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The post-larval and juvenile fish assemblage in the Sukhothai Floodplain, Thailand*

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Abstract This study investigated abundance, species composition and spatial and temporal distributions of fish larvae and their relationship with some environmental variables in the Sukhothai floodplain in northern Thailand. Fish larvae were collected from 33 sampling stations on 8 occasions between August 2010 and October 2013. The study collected and identified 149 296 individuals, representing 32 families and 165 taxa. The species composition of larval fish was dominated by the Cyprinidae (47.27%), Cobitidae (7.88%), Siluridae (6.67%), Bagridae (6.06%) and Mastacembelidae (3.33%) families. The most-abundant larval species were the Striped flying barb *Esomus metallicus* (16.90%), the Siamese mud carp *Henicorhynchus siamensis* (8.48%) and the Sumatran river sprat *Clupeichthys goniognathus* (8.31%). The greatest abundance and species diversity of larvae were found when the river flow runs onto the floodplain. PCA and nMDS analysis revealed that the samples plot is associated with temporal distribution among years. The discharge was a major factor determining fish larvae assemblage and environmental variables in the Sukhothai floodplain. Four fish larval species were positively correlated with the samples for 2013. The result of the CCA ordination plot showed that only the discharge variable was strongly correlated with fish larvae abundance, especially two cyprinid *Rasbora* species.

Keyword: fish larvae; distribution; diversity

1 INTRODUCTION

A floodplains is an ecotone that forms a transition between aquatic and terrestrial environments. Floodplains are very important because they provide a variety of habitats and areas of high biodiversity. All this depends on the natural water flow and the predictable, seasonal pattern of rising and falling floodwaters (Moss, 2010). Floodplains are one of the most important fishery resources, providing spawning and rearing grounds. Large river floodplains are considered key nursery habitats for many species of riverine fish (Górski et al., 2011), which allows aquatic organisms to migrate into inundated floodplains. One of the particular characteristics of river floodplains is that they provide dependable sources of food. Fish returning to the main channels as the floodwater recedes are fat from this source. In addition, floodplains provide some of the most productive and diverse freshwater fisheries, especially in tropical regions (Moss, 2010).

Asia is the continent most frequently affected by floods, especially tropical parts of the continent. During the past 30 year, more flood disasters have occurred in Asia (40% of the total) than on any other continent, including the Americas (25%), Africa (17%), Europe (14%), and Oceania (4%) (Dutta and Herath, 2004). Asia contains many floodplains, the largest three of which are in China, India and Bangladesh, respectively (Hussain, 2010). The largest floodplain in Southeast Asia is the Great Lake, located in the Mekong River basin of Cambodia. The water level of this area increases standing water bodies by up to 9 m in flood season. Most floodplains are covered by several meters of floodwater for 3–4

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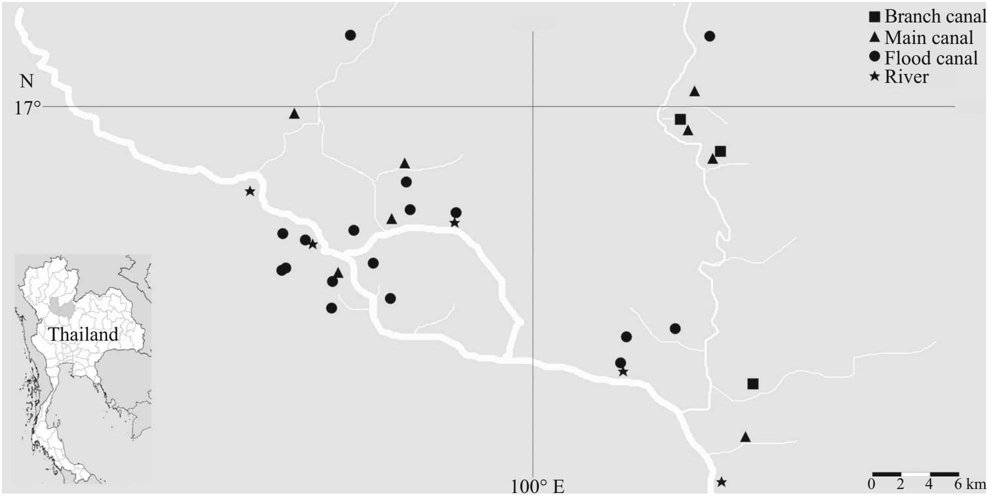

Fig.1 Map showing the location of sampling stations in the Sukhothai floodplain

months annually. In flood season, land and water together in the major flood zones account for 58 000 km^2, much of which is covered with rice fields. During floods, adult fish move onto the floodplain to feed and spawn (Hortle, 2009). The Sukhothai floodplain is the second large floodplain of Thailand, and covers area about 320 km^2. This floodplain is an importance area for fish productivity, spawning and rearing ground.

Unfortunately, the basic taxonomic and ecological status of fish larvae assemblages on the floodplains in Thailand has received little study, and most previous studies have focused on adult fish communities in various parts of Thailand (Choi et al., 2005; Kottelat, 2013; Phomikong et al., 2015). Tanaka et al. (2015) surveyed fish assemblages and investigated environmental and landscape parameters in a total of 135 floodplain waterbodies in the Chao Phraya River Basin. The study showed the population of juvenile fishes increasing in temporarily connected floodplain waterbodies to main rivers compared with isolated waterbodies (Tanaka et al., 2015). The hypotheses of this study were 1) fish larval assemblage are variable by the annual and seasonal patterns and 2) fish larvae and environmental factors are relate to those patterns. The objective of the present study was to evaluate the spatiotemporal variation in the abundance and diversity of fish larvae in the Sukhothai floodplain.

2 MATERIAL AND METHOD

2.1 Study areas

The Sukhothai floodplain is part of the Yom River Basin in northern Thailand. The floodplain is located in the Yom River Valley in southernmost northern Thailand (16°76′–17°04′N, 99°82′–100°13′E), at an altitude of 40–52 m above mean sea level. The Yom River Basin has a total catchment area of 23 616 km^2, and its main channel runs down a steep valley at about 1:700. There are narrow plains along the river itself, which flows southwest through a large plain (Thailand Water Partnership, 2014).

