Drift of fish juveniles and larvae and invertebrates over 24-hour periods in the Mekong River at Phnom Penh, Cambodia

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ABSTRACT

Fish production in the Mekong River system depends largely upon fish spawned in productive floodplain habitats during the wet season. Many of the important fish of the lower Mekong system are flood-spawners; they spawn at the start of and during the wet season, producing large numbers of eggs that hatch quickly. The resultant larvae and juvenile fish then drift downstream in the current of the river. Understanding the spatial and temporal distribution of these larvae and juveniles in the body of the river is a prerequisite to accurate monitoring this drift.

This study, therefore, set out to investigate the distribution of the drift fauna at various times during the day and at different positions within the body of the river. The study took place, at a single location, over three days in early July 2003. Fish and invertebrates were sampled using bongo nets set near the surface of the river and close to the riverbed. A pair of samples were taken every hour (each sample took 30 minutes to collect) to provide 24 pairs of samples per day, or 72 pairs of samples in total.

The 14,000 fish identified during the study belong to 53 taxa. A few fish species made up most of the assemblage; of these about 96% were either Cyprinidae or Pangasiidae. The average density of fish in bottom samples was about three times that of surface samples. This difference was because most drift fish stay near the bottom of the river during the day. At night, when some species move to the surface, the distribution of fish was more even.

The 4,800 invertebrates identified belong to 28 taxa; the most abundant were *Macrobrachium* shrimp larvae/post-larvae, the larvae of filter-feeding caddis flies (Hydropsychidae), and dragonfly nymphs (Odonata). However, dragonfly nymphs and larger shrimps made up most of the biomass. Invertebrates were more abundant in samples taken at night than during the day. Most taxa were more abundant in bottom samples, with greatest densities during the day. Two taxa of predatory dragonfly nymphs and bugs (hemipterans) were most abundant in surface samples taken at night, perhaps because they can see their prey more easily near the surface; this prey may include fish larvae.

The study showed that future long-term monitoring must include both surface and bottom sampling. Furthermore, because most taxa drift for short periods of one to two hours duration, samples taken at regular intervals (e.g. every six hours) may not be representative of the density of the drift as they could catch, or miss, one of these periods. Therefore, for long-term monitoring at least, continuous sampling is probably the best way to get accurate estimates of the density of drifting organisms. During such monitoring, samples should be collected throughout the day, pooled for the time-intervals of interest, and then sub-sampled.

KEY WORDS: Cambodia, Mekong, drift fish, invertebrates

INTRODUCTION

Fish production in the Mekong River system depends largely upon fish spawned in productive floodplain habitats during the wet season. Many of the important fish of the lower Mekong system are ‘whitefish’; these live in the main river channels for much of the year and spawn at the start of, and during, the wet season. They produce an abundance of eggs that hatch quickly; the resultant large numbers of larvae and juveniles float down stream in the current of the river (Poulsen *et al*. 2002, Sverdrup-Jensen 2002). Some authors call this downstream movement ‘drift’, but this usage is inaccurate because some larval and juvenile fish are not entirely passive and they are able move within

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the water body to some extent.

The composition of drift fish fauna in Viet Nam and Cambodia is well known. In Viet Nam, the records of the fauna go back to 1996. Here, specimens of fish larvae can be recovered from the large commercial *dai* nets used to catch *Pangasius* catfish for aquaculture (Nguyen *et al.* 2001, Nguyen 2003). These *dais,* which use 1-1.5 mm mesh nets, between 13 and 30 m wide, also catch large samples of drifting fish. The records to date include least 153 species of fish, belonging to 32 families and 10 orders.

In Cambodia, Chea *et al*. (2003) documented the larval drift in rivers near Phnom Penh, including the Tonle Sap, the Bassac and Mekong, both upstream and downstream of the city. Their study, which initially took place from July to September 2002, was extended into 2003. Every six hours they recorded the fish fauna collected from bongo nets set near the surface of the river. The fauna recorded so far contains over 133 species from 26 families and 16 orders. Their data also shows the drift of most species peaks during the early flood season.

Species of invertebrates also make up a large, and important, portion of the drift fauna and many, including some shrimps, crabs and insects, are part of the fishery. They form an essential element in the food chain, they prey on fish and fish prey on them. Invertebrates are also useful indicators of water quality. This paper presents the first detailed record of the invertebrate drift fauna in the Mekong basin.

However, there are few detailed records of spatial and temporal distribution of the either drift fauna, particularly variations of density within the cross-section of the river and daily or weekly fluctuations in abundance. Knowledge of these variations is essential in the design of future, long-term, monitoring of the drift fauna.

The current survey therefore involved intensive sampling over a short period with the objectives of:

- comparing the composition and abundance of the drift fauna during the day and at night
- comparing the composition and abundance of the drift fauna at the surface of the river and near the riverbed
- determining the best sampling frequency for surveys in the future

METHODS

The drift fauna was studied at a site about 5 km upstream of the well-known Quatre Bras, the junction of the Tonle Sap, Mekong and Bassac Rivers near Phnom Penh (11°34.103'N, 104°56.662'E). This important location is well downstream of many known spawning areas in the Mekong but upstream of the Tonle Sap into which the rising Mekong flow brings fish fry each flood season. At the site, this large turbid lowland river is about a kilometre wide and, at the time of sampling, the water was quite calm to about 100 m from its edge. Families who live by fishing or aquaculture often anchor their floating homes in this calm zone. At the outer edge of the strip of floating homes water depths reached 5 m, here the current was notably stronger. We employed one of the fishing families to carry out sampling near their home. They took samples 10 m beyond the houses where the water depth was around 6 m and the current typical of the main flow of the river.

