Impacts of Rainfall and Related Hydrological Factors on Spawning Characteristics of Silver Barb (*Barbonymus gonionotus* Bleeker, 1849) in a Tropical Reservoir Ecosystem

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ABSTRACT

Climate change has a major influence on aquatic biodiversity and hydrological conditions, and it will continue to adversely affect the structure and function of aquatic ecosystems. Ubolratana Reservoir is a shallow mesotrophic reservoir in Northeast Thailand and serves multiple purposes, including fisheries activity. This study investigates the possible impacts of rainfall, water inflow, and water storage of the reservoir on spawning characteristics of silver barb (*Barbonymus gonionotus* Bleeker, 1849). Results show that meteoro-hydrological factors affected fish larvae in the riverine zones of the Phong and Choen river inlets during the early rainy season (June of 2018 and 2019). High densities of larvae (1,096 and 12 individuals·1,000 m^{-3}) were found in Phong and Choen rivers, respectively. Principal Component Analysis (PCA) indicated that the density of newly hatched larvae (age<3 days) in the Phong River channel was correlated with rainfall ($\lambda = 0.19$) and its relative increase ($\lambda = 0.51$), while density of older larvae (age>3 days) was correlated with volume of inflow ($\lambda = 0.81$) and its relative increase ($\lambda = 0.76$). Therefore, rainfall and inflow are identified as important factors influencing the larval densities of silver barb in the reservoir's riverine ecosystem. These findings imply that rainfall and inflows into the reservoir ecosystem should be considered along with other factors for further conservation management of fishery resources.

Keywords: Conservative management, Inflow, New hatching larvae, Rainfall, Riverine reservoir ecosystem

INTRODUCTION

Meteorological and hydrological information can be integrated for flood control, hydroelectric generation, industrial water-supply, irrigation, and fishery management (Moss, 1988; Jørgensen *et al*., 2013). In terms of fisheries, changes in the meteorological and hydrological conditions influence reproduction modes, population recruitment and changes in population size. In tropical countries, the seasonal influx of floodwater can be an essential factor to induce reproductive development and cue adult fish to spawn in the reservoir ecosystem. In particular, some stream-dwelling fish species need an open water area for spawning and water current to transport their fertilized eggs and planktonic larvae to vegetated floodplains for growth (Sokheng *et al*., 1999; Azami *et al*., 2015). Ubolratana Reservoir has the highest capacity for fishery production in Thailand, reported as 2,193 tonnes·$year^{-1}$ in 1983 (Petr, 1985). The production at that time included 441 tonnes·$year^{-1}$ of silver barb (*Barbonymus gonionotus* Bleeker, 1849), accounting for about one-fifth of the total catch (Baluyut, 1983; Petr, 1985; Kakkaeo *et al*., 2004; Ingthamjitr *et al*., 2009). Thereafter, fish

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production decreased gradually during the following two decades. The lowest production of silver barb (86 tonnes·year^{-1}) was observed during 2013 (DOF, 2019). Such decreases in production of cyprinid fishes, including silver barb, in the Ubolratana Reservoir were suggested to be caused by gradual air temperature increase and a crisis of water scarcity due to insufficient inflows (Meksumpun *et al*., 2019; EGAT, 2019). Such low inflows can impact spawning migration of long-distance migratory fish species and reduce the ability to transport fertilized eggs and larvae to the nursery habitat (De Wit and Stankiewicz, 2006; Baumgartner *et al*., 2008; IPCC, 2014; Harrod *et al*., 2016).

The silver barb was chosen for this study as a representative of migratory fish species. First rains trigger the upstream migration of spawning adults (Kottelat, 1998). Thus, we hypothesized that changes in meteorological and hydrological conditions could affect silver barb reproduction. Since silver barb has recently been an important economic species in the Ubolratana Reservoir, this study aimed at investigating the impacts of the rainfall, water runoff, and water storage on the silver barb's larval population. Understanding these impacts will be useful for evaluating the population status, and in turn, for the development of conservation management of cyprinid resources of the tropical reservoir ecosystem.

MATERIALS AND METHODS

Study area

Ubolratana Reservoir is the largest reservoir in Thailand, with 12,089 km^2 of impoundment area and 2,263.3 million m^3 of maximum storage. It ranks first among reservoirs in the nation for fishery production. It is located in the Northeast, between Khon Kaen and Nong Bua Lam Phu provinces. The reservoir is a part of the Lower Mekong River Basin, which drains into the Mekong River at the boundary between Ubon Ratchathani Province of Thailand and Champasak Province of Lao People's Democratic Republic (Petr, 1985; Ingthamjitr *et al*., 2009). The dam was built at the confluence of the Phong and Choen tributaries (16°46'20"N, 102°37'12"E), which flow in from northern and southern parts of the reservoir, respectively.

