with annual discharge at Chiang Khan on average 30.2% or 30.2 km^3 more than at Luang Prabang. In this period, Luang Prabang annual discharge was 20.1 km^3 below previous averages (1967-2002) whereas Chiang Khan discharges were only 2.5 km^3 below previous averages. If correct, the data would imply significantly below-average rainfalls upstream of Luang Prabang, largely offset by above-average rainfalls downstream of Luang Prabang from 2003 to 2009. Alternatively, the apparent low flows at Luang Prabang in 2003-09 might be caused by filling of Dachaoshan Dam in China, which was completed in 2003. However, that dam holds about 0.88 km^3 of water when full, which is much less than the apparent decline in flows at Luang Prabang and insignificant relative to possible measurement errors. An alternative explanation would be that there are significant errors in the data. That such errors are possible is suggested by data for 1982 and 1998, when the recorded annual discharges at Chiang Khan were less than those at Luang Prabang. It seems highly unlikely that discharges could in fact be lower at Chiang Khan than at Luang Prabang, given that there are no significant abstractions from this section of the river.

To estimate daily discharges at the sampling stations, it was assumed that the increase in flow between the two gauging stations was linearly related to the increase in catchment area (CA). For each of the four sampling stations (x) the discharge (Q) on any day was estimated as:

$$Q_x = Q_{LP} + (CA_X - CA_{LP})/(CA_{CK} - CA_{LP}) \text{ x } (Q_{CK} - Q_{LP})$$

So for each of these sites, daily discharge was calculated as the discharge at Luang Prabang plus a proportion of the additional discharge to Chiang Khan, based on the increase in catchment area to that site. At Angnyai, using this formula, the discharge is higher than at Chiang Khan based on the additional catchment area.

Over the period of this sampling (1 May – 30 Sep 10), water level and discharge peaks and troughs at Chiang Khan appeared to lag those at Luang Prabang by 1 – 3 days. This was confirmed by a simple analysis which showed that the highest values for the correlation (r^2) between the sites in the dry season were achieved by lagging Chiang Khan flows by three days, whereas in the wet season the highest r^2 was associated with a one-day lag.

Over the period of the study, the best relationships between the two stations (highest r^2 values) were as follows:

17 May – 17 July 2010	Low flow	3-day lag
18-22 July 2010	Rising	2-day lag
23 July – 1 September 2010	High flow	1-day lag

Flow patterns from 1 Jan – 30 Apr 2010 (the dry season when there is little rain) also showed a lag of about three days, implying a mean current speed between the stations of about 1.13 m/s (as Chiang Khan is 294 km downstream of Luang Prabang). The shorter apparent lags at the onset of and during the wet season could be caused by faster flows (higher mean current speed) but also coincident local rainfall so cannot be used to estimate transit time. It also seems unlikely that mean current speed was in excess of 3 m s^{-1} between the gauging stations, which would be the result if a lag of one day is taken to represent mean transit time between the stations.

Table A1-1: Annual total discharges at Luang Prabang (LPQ) and Chiang Khan (CKQ), highlighting problematic values - 1982 and 1998 and 2003 - 2010

Refer to discussion. Averages are arithmetic means.

Year	LPQ km^3/yr	CKQ km^3/yr	Difference	Percent
1967	108.0	116.9	8.9	108.3%
1968	114.5	123.6	9.1	108.0%
1969	111.3	116.6	5.3	104.7%
1970	140.7	151.5	10.9	107.7%
1971	162.0	176.3	14.3	108.8%
1972	114.7	117.2	2.5	102.2%
1973	153.2	162.0	8.7	105.7%
1974	121.4	130.4	9.0	107.4%
1975	107.7	120.2	12.6	111.7%
1976	118.4	129.1	10.6	109.0%
1977	118.4	120.9	2.5	102.1%
1978	145.8	153.0	7.2	105.0%
1979	114.6	117.5	2.9	102.5%
1980	138.6	146.1	7.5	105.4%
1981	148.7	155.5	6.8	104.6%
1982	131.5	128.9	-2.7	98.0%
1983	122.1	127.5	5.5	104.5%
1984	124.6	128.1	3.5	102.8%
1985	134.0	145.4	11.4	108.5%
1986	108.3	121.3	13.0	112.0%
1987	95.9	107.1	11.2	111.7%
1988	104.5	116.5	12.0	111.5%
1989	101.9	114.7	12.8	112.6%
1990	120.9	135.5	14.6	112.0%
1991	138.2	143.0	4.8	103.5%

1992	76.6	90.3	13.7	117.9%
1993	101.9	117.2	15.3	115.0%
1994	120.9	145.2	24.3	120.1%
1995	135.6	152.2	16.6	112.2%
1996	133.0	146.8	13.8	110.4%
1997	118.4	128.4	10.0	108.4%
1998	115.6	115.3	-0.3	99.7%
1999	125.8	139.2	13.4	110.6%
2000	149.1	173.8	24.8	116.6%
2001	166.5	173.2	6.6	104.0%
2002	140.4	160.1	19.7	114.0%
2003	88.3	113.2	24.9	128.2%
2004	114.9	138.3	23.5	120.4%
2005	102.9	121.4	18.6	118.0%
2006	102.0	128.3	26.3	125.8%
2007	100.5	129.9	29.4	129.2%
2008	138.5	178.3	39.8	128.7%
2009	86.3	125.8	39.4	145.7%
2010	82.0	121.8	39.8	148.5%
Average	120.4	134.2	13.7	112.4%
Av. pre-2003	124.5	134.6	10.1	108.3%
Av. 2003-10	101.9	132.1	30.2	130.6%