Sampling fish larvae and juveniles can use many methods, but in large floodplains simple filtering devices that catch the drifting whitefish larvae and juveniles are most appropriate. We used oceanographic plankton bongo nets measuring 1 m in diameter and 5 m in length with a mesh aperture of 1 mm. This aperture is large enough to allow most sediment and detritus to pass through so that the net does not clog too rapidly, but small enough to retain the drifting larvae of the smallest common species, cyprinids, that are typically around 4-8 mm long.

A current meter, placed in the mouth of each net, recorded the number of rotations of a propeller; multiplying the rotations by the cross-sectional area of the mouth of the net (0.785 m^2) gave an estimate of the volume of water flowing through the net. Heavy metal weights and ropes anchored the nets. Two nets were used, one held about 2 m below the surface (measured to the centre of the net) and another set about 2 m above the riverbed, these are referred to as surface and bottom nets.

The three-day study took place in early July 2003 when the river was in early flood; over the 72-hour period, the discharge of the river increased from 9,850 m^3/s to 12,654 m^3/s. The bongo nets were set on the hour for half an hour (i.e. 06:00 to 06:30; 07:00 to 07:30, and so on) and then their contents washed over a 1 mm sieve. After several days left fixing in ~ 10% formalin they were washed over a 1 mm sieve once more and the fauna separated from the detritus. After inspection under a microscope, the animals were stored in 70% ethanol. Usually the quantity of detritus in a sample was quite small (less than a handful) so additional sorting aids were unnecessary.

Larval and juvenile fish were identified using descriptions from various sources but primarily using the Mekong Fish Database (2003) and other descriptions supplied by Professor Mai Dinh Yen of the National University, Hanoi. Invertebrates were identified mainly using Dudgeon (1999). Most fish juveniles were identified to species level, but many cyprinid larvae could only be attributed to families. Invertebrates were identified to family or to higher level.

As the sun rose at 05:40 and set at 18:30, 13 pairs of samples were collected during the daylight hours. The moon rose between 07:41 and 10:24 and set between 20:46 and 23:00 and, although the moon was waxing during the study period (illumination increased from 6% to 29%), moonlight probably did not greatly affect the levels of illumination in the river.

RESULTS

Over, 97,000 m^3 of water passed through the nets during the three-day sampling period. These large volumes probably mask any minor local variations in the abundance of drift faunas. On average, each sample is the product of 668 m^3 of river water. This is comparable to towing a net, 0.785 m in cross-section, through 851 m of stationary water, assuming no resistance to through-flow. The velocity of the current through the nets (mean 0.37 m/s, range 0.18-0.55 m/s) is much slower than that of the main river (1-2 m/s) because detritus clogs the nets. This factor may also account for some of the variations in the volume of water filtered.

Fish

Table 1. *Aggregate number of fish and species of fish grouped by family*

Family	Number of individuals	Proportion of total sample (%)	Number of species	Proportion of total number of species (%)
Cyprinidae	10,175	70.85	23	43.4
Pangasiidae	3,566	24.83	12	22.6
Clupeidae	380	2.65	4	7.5
Siluridae	119	0.83	1	1.9
Mastacembelidae	75	0.52	1	1.9
Tetraodontidae	21	0.15	1	1.9
Clariidae	11	0.08	1	1.9
Cynoglossidae	6	0.04	3	5.7
Sundasalangidae	3	0.02	1	1.9
Sisoridae	2	0.01	2	3.8
Soleidae	2	0.01	2	3.8
Belontiidae	1	0.01	1	1.9
Schilbeidae	1	0.01	1	1.9
Total	**14,362**		**53**	

Most fish (96%) and most taxa (66%) were cyprinids (river carp) or pangasiids (river catfish) (Table 1). The drift fauna included three categories of fish: larvae, post-larvae and juveniles of large species, and small pelagic species. Small unidentifiable cyprinid larvae dominated the fish fauna, comprising over 67% of the samples. For the purposes of this paper, these are grouped as Cyprinidae. It is likely that many of these were larvae of the abundant *trey riel* that is now the most common taxon caught in the Cambodian river fishery and comprise two main species, *Cirrhinus lobatus* and *C. siamensis* (Roberts 1997).

The remaining 52 taxa were all identified to species level; these were all juveniles and post-larvae of large species except for some small pelagic species including the clupeids *Clupeoides borneensis, Corica laciniata* and *Clupeichthys aesarnensis,* and the noodle fish *Sundasalanx praecox.*

Table 2. *Comparison of fish density in samples taken from the bottom and surface, during the day and at night*

	Bottom			Surface		
	Total fish	Total vol (m^3)	Mean density ($N^o/1000m^3$)	Total fish	Total vol (m^3)	Mean density ($N^o/1000m^3$)
Day	7,269	25,258	288	1,614	27,905	58
Night	2,763	21,753	127	2,716	21,346	127
Total	**10,032**	**47,011**	**213**	**4,330**	**49,251**	**88**

Overall, the density of fish in bottom samples was about two and a half times greater than in surface samples (Table 2). As the number of fish caught in bottom and surface samples taken at night were broadly equal, this difference was entirely due to the much greater numbers of fish drifting on the bottom during the day.