2.2 Sample collection and processing

Sampling was undertaken at 33 stations in the Sukhothai floodplain. The stations were divided into 4 habitat types: (1) river (R), 5 stations; (2) main canal (M), 8 stations; (3) branch canal (B), 3 stations; and (4) flood areas (F), 16 stations (Fig.1). To sample flow within the floodplain, 3 distinct types of flood periods were chosen, each defined by flow orientation: (1) river flow runs into the floodplain (P1, August); (2) constant water level in floodplain (P2, September); and (3) river flow runs off of the floodplain (P3, October). Samples were obtained during all 3 flooding periods in all 3 collection years: 2010, 2011 and 2013. Samples were taken at the water's surface. The pH, water temperature and electrical conductivity were measured in the field using the pH meter (YSI, pH100A), thermometer and conductivity meter (YSI, EC 300), respectively. Using titration methods, the water samples were analyzed in the field for dissolved oxygen (mg/L), alkalinity (mg/L), hardness (mg/L) and free CO_2 (mg/L). The transparency and depth were measured (m) for physical parameters. The daily periodicity of the discharge (m^3) and rainfall (mm) data were obtained from Hydrology Irrigation for the Lower Northern Region, the Royal Irrigation

Table 1 Mean value of some physico-chemical and hydrological parameters of the Sukhothai floodplain in the period of investigations from 2010 to 2013

Year	DO (mg/L)	Alkalinity (mg/L)	Hardness (mg/L)	Free CO_2 (mg/L)	pH	Conductivity (μs/cm)	Water temperature (°C)	Transparency (cm)	Depth (cm)	Rainfall (mm)	Discharge (m^3)
2010											
P1	3.57	93.78	155.13	21.43	7.33	184.52	29.37	6.39	130.43	6.05	332.75
P2	3.43	85.96	166.96	33.61	6.55	186.57	28.37	8.09	142.17	13.20	558.30
P3	3.46	93.04	159.87	30.30	6.99	184.17	29.48	8.04	121.30	25.73	460.18
2011											
P1	4.17	97.89	87.04	29.96	7.34	183.89	28.38	5.00	105.00	22.63	449.00
P2	3.49	102.80	111.76	29.98	7.11	182.94	30.05	7.45	109.18	24.05	1 214.00
2013											
P1	3.02	100.32	120.29	27.89	7.37	183.07	30.00	5.54	96.79	27.08	247.28
P2	3.88	120.32	79.79	36.04	7.44	179.64	31.12	6.07	116.07	15.58	368.00
P3	2.95	105.54	123.64	30.79	7.20	179.64	29.89	7.14	90.00	15.55	406.10

Department of Thailand (RID) (Royal Irrigation Department, 2014).

In the margins, fish larvae were sampled using a micromesh seine net 30 m wide and 4 m deep, with 1-mm sized mesh. At each sample site, 3 sweeps of the net were made in different locations.

The samples were fixed in 10% neutral buffered formalin. Then, specimens were transferred to glass vials and preserved in 70% ethyl alcohol for identification. Post-larval and juvenile stages of fishes were identified to the lowest possible taxon, usually the species level, according to Termvidchakorn (2003, 2005), Termvidchakorn et al. (2005, 2007) and Termvidchakorn and Hortle (2013).

2.3 Data analysis

From the sample data for each site, abundance of larvae was standardized using population density methods (Wootton, 1992). Fish larvae assemblage change in response to habitats and years were visualized by performing a non-metric, multidimensional scaling algorithm (nMDS) on abundance data matrices (habitats) and presence/absence data (years). Temporal change of environmental variables among years was analyzed by a Principal Component Analysis (PCA). The vectors of all environmental variables to evidence the relationship between variables, axes and samples were shown in PCA ordination. It required an initial standardization of abundance and environmental data, which was performed by the general relativizations. A Sorensen distance matrix, using presence/absence data of taxa among years, was analysed by nMDS. The distance was computed, random staring configurations were used and 100 iterations were completed, by sample, with the sample and abundance of species collected in each sampling site, sampling period and year. The relationship between species distribution (abundance) and environmental factors was investigated using canonical correspondence analysis (CCA). All statistical analyses were performed using PC-ORD software version 6.08 (McCune and Mefford, 2011).

3 RESULT

3.1 Environmental variables

Table 1 contains the study's physico-chemical parameters and hydrological data. Both physico-chemical and hydrological parameters varied by period and year. Slight variations in environmental variables were found, including dissolved oxygen (DO) (range, 2.95–4.17 mg/L), alkalinity (range, 85.96–120.32 mg/L), free CO_2 (range, 21.43–36.04 mg/L), conductivity (range, 179.64–186.57 μs/cm), water temperature (range, 28.37–31.12°C) and transparency (range, 5.00–8.09 cm). Water pH varied from 6.55–7.44. Hardness (range, 79.79–166.96 mg/L) and depth (range, 90–142.17 cm) increased during 2010. During the study period, peak discharge occurred in 2011, and the lowest discharge in 2013 (Fig.2). The rainfall (range, 6.05–27.08 mm) and discharge (range, 247.28–1 214.00 m^3) increased during periods of a constant water level in the floodplain (P2) during 2010 and 2011. In addition, the PCA analysis revealed that the environmental parameters in 2010 were clearly different from those

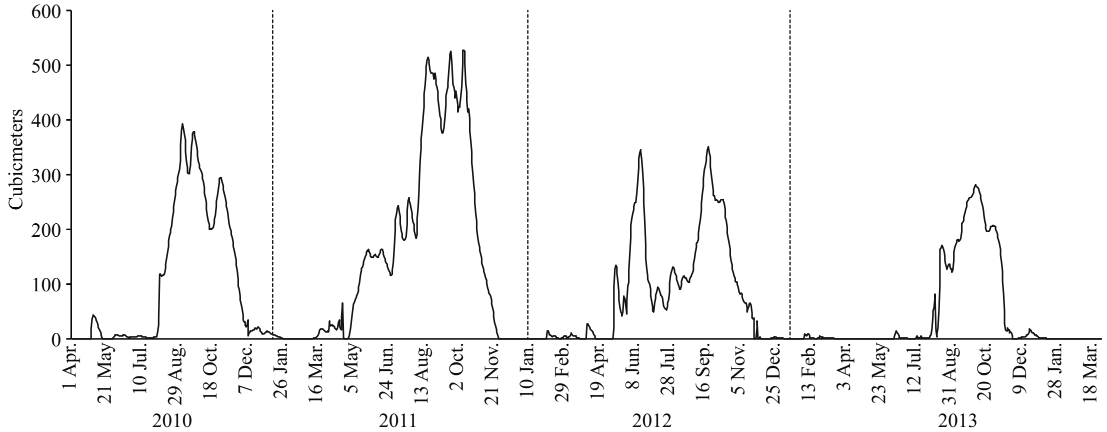

Fig.2 Hydrograph showing the annual flow events (discharge, m³) in the Sukhothai during the study period (2010–2013)