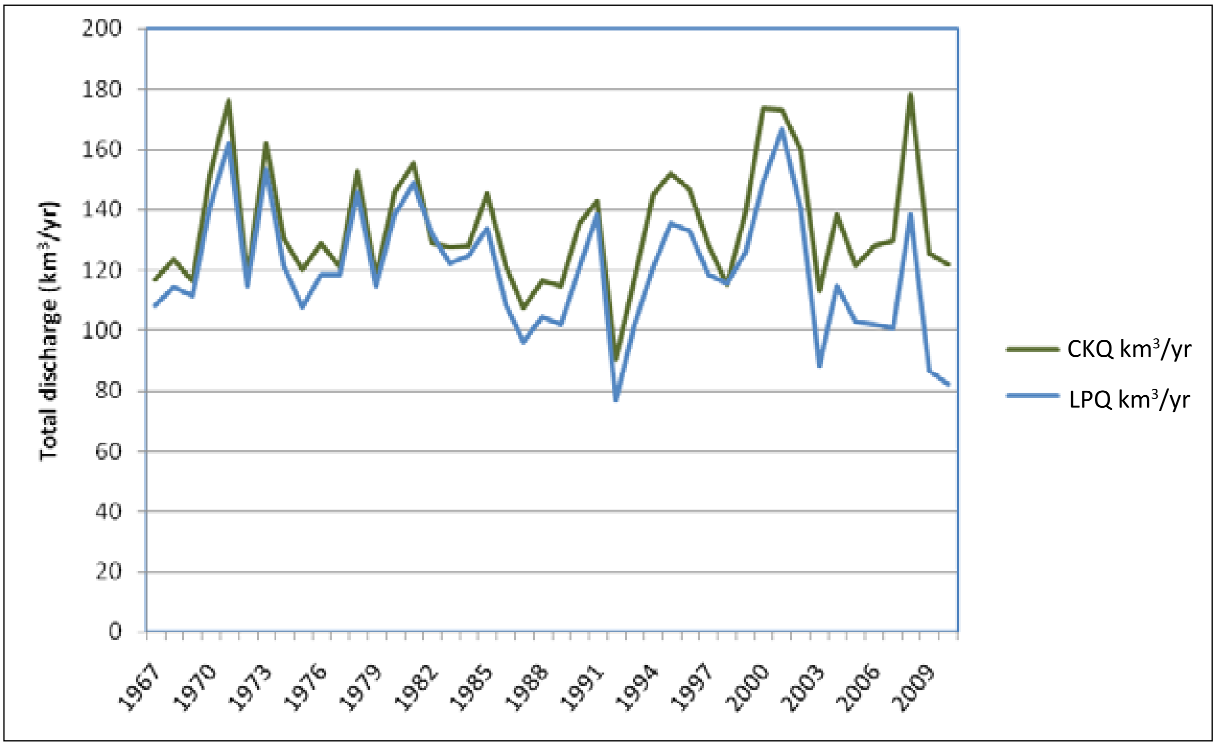

Figure A1-1: Annual discharges at Luang Prabang (LPQ) and Chiang Khan (CKQ)
Units are cubic kilometres per year.

Appendix 2: Data used for estimating age of fish

The data are summarised from Apichart and Hortle (2013). Estimates are from hatcheries; growth rates of wild fish may vary.

Family	Species	Yolk-sac larvae				Pre-Larvae				Post Larvae				Juvenile		Max. length (cm)	Lmat (cm)	Size Category
		Min		Max		Min		Max		Min		Max		Min				
		Days	Lth	Days	Lth	Days	Lth	Days	Lth	Days	Lth	Days	Lth	Days	Lth			
Ambassidae	*Parambassis apogonoides*					2	3.8	4	4.9	5	5.3	23	18.1	30	21.6	10.0	6.9	Very Small
Ambassidae	*Parambassis siamensis*					2	3.9			5	4.9	30	27.8	35	35.1	7.0	5.1	Very Small
Anabantidae	*Anabas testudineus*	1 hr	2	0.38	2.6	1	3	2	3.4	3	3.7	15	12.2	23	16.9	23.0	14.4	Small
Bagridae	*Hemibagrus filamentus*					1	4	2	5	3	5.7	25	15.8	31	17.1	60.0	33.3	Large
Bagridae	*Hemibagrus wyckioides*					0.5	3	1	4	2	4.4	19	23.4	35	35	138.0	69.2	Giant
Bagridae	*Mystus albolineatus*									5	7.4	35	33	40	37.1	35.0	20.8	Medium
Bagridae	*Mystus bocourti*										8.4		42.4		51.3	24.0	14.9	Small
Bagridae	*Mystus gulio*	6 hrs	3.1			0.5	3.1	2	4.2	5	7.1	23	21.4	45	26.1	40.0	23.3	Medium
Bagridae	*Mystus mysticetus*										9.6		33.7		42.6	13.0	8.7	Small
Bagridae	*Pseudomystus siamensis*	6 hrs	3.5			1	5	2	5.4	4	7.8	27	17.8	50	31.4	20.0	12.7	Small
Belonidae	*Xenentodon cancila*									1	9.4	19	26.9	23	32.8	40.0	23.3	Medium
Channidae	*Channa striata*	12 hrs	3.3			3	4.5	5	6	7	7	40	24	45	28.1	90.0	47.5	Large
Cobitidae	*Syncrossus helodes*	12 hrs	3.4			1	4.5	3	4.9	5	5.2	31	27.7	50	38.3	25.0	15.4	Small
Cobitidae	*Yasuhikotakia modesta*	12 hrs	3.5			1	3.8	3	5	7	5.6	27	15	31	16.0	25.0	15.4	Small
Cobitidae	*Yasuhikotakia nigrolineata*	1 hr	3.1			1	4	2	4.7	3	5	31	18	50	23.8	9.0	6.3	Very Small
Cynoglossidae	*Cynoglossus microlepis*						5.8		9.8		12				18	35.0	20.8	Medium
Cyprinidae	*Bangana behri*	1 hr	4.4			1	4.7	3	6.1	5	7.2	40	30.3	50	34.4	52.0	29.4	Medium
Cyprinidae	*Barbonymus altus*	1 hr	3			1	4.1	3	4.8	5	5.4	35	22.5	45	25.3	20.0	12.7	Small
Cyprinidae	*Barbonymus gonionotus*					1	3.7	3	4.3	7	5.6	40	18.9	50	27.8	33.0	19.7	Medium
Cyprinidae	*Barbonymus schwanenfeldii*	1 hr	3.1			1	3.9	3	4.9	12	6.5	35	21.5	50	28.1	35.0	20.8	Medium
Cyprinidae	*Catlocarpio siamensis*	6 hrs	4.3	1	5.5	2	6.3	3	6.9	5	7.6	23	34.1	40	47.1	300.0	136.7	Giant
Cyprinidae	*Cirrhinus molitorella*	1 hr	3.8			1	5.2	2	5.8	5	7.4	31	22.6	50	33.2	50.0	28.4	Medium
Cyprinidae	*Crossocheilus reticulatus*	1 hr	3.2			2	3.8	5	4.4	7	5	35	23.2	50	41.5	17.0	11.0	Small
Cyprinidae	*Cyclocheilichthys enoplos*	1 hr	4.0			1	5	2	5.2	3	5.5	35	30.8	40	36.1	74.0	40.0	Large
Cyprinidae	*Cyprinus carpio*	6 hrs	4.9			2	5.8	3	6.9	5	7.8	30	29.7	40	32.7	126.5	64.1	giant
Cyprinidae	*Epalzeorhynchos frenatus*	1 hr	3.1	0.5	3.7	1	4.3	3	4.8	7	5.6	27	23	40	43.3	12.0	8.1	Very Small
Cyprinidae	*Garra cambodgiensis*	6 hrs	4.1			0.5	4.6	3	5.2	5	6.1	40	21.3	50	27.5	15.0	9.9	Small
Cyprinidae	*Hampala dispar*									5	6.6	50	28.2			35.0	20.8	Medium
Cyprinidae	*Henicorhynchus siamensis*	1 hr	4			1	4.6	3	6.3	4	7	31	29.5	40	41.9	20.0	12.7	Small
Cyprinidae	*Hypsibarbus malcolmi*	1 hr	3.7	0.5	4.4	1	4.9	3	5.7	5	6.5	27	28.1	45	37.3	50.0	28.4	Medium
Cyprinidae	*Labeo chrysophekadion*	1 hr	4			2	4.9	3	5.5	4	6.4	27	21.2	50	28.6	90.0	47.5	Large
Cyprinidae	*Labeo dyocheilus*	1 hr	3.7			2	4.6	3	5.8	4	7.4	27	24.6	50	38.9	50.0	28.4	Medium
Cyprinidae	*Leptobarbus hoevenii*	1 hr	4.4			1	5.3	3	5.9	5	7	23	25.5	25	31.3	70.0	38.1	Large
Cyprinidae	*Opsarius koratensis*	12 hrs	3.7			2	4.4	3	6.8	5	7.3	30	37.8	40	45.5	10.0	6.9	Very Small
Cyprinidae	*Probarbus jullieni*	1 hr	7.0			1	7.9	2	8.2	4	8.9	40	21.6	50	29.4	165.0	80.9	Giant
Cyprinidae	*Puntius aurotaeniatus*									15	7.8	40	20.3	50	26	6.0	4.4	Very Small
Cyprinidae	*Puntius orphoides*	1 hr	3.1			12 hr	3.6	2	4.2	3	4.4	40	17	50	31.2	25.0	15.4	Small
Cyprinidae	*Tor tambroides*					1	10.5	3	12.2	5	13.4	27	22.9	31	25.8	80.0	42.9	Large
Datnioididae	*Datnioides undecimradiatus*									12	5.7	46	18.4	56	26.2	46.0	26.4	Medium
Eleotridae	*Oxyeleotris marmorata*	1	2.1	2	2.9	3	3.6	9	4.5	19	5.9	40	14.8	50	22.1	50.0	28.4	Medium
Gobiidae	*Gobiopterus* cf. *chuno*										8		19.5		21.2	3.0	2.4	Very Small
Gyrinocheilidae	*Gyrinocheilus aymonieri*	1 hr	2.3			1	4.3	3	5.5	5	6.6	27	27	40	41.6	26.0	16.0	Medium
Helostomatidae	*Helostoma temminkii*	1 hr	3.5			1	4.7	2	5.3	3	6.9	40	21.1	50	25.4	30.0	18.1	Medium
Hemiramphidae	*Dermogenys siamensis*									1	8.9	15	22.3	20	24	7.0	5.1	Very Small
Heteropneustidae	*Heteropneustes kemratensis*					1	3.9	3	6.3	5	7.1	27	17	35	26	30.0	18.1	Medium
Mastacembelidae	*Macrognathus semiocellatus*									12	14.1	40	42.5	50	50.9	22.0	13.8	Small
Notopteridae	*Chitala ornata*					3	12.2	5	15.3	7	17.3	40	57	70	67.8	115.0	58.9	Giant
Notopteridae	*Notopterus notopterus*					3	5.5	5	6.2	7	7.1	40	41.9	70	61.7	60.0	33.3	Large
Osphronemidae	*Betta splendens*	1 hr	2.6			1	2.8	5	3.7	9	4.7	35	14.9	45	22.6	6.0	4.4	Very Small
Osphronemidae	*Osphronemus goramy*	1	5.2			3	6.3			7	7	27	11.7	35	18	70.0	38.1	Large
Osphronemidae	*Trichogaster pectoralis*	1 hr	2.4			1	3	7	4.1	12	7.1	40	21.6	45	24.4	25.0	15.4	Small