Table 3 gives a more a detailed breakdown of the data in Table 2. Cyprinid larvae comprise the bulk of drift fauna in bottom/day samples. A few other species (*Pangasius macronema*, *Pangasius* sp.2 and *Ompok* sp.) are also most abundant in these samples. Several species were also particularly rare in surface/day samples, contributing to the difference in overall mean densities between these and bottom/ night samples (see Table 2). The unusual distribution of *Pangasianodon hypophthalmus* (most fry of which were caught in surface/night samples) is particularly interesting as this the main species targeted by the fry fishery.

Table 3. *Mean density (N^o/1000 m^3) and total numbers of the 13 most abundant fish*

Species	Bottom			Surface			Mean	3-day Total N^o
	Day	Night	Mean	Day	Night	Mean	Density	
Cyprinid larvae	212.3	76.6	149.5	43.0	71.9	54.8	100.0	9,763
Pangasius siamensis	19.4	24.6	21.8	2.4	29.7	14.0	17.7	1,728
P. macronema	30.1	9.7	20.6	2.4	4.2	3.1	11.5	1,127
Pangasius conchophilus	3.8	4.0	3.9	0.2	2.7	1.2	2.5	247
C. borneensis	4.4	1.0	2.8	3.0	1.4	2.3	2.5	246
Pangasius sp. 2	5.2	2.4	3.9	0.0	0.0	0.0	1.9	186
Pangasianodon hypophthalmus	1.0	0.5	0.7	0.4	6.4	3.0	1.9	183
Sikukia stejnegeri	1.8	1.0	1.4	1.4	1.0	1.2	1.3	126
Ompok sp.	3.4	0.0	1.9	1.0	0.1	0.6	1.2	119
C. laciniata	0.9	1.2	1.1	1.4	1.4	1.4	1.2	118
Hypsibarbus sp1	1.7	1.3	1.5	0.6	0.5	0.5	1.0	98
Mastacembelus armatus	1.0	0.5	0.8	0.4	1.4	0.8	0.8	75
Pangasius polyuranodon	0.0	0.4	0.2	0.3	1.9	1.0	0.6	57
Other species	2.7	3.7	3.2	1.4	4.7	2.8	3.0	289
All fish	**287.8**	**127.0**	**213.4**	**57.8**	**127.2**	**86.7**	**147.1**	**14,362**

Note: Mean values are flow-weighted not simple arithmetic averages

Figures 1-3 (over page) illustrate the variation in density through time of the three most abundant fish taxa. Generally, the density of fish varies widely between samples with little evidence for peaks that repeat at a particular time each day. Fish drift seems to occur in random bursts within individual categories of samples (day, night, bottom and surface); most fish appear to drift in a few peaks of short duration. This means distribution of all species was highly skewed, so, for example, most species are present in under half of the samples.

The correlation between the abundance of taxa in pairs of surface and bottom samples was tested by calculating Spearman non-parametric correlation coefficients. A positive correlation indicates the fish are drifting synchronously while a negative correlation suggests the fish are moving vertically within the water column. For all except one species the coefficients were not significant, suggesting little correlation. However, in the instance of *C. borneensis*, the coefficient (Rho = 0.245, p=0.034) shows a

