Changes in the Asian Clam Population in a Tropical Mesotrophic Reservoir during Severe Drought

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ABSTRACT

This study examined changes in the Asian clam (*Corbicula* spp.) population of a productive mesotrophic reservoir during severe drought. Two important clam habitats of the Ubolratana reservoir in northeastern Thailand were surveyed: Tha Lat and Nong Muad Ae. Sampling was performed five times during periods of low storage volume (22-25 % of maximum capacity) in April, June, July, August, and November 2019. Both clam areas had low population densities, and density tended to decrease over the study period. The adult *Corbicula* clams ranged in size from 16 to 25 mm (shell length). Total clam density had negative relationships ($p<0.05$) with water temperature and sedimentary organic content. The clam habitat of Nong Muad Ae tended to be more suitable than Tha Lat because it had a sandy sediment with comparatively lower water content (17.79-33.03 %) and organic matter content (1.60-5.09 %). During all of the sampling periods, the level of sedimentary sulfides remained at a safe level for benthic organisms. However, the inflows during 2019 were also dramatically decreased compared to 2018, and are expected to restrict population development. No new-born *Corbicula* clams were found except in the last sampling in November 2019. The density of small (0-10 mm) clams had positive relationships ($p<0.05$) with the prior five months' rainfall, inflow, relative change of inflow, and relative change of water storage. The overall view of this study implies that the *Corbicula* population in this reservoir may reach a deteriorated status during periods of ongoing drought. Future management approaches should therefore be conservative and carefully considered.

Keywords: Asian clam (*Corbicula* spp.), Drought condition, Hydro-ecological factor, Mesotrophic reservoir, Sediment quality, Water quality

INTRODUCTION

Fishery resources in reservoirs are an important source of protein-rich food for local communities in many tropical countries (Amarasinghe *et al*., 1999; Guo *et al*., 2011). However, the resources are negatively affected by a decrease of water storage and an increase of water temperature, both which potentially affect the survival and reproductive strategies of aquatic animals (Straskraba *et al*., 1990; Tundisi and Matsumura-Tundisi, 2012). Shellfish populations living along the littoral or coastal areas of reservoirs may be particularly impacted (Mackie, 2007; Thanasomwang, 2013). Changes in dissolved oxygen in particular areas were revealed to impact the abundance and diversity of common clam populations (Tantipanatip, 2018). In-depth studies are, thus, essential for future sustainable utilization of the fishery.

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The Ubolratana reservoir is the second largest reservoir in Thailand, with a maximum surface area of 410 km^2 and a storage volume of 4,640 million cubic meters (Electricity Generation Authority of Thailand, 2019). It is a relatively shallow (average depth of 5.6 m), but highly productive mesotrophic to eutrophic reservoir (chlorophyll *a* maximum of 22.70 $\mu g \cdot L^{-1}$ during 2017-2018) (Meksumpun *et al*., 2019; Mengchouy *et al*., 2019). Fishery production from Ubolratana reservoir is among the most important in northeastern Thailand, based on yield per area (Chookajorn *et al*., 1994; Thanasomwang, 2013). The maximum fish harvest from this reservoir was 2,122 tons during the first 10 years of water storage (Meksumpun *et al*., 2019). Unfortunately, the reservoir ecosystem has faced severe drought conditions since 2018. Very low precipitation and inflows have caused the water storage volume to be drastically decreased, compared to levels in the previous decade (Thai Meteorological Department, 2019). Such climate changes and drought conditions have been shown to have an impact on water quality and living resources of the reservoir ecosystem (Asawamanasak *et al*., 2019; Mengchouy *et al*., 2019). During 2018-2019, the water storage volume in Ubolratana reservoir gradually decreased to a level lower than its minimum storage criteria and had the lowest recorded volume of *ca* 18 % (Electricity Generation Authority of Thailand, 2019) in November 2019. Therefore, several fishery resources in Ubolratana reservoir have been affected and need to be conservatively managed for further sustainable utilization (Meksumpun *et al*., 2019). In the Ubolratana reservoir, the Asian clam (*Corbicula fluminea*) is the most economically important shellfish. The clam can be found in littoral zones all year round and, thus, is an important protein source used by local and nearby communities (Tantipanatip, 2018). In recent years, drought conditions have persisted. The inflow volume during the late rainy season (October–December 2019) was about 340 times lower than during the previous five years (Electricity Generation Authority of Thailand, 2019). Such a change could substantially impact water conditions and negatively impact the Asian clam population in some areas. Nevertheless, no study on such an impact has been carried out yet.