Osphronemidae	*Trichopodus trichopterus*	1 hr	2.6			1	3.1	7	4.4	9	5.7	31	18.2	50	32.2	15.0	9.9	Small
Osphronemidae	*Trichopsis schalleri*	1 hr	3.1			1	3.4	2	3.8	5	4.6	40	17.5	45	30.5	4.0	3.1	Very Small
Osphronemidae	*Trichopsis vittata*	1 hr	2.8			1	3	3	3.9	7	5.5	35	16.4	45	19.8	7.0	5.1	Very Small
Pangasiidae	*Helicophagus leptorhynchus*	1 hr	3.0			1	5			2	7.4	40	38.6	50	46.6	54.0	30.4	Medium
Pangasiidae	*Pangasianodon hypophthalmus*					0.25	3.8			2	6.1	40	50.5	50	55.8	150.0	74.4	Giant
Pangasiidae	*Pangasius larnaudii*	6 hrs	3.9			1	5.9			2	6.5	31	41.2	35	49.5	150.0	74.4	Giant
Pangasiidae	*Pangasius macronema*					0.5	4.2	2	5.4	5	7.2	35	28.2	45	50.3	40.0	23.3	Medium
Schilbeidae	*Laides longibarbis*					1	6.8	3	8.8	4	9.9	35	33.1	45	46.7	20.0	12.7	Small
Siluridae	*Belodontichthys truncatus*	1 hr	5.8	0.5	6.3	2	6.9	5	7.8	7	10.8	31	24.9	40	42.3	80.0	42.9	Large
Siluridae	*Phalacronotus apogon*					1	5	3	6.5	5	7.2	35	38.8	45	46.5	77.0	41.5	Large
Siluridae	*Phalacronotus bleekeri*	1 hr	4.2			1	4.4	2	5.5	3	6.2	23	23.3	40	44.2	60.0	33.3	Large
Siluridae	*Wallago micropogon*	1 hr	4.6			0.25	5.4	2	8.3	3	10.4	19	35.9	27	51.9	145.0	72.2	Giant
Soleidae	*Brachirus harmandi*						9.1				14		19.9		26.8	10.0	6.9	Very Small
Tetraodontidae	*Tetraodon cochinchinensis*										3.7		16.9		27	15.0	9.9	Small

Appendix 3: List of species recorded

Family	Species	Total Number	Notes	Species used to estimate ages from length-age relationship and notes	Size Category	Min Lth in samples TL (cm)	Max Lth in Samples TL (cm)	Max. size known TL (cm)	Estimated Lmat (cm)
Ambassidae	*Parambassis siamensis*	151		*Parambassis siamensis*	Very Small	6	79	7	5.1
Anabantidae	*Anabas testudineus*	1		*Anabas testudineus*	Small	52	52	23	14.4
Bagridae	*Hemibagrus spilopterus*	171	H. sp. aff. nemurus in Kottelat (2001)	*Hemibagrus filamentus*, PLs start at about 6 mm. juv., at about 16 mm	Large	5	76	75	40.5
	Mystus multiradiatus	4		*Pseudomystus siamensis*	Small	8	13	14	9.3
	Mystus mysticetus	6		*Pseudomystus siamensis*	Small	9	12	13	8.7
Balitoridae	*Homaloptera yunnanensis*	1		Cobitidae 3 species (samples had one post-larva only)	Very Small	14	14	7	5.1
Channidae	*Channa gachua*	12		*Channa striata*	Small	15	58	20	12.7
	Channa striata	4		*Channa striata*	Large	25	48	90	47.5
Cichlidae	*Oreochromis niloticus*	2		*Oreochromis niloticus*	Medium	13	40	46	26.4
Clupeidae	*Clupeichthys aesarnensis*	50		*Epalzeorhynchos frenatus, Opsarius koratensis, Puntius aurotaeniatus* (3 very small cyprinids)	Very Small	9	67	7	5.1
	Clupeoides borneensis	1		*Epalzeorhynchos frenatus, Opsarius koratensis, Puntius aurotaeniatus* (3 very small cyprinids)	Very Small	19	19	8	5.7
	Corica laciniata	12		*Epalzeorhynchos frenatus, Opsarius koratensis, Puntius aurotaeniatus* (3 very small cyprinids)	Very Small	15	68	7	5.1
Cobitidae	*Pangio anguillaris*	1		Cobitidae - 3 species	Very Small	29	81	9	6.3
Cyprinidae	*Aaptosyax grypus*	17	Identity uncertain, large cyprinid, not Probarbus	Very small yolk-sac or pre-larvae, assumed about 1 day old	Giant	5	8	165	80.9
	Barbonymus altus	1		*Barbonymus altus*	Small	16	62	20	12.7
	Barbonymus gonionotus	8		*Barbonymus gonionotus*	Medium	23	62	33	19.7
	Barbonymus schwanenfeldii	5		*Barbonymus schwanenfeldii*	Medium	23	48	35	20.8
	Cosmochilus harmandi	537		*Labeo chrysophekadion*	Giant	6	90	100	52.1
	Crossocheilus cobitis	1		*Crossocheilus reticulatus*	Very Small	25	25	7	5.1