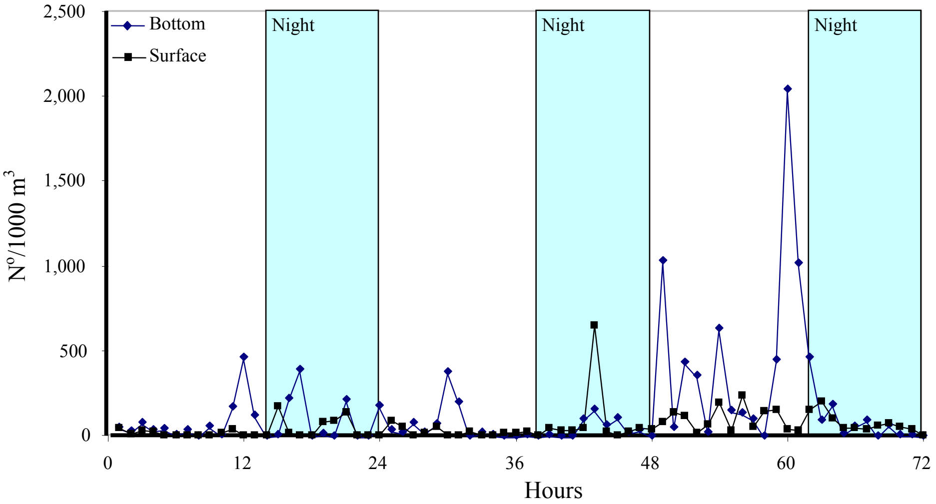

Figure 1. Drift pattern of Cyprinidae larvae

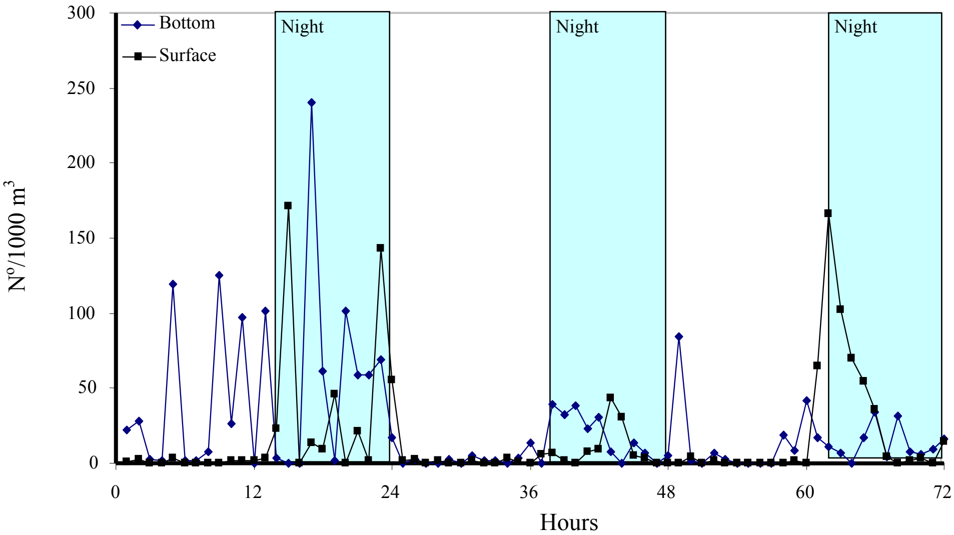

Figure 2. Drift pattern of *P. siamensis*

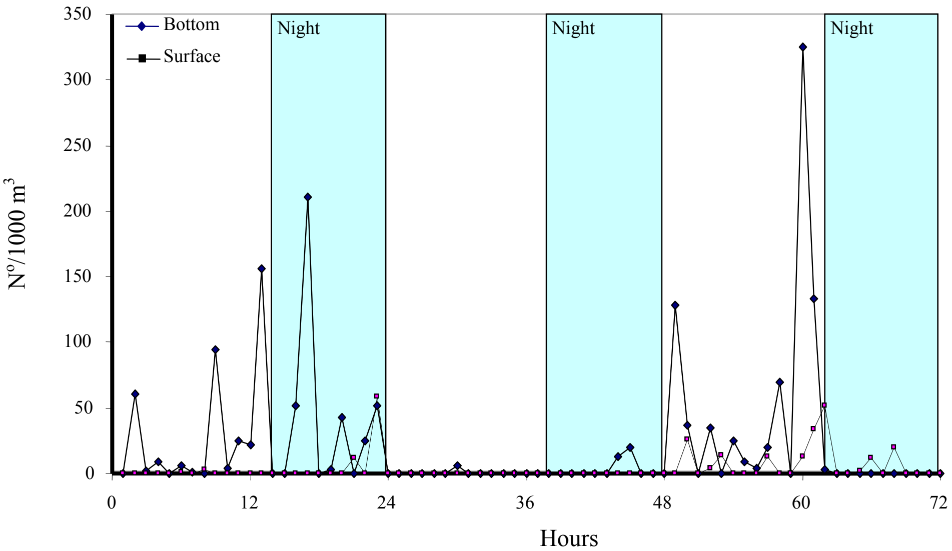

Figure 3. Drift pattern of *P. macronema*

weak correlation between surface and bottom density. Therefore, with the exception of this species, there appears to be no simple relationship between surface and bottom sample densities. The data from the three most common fish illustrates this point well (Figures 1-3).

The main objective of this study was to determine the best sampling frequency for long-term monitoring. Whilst sampling at random time intervals may be statistically ideal, sampling continuously or at regular intervals is more usual and more practical. The effect of increasing the sampling interval (and reducing the number of samples) on the estimates of mean counts of fish has been analysed in Table 4.

Table 4. *The effect of reducing sampling frequency on estimates of the mean abundance of fish*