The Asian clam is a common freshwater clam originally distributed in Asian waters (McMahon, 1983). Electrophoretic analyses on 21 nominal species in Asia indicated that all species were actually a single species, namely *Corbicula fluminea* (Kijviriya *et al*., 1991). *C. fluminea* has an ability to disperse widely since the young juveniles can be transported by inflows or tidal currents, and can be distributed by the feathers or feet of birds (McMahon, 2000; 2002). These modes of distribution may play an important role in clam populations (Figuerola and Green, 2002; Green and Figuerola, 2005). *C. fluminea* can live in both lentic and lotic habitats (Sousa *et al*., 2008a), although McMahon (1983) noted that their populations in lentic habitats were restricted to near-shore, shallow waters with well-oxygenated sediments. According to McMahon (2002), *C. fluminea* had very high production efficiencies with short turnover periods of 73-91 days. Nevertheless, when compared to other freshwater bivalves, *C. fluminea* appears to be less tolerant of increased temperature, low pH, and low dissolved oxygen (Byrne and McMahon, 1994; Johnson and McMahon, 1998; McMahon, 2000; McMahon and Bogan, 2001; Sousa *et al*., 2007; 2008b). This species was reported to prefer low water temperatures and sandy deposits mixed with silt or clay. The integration of several factors (e.g., low flows, decreasing dissolved oxygen, increasing temperature, high amounts of organic matter) may induce massive mortalities of *C. fluminea*, particularly in summer (Strayer, 1999; Cherry *et al*., 2005; Cooper *et al*., 2005; Sousa *et al*., 2007; 2008b). In this study, therefore, temporal changes in Asian clam abundance throughout the drought years were analyzed along with related water and sediment qualities. Changes in clam size composition during the study periods were also examined. The present paper provides information concerning population response to the inflow conditions and related water and sediment characteristics of the clam habitats. Future conservation approaches for the Asian clam stock are also discussed.

MATERIALS AND METHODS

Study area

The study areas were chosen along the two coastal sites of Tha Lat (TL) and Nong Muad Ae (NMA) districts, both important Asian clam capture sites within the Ubolratana reservoir, Khon Kaen Province, Thailand (Figure 1).

Sampling of Asian clams

Sampling was carried out five times in 2019: in April, June, July, August and November. During these months, the water storage volume of the reservoir was very low: 25 %, 25 %, 24 %, 22 % and 23 % of capacity, respectively. On each sampling occasion, two areas within each site, including a shallow habitat (S; 20 cm water depth) and a deep habitat (D; 70 cm water depth) were investigated. Asian clam (*Corbicula* spp.) samples in these habitats were collected by sieving the surface sediment (0-5 cm deep) within 50×50 cm quadrats. All specimens were preserved in 10% formalin solution in the field and taxonomic identification was performed according to Brandt (1974). Both live and dead *Corbicula* clams were counted, and measurements of shell length were made at the laboratory.

Collection of hydrological and meteorological parameters

Meteorological data were obtained from the Meteorological Department's Khon Kaen Air Monitoring Station (Thai Meteorological Department, 2019). In addition, related hydrological data were collected: rainfall was from the Loei Air Monitoring Station, while water storage volume and inflow information were from the Electricity Generating Authority of Thailand (2019).