Family	Species	Total Number	Notes	Species used to estimate ages from length-age relationship and notes	Size Category	Min Lth in samples TL (cm)	Max Lth in Samples TL (cm)	Max. size known TL (cm)	Estimated Lmat (cm)
	Cyclocheilichthys apogon	1		*Cyclocheilichthys enoplos*	Small	11	48	17	11.0
	Cyclocheilichthys armatus	89		*Cyclocheilichthys enoplos*	Medium	7	89	26	16.0
	Cyclocheilichthys enoplos	1		*Cyclocheilichthys enoplos*	Large	46	61	74	40.0
	Cyclocheilichthys lagleri	6		*Cyclocheilichthys enoplos*	Small	16	48	15	9.9
	Cyclocheilichthys repasson	1		*Cyclocheilichthys enoplos*	Medium	32	43	26	16.0
	Danio roseus	6		*Puntius aurotaeniatus*	Very Small	29	51	4	3.1
	Discherodontus ashmeadi	1		Five small cyprinids average	Small	32	32	16	10.4
	Esomus metallicus	7		*Epalzeorhynchos frenatus, Opsarius koratensis, Puntius aurotaeniatus* (3 very small cyprinids)	Very Small	27	58	8	5.7
	Hampala dispar	1		*Hampala dispar*	Medium	40	40	35	20.8
	Henicorhynchus spp.	755	*H. siamensis* and *H. lobatus*	*Henicorhynchus siamensis* PL at 7 mm, Juv. at 30 mm	Small	4	82	20	12.7
	Hypsibarbus malcolmi	3		*Hypsibarbus malcolmi*	Medium	30	69	50	28.4
	Labeo chrysophekadion	1		*Labeo chrysophekadion*	Large	16	16	90	47.5
	Labiobarbus leptocheilus	1		Five small cyprinids average	Small	28	28	20	12.7
	Mystacoleucus atridorsalis	25		Small - very small cyprinids - 8 species average	Very Small	25	55	7	5.1
	Mystacoleucus ectypus	4		Small - very small cyprinids - 8 species average	Very Small	28	44	8	5.7
	Mystacoleucus greenwayi	25		Small - very small cyprinids - 8 species average	Very Small	24	54	8	5.7
	Mystacoleucus lepturus	1		Five small cyprinids average	Very Small	59	59	11	7.5
	Mystacoleucus marginatus	69		Five small cyprinids average	Small	15	113	20	12.7
	Opsarius koratensis	16		*Epalzeorhynchos frenatus, Opsarius koratensis, Puntius aurotaeniatus* (3 very small cyprinids)	Very Small	25	73	10	6.9
	Paralaubuca barroni	255		Five small cyprinids average	Small	10	95	15	9.9
	Paralaubuca riveroi	31		Five small cyprinids average	Small	10	96	18	11.6
	Poropuntius normani	1		Five small cyprinids average	Small	52	52	15	9.9

Family	Species	Total Number	Notes	Species used to estimate ages from length-age relationship and notes	Size Category	Min Lth in samples TL (cm)	Max Lth in Samples TL (cm)	Max. size known TL (cm)	Estimated Lmat (cm)
	Puntioplites falcifer	4		*Puntius orphoides*	Medium	25	56	35	20.8
	Puntioplites proctozystron	90		*Puntius orphoides*	Small	12	78	25	15.4
	Puntius stoliczkanus	28		*Puntius aurotaeniatus*	Very Small	11	62	5	3.8
	Raiamas guttatus	4		*Hampala dispar* (medium predator)	Medium	9	36	30	18.1
	Rasbora daniconius	1		Five small cyprinids average	Small	27	27	15	9.9
	Sikukia gudgeri	27		Five small cyprinids average	Small	24	107	18	11.6
Eleotridae	*Oxyeleotris marmorata*	3		*Oxyeleotris marmorata*	Medium	10	58	50	28.4
Gobiidae	*Gobiopterus* sp.	215		*Trichopsis schalleri* - smallest species with data Lmax 4 cm, assume juveniles after 15 mm	Very Small	6	40	5	3.8
	Oxuderces sp.	2		*Trichopsis schalleri* - smallest species with data Lmax 4 cm, assume juveniles after 15 mm	Very Small	6	7	10	6.9
	Rhinogobius sp.	84		*Oxyeleotris marmorata* - large species but slow growth rate	Very Small	11	50	4	3.1
Loricariidae	*Pterygoplichthys disjunctivus*	5		All juvenile > 44 mm - assumed > 30 days	Large	40	63	70	38.1
Mastacembelidae	*Mastacembelus armatus*	6		Stages checked, age assumed from all species data	Large	5	35	80	42.9
Nandidae	*Badis ruber*	3		*Betta splendens*	Very Small	11	34	6	4.4
	Pristolepis fasciata	3		*Trichopodus trichopterus, Trichogaster pectoralis*	Small	11	61	24	14.9
Notopteridae	*Chitala ornata*	13		*Chitala ornata*	Giant	28	90	115	58.9
	Notopterus notopterus	10		*Notopterus notopterus*	Large	10	33	60	33.3
Osphronemidae	*Trichopodus trichopterus*	1		*Trichopodus trichopterus*	Small	18	18	15	9.9
	Trichopsis pumila	2		*Trichopsis schalleri & T. vittata*	Very Small	14	20	4.6	3.5
	Trichopsis vittata	4		*Trichopsis vittata*	Very Small	8	59	7	5.1
Pangasiidae	*Pangasius bocourti*	3		*Pangasianodon hypopthalmus* and *P. larnaudii*	Giant	7	26	100	52.1
	Pangasius conchophilus	12		*Pangasianodon hypopthalmus* and *P. larnaudii*	Giant	6	28	120	61.2
	Pangasius elongatus	1		*Pangasianodon hypopthalmus* and *P. larnaudii*	Giant	10	13	100	52.1