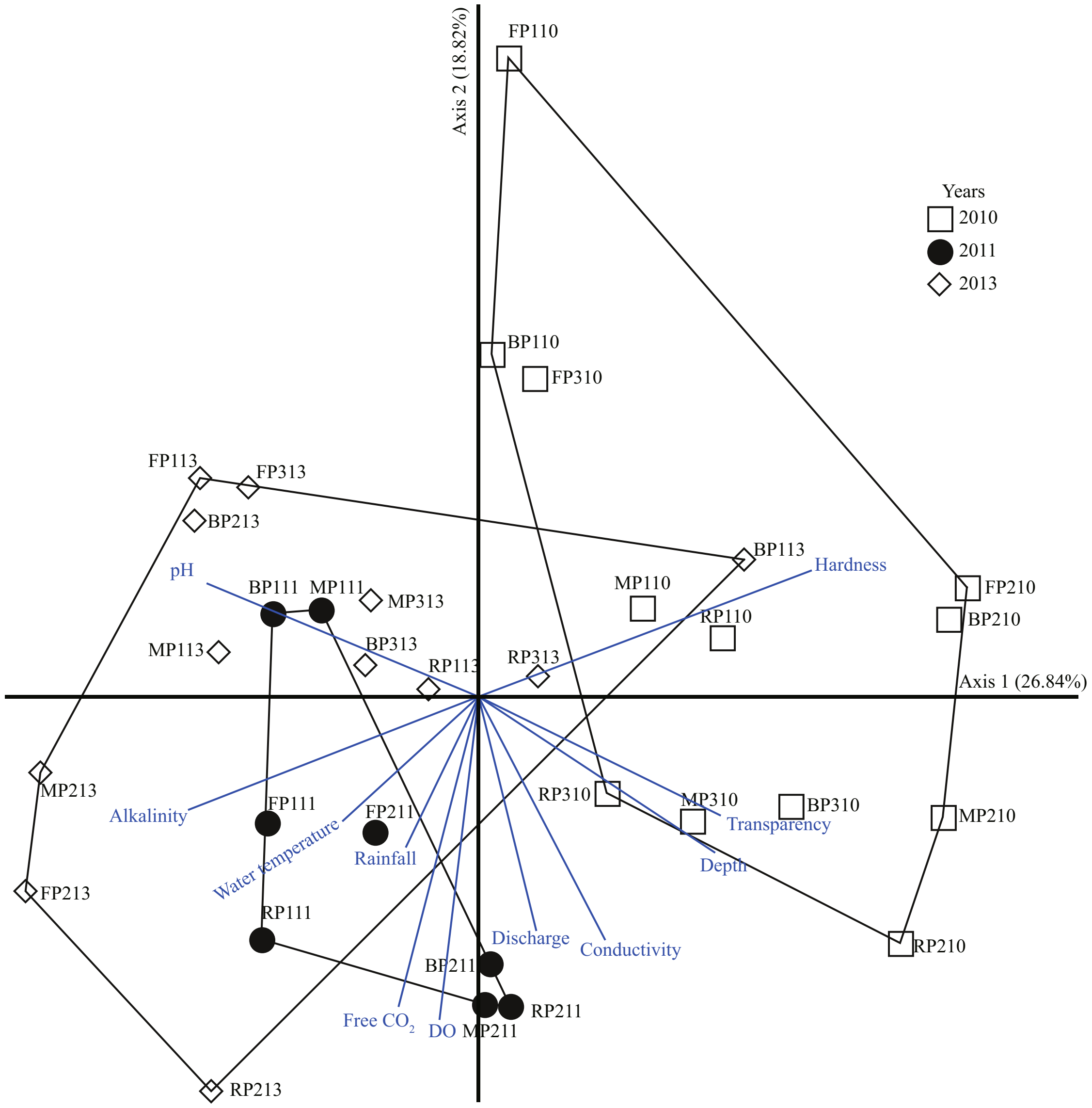

Fig.3 Biplot of sample coordinates on the first two axis of PCA with distance-based biplot scores, including all 32 samples for those an environmental variables

in 2011 and 2013. Among the environmental variables, discharge strongly correlated with axis 2 and increased in periods of a constant water level in the floodplain (P2) in 2011 (Fig.3).