The reservoir can be divided into two parts, according to the influence from water discharges of the Phong and Choen tributaries, and also can be classified into three zones that change with season: 1) Riverine zone, the upper river channel containing water throughout the year; 2) Transitional zone, the dry (during January-April) portion of the river channel and the surrounding land that are flooded during the rainy season (September-November); and 3) Lacustrine zone, the lower-lying areas of land flooded throughout the year (i.e., a lake ecosystem). Twelve sampling stations were set up for the Choen River (CR) and Phong River (PR) tributary channels, with six stations for each channel. Both tributary channels contained two sampling stations each within the riverine, transitional, and lacustrine zones. Stations were numbered sequentially (1-6) from riverine to lacustrine zones (Figure 1). At each sampling station, surveys were conducted 10 times: in February, June, July, August, and October 2018; and in April, June, July, August, and November 2019.

Meteoro-hydrological information and related water quality

The information on meteoro-hydrological conditions (rainfall, water inflow, and water storage) used in this study was from http://watertele.egat.co.th/ubolratana/, developed by the Electricity Generating Authority of Thailand (EGAT, 2019). This data source was used because it provided the most reliable and precise information. Accordingly, information on rainfall (mm) and water inflow volume (million m^3) from telemetry stations nearest to the Phong and Choen sites was used, along with water storage (million m^3) data for 2018 and 2019. Additionally, all meteoro-hydrological parameters were analyzed in terms of relative increase (%) from the previous month. At each sampling station, water temperature was measured using a Multiparameter YSI probe (Model 600QS). Water depth was measured using Water Portable Sounder and Depth Meter (Laylin Speedtech Model SM-5).

Larval collection and laboratory procedures

Fish larvae were sampled with a larvae net (50 cm mouth diameter, 650 µm mesh for the cylindrical net body, and 330 µm mesh for the conical cod end) equipped with a flow meter for measuring water volume passing through the net mouth. The larvae net was operated by towing horizontally 0.5-1.0 m beneath the surface for 10 min at approximately 3-5 $km \cdot h^{-1}$ of boat speed. The operation was done once during each sampling period at each sampling site (Figure 1). The collected samples were fixed in 10% buffered formalin. In the laboratory, the specimens of silver barb larvae were sorted from other species based on a guide by Termvidchakorn and Hortle (2013), and notochord length (NL) was measured to the nearest 0.01 mm using vernier caliper under stereomicroscope. Then, the larvae were classified into two groups according to Balon (1985) and Termvidchakorn and Hortle (2013), with slight modification: (1) the pre-larval phase-larvae smaller than 4.3 mm NL, newly hatched to 3 days, notochord tip still not bent upward; and (2) post-larval phase-larvae longer than 4.3 mm NL, age more than 3 days, urostyle bone completely bent upward. Densities of silver barb larvae at each sampling station were estimated as "larvae individuals$\cdot$1,000 m^{-3}" by dividing the total number of larval specimens (individuals) from the volume of water that passed through the net during sampling.

Data analysis

Data analyses were carried out to identify the meteoro-hydrological variables that affect the pre-larval phase and post-larval phase densities, and to provide information on the spawning period and spawning grounds of the silver barb in Ubolratana Reservoir. The meteoro-hydrological variables and larval densities were analyzed using descriptive statistics in terms of mean and standard deviation (SD). Thereafter, the correlation between the meteoro-hydrological variables and larval density was examined using principal component analysis (PCA) facilitated by FactoMineR (R Package for Multivariate Analysis). Before running the ordination, all variables were centralized according to the method of Lê *et al*. (2008). Accordingly, linear combinations of high dimensional variables and larval density were illustrated and discussed.