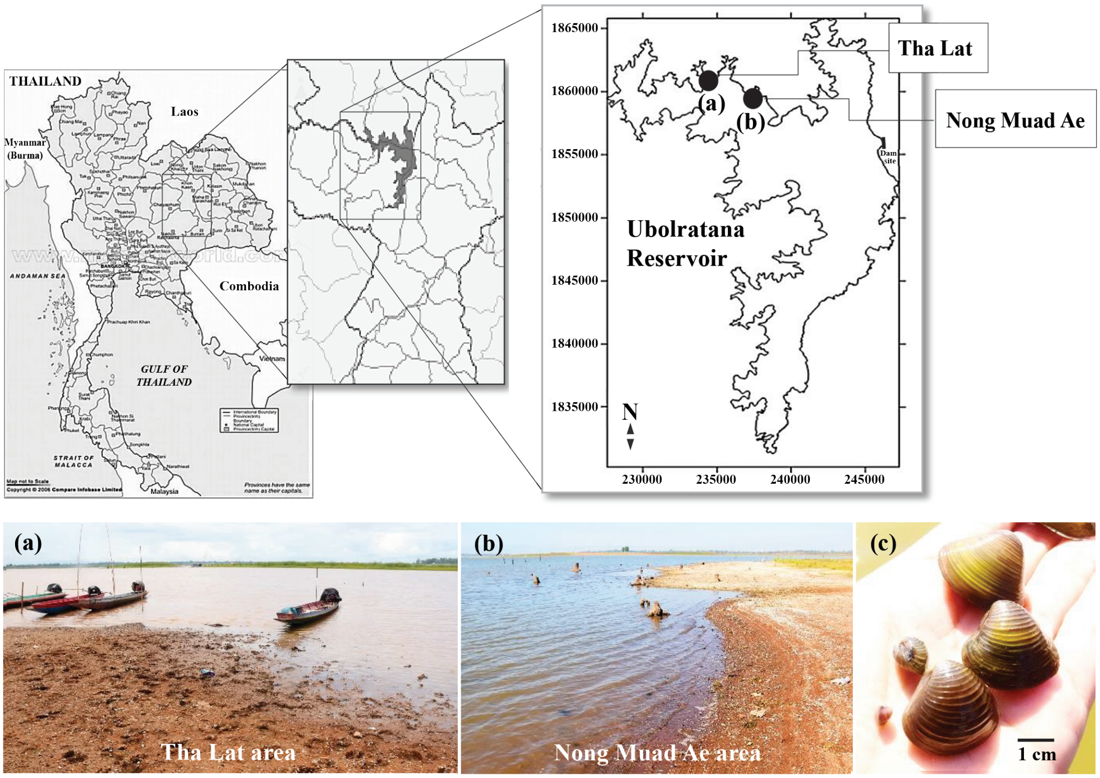

Figure 1. Two surveyed sites (Nong Muad Ae, a; and Tha Lat, b) for the study of changes in Asian clam (*Corbicula* spp., c) populations during drought conditions in the Ubolratana reservoir during April–November, 2019.

Study of water and sediment quality

At each sampling location (in both shallow and deep habitats), water temperature, dissolved oxygen, and pH were measured at 10 cm above the sediment surface using multiparameter YSI probe (Model 600QS). Total suspended solids (TSS) of the water column were also analyzed. Water samples for TSS were passed through GF/C glass–fiber filter, and dried using freeze–drying technique for measurement of the dry weight per volume of filtered water.

Sediment samples were collected in each habitat by using hand corers with a diameter of 5 cm. The uppermost layer of 1 cm was selected for analysis. The obtained sediment layer was stored in a small zip-locked plastic bag and preserved immediately in a freezer for later analysis.

Laboratory analysis of sedimentary water content (WC, %) was performed by measurement of water weight loss after drying the sediment samples in a 105 °C hot air oven for three days. The total organic matter (TOM, %) of the sediment was analyzed by ignition loss method (using furnace heater; 550-600 °C for 3 h). Acid volatile sulfides (AVS; $mg \cdot g\ dw^{-1}$) of the sediment samples were examined by H_2S absorbent columns (Gastec Model 201L).

Data analysis

Descriptive statistics (means and standard deviations) were calculated to depict the changes over sampling periods. Differences in parameters among sampling periods and locations were evaluated by paired sample T-test ($p<0.05$). Correlations between densities of *Corbicula* clams (for all individuals and for 0-10 mm clams) and various water and sediment parameters were analyzed using Spearman's rank correlation coefficient ($p<0.05$). In addition, correlations between density of small (0-10 mm) *Corbicula* clams and meteorological and hydrological factors during the prior five months and their relative changes during the prior 4-5 months during 2018-2019 were analyzed using Spearman's rank correlation coefficient ($p<0.05$).