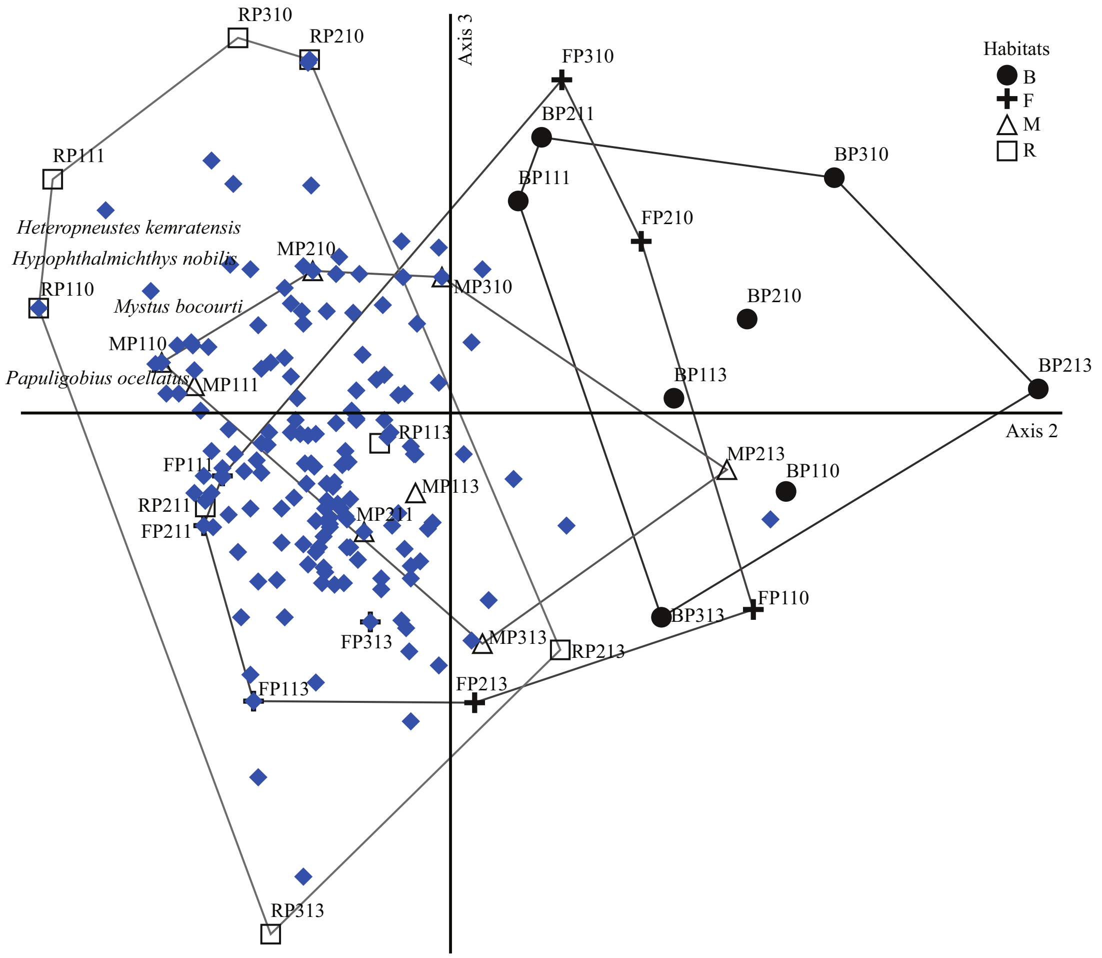

Fig.4 nMDS ordination plot of samples by taxa dissimilarities (abundance data), with habitat identified (stress=16.82%), including all 32 samples for those a faunal list was established (solid dots=fish species)

3.2 Larval fish composition, abundance and habitats

Table 2 contains the species number and abundance of fish larvae in each habitat. The main canal (M) and flood areas (F) habitats accounted for 147 species and 140 species, respectively, of the total catch, while the river (R) and branch canal (B) habitats accounted for 131 and 108 species, respectively. In terms of larval density, the catch was dominated by taxa associated with the flood areas and branch canal habitats, which accounted for 4 733 and 4 006 ind./100 m^2, respectively. The remaining portion of the catch consisted of taxa associated with the main canal (3 376 ind./100 m^2) and river (2 529 ind./100 m^2) habitats. Figure 4 presents the results of ordination using nMDS analysis on transformed larval fish-abundance data. It is clear that the river habitat samples on the left side of the plot (axis 3) were separated from the other habitats on the right side of the plot. Four species were positively correlated with the river habitat, including *Papuligobius ocellatus*, *Mystus bocourti*, *Hypophthalmichthys nobilis* and *Heteropneustes kemratensis*, indicating that they were the most-

Table 2 Species number and abundance of fish larvae assemblages of the Sukhothai floodplain in each habitat during 2010 to 2013

	2010	2011	2013	3 years
	Species number			
Branch canal	72	82	61	108
Flood areas	80	113	109	140
Main canal	127	103	89	147
River	94	98	71	131
All habitats	143	131	123	165
	Abundance (ind./100 m^2)			
Branch canal	1 642	969	1 395	4 006
Flood areas	1 628	1 248	1 857	4 733
Main canal	1 374	1 283	719	3 376
River	874	600	1 055	2 529
All habitats	5 518	4 100	5 026	14 644

abundant species in the river habitat. This, in turn, indicates that the spatial pattern of the larval fish abundance was better represented by the river habitat type.

The study collected 149 296 fish larvae representing 11 orders, 32 families, 84 genera and 165 species from 33 sampling stations along the Sukhothai floodplain. Figure 5 shows each of the dominant families of fish larvae as a percentage of total catch, including the number of species within each family. The catch was dominated by five families: Cyprinidae (78 species, 47.27%), Cobitidae (13 species, 7.88%), Siluridae (11 species, 6.67%), Bagridae (10 species, 6.06%) and Mastacembelidae (5 species, 3.33%). Table 3 lists the 10 most-dominant larval fish species, each of which contributed more than 2% of the total catch. Of these 10, the top 4 were the cyprinid *Esomus metallicus*, the cyprinid *Henicorhynchus siamensis*, the clupeid *Clupeichthys gonionathus* and the cyprinid *Henicorhynchus caudimaculatus*, which accounted for 16.90%, 8.48%, 8.31% and 6.66% of the total catch, respectively. The next six species each accounted for less than 5% of the total catch: cyprinids *Parachela oxygastroides* (4.83%), *Barbonymus gonionotus* (3.41%), *Amblypharyngodon chulabhornae* (2.88%) and *Parambassis siamensis* (2.45%), the gobiid *Gobiopterus chuno* (3.01%) and the clupeid *Clupeichthys aesarnensis* (2.29%).

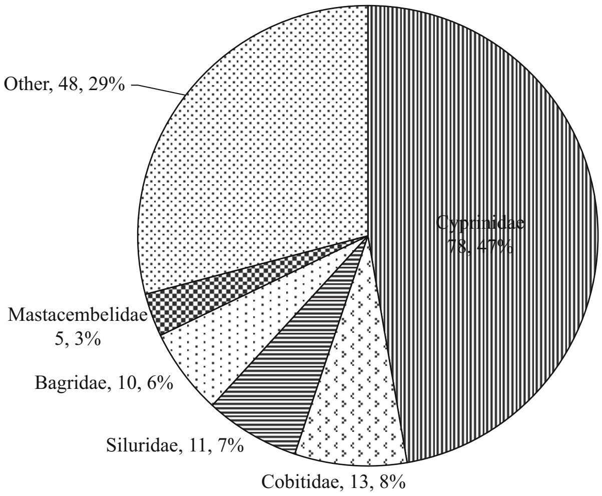

Fig.5 Percentage of species composition of the dominant families of fish larvae sampled in the Sukhothai floodplain from 2010–2013