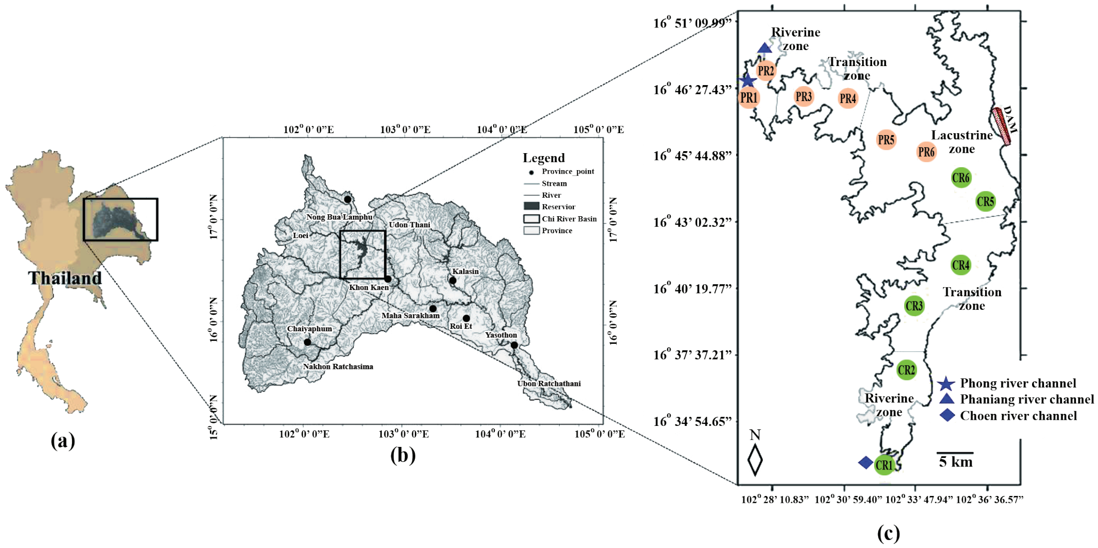

Figure 1. Location of the Ubolratana Reservoir in Northeast Thailand and larval fish sampling stations: (a) Map of Thailand; (b) Map of watershed and related catchment areas; and (c) Boundary of the Ubolratana Reservoir with numbered sampling sites, where PR and CR are stations along the Phong and Choen river channels, respectively.

RESULTS

Meteoro-hydrological variables

Rainfall

Meteoro-hydrological values and their change (relative increase) from the previous month during 2018 and 2019 are presented in Figure 2. In 2018, monthly rainfall ranged from 0 to 278 mm. In the dry season (January-April), the mean rainfall at PR was 69.5 mm, and ranged from 2 to 171 mm; notably, in April 2018 rainfall was about six times higher than in March 2018. The relative increases in rainfall during March and April were -64 and 511 %, respectively. The CR site had a mean rainfall of 45 mm in the dry season, with a range of 0 to 86 mm. Like at PR, rainfall at CR increased about six-fold from March to April 2018. The relative increases in rainfall during March and April were found to be -81 and 437 %, respectively. Monthly rainfall during the rainy (flooding) season (May-October) at PR varied from 89 to 278 mm. The levels were high (89-153 mm) during the early