		Mean abundance (N°/1000m³)					Mean as % of mean of all data			
	Sample interval	**All**	**2h**	**3h**	**6h**	**12h**	**2h**	**3h**	**6h**	**12h**
	N° of samples	**72**	**36**	**24**	**12**	**6**	**36**	**24**	**12**	**6**
Cyprinid larvae	Bottom	150.7	149.0	156.8	241.9	375.6	99*	104	161	249
	Surface	54.0	64.9	61.3	87.2	42.7	120*	113	161	79
Pangasius siamensis	Bottom	23.6	30.1	17.1	20.4	37.6	128	72	87	159
	Surface	16.0	19.5	10.8	14.4	12.9	122	68	90	80
P. macronema	Bottom	22.1	23.7	26.0	35.9	69.6	107	118	162	315
	Surface	3.7	3.7	1.6	2.8	5.6	101	43	76	152
Pangasius conchophilus	Bottom	4.2	4.9	5.3	5.4	7.7	116	125	129	183
	Surface	1.4	2.6	0.5	0.9	0.0	185	36	64	0
Clupeoides borneensis	Bottom	2.9	2.8	2.8	2.6	2.6	98	96	91	90
	Surface	2.4	2.7	2.9	4.6	8.1	109	117	189	331
Pangasius sp 2	Bottom	3.7	4.3	6.7	9.5	18.9	115	182	255	510
	Surface	0.02	0.04	0.00	0.00	0.00	200	100	100	100
Pangasianodon hypophthalmus	Bottom	0.7	1.0	0.9	1.8	3.5	130	119	238	475
	Surface	4.1	0.6	0.5	0.3	0.5	14	12	8	12
Sikukia stejnegeri	Bottom	1.5	1.6	1.5	2.2	2.3	111	100	154	155
	Surface	1.3	1.1	0.9	1.1	0.9	82	70	82	70
Ompok sp.	Bottom	1.4	2.4	4.0	6.9	13.9	176	287	501*	1002
	Surface	0.7	0.9	0.2	0.2	0.4	117	32	26	52
C. laciniata	Bottom	1.0	1.1	1.0	1.0	0.8	106	96	100	83
	Surface	1.4	1.2	1.2	1.1	1.0	82	86	76	73
Hypsibarbus sp1	Bottom	1.5	1.9	2.3	3.0	4.7	123	152	197	305
	Surface	0.6	0.7	0.6	0.9	1.9	108	98	156	312
Mastacembelus armatus	Bottom	0.7	1.2	0.3	0.5	0.3	174	47	79	46
	Surface	0.8	0.7	0.3	0.3	0.5	87	37	32	65
Pangasius polyuranodon	Bottom	0.2	0.2	0.0	0.0	0.0	108	0	0	0
	Surface	1.2	0.4	0.2	0.2	0.0	33	15	20	0
Total	**Bottom**	**217.3**	**226.4**	**227.8**	**335.1**	**538.5**	**104**	**105***	**154***	**248**
	Surface	**91.2**	**103.2**	**83.2**	**115.4**	**75.6**	**113**	**91***	**127***	**83**

Note: * samples used as examples in the following text

The left hand columns of this table show the mean abundance of the most common taxa using the complete data set (all), and the means obtained using subsets of data taken at increasing time intervals, i.e. at 2, 3, 6 and 12 hours. The columns on the right half of the table give the mean values of these subsets as percentages of the mean value for all 72 samples. For example, if half the number of samples are taken (i.e. every two hours rather than every hour), the estimated mean density of cyprinid larvae for bottom samples changes by only 1%, but on the surface it changes by 20%. For total fish numbers, sampling eight times per day (i.e. every three hours) generates means that are 5% greater (bottom samples) and 9% less (surface samples) than the means derived from the whole dataset. These small differences are not statistically significant.

However, increasing the sampling interval to six hours (four per day) noticeably increases the difference between the means of the subsets and total dataset. Sampling only four times per day overestimates the abundance of fish, by 54% in surface samples and 27% in bottom samples. In the instance of individual species, estimates of abundances using low sampling frequencies deviate even more. In one example, *Ompok* sp., sampling four times a day leads to a variance of 500%. The reasons for the variances depends largely upon whether the subset of samples happens to include a peak in abundance of that species; for example, for Cyprinidae larvae have a single large peak late on the third day (Figure 1).

Table 5. *Summary of the invertebrate drift*

Major group	**Common name**	**Taxon**	**Total**
Coleoptera	Beetles	Dytiscidae la.	1
		Hydrophilidae ad.	23
		Noteridae ad.	8
		Psephenidae la.	1
		Unid ad. Coleoptera	5
Collembola	Springtails	Collembola	2
Diptera	Two-winged flies	Chiron/Culicid pupae	141
		Chironomidaela.	1
		Empididae	1
Ephemeroptera	Mayflies	Baetidae	64
		Caenidae	1
		Heptageniidae	2
		Prosopistoma	65
Hemiptera	Bugs	Corixidae	3
		Naucoridae	78
		Veliidae	1
Odonata	Dragonflies	Corduliidae	3
		Gomphidae	417
Plecoptera	Stoneflies	Perlidae	26
Trichoptera	Caddis flies	Hydropsychidae	950
		Leptoceridae	2
		Philopotamidae	3
		Rhyacophilidae	2
		Unid. Trichoptera Family	8
Copepoda	Copepods	Copepoda	1
Decapoda	Shrimps	*Macrobrachium* la./post arvae	2,858
		Macrobrachium large	46
Isopoda	Isopods	Isopoda	52
Total			**4,765**

Invertebrates

In all, 4,765 invertebrates belonging to 28 taxa were identified (Tables 5 and 6). Table 7 shows that *Macrobrachium* larvae/post-larvae drifted at much higher densities on the bottom than near the surface, and that their greatest density was during the day. Unsurprisingly, the density patterns the total invertebrate fauna mirrors that of *Macrobrachium,* which forms the bulk of the drift. The same is true for omnivores and detritivores, but not for predatory carnivores. The two invertebrate swimming predators, Gomphidae (dragonfly nymphs) and Naucoridae (carnivorous bugs), were most abundant on the surface during the night. The mean density of all but one taxon, Isopoda, was greatest on the surface during the day.