3.3 Larval fish distribution

Figure 6 summarises nMDS analysis of the composition and structure of the fish larvae assemblages at each station during each period in each year. After 100 iterations, the stability criterion was met with a final stress of 14.33 (Monte Carlo test: P=0.009 91) for a three-dimensional solution. The

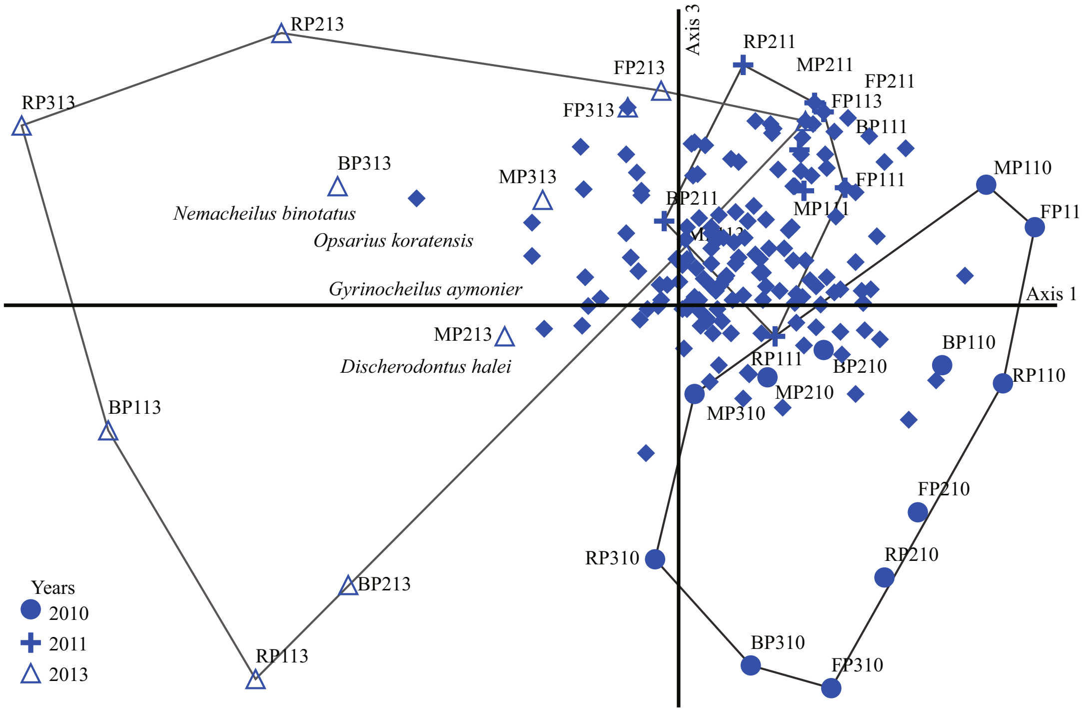

Fig.6 nMDS ordination plot of samples by taxa dissimilarities (presence/absence data), with year identified (stress=14.33%), including all 32 samples for those a faunal list was established (solid dots=fish species)

Table 3 Species list of fish larvae collected during the period (ordering by dominant taxon)

Species	Family	(ind./100 m^2)	Percentage (%)	Species	Family	(ind./100 m^2)	Percentage (%)
Esomus metallicus	Cyprinidae	2 060	14.37	*Puntius orphoides*	Cyprinidae	62	0.43
Clupeichthys goniognathus	Clupeidae	1 443	10.07	*Osteochilus vittatus*	Cyprinidae	61	0.43
Henicorhynchus siamensis	Cyprinidae	1 057	7.37	*Crossocheilus reticulatus*	Cyprinidae	56	0.39
Henicorhynchus caudimaculatus	Cyprinidae	784	5.47	*Puntius brevis*	Cyprinidae	50	0.35
Parachela oxygastroides	Cyprinidae	649	4.53	*Xenentodon cancila*	Belonidae	43	0.30
Barbonymus gonionotus	Cyprinidae	613	4.28	*Rasbora dusonensis*	Cyprinidae	41	0.29
Amblypharyngodon chulabhornae	Cyprinidae	467	3.26	*Pangasianodon hypophthalmus*	Pangasiidae	41	0.29
Clupeichthys aesarnensis	Clupeidae	418	2.92	*Epalzeorhynchos frenatus*	Cyprinidae	40	0.28
Parachela siamensis	Cyprinidae	409	2.85	*Puntius binotatus*	Cyprinidae	37	0.26
Parambassis apogonoides	Ambassidae	408	2.85	*Mystacoleucus greenwayi*	Cyprinidae	35	0.24
Gobiopterus chuno	Gobiidae	378	2.64	*Cyclocheilichthys repasson*	Cyprinidae	34	0.24
Puntioplites proctozystron	Cyprinidae	319	2.23	*Channa striata*	Channidae	34	0.24
Cyclocheilichthys apogon	Cyprinidae	305	2.13	*Rasbora myersi*	Cyprinidae	33	0.23
Parambassis siamensis	Ambassidae	279	1.95	*Mystacoleucus marginatus*	Cyprinidae	33	0.23
Barbonymus altus	Cyprinidae	240	1.67	*Luciosoma bleekeri*	Cyprinidae	32	0.22
Labiobarbus spilopleura	Cyprinidae	214	1.49	*Puntius masyai*	Cyprinidae	31	0.22
Paralaubuca harmandi	Cyprinidae	210	1.46	*Trichopsis pumila*	Osphronemidae	31	0.22
Cyclocheilichthys armatus	Cyprinidae	204	1.42	*Labeo chrysophekadion*	Cyprinidae	29	0.20
Labiobarbus siamensis	Cyprinidae	185	1.29	*Brachygobius aggregatus*	Gobiidae	29	0.20
Mystus mysticetus	Bagridae	175	1.22	*Cyclocheilichthys enoplos*	Cyprinidae	27	0.19
Trichopodus trichopterus	Osphronemidae	175	1.22	*Yasuhikotakia modesta*	Cobitidae	27	0.19
Henicorhynchus lineatus	Cyprinidae	161	1.12	*Osteochilus microcephalus*	Cyprinidae	26	0.18
Trichopodus microlepis	Osphronemidae	150	1.05	*Paralaubuca typus*	Cyprinidae	25	0.17
Rasbora aurotaenia	Cyprinidae	140	0.98	*Mystus multiradiatus*	Bagridae	25	0.17
Cirrhinus molitorella	Cyprinidae	127	0.89	*Syncrossus helodes*	Cobitidae	24	0.17
Laides longibarbis	Schilbeidae	123	0.86	*Hypostomus plecostomus*	Loricariidae	24	0.17
Pseudolais pleurotaenia	Pangasiidae	111	0.77	*Rasbora paviana*	Cyprinidae	23	0.16
Kryptopterus cryptopterus	Siluridae	108	0.75	*Puntius aurotaeniatus*	Cyprinidae	23	0.16
Anabas testudineus	Anabantidae	104	0.73	*Lepidocephalichthys hasselti*	Cobitidae	23	0.16
Rasbora borapetensis	Cyprinidae	95	0.66	*Pterygoplichthys pardalis*	Loricariidae	21	0.15
Sundasalanx mekongensis	Sundasalangidae	91	0.63	*Pangasius larnaudii*	Pangasiidae	21	0.15
Oryzias minutillus	Adrianichthyidae	80	0.56	*Pristolepis fasciata*	Nandidae	21	0.15
Acanthopsoides gracilentus	Cobitidae	71	0.50	*Pangasius macronema*	Pangasiidae	20	0.14
Labiobarbus lineatus	Cyprinidae	70	0.49	*Macrognathus siamensis*	Mastacembelidae	20	0.14
Trichopsis vittata	Osphronemidae	70	0.49	*Notopterus notopterus*	Notopteridae	18	0.13
Corica laciniata	Clupeidae	69	0.48	*Parachela maculicauda*	Cyprinidae	17	0.12
Oxygaster pointoni	Cyprinidae	69	0.48	*Acanthopsis choirhynchos*	Cobitidae	17	0.12
Dermogenys siamensis	Hemiramphidae	67	0.47	*Mystus albolineatus*	Bagridae	17	0.12