RESULTS AND DISCUSSION

Changes in meteorological and hydrological parameters

In 2019, the ranges of air temperature during the dry season (January–April), early rainy season (May–July), and mid rainy season (August–September) were 25.2-31.6, 29.4-30.3, and 27.8-28.2 °C, respectively. Air temperature during late rainy season (October) was 28.4 °C. The lowest temperature (25.2 °C) was found in January 2019, while highest air temperature (31.6 °C) occurred in April 2019 (Thai Meteorological Department, 2019). The ranges of air temperature were significantly higher than during the previous 10 years, which had the average ranges of 23.5-29.9, 28.0-29.4, 27.5-27.7, and 24.1-27.0 °C, respectively. In the present study, comparatively higher air temperature of the reservoir ecosystem was apparent. Such increases could be responsible for changes in clam behavior and related deterioration of natural clam resources (Nahok *et al.*, 2017).

Monthly values for rainfall, inflow, and water storage of the Ubolratana reservoir during the year 2019 are shown in Table 1, along with figures from 2018. During the rainy season of 2019, the rainfall was found to notably increase in May. Accordingly, an increase in inflow into the reservoir was observed in June. Thereafter, inflows fluctuated slightly and tended to decrease from the late rainy season until the end of the year. There were significant differences between the inflows of 2019 and the monthly averages from 2014-2018 ($p = 0.024$). During the late rainy season of 2019, water storage volume gradually decreased to levels lower than the prescribed "minimum storage volume" of the reservoir (Electricity Generation Authority of Thailand, 2019). This status implies the occurrence of drought conditions in the reservoir ecosystem during the entire study period. In 2019, the decreases of rainfall and inflow resulted in decreases of water storage volume for this reservoir, which declined to its lowest level of the past decade (Thai Meteorological Department, 2019).

Table 1. Monthly means of rainfall (mm), inflow (million tonne), and water storage (million tonne) of the Ubolratana reservoir during 2018-2019 (source: Electricity Generation Authority of Thailand, 2019).

Factors	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall													
	2018	1.0	5.4	28	206.2	172.1	215.7	213.3	66.8	299.7	77.6	14.8	4.2
	2019	ND	13.9	44.9	57.6	216.4	63.9	110.5	212.4	308.4	10.0	1.0	0.0
Inflow													
	2018	9.96	5.81	8.76	21.00	122.32	96.58	46.78	10.86	28.22	33.90	11.89	4.94
	2019	4.75	3.33	2.74	1.26	18.18	216.87	4.50	24.75	56.01	0.57	0.35	0.00
Water storage	2018	1982	1635	1393	1130	991	954	756	718	929	843	837	800
	2019	756	707	655	606	576	603	576	539	635	619	565	514

Note: ND = No Data

Changes in water quality

In this study, water quality parameters were investigated to assess suitability for *Corbicula* clams. Water temperatures in the shallow habitat of the Tha Lat sampling area were in the range of 28.2-34.7 °C. In June 2019, the water temperature decreased ($p>0.05$) to 30.8 °C from the maximum in April 2019, a difference of about 4 °C (Table 2). The deep habitat had slightly lower water temperatures, in the range of 26.2-31.4 °C. Both habitats showed a decreasing trend of water temperatures from April to November 2019.

In Nong Muad Ae, water temperatures in the shallow habitat were in the range of 27.3-37.0 °C (Table 2). The highest temperature was in April 2019. Thereafter, the water temperature decreased by about 6 °C to June 2019 (31.3 °C), during the early rainy season. The deep habitat had a similar range of water temperatures (26.6-36.8 °C), and a notable decrease of water temperature was also found in June. The water temperature had a similar downward trend to Tha Lat from June until the end of the year. The decrease of water temperature, in particular during June 2019, could stimulate the reproduction of *Corbicula* clams (Mouthon, 2001; Sousa *et al*., 2008a; Mouthon and Parghentanian, 2004).

Table 2. Mean water quality parameters (Temperature, °C; Dissolved oxygen, mg•L^{-1}; pH and TSS, mg•L^{-1}) of shallow (S) and deep (D habitats of Tha Lat and Nong Muad Ae sampling locations in Ubolratana reservoir during April–November, 2019.