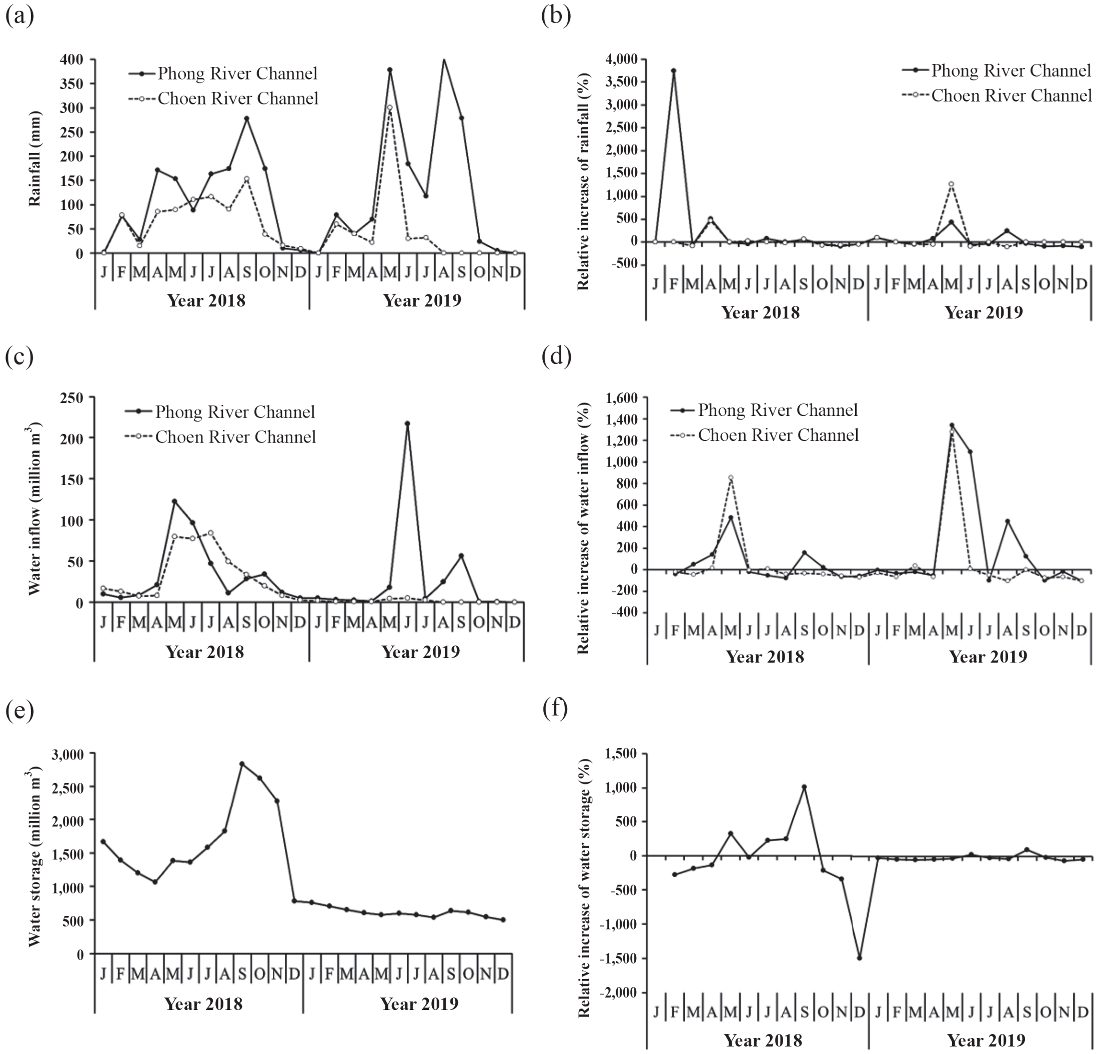

Figure 2. Variation in meteoro-hydrological factors measured at Ubolratana Reservoir during 2018 to 2019, represented by actual values and relative increase of rainfall (a-b), inflow (c-d), and water storage (e-f).

rainy season (May-June), then increased further during the mid-rainy season (July-August; 163-174 mm) and the late rainy season (September-October; 174-278 mm). The CR had a mean rainfall of 96.83 mm during the rainy season. The levels were high (133±117 mm) during the early rainy season (May-June). The rainfall was found to decrease during the mid-rainy season (July-August; 60±53 mm) and the late rainy season (September-October; 48±72 mm) (Figure 2a and 2b).

In 2019, the PR had rainfall ranging from 0 to 79 mm during the dry season. The relative increases during March and May were -49 and 440 %, respectively. The rainfall during the rainy season (May-October) varied from 24 to 401 mm. During the early rainy season, the rainfall was high (184-378 mm), and more variable during the mid-rainy season (117-401 mm) and the late rainy season (24-249 mm). The CR had rainfall during the dry season of 0 to 60 mm. The relative increases during April and May were found to be -45 and 1,268 %, respectively. The rainfall at CR during the rainy season (May-October) varied from 0 to 301 mm. During the early rainy season, the rainfall was high (30-301 mm). The rainfall levels decreased during the mid-rainy season (0-32 mm) and the late rainy season (0 mm) (Figure 2a and 2b).

Water inflow

Water inflows from PR and CR in 2018 varied seasonally, with ranges from 5 to 122 and from 3 to 84 million m^3, respectively. The inflows from PR were 6 to 12 million m^3 during the dry season and 97 to 122 million m^3 during the early rainy season. The first period of increased inflow occurred in early April 2018 (140 %). A second period of increase (September 2018, 160 %) was related to rainfall. The inflows from CR also differed between the dry and early rainy seasons (7-17 vs. 77-79 million m^3, respectively). A notable increase in inflow from CR was found in May 2018, with a relative increase of 855 % (Figure 2c and 2d).

During 2019, the inflows from PR and CR were lower than in 2018, ranging from 0 to 217 and from 0 to 5 million m^3, respectively. As in 2018, differences were found for PR between the dry and early rainy seasons (1-5 vs. 18-217 million m^3, respectively). The first period of increased inflow from PR was found in early May 2019 (1,343 %), with a second increase in August 2019 (450 %). The inflows from CR also differed between the dry and early rainy seasons (0-2 vs. 4-5 million m^3), respectively. Similar to 2018, a large increase in inflow from CR was found in May 2019 (1,281 %) (Figure 2c and 2d).

Water storage and related water quality parameters

Water storage of the reservoir in 2018 ranged from 783 to 2,832 million m^3 (Figure 2e and 2f). The storage volume gradually decreased from 1,665 to 1,061 million m^3 during the dry season. During the rainy season, the volume increased again, to a maximum level of 2,832 million m^3. Water storage data from 2019 revealed a gradual decrease in water storage from the early rainy season (May, 991 million m^3), mid rainy season (July, 756 million m^3), to the late rainy season (September, 707 million m3). The storage volume further decreased until December 2019 (503 million m^3). The volume in 2019 was lower than the “minimum storage level” determined for the reservoir’s sustainability (Electricity Generation Authority of Thailand, 2019).

During the study period, water depth of the Phong and Choen River channels ranged from 0.8-8.3 m and 2.4-8.9 m, respectively. Water temperature at PR ranged from 26.7-34.6 °C, with an average of 30.6±1.9 °C. The water temperature at CR was similar to PR, with range of 26.1-34.0 °C and an average of 30.2±1.9 °C. Such variations of water temperature could be impacted by inflow, air temperature, and water depth at each sampling site.