To be continued

Table 3 Continued

Species	Family	(ind./100 m^2)	Percentage (%)	Species	Family	(ind./100 m^2)	Percentage (%)
Macrognathus semiocellatus	Mastacembelidae	17	0.12	*Phalacronotus micronemus*	Siluridae	5	0.03
Brachygobius xanthomelas	Gobiidae	17	0.12	*Mystus bocourti*	Bagridae	5	0.03
Crossocheilus oblongus	Cyprinidae	16	0.11	*Poropuntius bantamensis*	Cyprinidae	4	0.03
Oxyeleotris marmorata	Eleotridae	16	0.11	*Syncrossus beauforti*	Cobitidae	4	0.03
Rasbora hobelmani	Cyprinidae	15	0.10	*Ompok binotatus*	Siluridae	4	0.03
Discherodontus ashmeadi	Cyprinidae	15	0.10	*Wallago attu*	Siluridae	4	0.03
Hemibagrus nemurus	Bagridae	15	0.10	*Mystus singaringan*	Bagridae	4	0.03
Kryptopterus cheveyi	Siluridae	14	0.10	*Mastacembelus armatus*	Mastacembelidae	4	0.03
Papuligobius ocellatus	Gobiidae	14	0.10	*Channa micropeltes*	Channidae	4	0.03
Hampala macrolepidota	Cyprinidae	13	0.09	*Crossocheilus atrilimes*	Cyprinidae	3	0.02
Amblyrhynchichthys truncatus	Cyprinidae	12	0.08	*Lobocheilos delacouri*	Cyprinidae	3	0.02
Discherodontus halei	Cyprinidae	12	0.08	*Nemacheilus pallidus*	Balitoridae	3	0.02
Paralaubuca barroni	Cyprinidae	12	0.08	*Phalacronotus apogon*	Siluridae	3	0.02
Mystus atrifasciatus	Bagridae	12	0.08	*Wallago leerii*	Siluridae	3	0.02
Parambassis wolffii	Ambassidae	12	0.08	*Helicophagus leptorhynchus*	Pangasiidae	3	0.02
Gyrinocheilus aymonieri	Gyrinocheilidae	11	0.08	*Pseudomystus siamensis*	Bagridae	3	0.02
Nemacheilus binotatus	Balitoridae	10	0.07	*Oreochromis niloticus*	Cichlidae	3	0.02
Hemibagrus filamentus	Bagridae	10	0.07	*Osteochilus melanopleurus*	Cyprinidae	2	0.01
Phenacostethus smithi	Phallostethidae	10	0.07	*Barbonymus schwanenfeldi*	Cyprinidae	2	0.01
Oxygaster anomalura	Cyprinidae	9	0.06	*Poropuntius laoensis*	Cyprinidae	2	0.01
Barbichthys laevis	Cyprinidae	8	0.06	*Yasuhikotakia morleti*	Cobitidae	2	0.01
Kryptopterus geminus	Siluridae	8	0.06	*Aplocheilus panchax*	Aplocheilidae	2	0.01
Phalacronotus bleekeri	Siluridae	8	0.06	*Monopterus albus*	Synbranchidae	2	0.01
Macrognathus circumcinctus	Mastacembelidae	8	0.06	*Boraras urophthalmoides*	Cyprinidae	1	0.01
Osteochilus waandersii	Cyprinidae	7	0.05	*Cirrhinus mrigala*	Cyprinidae	1	0.01
Pangio anguillaris	Cobitidae	7	0.05	*Cosmochilus harmandi*	Cyprinidae	1	0.01
Pangio oblonga	Cobitidae	7	0.05	*Hypophthalmichthys nobilis*	Cyprinidae	1	0.01
Toxotes chatareus	Toxotidae	7	0.05	*Mystacoleucus argenteus*	Cyprinidae	1	0.01
Opsarius koratensis	Cyprinidae	6	0.04	*Parasikukia maculata*	Cyprinidae	1	0.01
Hampala dispar	Cyprinidae	6	0.04	*Lepidocephalichthys furcatus*	Cobitidae	1	0.01
Poropuntius deauratus	Cyprinidae	6	0.04	*Nemacheilus longistriatus*	Balitoridae	1	0.01
Mastacembelus favus	Mastacembelidae	6	0.04	*Tuberoschistura baenzigeri*	Balitoridae	1	0.01
Trichopodus pectoralis	Osphronemidae	6	0.04	*Kryptopterus limpok*	Siluridae	1	0.01
Mystacoleucus atridorsalis	Cyprinidae	5	0.03	*Heteropneustes kemratensis*	Heteropneustidae	1	0.01
Paralaubuca riveroi	Cyprinidae	5	0.03	*Hemibagrus wyckii*	Bagridae	1	0.01
Sikukia gudgeri	Cyprinidae	5	0.03	*Gambusia affinis*	Poeciliidae	1	0.01
Thynnichthys thynnoides	Cyprinidae	5	0.03	*Polynemus multifilis*	Polynemidae	1	0.01
Ompok bimaculatus	Siluridae	5	0.03	*Brachirus harmandi*	Soleidae	1	0.01