Locations	Water quality paremeters	April		June		July		August		November	
		S	D	S	D	S	D	S	D	S	D
Tha Lat	Temperature (°C)	34.7	31.3	30.8	31.4	29.7	28.8	30.3	29.3	28.2	26.2
	Dissolved oxygen (mg•L^{-1})	7.3	6.4	5.7	4.8	6.1	6.0	7.4	7.1	7.0	5.9
	pH	8.5	7.3	7.8	7.2	8.0	7.8	8.0	8.0	6.8	7.1
	TSS (mg•L^{-1})	115	61	167	118	251	329	242	229	152	65
Nong Muad Ae	Temperature (°C)	37.0	36.8	31.3	31.0	29.2	29.1	28.7	27.8	27.3	26.6
	Dissolved oxygen (mg•L^{-1})	8.4	7.6	6.7	4.8	6.2	6.0	7.5	8.2	7.0	6.9
	pH	9.1	9.0	7.6	7.3	7.9	7.9	7.7	7.7	7.5	7.5
	TSS (mg•L^{-1})	36	33	48	77	59	70	42	44	33	84

Dissolved oxygen (DO) levels in both locations were adequate for survival of *Corbicula* clams (Table 2). In Tha Lat, the shallow habitat had DO in the range of 5.7-7.4 mg·L^{-1}, while the deep habitat had DO in the range of 4.8-7.1 mg·L^{-1}. In Nong Muad Ae, DO ranges were 6.2-8.4 mg·L^{-1} and 4.8-8.2 mg·L^{-1}, respectively. In both study areas, the levels of DO were generally high, with the maximum of 8.4 mg·L^{-1} recorded during dry season (April 2019). Such conditions were considered to be due to an increasing abundance of phytoplankton in the reservoir ecosystem. In addition, the minimum DO levels (about 4 mg·L^{-1}) were considered to be sufficient for the survival of the *Corbicula* clam (Strayer, 1999; Mackie, 2007; Kanlapapuk *et al*., 2016). This species has been reported to live in waters with DO of about 4-10 mg·L^{-1} (Mouthon, 2001; Sousa *et al*., 2008b; Nahok *et al*., 2017).

The water in both areas had moderate to slightly high pH levels (Table 2). In Tha Lat, shallow and deep habitats had pH in the ranges of 6.8-8.5 and 7.1-8.0, respectively. In Nong Muad Ae, pH was in the ranges of 7.5-9.1 and 7.3-9.0, respectively. The maximum pH of 9.1 was found in the location also with the highest DO (April 2019). Increases in both parameters are considered to be enhanced by photosynthetic activity of phytoplankton. Nevertheless, the increased pH levels should have no particular impact to *Corbicula* clams because they have been reported to survive well in a pH range of 7-10 (Byrne and McMahon, 1994; Johnson and McMahon, 1998; McMahon, 2000; McMahon and Bogan, 2001; Sousa *et al*., 2007; 2008b).

The study of total suspended solids (TSS) in the water column of the sampling areas implied the influence of inflow mass during the rainy periods. The results indicated that the two areas had different TSS profiles. In general, Tha Lat had higher TSS than Nong Muad Ae (Table 2). In Tha Lat, shallow and deep habitats had TSS in the ranges of 115-242 and 61-329 mg·L^{-1}, respectively. In Nong Muad Ae, TSS values were lower, in the ranges of 33-59 and 33-84 mg·L^{-1}, respectively. TSS levels were quite high during the mid-rainy season (July to August 2019), and coincided with increasing inflows into the reservoir ecosystem (Electricity Generation Authority of Thailand, 2019). The variations of TSS found in different sampling periods may also be due to local winds. Since *Corbicula* clams are filter feeders, the increase of TSS could stimulate their growth (Nahok *et al*., 2017).

Changes in sediment quality parameters

Sediment quality parameters were investigated to assess benthic conditions for survival of *Corbicula* clams, and are depicted in Figure 2. The water content (WC) of the sediments were higher in Tha Lat than in Nong Muad Ae (Figure 2a). In Tha Lat, sediments in shallow and deep habitats had WC in the ranges of 30.37-56.21 % and 46.10-68.77 %, respectively. In Nong Muad Ae, sediments had lower WC, in the ranges of 17.78-19.81 % and 17.94-33.07 %, respectively.