Family	Species	Total Number	Notes	Species used to estimate ages from length-age relationship and notes	Size Category	Min Lth in samples TL (cm)	Max Lth in Samples TL (cm)	Max. size known TL (cm)	Estimated Lmat (cm)
	Pangasius larnaudii	1		*Pangasius larnaudii*	Giant	22	22	150	74.4
	Pangasius macronema	3,326		*Pangasius macronema* PL at 7 mm, Juv. at 35 mm	Medium	3	59	40	23.3
	Pangasius sanitwongsei	3		*Pangasius hypopthalmus* and *P. larnaudii*	Giant	9	13	250	116.5
	Pseudolais pleurotaenia	19		*Laides longibarbis*	Medium	7	37	34	20.2
Salangidae	*Neosalanx* sp. cf. *jordani*	139		*Epalzeorhynchos frenatus, Opsarius koratensis, Puntius aurotaeniatus* (3 very small cyprinids)	Very Small	11	85	8.5	6.0
	Sundasalanx mekongensis	1		Only adult present, assumed > 30 days	Very Small	38	38	3	2.4
Schilbeidae	*Clupisoma sinense*	17		*Laides longibarbis*	Medium	15	81	36	21.3
	Laides longibarbis	32		*Laides longibarbis*	Small	5	90	20	12.7
Siluridae	*Belodontichthys truncatus*	1		*Belodontichthys truncatus*	Large	12	12	80	42.9
	Kryptopterus spp.	73	Includes *K. cheveyi, K. geminus* and *K. schilbeides*	*Phalacronotus bleekeri*	Small	6	58	20	12.7
	Ompok bimaculatus	135		*Phalacronotus apogon, P. bleekeri, Belodontichthys truncatus*	Medium	9	10	50	28.4
	Ompok urbaini	2		*Phalacronotus apogon, P. bleekeri, Belodontichthys truncatus*	Small	7	75	20.8	13.1
	Phalacronotus apogon	39		*Phalacronotus apogon*	Large	63	63	77	41.5
	Phalacronotus bleekeri	1		*Phalacronotus bleekeri*	Large	9	59	60	33.3
	Pterocryptis sp.	6		*Phalacronotus bleekeri*	Small	8	11	20	12.7
	Wallago attu	2		*Wallago micropogon*	Giant	5	85	200	95.8
Sisoridae	*Bagarius bagarius*	3		*Mystus gulio*	Small	6	9	25	15.4
	Bagarius yarrelli	1		*Hemibagrus wyckioides*	Giant	39	39	200	95.8
	Glyptothorax fuscus	7		*Pseudomystus siamensis*	Very Small	10	44	8	5.7
	Glyptothorax lampris	480		*Pseudomystus siamensis*	Very Small	5	84	7	5.1
Soleidae	*Brachirus panoides*	2		Only two small clearly PL stage, age assumed from all species data	Small	14	14	20	12.7

Appendix 4: Summary of larval abundance by location and stage

Fish are sorted from most to least abundant.

The top ten species are highlighted. YS = yolk-sac larvae, Pre = pre-larvae, PL = post-larvae

Species	Total larvae	Pakhao	Thadeua	Nasak	Angnyai	Larvae present	Note
Pangasius macronema	3,318	170 Pre, 97 PL	251 Pre, 405 PL	13 YS, 669 Pre, 507 PL	3 YS, 7 15 Pre, 488 PL	May to August	Increasing abundance from Pakhao to Angnyai
Henicorhynchus spp.	753	22 Pre, 4 PL	37 Pre, 8 PL	14 YS, 16 Pre, 2 PL	3 YS, 615 Pre, 32 PL	May to August	Variable, large peak at Angnyai
Glyptothorax lampris	458	4 Pre, 24 PL	40 Pre, 305 PL	8 Pre, 18 PL	10 Pre, 49 PL	May to August	Similar load all sites, but little development from Pre to PL
Cosmochilus harmandi	270	1 Pre, 27 PL	117 PL	1 Pre, 7 PL	4 Pre, 113 PL	May to August	Increase Nasak - Angnyai
Gobiopterus cf. *chuno*	158	34 PL	95 PL	15 PL	14 PL	May to August	Similar load all sites, but little development
Ompok bimaculatus	121	28 PL	73 PL	5 PL	15 PL	May to August	Variable, most at Thadeua
Hemibagrus spilopterus	116	11 PL	17 PL	1 Pre, 7 PL	24 Pre, 56 PL	May to August	Increase Nasak - Angnyai
Paralaubuca barroni	81	36 PL	41 PL	2 PL	2 PL	May to August	Most at Pakhao and Thadeua
Kryptopterus spp.	70	4 Pre, 22 PL	27 PL	1 YS, 13 PL	3 PL	May to August	Decrease in larvae to Angnyai/ variable
Cyclocheilichthys armatus	68	6 PL	14 PL	9 PL	39 PL	May to August	Increase Pakhao to Angnyai
Phalacronotus apogon	36	1 PL, Pakhao 12 June		8 PL, 1-2 July	1 Pre, 8 June. 26 PL, on days from 12 June to 21 August	June - August	Pakhao - Angnyai, most at Nasak and Angnyai
Rhinogobius sp.	22	1 PL, 28 May 10	21 PL, on 10 days 31 May - 17 June 10			May - June	Pakhao - Thadeua, upland species
Parambassis siamensis	20	1 PL 6 June	10 PL, on 8 days, 31 May to 17 June	4 PL, on 3 days, 8 June to 7 July	5 PL, on 4 days, 6 June - 22 July	May - July	Pakhao - Angnyai, most at Thadeua
Aaptosyax grypus	17				4 pre- and 13 YS, 14 - 22 July 10	July	Only at Angnyai

Species	Total larvae	Pakhao	Thadeua	Nasak	Angnyai	Larvae present	Note
Laides longibarbis	17	1 PL at Pakhao, 16 August	1 YS, 28 May. 6 PL, on 6 days, 26 May to 5 August.	1 PL, 24 May	2 Pre 20 July. 2 PL, 28 May, 2 PL, 20 July	May - August	Pakhao - Angnyai
Puntioplites proctozystron	13				13 PL on 7 days, 27 May to 7 August	May - August	Only at Angnyai
Clupisoma sinense	12		12 PL, on 7 days between 4 and 14 August			August	Only at Thadeua
Pangasius conchophilus	12	8 PL on 3 days 22 May to 15 June	1 PL 6 June	1 Pre, 19 July	2 PL, 19 July	May - July	Pakhao - Angnyai, most at Pakhao
Paralaubuca riveroi	12		12 PL, 25 - 31 May			May	Only at Thadeua
Mystacoleucus marginatus	10		1 PL, 8 August		9 PL, 27 - 29 May	May - August	Thadeau and Angnyai, most at Angnyai. May to August
Notopterus notopterus	10	1 PL 10 June	1 PL, 1 June	2 PL ,13 July and 5 August	6 PL on 4 days, 17 June - 13 August	June - August	Pakhao - Angnyai, most at Angnyai
Channa gachua	8	1 PL, 23 May	7 PL on 7 days, 3 June and 5 July			May - July	Pakhao - Thadeua, upland species
Mystus mysticetus	6				6 PL at Angnyai, on 5 days 29 May - 17 June	May - June	Only at Angnyai
Pseudolais pleurotaenia	6	3 PL, 29 - 30 June	2 PL, 20 June and 12 July		1 Pre, 27 May 10	May - July	Pakhao - Angnyai, uncommon
Mastacembelus armatus	5		1 Pre, 29 June. 1 PL, 14 July	1 PL, 17 July	2 PL, 30 Jun, 1 July	July	Thadeua - Angnyai, uncommon
Cyclocheilichthys lagleri	4	1 PL, 11 July		3 PL, 16, 17 July, 4 August		July - August	Pakhao & Nasak, uncommon
Mystus multiradiatus	4			4 PL on 4 days, 30 May to 12 June		May - June	Only at Nasak
Bagarius bagarius	3		3 PL, 23 May 10			May	Only at Thadeua
Chitala ornata	3		3 PL, 3 June, 5 July			June - July	Only at Thadeua
Glyptothorax fuscus	3	1 PL, 28 June			2 PL, 15 June	June	Pakhao & Angnyai
Pangasius bocourti	3		1 PL, 6 July		1 PL, 9 June	June - July	Thadeua & Angnyai
Pangasius sanitwongsei	3		2 PL, 13 June, 1 PL, 16 July			July	Only at Thadeua
Pterocryptis sp.	3				2 PL, 21 July & 1 PL, 15 August	July - August	Only at Angnyai