Assemblages of silver barb larvae

The investigation on the drift of early developmental stages of silver barb larvae revealed the seasonal dynamics of the larvae. Two stages (pre-larvae and post-larvae) were found during sampling (Figure 3), and reflected the timing of spawning. In both 2018 and 2019, silver barb larvae were found in highest densities in the riverine zone during June (Figure 4). However, differences in density were found between the two years. In 2018 the silver barb larvae were observed in only two months (June-July), while in 2019, the larvae were observed in five months (April-August).

In 2018, silver barb larvae were found at both the PR and CR sites. The peak of spawning was in June, with mean total larvae of 1,096±2,660 and 12±19 individuals·1,000 m^{-3} collected at PR and CR, respectively. At PR, only pre-larvae were found in the riverine zone (PR1), with maximum density of 6,526 individuals·1,000 m^{-3}. Post-larvae were found in the transition zone of PR (PR3-PR4), and at lower densities of 23 to 25 individuals·1,000 m^{-3}. In the CR, only pre-larvae were found in the riverine stations (CR1 and CR2), at densities of 46 and 23 individuals·1,000 m^{-3}, respectively (Figure 4a).

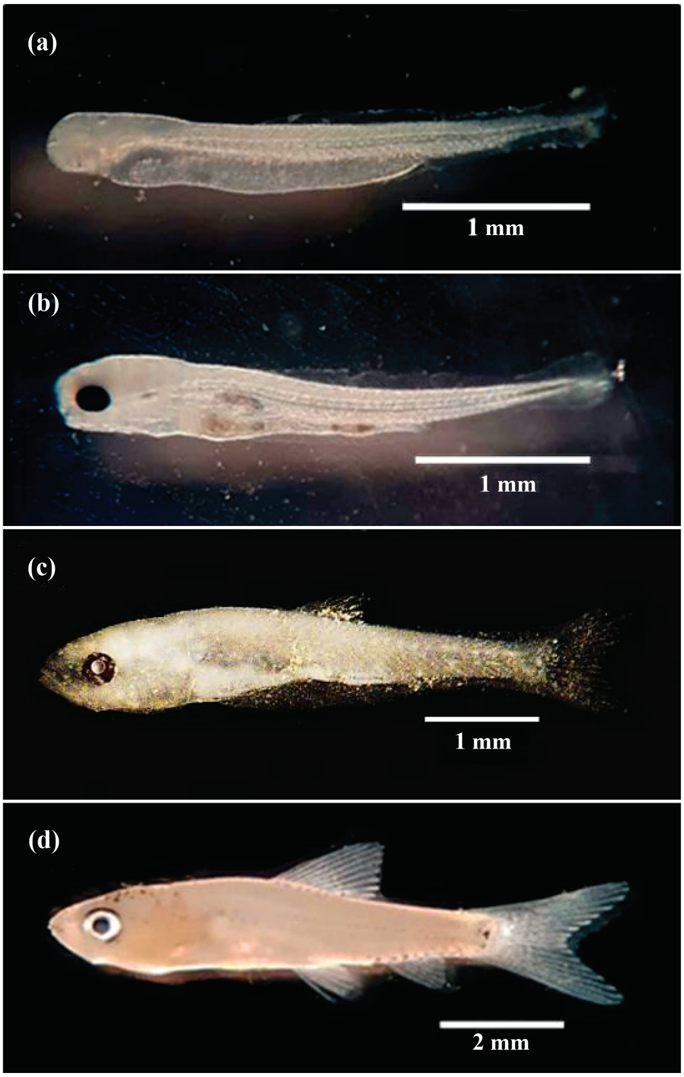

Figure 3. Development stages of silver barb larvae collected from Ubolratana Reservoir from February 2018 to August 2019: (a) pre-larvae, 2.83 mm notochord length; (b) post-larvae, 3.10 mm notochord length; and (c-d) post-larvae, 4.22-7.64 mm standard length.

In 2019, silver barb larvae were found only at PR stations in the riverine and transition zones. Pre-larvae were found in April only in the riverine zone (PR2), at a density of 60 individuals·1,000 m^{-3}. Later, near the end of the peak spawning period (June), most of the pre-larvae were found at sites in the riverine zone (PR1 and PR2), at densities of 55 and 1,050 individuals·1,000 m^{-3}, respectively. Fewer post-larvae were found in the riverine zone (83 and 16 individuals·1,000 m^{-3}) and in the transition zone (PR4; 58 individuals·1,000 m^{-3}) (Figure 4b). The numbers of pre-larval stage silver barb gradually decreased in July (10 individuals·1,000 m^{-3}) and August (2 individuals·1,000 m^{-3}) of 2019. No larvae were found in November, nor were any silver barb larvae found in the lacustrine zone throughout the two years of investigation.