The levels of sedimentary total organic matter (TOM) were found in a similar pattern to WC (Figure 2b). Nong Muad Ae had lower TOM than Tha Lat. The TOM of Nong Muad Ae and Tha Lat sediments were in the ranges of 1.60-5.09 % and 3.58-9.40 %, respectively. Slight increases in WC and TOM along the surveyed times, particularly in Tha Lat, were due to changes of sampled habitats from sandy to muddy substrates because of the decreases of water levels.

Sousa *et al*. (2008a), Marchant and Barmuta (1994) and Hakenkamp and Palmer (1999) found that population density of benthic clams is related to characteristics of the substrate, such as sand, mud, and organic content. Hakenkamp and Palmer (1999), Hakenkamp *et al*. (2001), Vaughn and Hakenkamp (2001), and Nahok *et al*. (2017) also reported that suitable benthic conditions for *Corbicula* clam growth include gravel and sandy substrates. In this study, lower levels of WC and TOM in the Nong Muad Ae site could, thus, provide better conditions for clam growth. Comparatively lower WC and TOM reflected the sandy habitat at this location. Such an area should have better water circulation that would benefit the growth of the clams.

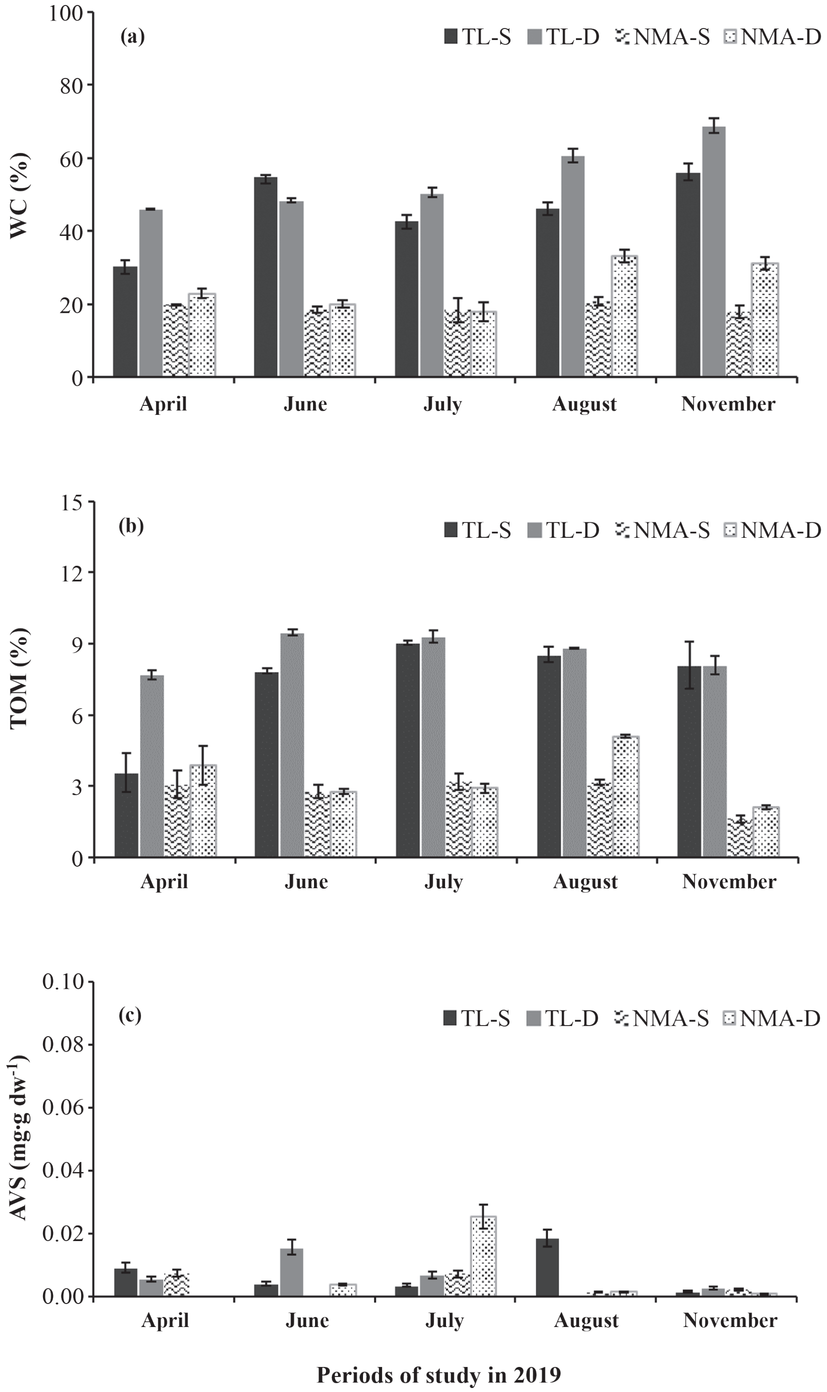

Figure 2. Sediment quality parameters of Tha Lat (TL) and Nong Muad Ae (NMA) sampling sites in shallow (S) and deep (D) habitats during April–November, 2019: (a) water content (WC, %), (b) total organic matters (TOM, %), and (c) acid volatile sulfides (AVS, mg•g dw^{-1}).