Table 6. *Summary of the invertebrate drift by major groups*

	Total	Per cent
Insects	**1,808**	**37.9**
Coleoptera	38	0.8
Collembola	2	0.04
Diptera	143	3.0
Ephemeroptera	132	2.8
Hemiptera	82	1.7
Odonata	420	8.8
Plecoptera	26	0.5
Trichoptera	965	20.3
Crustacea	**2,957**	**62.1**
Copepoda	1	0.02
Decapoda	2,904	60.9
Isopoda	52	1.1
Total	**4,765**	

Note: Data taken from Table 5

Table 7. *Mean density (N^o/1000 m^3) and total numbers of the nine most abundant invertebrates*

Taxa	Bottom			Surface			Mean density	Total Number
	Day	Night	Mean	Day	Night	Mean		
Macrobrachium larvae post-larvae	51.1	42.2	47.0	10.8	16.3	13.0	29.3	2858
Hydropsychidae	13.6	9.5	11.7	6.3	10.5	8.0	9.7	950
Gomphidae	2.8	4.3	3.5	1.9	9.4	5.1	4.3	417
Chiron/Culicid Pupae	1.1	3.2	2.1	0.1	1.9	0.9	1.4	141
Naucoridae	0.5	1.1	0.8	0.2	1.6	0.8	0.8	78
Prosopistoma	1.2	0.9	1.1	0.1	0.6	0.3	0.7	65
Baetidae	1.2	1.0	1.1	0.2	0.4	0.3	0.7	64
Isopoda	0.8	0.6	0.7	0.4	0.3	0.4	0.5	52
Macrobrachium large	0.6	0.6	0.6	0.4	0.4	0.4	0.5	46
Other taxa	0.8	1.4	1.1	0.2	1.7	0.9	1.0	93
All taxa	**73.6**	**65.0**	**69.6**	**20.6**	**43.1**	**29.9**	**48.8**	**4765**

Note: Mean values are flow-weighted not simple arithmetic averages

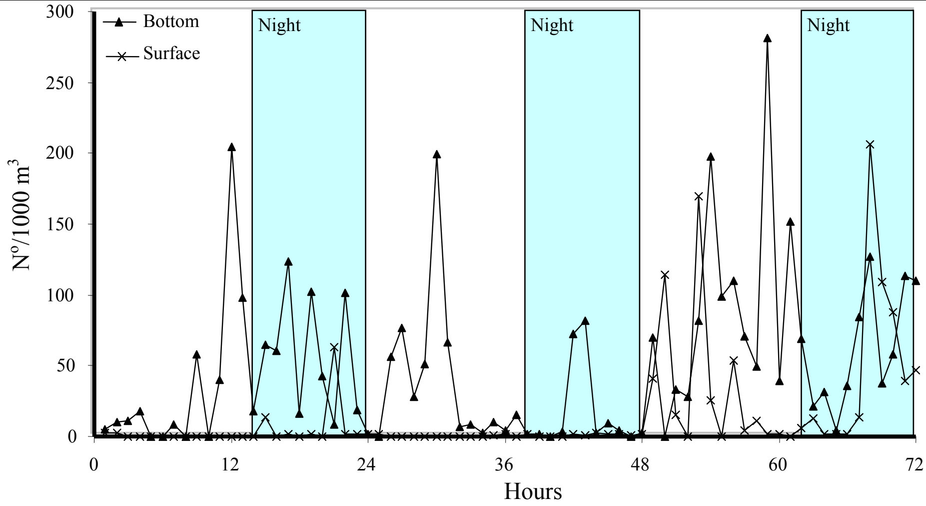

Figure 4. Drift pattern of *Macrobrachium* (shrimp) larvae/post-larvae

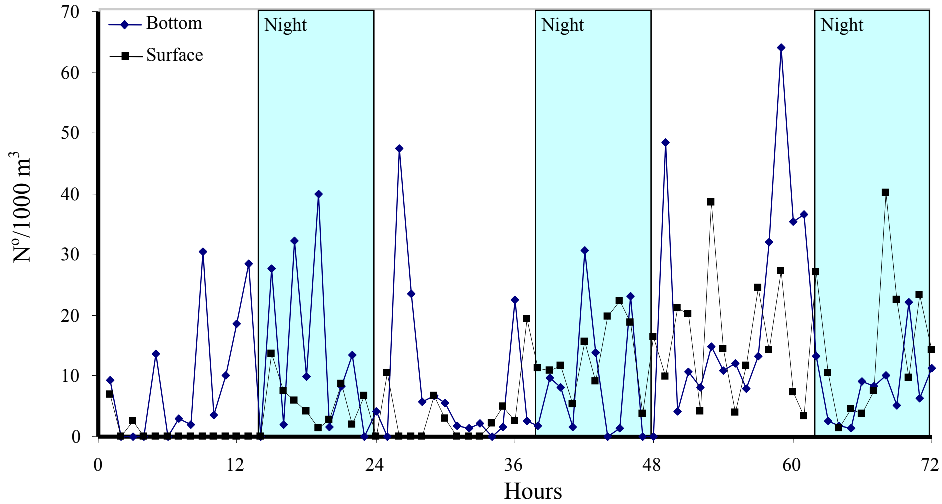

Figure 5. Drift pattern of Hydropsychidae (filter-feeding caddis fly larvae)