Relationship between meteoro-hydrological factors and silver barb larval densities

PCA results show the influence of meteoro-hydrological factors on silver barb larval densities in the riverine and the transition zones of the Phong and Choen rivers (Table 1 and Figure 5). The first axis of the PCA for PR and CR meteoro-hydrological factors explain 32.16 % and 29.93 % of variance in larval density, respectively. For PR, the factors highly correlated to PC1 were water inflow (λ = 0.76), relative increase of inflow (λ = 0.81), and water storage (λ = 0.83).

In the Choen River channel, the factors highly correlated to PC1 were water inflow (λ = 0.72) and relative increase of inflow (λ = 0.63),

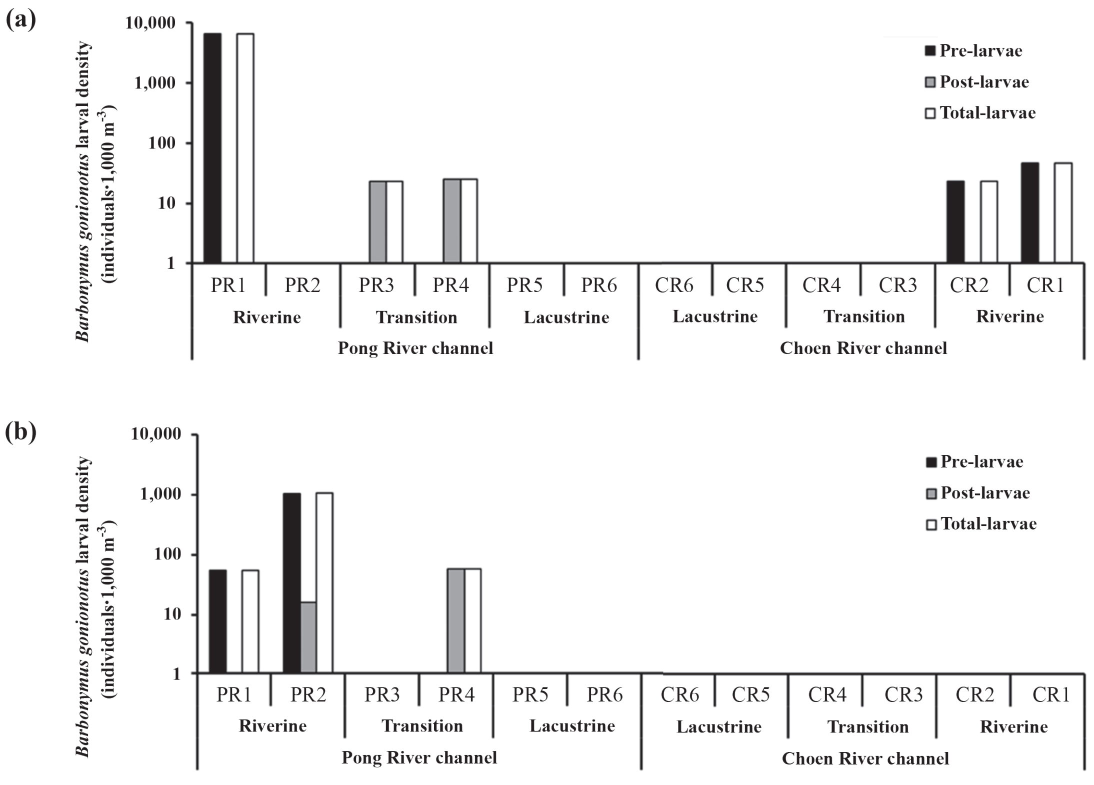

Figure 4. Spatial variation of silver barb larval densities (log scale) found in the Ubolratana Reservoir in (a) June 2018 and (b) June 2019.

Table 1. Results of the Principal Component Analysis (PCA) of correlations between meteoro-hydrological factors and silver barb larval densities in two tributaries of the Ubolratana Reservoir during 2018 to 2019. Eigenvalues greater than 0.6 are marked in bold.