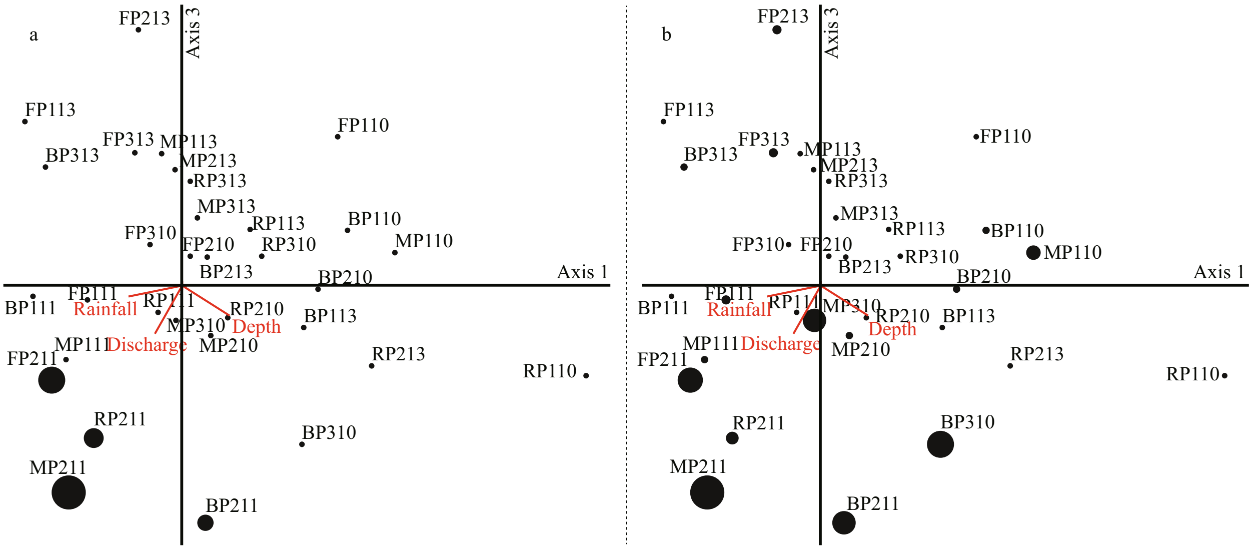

Fig.7 CCA ordination plot of samples by environmental variable vector (discharge) and abundance of *Rasbora aurotenia* (a) (R^2=0.389) and *Rasbora dusonensis* (b) (R^2=0.402), with taxa abundance superimposed

In the plot, the larger symbols denote greater values (higher abundance).

location of the points along axis 1 (Fig.6) identified years (temporal scale) as the main pattern in the composition and structure of the fish larvae assemblages. Samples for 2010 were positively correlated with axis 1. In contrast, samples for 2013 were negatively correlated with axis 1. It is clear that the samples plot is associated with temporal distribution among years. Figure 6 shows the species plot: cyprinid *Discherodontus halei*, gyrinocheilid *Gyrinocheilus aymonieri*, cyprinid *Opsarius koratensis* and balitorid *Nemacheilus binotatus* typically populate the samples for 2013, located on the left side of the plot. This ordination indicates that they were positively correlated with the samples for 2013. No spatial or temporal patterns were observed in axis 3.

3.4 Larval fish abundance and environmental linkages

Relationships between fish larvae abundance and abiotic variables were analysed using CCA analysis. The result of the ordination plot showed that only the discharge variable was strongly correlated with fish larvae abundance (Fig.7). The discharge vector strongly correlated with axis 3, increasing in periods of a constant water level in the floodplain (P2) in 2011. Two cyprinid species, *Rasbora aurotenia* and *Rasbora dusonensis*, were strongly correlated with axis 3, providing values of R^2=0.389 and 0.402, respectively (Fig.7). These species were observed on the lower part of the plot, associated with the P2 samples and with high discharge values. The larvae of *R. aurotenia* and *R. dusonensis* dominated and accounted for mean values (±SD) of 32.48±11.04 and 70.19±29.70 ind./100 m^3, respectively.

4 DISCUSSION

4.1 Environmental variables

Generally, both physico-chemical and hydrological parameters varied by year and period. Most parameters did not exceed the surface-water quality standard of Thailand and the appropriate water-quality criteria for aquatic living. The water temperature and pH varied from 23–32°C and from 5.0–9.0, respectively. Most dissolved oxygen concentrations were greater than 3 mg/L, which is appropriate for freshwater aquatic resources (Pollution Control Department, 1992). In periods of a constant water level in the floodplain, the discharge profile and the water level showed increasing trends in 2011. Changing in limnological characteristics during the flooding period may be affect to fish species (Baumgartner et al., 1997). Increasing floodplain area probably reflected a direct association with floodplain utilization by migratory fish species (Tanaka et al., 2015).

4.2 Larval fish assemblages

The dominant larval species were the cyprinids, represented mainly by the common species *Esomus metallicus*. This cyprinid specie is abundant in the Mekong and Chao Phraya River systems and is found in both freshwater and brackish habitats. It is the most-common and widely distributed species in

Indochina and Sumatra. In all floodplains within its natural distributional range, this species is usually abundant and one of the commonest freshwater fish (Arbsuwan et al., 2012). The larvae of *E. metallicus* were approximately 17% of the total catch, which means it was relatively highly abundant. According to Tanaka et al. (2015) found that *E. metallicus* is one of four common species increased in temporarily connected survey sites in waterbodies of the Chao Phraya river basin.

The second most-abundant species of freshwater cyprinid fish, the Siamese mud carp *Henicorhynchus siamensis*, is a variety of Asian carp native to the Mekong and Chao Phraya Rivers in Southeast Asia. It is very common in floodplains during the wet season and migrates upstream in the Mekong, the migration pathway begins in Cambodia (Suvarnaraksha et al., 2011).