The levels of acid volatile sulfides (AVS) of bottom sediments were examined to assess the possibility of harmful impact to the *Corbicula* clam population in the reservoir. Results are depicted in Figure 2c. During the sampling periods of 2019, most sediment samples obtained from both locations indicated low levels of AVS (< 0.025 mg·g dw^{-1}). Shallow and deep habitats of Tha Lat had AVS in the ranges of 0.002-0.019 and 0.000-0.016 mg·g dw^{-1}, respectively. The AVS levels of Nong Muad Ae were in the ranges of 0.000-0.007 and 0.000-0.025 mg·g dw^{-1}, respectively. There should be no negative impacts on living benthic filter feeders, including the *Corbicula* clams in the study area from this amount of AVS (Ritnim and Meksumpun, 2012).

Changes in composition and density of the Corbicula population

Density and composition of *Corbicula* clams sampled during the surveyed periods are illustrated in Figure 3. The densities of living *Corbicula* clams in both study sites were very low when compared to the study of Nahok *et al*. (2017), who studied the same species in the Choen River basin, located in the southern part of the Ubolratana reservoir, and reported densities of 6-243 inds·m^{-2}. The Tha Lat clam population had individuals in the range of 11-25 mm (Figure 3a), which were categorized as adult stage (Sousa *et al*., 2008a).