Meteoro-hydrological factors	Abbreviation	Phong channel		Phong channel	
		PC1	PC2	PC1	PC2
Rainfall	Rain	0.19	0.28	0.07	**0.74**
Relative increase of rainfall	X. Rain	0.51	0.45	0.12	**0.80**
Water inflow	Inflow	**0.81**	-0.19	**0.72**	-0.17
Relative increase of water inflow	X. Inflow	**0.76**	-0.44	**0.63**	-0.19
Water storage	Storage	-0.40	0.27	0.45	**-0.60**
Relative increase of water storage	X. Storage	**0.83**	-0.17	-0.23	0.57
Water temperature	WTemp	0.37	-0.19	-0.26	0.32
Water depth	Depth	-0.15	-0.13	-0.13	-0.21
Eigenvalue	Λ	2.99	2.14	2.45	2.28
Percent of variance	-	32.19	23.42	29.93	26.51
Cumulative percent of variance	-	32.19	55.54	29.93	58.39

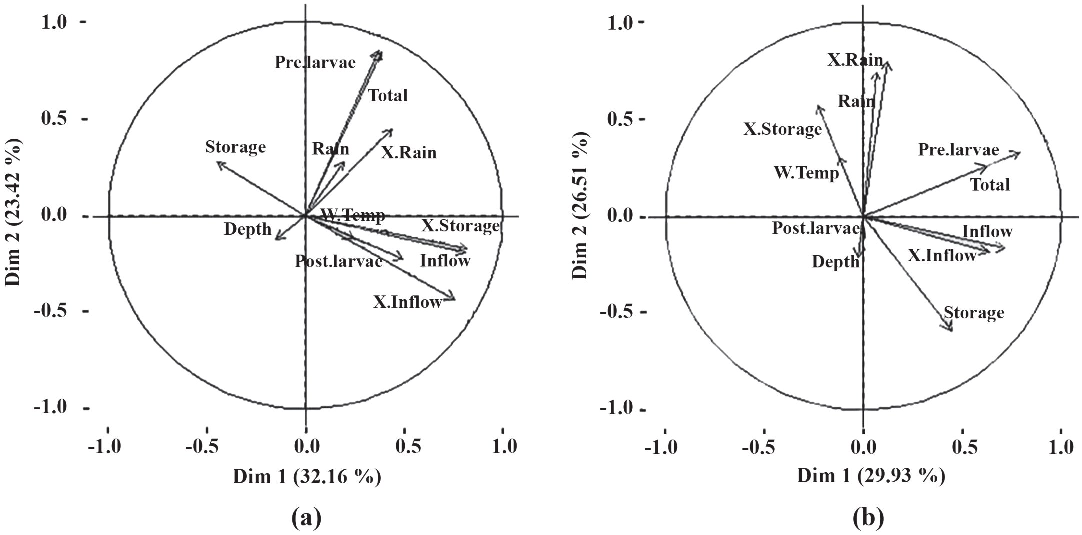

Figure 5. PCA ordination of correlations between meteoro-hydrological factors and silver barb larval densities in two tributaries of the Ubolratana Reservoir from 2018 to 2019. Rain = rainfall; X.Rain = relative increase of rainfall; Inflow = water inflow; X.Inflow = relative increase of inflow; Storage = water storage; X.Storage = relative increase of storage; WTemp = water temperature; Depth = water depth; Pre-larvae = Pre.Larvae; Post-larvae = Post.Larvae; and Total = total larvae.

while the factors most correlated to PC2 were rainfall (λ = 0.74) and relative increase of rainfall (λ = 0.80); water storage was negatively correlated to larval density (λ = -0.60).

Eigenvalues (λ) of the Principal Component Analysis (PCA) indicated that the densities of pre-larvae (age<3 days) of the Phong River channel were correlated with rainfall (λ = 0.19) and relative increase in rainfall (λ = 0.51), while the post-larvae (age>3 days) density was correlated with inflow (λ = 0.81) and relative increase in inflow (λ = 0.76). Additionally, the PCA analysis indicated that the riverine zone of both channels had particularly strong correlations during the early rainy season.

DISCUSSION

The relative increase of rainfall from March to April in both 2018 and 2019 implied high inflow during May (Table 1 and Figure 2a and 2b). The month of May, thus, could be the first inflow stimulation of fish spawning in the riverine ecosystem of the Ubolratana Reservoir. The rainfall is initiated by the southwest monsoon, which usually blows moisture-laden air from the Andaman Coast, where there is a significant difference between land and sea temperatures. During the southwest monsoon, hot air rises and creates low pressure, causing winds blowing towards the northeastern part of the country (Jutagate *et al*., 2005; IPCC, 2014; Jutagate *et al*., 2016; Phomikong *et al*., 2018). The Ubolratana Reservoir, thus, receives higher amounts of rainfall during the southwest monsoon period, in particular from May to September.

Analysis of water inflows during the two-year research revealed notable increases of inflows during two periods of the year (Table 1 and Figure 2c and 2d). The first period is April to May (transition season between the dry and rainy seasons) (Jutagate *et al*., 2005). The second period is September (late rainy season). Nevertheless, the relative increases in inflows in May of 2019 were lower than those of 2018, due to the differences of rainfall between years. In other reservoirs, it was also found that increased water inflows were affected by the rainfall in the watershed, with a delay of roughly one month before reaching the reservoir (Ingthamjitr *et al*., 2009). The trend in water storage of Ubolratana Reservoir during the two years of the study showed a gradual decrease to critical status by the end of 2019 (Table 1 and Figure 2e and 2f), resulting from lower rainfall and loss of water inflows. Additionally, water outflow was another critical aspect, because outflows also determine storage volume during the year. The crisis of low water storage in this reservoir has been attributed to excessive water release (i.e., outflows) during 2018 for the prevention of flooding (following serious flooding in 2017) (Asawamanasak *et al*., 2019; EGAT, 2019).