The third most-abundant species, *Clupeichthys goniognathus*, is a pelagic clupeid fish inhabiting the lower reaches of rivers, although it has also been recorded in reservoirs. This species also occurs in floodplains and lakes during flooding season, which agrees with the results of the present study. It is widely distributed in Thailand, Malaysia, Indonesia, Cambodia, and the Lao PDR (Vidthayanon, 2012a). Jutagate et al. (2003) and Cowx et al. (2015) have identified differences in species composition in the ichthyoplankton drift in the Lower Mekong Basin in various seasons. They found that the flooding period (maximum water level in the Mekong is from August–October) was dominated by Cyprinidae, which agrees with the results of this study. In the study by Cowx et al. (2015), the most abundant species were *Laides longibarbis* (11.2%), *Cyclocheilichthys enoplos* (10.3%) and *Puntioplites proctozysron* (8.0%), all which were found in the main channels of rivers. In the present study, all the commonly abundant fish larvae are associated with floodplain areas, and all are used locally both as food and commercially, in the aquarium trade, although pollution and large-scale overfishing may be threaten these species in the future (Mondal et al., 2010).

The spatial pattern of larval fish abundance is represented by the habitat type. The abundance of four larval fish species, *Papuligobius ocellatus*, *Mystus bocourti*, *Hypophthalmichthys nobilis* and *Heteropneustes kemratensis*, correlated with the river (R) habitat. Two native fish species, *P. ocellatus* and *M. bocourti*, are riverine fish recorded in several areas of Thailand. In addition, *M. bocourti* is a vulnerable fish species. Another native fish species, *H. kemratensis*, is distributed throughout the Irrawaddy, Sittoung and Salaween Basins in Myanmar and the Chao Phraya, Eastern and Tapi Basins in Thailand (Ratmuangkhwang, 2007). The present study also found an invasive species, a bighead carp, *H. nobilis*. Bighead carp are native to the large rivers and associated floodplain lakes of eastern Asia. This specie is one of the most important fish in aquaculture (Kara, 2012).

In 2010, the main canal (M) habitat showed the highest values for fish larvae species richness, evenness and SDI, but slight differences were observed in the diversity and richness of species among the spatiotemporal scales, which may be related to the characteristics of these sites (Daga et al., 2009). The Sukhothai floodplain suffered flooding in 2011 and drought in 2013, causing changes in the pattern, quantity and intensity of flow in the area. If they continue, these condition may affect the diversity and richness of larval fish species in the Sukhothai floodplain.

In 2013, four distinctive species were observed in the larval fish assemblage. The first was the cyprinid *Discherodontus colemani*, which found in the upper Chao Phraya basin in northern (Vidthayanon, 2012b). The second was the cyprinid *Opsarius koratensis*, which is also found in clear water with sandy-rocky bottoms (Rainboth, 1996). The third was the gyrinocheilid *Gyrinocheilus aymonieri*, which inhabits flowing streams and tributaries with substrates of boulders, pebbles, gravel and sand (Rainboth, 1996) and occurs in medium- to large-sized rivers and enters flooded fields. The fourth was the balitorid *Nemacheilus binotatus*, which inhabits streams and rivers with moderate current over sandy or pebbly substrate.

The study's CCA analysis revealed that in addition to the temporal changes noted, the main environmental gradient was due to discharge. Discharge gradient is a common feature of tropical rivers and has pronounced temporal effects on fish composition and distribution. Shuai et al. (2016) found that mean water temperature, river discharge, atmospheric pressure, maximum temperature and precipitation play important roles in larval occurrence patterns. The cyprinid larval species, *Megalobrama terminalis*, *Xenocypris davidi*, and *Cirrhinus molitorella*, are associated with high precipitation, high river discharge, low atmospheric pressure and low DO concentrations which featured during the summer month (Shuai et al., 2016). While, no association was observed between environmental variables and spatial and temporal patterns of the ichthyoplankton assemblages of the floodplain of Upper Parana River, in Ilha Grande National Park, southern Brazil (Gogola et al., 2013).

River discharge and the timing of floods are increasingly being recognised as important causes of inter-annual variability in the recruitment success of cyprinid fish (Nunn et al., 2007). In addition, discharge variables correlate with the abundance of larval *R. aurotenia* and *R. dusonensis*. Both two species occur near the surfaces of ponds, canals and streams, are often found in turbid waters and migrate from rivers into flooded forests and swamps (Rainboth, 1996). In the present study, two *Rasbora* species seem not to be migratory species, however, two larval species (*Hemicorhynchus siamensis* and *Hemicorhynchus caudimaculatus*) of top 10 abundant fishes categorise as migratory fishes (Cowx et al., 2015). This presence of the larvae of migratory species indicated that the Sukhothai floodplain may be important to maintaining these species. In general, migratory species spawn in the open waters of the main channel or in tributaries, and the eggs and larvae are transported passively by currents to flooded areas and marginal lagoons, where they complete their development (Daga et al., 2009). Therefore, the larvae of migratory species in the Sukhothai floodplain possibly originated from spawning events in the Yom River.

5 CONCLUSION

The post-larval and juvenile fish assemblages and environmental parameters in the Sukhothai floodplain were investigated in August 2010 and October 2013. The dominant larval family was Cyprinidae, accounting for 78 taxa. *Esomus metallicus* was the most abundant species, followed by *Henicorhynchus siamensis*, *Clupeichthys gonionathus* (Clupeidae) and *Henicorhynchus caudimaculatus*. The results of this study indicate that variations in larval fish assemblage are temporal in nature. The larval fish assemblage in 2013 was different from that in 2010 and 2011, and some trends were distinguishable. Four fish species, *Discherodontus colemani*, *Gyrinocheilus aymonieri*, *Opsarius koratensis* and *Nemacheilus binotatus* typically populate the samples for 2013. The water discharge was a major factor determining fish larvae composition and structure in floodplain. Specifically, there was evidence for the changes in larval fish assemblage in 2013 (the discharge decreasing, and the water level and rainfall also showed decreasing trends in 2013). Moreover, *Rasbora aurotenia* and *Rasbora dusonensis* were strongly correlated with the discharge parameter.

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