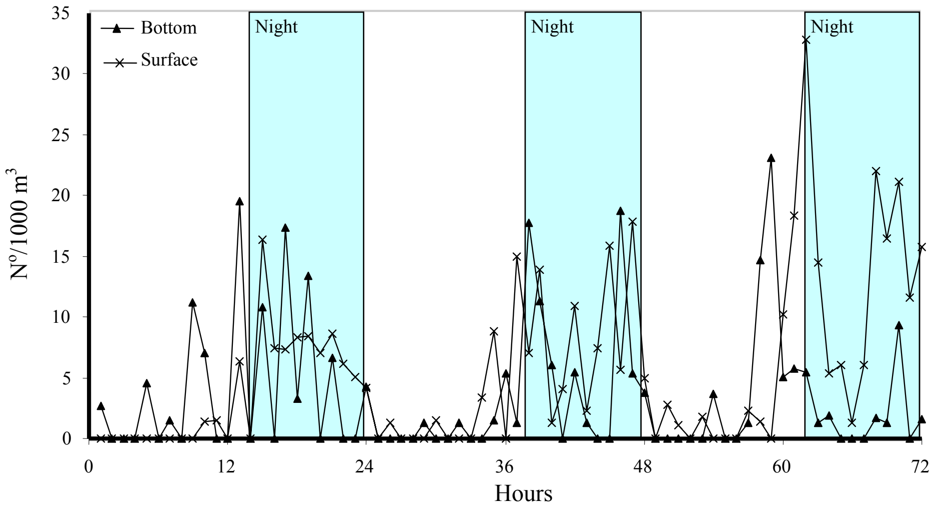

Figure 6. Drift pattern of Gomphidae (predatory dragonfly nymphs)

Figures 4-6 give the temporal drift of the three most common invertebrate taxa. Although drift of *Macrobrachium* larvae/post-larvae do not show regular peaks at the same time in each 24-hour period (Figure 4), the data for the other taxa may show repeating peaks. Hydropsychids, for example appear to be most abundant in bottom samples taken in the early morning and late afternoon (Figure 5) and the density of gomphids reaches a peak at dusk and before dawn (Figure 6). However, only additional data, collected over several more days, will confirm if these patterns are meaningful or just anomalies.

The correlations between the abundance of each taxon in surface and bottom samples were tested by calculating Spearman non-parametric correlation coefficients. For all but one species, coefficients were not significant. However, in the case of *Prosopistoma* sp. (a mayfly) the coefficient (Rho = 0.382, p=0.001) signified a strong correlation between surface and bottom densities. Despite this single example, no simple relationship exists between the density of the invertebrate drift in samples taken from the surface and those from the bottom. The data from the three most common invertebrate taxa illustrates this lack of correlation (Figures 4-6).

Table 8. *The effect of reducing sampling frequency on estimates of mean abundance of invertebrates*

		Mean abundance (N°/1000m^3)					**Mean as % of mean of all data**			
	Sample interval	**All**	**2h**	**3h**	**6h**	**12h**	**2h**	**3h**	**6h**	**12h**
	N° of samples	**72**	**36**	**24**	**12**	**6**	**36**	**24**	**12**	**6**
Baetidae	Bottom	1.3	0.8	1.4	2.0	1.4	65	108	163	165
	Surface	0.3	0.5	0.0	0.0	0.0	149	0	0	0
Chiron/Culicid pupae	Bottom	2.2	1.6	1.5	2.6	1.1	72	66	118	70
	Surface	1.1	2.0	0.3	0.2	0.0	185	26	16	0
Gomphidae	Bottom	3.6	4.1	4.3	3.8	4.9	115	119	105	118
	Surface	5.6	8.0	4.6	4.7	6.6	144	82	85	83
Hydropsychidae	Bottom	11.9	13.7	13.5	17.0	20.9	115	113	143	153
	Surface	8.6	14.4	6.0	6.0	8.4	167	69	70	58
Isopoda	Bottom	0.8	0.6	0.8	0.9	0.6	79	103	118	100
	Surface	0.4	0.7	0.3	0.2	0.2	165	88	46	30
Macrobrachium larvae post-larv.	Bottom	50.3	59.2	48.5	65.2	56.7	118	97	130	96
	Surface	14.9	27.6	6.9	5.1	7.5	185	46	34	27
Macrobrachium large	Bottom	0.6	0.8	0.5	0.7	0.6	136	79	117	77
	Surface	0.4	0.7	0.5	0.4	0.3	149	103	93	40
Naucoridae	Bottom	0.8	1.1	1.3	1.0	0.0	147	168	126	0
	Surface	0.9	1.2	0.6	0.2	0.0	139	62	24	0
Prosopistoma	Bottom	1.2	0.8	1.2	1.5	1.9	66	97	130	238
	Surface	0.4	0.7	0.1	0.2	0.0	189	26	51	0
All Invertebrates	Bottom	73.7	84.0	74.2	96.9	89.2	114	101	131	106
	Surface	33.6	57.1	20.2	17.2	23.4	170	60	51	41

The effect of reducing sample numbers (increasing sampling intervals) on estimates of mean density of invertebrates was compared (Table 8). As was the case in fish, increasing sample may lead to large errors in the estimations of abundance of particular taxa.