The variation in silver barb larval densities reflects spawning efficiency of the parental fish in Ubolratana Reservoir. The densities of larvae, especially the pre-larvae, can help identify spawning sites. High densities of pre-larvae in the riverine zone of the Phong River channel in June of both 2018 and 2019 suggested that the peak of spawning of silver barb in the reservoir was in June, and that the spawning ground was along the Phong River channel. Differences observed in meteoro-hydrological events and river discharge may influence fish spawning. The results of PCA showed that increased rainfall was significantly correlated with pre-larval densities in the riverine zones of both river channels. The results indicate that rainfall was an essential stimulating factor for silver barb spawning, similar to the finding of Shkil *et al*. (2015). In addition, water inflows showed correlation with larval densities in riverine and transition zones of the Phong River (PC1; Table 1, Figure 5). According to Sokheng *et al*. (1999) and Azami *et al*. (2015), although rainfall affects fish spawning, high rainfall may not be the only factor that induces high larval fish densities. For example, the number of fish larvae should depend on the spawning stock biomass in each year (Lassen and Medley, 2001).

Increases of water inflow into the reservoir ecosystem require continuous rainfall for an extended period. Rainfall is also known to be an essential factor influencing fish species, particularly those exhibiting up-stream migration. Rainfall can affect cycling of soil organic matter and the texture of the soil. Rainfall can also influence runoff rate and erosion, which might add sediment and nutrients into a stream. In many fish species, the inflowing water mass, with comparatively lower temperature and higher dissolved oxygen than the receiving water body, can stimulate the gonadal development of parent stocks for spawning (Jutagate, 2009; Kernan *et al*., 2010; Esmaeili *et al*., 2017). A previous study by Wattanadilokkul and Nabandit (1987) on gonadosomatic index of *Cirrhinus jullieni*, a long-distance migratory Cyprinid in the Ubolratana Reservoir, also revealed that the early rainy season (June) is particularly important for that species in the reservoir ecosystem.

According to Sihapitukgiat *et al*. (2002) the monthly fish catch in the Ubolratana reservoir showed positive significant relationships to monthly rainfall ($r = 0.46$, $p<0.01$) and monthly inflow ($r = 0.32$, $p<0.01$). From the present results, the levels of rainfall during two months prior to each survey period increased water inflow into the reservoir. Thus, the water inflows increased during two periods of the year (Figures 2c and 2d). During the first period (between the dry and rainy seasons, March-May), the silver barb adults may have been stimulated to develop their gonads. Those parent stocks then spent two to three months (depending on meteoro-hydrological conditions) in development from an immature to mature phase. During the rainy season (June), the adults would be in a condition to migrate for spawning in the riverine zones (Sokheng *et al*., 1999; Baumgartner *et al*., 2008; MPI, 2015; Esmaeili *et al*., 2017).

The silver barb female possesses group-synchronous oocyte development (Jasmine and Begum, 2016). The lower rainfall and inflow can, thus, cause late development and spawning (Moss, 1988; Termvidchakorn and Hortle, 2013). In this study, two stages of silver barb larvae were found in the riverine and transition zones of the reservoir ecosystem at different periods. Thus, reproductive conditions including timing and scale of migration (or even the formation of barriers to migration) could be impacted by climate-induced changes to the reservoir ecosystem. Such changes would have consequences for reproduction, growth, and yield of fishes (Harrod, 2016).

CONCLUSION

The study indicates that silver barb larval densities in the Ubolratana Reservoir are related to typical metero-hydrological factors and ecological zonation. Increase in water inflows correlated strongly to the density of newly hatched larva and, thus, likely stimulates or regulates reproductive strategies of the silver barb and similar up-stream migrating cyprinids. Based on this study, the Phong riverine zone, with the highest pre-larvae density during the early rainy period, is considered to be the most important silver barb spawning grounds of the reservoir ecosystem.

Overall, the research implies that inflows should be enhanced appropriately for conservative management of reservoir fishery resources. Additionally, alternative approaches for fishery resource sustainability should include the assessment of a defined conservation period and protected area for parental stock development and spawning. In this aspect, the upstream riverine zone should be set as a protected area during periods of apparent increasing inflows. Ecological models relating to the impacts of inflows, together with other related water and habitat parameters, should also be developed and evaluated further with fish stock information.

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