Species	Total larvae	Pakhao	Thadeua	Nasak	Angnyai	Larvae present	Note
Raiamas guttatus	3		3 PL, 28 May			May	Only at Thadeua
Brachirus panoides	2				2 PL, 8 & 19 June	June	Only at Angnyai
Hypsibarbus malcolmi	2	1 PL, 26 June	1 PL, 28 May			May - June	Pakhao & Thadeua
Ompok urbaini	2				2 PL, 29 May	May	Only at Angnyai
Oxuderces sp.	2				2 PL, 3 July	July	Only at Angnyai
Oxyeleotris marmorata	2		1 PL, 14 August		1 PL, 16 June	June - August	Thadeua & Angnyai
Pristolepis fasciata	2				2 PL, 12 June & 16 August	June - August	Only at Angnyai
Wallago attu	2		1 PL, 16 Jul 10		1 PL 22 July 10	July	Thadeua & Angnyai
Badis ruber	1		1 PL, 7 June			June	Only at Thadeua
Barbonymus altus	1				1 PL, 1 June	June	Only at Angnyai
Barbonymus schwanenfeldii	1				1 PL, 22 July	July	Only at Angnyai
Belodontichthys truncatus	1		1 PL, 30 June			June	Only at Thadeua
Clupeichthys aesarnensis	1		1 PL, 28 June			June	Only at Thadeua
Homaloptera yunnanensis	1		1 PL, 8 June			June	Only at Thadeua
Labeo chrysophekadion	1				1 PL, 22 July	July	Only at Angnyai
Labiobarbus leptocheilus	1				1 PL, 14 August	August	Only at Angnyai
Opsarius koratensis	1				1 PL, 3 June	June	Only at Angnyai
Oreochromis niloticus	1	1 PL, 24 May				May	Only at Pakhao
Pangasius elongatus	1		1 PL, 30 Jun 10			June	Only at Thadeua
Pangasius larnaudii	1	1 PL, 21 Jun 10 Pakhao				June	Only at Pakhao
Puntius stoliczkanus	1		1 Pl, 24 May			May	Only at Thadeua
Trichopodus trichopterus	1				1 PL, 18 July	July	Only at Angnyai
Trichopsis pumila	1				1 PL, 20 July	July	Only at Angnyai
Trichopsis vittata	1		1 PL, 18 Jul 10			July	Only at Thadeua
Osphronemidae	*Trichopodus trichopterus*	1		*Trichopodus trichopterus*	Small	18	18
	Trichopsis pumila	2		*Trichopsis schalleri* & *T. vittata*	Very Small	14	20
	Trichopsis vittata	4		*Trichopsis vittata*	Very Small	8	59
Pangasiidae	*Pangasius bocourti*	3		*Pangasianodon hypopthalmus* and *P. larnaudii*	Giant	7	26
	Pangasius conchophilus	12		*Pangasianodon hypopthalmus* and *P. larnaudii*	Giant	6	28

Species	Total larvae	Pakhao	Thadeua	Nasak	Angnyai	Larvae present	Note
	Pangasius elongatus	1		*Pangasianodon hypopthalmus* and *P. larnaudii*	Giant	10	13
	Pangasius larnaudii	1		*Pangasius larnaudii*	Giant	22	22
	Pangasius macronema	3,326		*Pangasius macronema* PL at 7 mm, Juv. at 35 mm	Medium	3	59
	Pangasius sanitwongsei	3		*Pangasius hypopthalmus* and *P. larnaudii*	Giant	9	13
	Pseudolais pleurotaenia	19		*Laides longibarbis*	Medium	7	37
Salangidae	*Neosalanx* sp. cf. *jordani*	139		*Epalzeorhynchos frenatus, Opsarius koratensis, Puntius aurotaeniatus* (3 very small cyprinids)	Very Small	11	85
	Sundasalanx mekongensis	1		Only adult present, assumed > 30 days	Very Small	38	38
Schilbeidae	*Clupisoma sinense*	17		*Laides longibarbis*	Medium	15	81
	Laides longibarbis	32		*Laides longibarbis*	Small	5	90
Siluridae	*Belodontichthys truncatus*	1		*Belodontichthys truncatus*	Large	12	12
	Kryptopterus spp.	73	Includes *K. cheveyi, K. geminus* and *K. schilbeides*	*Phalacronotus bleekeri*	Small	6	58
	Ompok bimaculatus	135		*Phalacronotus apogon, P. bleekeri, Belodontichthys truncatus*	Medium	9	10
	Ompok urbaini	2		*Phalacronotus apogon, P. bleekeri, Belodontichthys truncatus*	Small	7	75
	Phalacronotus apogon	39		*Phalacronotus apogon*	Large	63	63
	Phalacronotus bleekeri	1		*Phalacronotus bleekeri*	Large	9	59
	Pterocryptis sp.	6		*Phalacronotus bleekeri*	Small	8	11
	Wallago attu	2		*Wallago micropogon*	Giant	5	85
Sisoridae	*Bagarius bagarius*	3		*Mystus gulio*	Small	6	9
	Bagarius yarrelli	1		Hemibagrus wyckioides	Giant	39	39
	Glyptothorax fuscus	7		*Pseudomystus siamensis*	Very Small	10	44
	Glyptothorax lampris	480		*Pseudomystus siamensis*	Very Small	5	84
Soleidae	*Brachirus panoides*	2		Only two small clearly PL stage, age assumed from all species data	Small	14	14

Appendix 5: Comparison of LEK data and 2010 survey data

LEK - Local Ecological Knowledge data collected by the MRC in 1999.