DISCUSSION

The dominance of juvenile and larval Pangasiids and Cyprinids in drift populations sampled at the start of the wet season floods corresponds with the findings of other studies in the lower Mekong river system (Chea *et al*. 2003, Nguyen *et al*. 2001 and Nguyen 2003).

The current study reveals spatial and temporal variability in the composition and abundance of the drift fauna. About half of all the fish drift on the bottom during the day. This is consistent with data from Viet Nam, where catches from the large commercial *dais* (which sample the entire water column) were also highest during the day (Nguyen 2003). It appears that fish larvae and juveniles generally avoid surface waters where higher light levels favour visual predators, but there is no obvious reason why the density of the drift fauna is higher during the day than at night. Only one fish species showed a very different pattern, the catfish, *P. hypophthalmus,* drifts in much higher densities in surface waters at night and, interestingly, the fry fishery for this species utilises surface-fishing hooks and nets.

To obtain representative counts of fish density, future monitoring must allow for this depth effect. Sampling across the river section will determine whether these samples, which were taken close to the edge of the river, are representative of the drift as a whole. If they are representative, we estimate that around 120 million fish per day drift in this section of the river during the flood (assuming a discharge of about 10,000 m^3/s, based on MRC hydrological records). Even if this figure is a gross over-estimation (for example, if fish are concentrated near the river's edge), the importance of this huge natural source of recruitment and the impossibility of replacing it by aquaculture (which the drift currently supports anyway) can readily be appreciated.

In their earlier investigations of drift fauna in Cambodian stretch of the Mekong, Chea *et al*. (2003) took six-hourly samples (four per day) from the surface only. As the distribution of peaks of the abundance of drift appears to be random, it is likely that their sampling generates mean values that are representative of only long-term averages. Over short periods however, samples taken at these frequencies will miss many of these peaks thereby causing inaccurate estimation of the mean abundance values. Furthermore, as they did not take bottom samples, the volume of the total drift is probably a gross under-estimate.

Long-term sampling, such as taking 24 samples per day from the surface and bottom (and taking further samples to account for variation across the river), for extended periods is prohibitively expensive. However, as we have demonstrated, if fewer samples are taken, some peaks of short duration may be missed. Continuous sampling may offer a solution. In this method, the aggregated 'all-day' sample day is itself sub-sampled to provide a daily average. This approach is probably preferable as all peaks would be sampled; however the nets still must be cleared and sampled to prevent the them clogging with detritus and to prevent decomposition of (or predation on) fish.

Expect for in instance the one species of herring (Clupeidae), the data did not show any simple relationship between surface and bottom drift of fish (when comparing each pair of samples) indicating that fish are not drifting in synchrony through the water column. Synchrony of this nature produces positive correlations between surface and bottom samples. Nor are the fish simply moving up and down the water column, which would show as negative correlations. Rather the phenomenon of drift may involve vertical movements, as well as movements between the edges and the mainstream and between sheltered and fast-flowing areas.

Other studies have shown that larval and juvenile fish are patchily distributed because of schooling behaviour, passive movement within the water column and their preference for specific micro-habitats, especially shallow, sheltered edges (Nellen and Schnack, 1975, Bagenal and Nellen 1980, Holland 1986, Sheaffer and Nickum 1986, Casselman *et al.* 1990, Scheidegger and Bain, 1995). While most larval fish may be initially restricted to the area in close proximity to the spawning site, within days to weeks of hatching, they are sufficiently developed to move freely within the water column (Garner, 1996) and may select micro-habitats (Casselman *et al.* 1990, Scheidegger and Bain 1995, Garner, 1996, Watkins *et al*. 1997, Gozlan *et al*. 1998). Moreover, the data for each species include a range of sizes and/or ages, which may individually be showing distinct patterns, a possibility that needs further investigation.

The most abundant invertebrates in drift were larvae or post-larvae of small *Macrobrachium* shrimps, filter-feeding caddis flies (Hydropsychidae), and dragonfly nymphs (Gomphidae). The invertebrates are an interesting mixture of primarily benthic groups (such as shrimps, mayflies, stoneflies and caddis flies), which appear to drift at certain times of the day, principally dusk and dawn, and groups which swim actively for periods in the water column in pursuit of their prey (dragonfly nymphs and some beetles and bugs). Invertebrate abundance in drift samples probably reflects drift within the Mekong River, as well as input from adjacent wetlands.

Another factor may be the hard substrate provided by thousands of floating houses and associated structures that line the river for many kilometres upstream of the sampling site. Hard substrate supports more invertebrates, such as the net-building filter-feeding Hydropsychidae, which would normally be uncommon in a muddy lowland river with unstable substrate. As with fish, highest densities of most drift invertebrate taxa are in bottom waters during the day, although this pattern is less pronounced than for fish.

Dragonfly nymphs and predatory bugs were most abundant in surface waters at night, which may be because they need less light to find prey, including fish larvae. Most taxa showed no simple relationship between surface and bottom drift. The data suggest invertebrate drift peaks around dawn and dusk (as has been reported in many other studies (Dudgeon, 1999)), but more samples would be required to confirm these patterns.

With regard to long-term monitoring of invertebrates, the same considerations apply as were discussed for fish. However, as the peaks of abundance of some invertebrate drift taxa appear to repeat each day there is an even greater chance of bias, with regular, but infrequent, sampling consistently including or excluding particular acmes.

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