Species	LEK - Month migrating upstream		LEK - Month eggs seen in fish		Icthyoplankton study 2010	Comparison with - 2010 study	Total larvae 2010
	Start	End	Start	End	Larvae present		
Pangasius macronema	2	10	4	7	May to August	LEK-2010 Consistent	3,318
Henicorhynchus spp.	3	9	5	9	May to August	LEK-2010 Consistent	753
Glyptothorax lampris					May to August	2010 la but No LEK data	458
Cosmochilus harmandi	4	4	5	6	May to August	LEK-2010 Consistent	270
Gobiopterus cf. *chuno*					May to August	2010 la but No LEK data	158
Ompok bimaculatus					May to August	2010 la but No LEK data	121
Hemibagrus spilopterus	5	6	4	11	May to August	LEK-2010 Consistent	116
Paralaubuca barroni					May to August	2010 la but No LEK data	81
Kryptopterus spp.					May to August	2010 la but No LEK data	70
Cyclocheilichthys armatus					May to August	2010 la but No LEK data	68
Phalacronotus apogon					June to August	2010 la but No LEK data	36
Rhinogobius sp.					May to June	2010 la but No LEK data	22
Parambassis siamensis					June to July	2010 la but No LEK data	20
Aaptosyax grypus					July	2010 la but No LEK data	17
Laides longibarbis	3	6	5	5	May to August	LEK-2010 Consistent	17
Puntioplites proctozystron					August	2010 la but No LEK data	13
Clupisoma sinense					August	2010 la but No LEK data	12
Paralaubuca riveroi					May	2010 la but No LEK data	12
Pangasius conchophilus	3	7	3	8	June to July	LEK-2010 Consistent	12
Mystacoleucus marginatus					May to August	2010 la but No LEK data	10
Notopterus notopterus			4	4	June to August	LEK-2010 Not consistent	10
Channa gachua					May to July	2010 la but No LEK data	8
Mystus mysticetus					May to June	2010 la but No LEK data	6
Pseudolais pleurotaenia	2	6	5	6	May to July	LEK-2010 Consistent	6
Mastacembelus armatus	9	9	3	8	July	LEK-2010 Consistent	5
Cyclocheilichthys lagleri					July to August	2010 la but No LEK data	4
Mystus multiradiatus					May to June	2010 la but No LEK data	4
Glyptothorax fuscus					June	2010 la but No LEK data	3
Pterocryptis sp.					July-August	2010 la but No LEK data	3
Raiamas guttatus					May	2010 la but No LEK data	3
Bagarius bagarius					May	2010 La but no LEK data	3
Pangasius sanitwongsei	3	6	4	7	July	LEK-2010 Consistent	3
Pangasius bocourti	3	7	3	9	June to July	LEK-2010 Consistent	3
Chitala ornata			8	9	June to July	LEK-2010 Not consistent	3
Brachirus panoides					June	2010 la but No LEK data	2
Ompok urbaini					May	2010 la but No LEK data	2
Oxuderces sp.					July	2010 la but No LEK data	2
Oxyeleotris marmorata					June to August	2010 la but No LEK data	2
Hypsibarbus malcolmi	2	5	3	6	May to June	LEK-2010 Consistent	2
Wallago attu	5	7	7	8	July	LEK-2010 Consistent	2

Species	LEK - Month migrating upstream		LEK - Month eggs seen in fish		Icthyoplankton study 2010	Comparison with - 2010 study	Total larvae 2010
	Start	End	Start	End	Larvae present		
Badis ruber					June	2010 la but No LEK data	1
Barbonymus schwanenfeldii					July	2010 la but No LEK data	1
Clupeichthys aesarnensis					June	2010 la but No LEK data	1
Homaloptera yunnanensis					June	2010 la but No LEK data	1
Labiobarbus leptocheilus					August	2010 la but No LEK data	1
Opsarius koratensis					June	2010 la but No LEK data	1
Oreochromis niloticus					May	2010 La but no LEK data	1
Puntius stoliczkanus					May	2010 La but no LEK data	1
Trichopodus trichopterus					July	2010 La but no LEK data	1
Trichopsis pumila					July	2010 La but no LEK data	1
Trichopsis vittata					July	2010 La but no LEK data	1
Belodontichthys truncatus	5	5			June	LEK-2010 Consistent	1
Pangasius elongatus	4	6	5	7	June	LEK-2010 Consistent	1
Labeo chrysophekadion	3	7	5	8	July	LEK-2010 Consistent	1
Pangasius larnaudii	4	10	3	8	June	LEK-2010 Consistent	1
Barbonymus altus	2	2	2	2	June	LEK-2010 Not consistent	1
Barbonymus gonionotus	3	5	3	6		LEK data, but only juveniles &/or adults in 2010, consistent with dry-season spawning	0
Hampala dispar	4	5	3	7		LEK data, but only juveniles &/or adults in 2010, consistent with dry-season spawning	0
Phalacronotus bleekeri	5	6	5	10		LEK data, but only juveniles &/or adults in 2010, consistent with dry-season spawning	0
Cyclocheilichthys enoplos	4	7	4	8		LEK data, but only juveniles &/or adults in 2010, consistent with dry-season spawning	0
Puntioplites falcifer	2	7	5	5		LEK data, but only juveniles &/or adults in 2010, consistent with dry-season spawning	0
Bagarius yarrelli	3	11	1	9		LEK data, but only juveniles &/or adults in 2010, consistent with dry-season spawning	0
Danio roseus						No LEK data, 2010 juveniles &/or adults only	0
Sundasalanx mekongensis						No LEK data, 2010 juveniles &/or adults only	0

Species	**LEK - Month migrating upstream**		**LEK - Month eggs seen in fish**		**Icthyoplankton study 2010**	**Comparison with - 2010 study**	**Total larvae 2010**
	Start	End	Start	End	Larvae present		
Mystacoleucus atridorsalis						No LEK data, 2010 juveniles &/or adults only	0
Neosalanx sp. cf. *jordani*						No LEK data, 2010 juveniles &/or adults only	0
Anabas testudineus						No LEK data, 2010 juveniles &/or adults only	0
Channa striata						No LEK data, 2010 juveniles &/or adults only	0
Clupeoides borneensis						No LEK data, 2010 juveniles &/or adults only	0
Crossocheilus cobitis						No LEK data, 2010 juveniles &/or adults only	0
Cyclocheilichthys apogon						No LEK data, 2010 juveniles &/or adults only	0
Cyclocheilichthys repasson						No LEK data, 2010 juveniles &/or adults only	0
Discherodontus ashmeadi						No LEK data, 2010 juveniles &/or adults only	0
Esomus metallicus						No LEK data, 2010 juveniles &/or adults only	0
Mystacoleucus ectypus						No LEK data, 2010 juveniles &/or adults only	0
Mystacoleucus greenwayi						No LEK data, 2010 juveniles &/or adults only	0
Mystacoleucus lepturus						No LEK data, 2010 juveniles &/or adults only	0
Pangio anguillaris						No LEK data, 2010 juveniles &/or adults only	0
Poropuntius normani						No LEK data, 2010 juveniles &/or adults only	0
Pterygoplichthys disjunctivus						No LEK data, 2010 juveniles &/or adults only	0
Rasbora daniconius						No LEK data, 2010 juveniles &/or adults only	0

Species	LEK - Month migrating upstream		LEK - Month eggs seen in fish		Icthyoplankton study 2010	Comparison with - 2010 study	Total larvae 2010
	Start	End	Start	End	Larvae present		
Datnioides undecimradiatus	2	2	3	3		LEK data but no 2010 data	
Cirrhinus molitorella	2	2				LEK data but no 2010 data	
Yasuhikotakia modesta	2	4	4	6		LEK data but no 2010 data	
Mekongina erythrospila	2	5	5	5		LEK data but no 2010 data	
Hampala macrolepidota	2	6	4	11		LEK data but no 2010 data	
Probarbus jullieni	2	7	3	8		LEK data but no 2010 data	
Syncrossus helodes	2	7	4	4		LEK data but no 2010 data	
Tenualosa thibaudeaui	3	4	5	6		LEK data but no 2010 data	
Lycothrissa crocodilus	3	4				LEK data but no 2010 data	
Paralaubuca typus	3	6	1	9		LEK data but no 2010 data	
Bangana behri	3	6	6	8		LEK data but no 2010 data	
Probarbus labeamajor	3	7	3	4		LEK data but no 2010 data	
Boesemania microlepis	4	4				LEK data but no 2010 data	
Helicophagus waandersii	4	6	6	6		LEK data but no 2010 data	
Pangasianodon hypophthalmus	4	8	1	7		LEK data but no 2010 data	
Hemibagrus wyckii	5	5	7	7		LEK data but no 2010 data	
Hypophthalmichthys molitrix	5	5				LEK data but no 2010 data	
Mystus bocourti	5	5				LEK data but no 2010 data	
Pangasius kunyit	5	7	5	7		LEK data but no 2010 data	
Wallago micropogon	5	9	6	6		LEK data but no 2010 data	
Chitala blanci	6	6	3	9		LEK data but no 2010 data	
Osteochilus vittatus	6	6	6	6		LEK data but no 2010 data	
Cirrhinus microlepis	7	7	7	7		LEK data but no 2010 data	
Pangasius krempfi	7	9	6	7		LEK data but no 2010 data	
Chitala lopis			6	6		LEK data but no 2010 data	
Osphronemus exodon			6	6		LEK data but no 2010 data	

Appendix 6: Flowmeter errors and data adjustments

In field records, two types of flowmeter errors were found which required adjustments to data:

1) Readings that were less than the threshold of the flowmeter (0.1 m s^{-1}), which would cause very high values for calculated concentrations or load of fish as flow values are the divisor in calculating concentrations, were reset to 0.1 m s^{-1}.

2) Readings which were probably erroneous, based on criteria as follows:

   - The values on the manual recorder should follow a sequence so that the first value for any set should be similar to the final value of the prior set, because the meter uses simple mechanical rotors.

   - Outliers were values that were extremely high or low compared with the run of prior or subsequent readings.

   - Erroneous values were reset to the average of the prior and subsequent flow velocity.

These adjustments had negligible effect on the data at Thadeua and Angnyai, as shown in Table A2, because they were made for a small proportion of samples which contained a small proportion of all fish from those sites. At Pakhao, the proportion of samples for which flowmeter values were corrected was relatively high, but those samples contained relatively few fish so there would be little effect on the final data. Overall, for these three sites the flow data can be considered to be of good quality.

At Nasak, the flowmeter was not functioning correctly up to 20 June so for that period the mean filtered volume of subsequent samplings was used. On average, this procedure would cause minor errors if the filtered volumes in pre-20 June samples were similar on average to those for post-20 June, which is expected because the net was moved as the river rose. At Nasak there was, as expected, no trend over time in filtered volumes after 20 June, and at Thadeua – the most similar site morphologically - there was also no trend in filtered volumes over time for the entire period. At Pakhao, there was a weak trend over time to decreasing volumes and at Thadeua a weak trend to increasing volumes. Nasak data were retained in analyses, but density and load estimates for that site should be considered less reliable than at the other three sites.

Sampling duration – the time between setting and retrieving a plankton net – was recorded for most samples as 30 minutes, the target time, as shown in Table A3. Most of the samples that were recorded as being collected over a period less than or greater than 30 minutes were from Pakhao. This result appears to show poor compliance with the target duration at Pakhao. It is, however, possible that fishers at the other sites in fact achieved less compliance but simply recorded the duration as 30 minutes because recordings within 1-2 minutes of the target would be expected under field conditions. Accurate data recording should be given some more attention in any future studies. Errors in recording sampling duration do not affect results for fish density or fish load, but would affect numbers per sample per unit time or estimates of mean current speed. All values expressed 'per sample' were adjusted to a standard 30-minute duration or to a 2-hour duration for daily averages. For any overall comparisons between sites, Nasak values were adjusted to account for the lower number of samples taken there (280 versus 300 at the other sites).

Table A6-1: Summary of corrections made to flowmeter data

Variable	Pakhao		Thadeua		Nasak		Angnyai	
	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Total samples	300		300		280		300	
Total fish	810		2,127		1,496		2,663	
Samples reset to 0.1 m s^{-1} (a)	21	7.0%	0	0.0%			0	0.0%
No. of reset samples with fish	7	2.3%	0	0.0%			0	0.0%
No. of fish in samples reset to 0.1 m s^{-1}	10	1.2%	0	0.0%			0	0.0%
Samples reset to average (b)	13	4.3%	6	2.0%	22	7.9%	18	6.0%
No. of reset samples with fish	6	2.0%	4	1.3%	17	6.1%	17	5.7%
No. of fish in samples reset to average	8	1.0%	29	1.4%	60	4.0%	144	5.4%
Samples reset to average pre- 20-Jun-12 (c)					100	35.7%		
No. of reset samples with fish					74	26.4%		
No. of fish in samples reset to average					829	55.4%		
All corrected samples (a) + (b) + (c)	34	11.3%	6	2.0%	122	43.6%	18	6.0%
All corrected samples with fish	13	4.3%	4	1.3%	91	32.5%	17	5.7%
No. of fish in all corrected samples	18	2.2%	29	1.4%	889	59.4%	144	5.4%

Note: *at Nasak, the flowmeter malfunctioned prior to 20 June*

Table A6-2: Summary of recorded duration of sampling for individual plankton net samples
The target duration was 30 minutes

Site	No. of samples of duration (minutes)			Total No.	Sample Duration (minutes)		
	14 – 29 min.	30 min.	31 – 40 min.		Mean	Min.	Max.
Pakhao	4	151	145	**300**	31	14	40
Thadeua	0	300	0	**300**	30	30	30
Nasak	0	268	12	**280**	30	30	40
Angnyai	3	296	1	**300**	30	22	33
Total	**7**	**1,015**	**158**	**1,180**	**30**	**14**	**40**

There were considerable variation in volumes filtered between sites and also a wide range within each site as shown in Table A4. If smaller volumes are filtered, there is less chance of rare fish being caught in the sampling net. For estimates of fish load, higher discharges further reduce the chance of collection of rarer fish. For example, at a discharge of 1,000 m^3 s^{-1}, if 1,000 m^3 is filtered (and assuming the river is well mixed), a single fish represents a daily load of 86,400 fish (Table A4 summarises volumes and discharges). Current speeds also varied between sites, possibly affecting filtration efficiency. No allowance could be made for these effects, but they should be considered in future studies (see discussion). Discharge increased during the study by a factor of about six to eightfold, which had a major effect on calculated loads of fish, largely offsetting declining density of fish in samples.

Table A6-3: Summary of volume and current speed data for all samples, with basic discharge statistics for the period

Site	Volume Filtered (m^3)			Current speed ($m\ s^{-1}$)			Discharge ($m^3\ s^{-1}$)		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Pakhao	579	142	2,058	0.41	0.10	1.46	2,851	1,063	6,482
Thadeua	876	216	2,014	0.62	0.15	1.42	2,859	1,064	6,500
Nasak	479	142	1,175	0.34	0.10	0.83	3,506	1,215	8,032
Angnyai	521	163	1,051	0.37	0.12	0.74	4,479	1,321	11,109
Total	**614**	**142**	**2,058**	**0.44**	**0.10**	**1.46**			

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