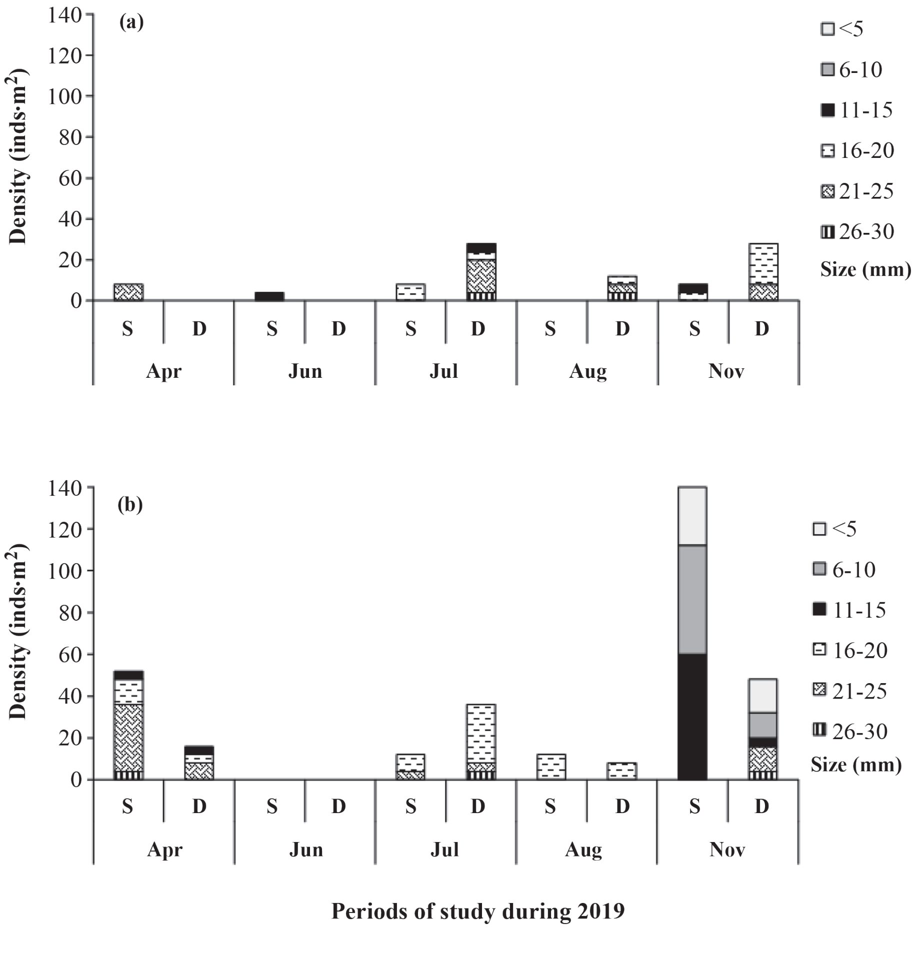

Figure 3. Size composition and mean density of *Corbicula* clams in Tha Lat (a) and Nong Muad Ae sampling areas (b) in shallow (S) and deep (D) habitats during April–November, 2019.

During April, June, July, and November 2019, clams in the shallow habitat of Tha Lat had the size ranges of 21-25, 11-15, 16-20, and 11-20 mm, with the densities of 8, 4, 8, and 8 inds·m^{-2}, respectively. There were no *Corbicula* clams found in the shallow habitat in August. In the deep habitat, *Corbicula* clams were found only during July (11-30 mm size), August (16-30 mm size), and November (16-25 mm size) with the densities of 28, 12, and 28 inds·m^{-2}, respectively. No juvenile clams (<10 mm size) were found in Tha Lat in any of the sampling periods.

In Nong Muad Ae (Figure 3b), there was a comparatively higher density of *Corbicula* clams. During April and July–August, the majority of clams were in the size ranges of 21-25 mm and 16-20 mm, respectively. These sizes were also common in Tha Lat. The average population densities of shallow and deep habitats were comparatively higher (20 and 24 inds·m^{-2}, respectively) than in Tha Lat. In November 2019, the clam population in Nong Muad Ae increased, and the density reached its highest level of 140 inds·m^{-2} (in the shallow habitat). The higher densities in November 2019 were due to the increase of very young clams, with the sizes of <5 mm, 6-10 mm, and 11-15 mm.

Corbicula clams and related environmental factors

In this study, correlations between environmental factors and density of the *Corbicula* clams were analyzed (Table 3). The density of the young clams of 0-10 mm size had a negative relationship ($p<0.05$) with water temperature and sedimentary TOM. Thus, sediments with lower TOM (that is, less fine grain) and lower temperature are more suitable for the *Corbicula* clams. Accordingly, it is possible that decreases in density occurred at high TOM sites and during continuous drought conditions of the reservoir ecosystem.

Sousa *et al*. (2008a) reported that *Corbicula* clams with the sizes of 6-10 mm should be about 3-6 months old. Considering the size classes found in the Nong Muad Ae area in November 2019, the young clams should, thus, have already settled in the benthic habitat since June or July 2019. These settling periods coincided with the remarkable increase of inflow and related decreases of water temperature (in June 2019; Tables 1-2). In addition, water temperature tended to decline from June 2019 (Table 2). There were significant differences in water temperatures between the dry season and early rainy season ($p = 0.006$), the early rainy season and the mid-rainy season ($p = 0.026$), and the mid-rainy season and the end of rainy season ($p = 0.036$). Thus, the changes in water temperature are a likely factor affecting the reproductive strategy of *Corbicula* population. Previous studies of Mouthon (2001), Sousa *et al*. (2008a), and Mouthon and Parghentanian. (2004) revealed that changes of some factors, i.e., water temperature and availability of organic food could stimulate the reproduction and growth of *Corbicula* population.

Correlations of meteorological and hydrological factors and density of the small size (0-10 mm) *Corbicula* clams of Nong Muad Ae are shown in Table 4. November 2019 was considered as an appropriate time for *Corbicula* clam reproduction. The meteorological (rainfall) and hydrological (inflow and water storage) data of the prior five months and their relative changes during the prior 4-5 months were used in the analysis with density of small (0-10 mm) clams.

Table 3. Correlation coefficients between *Corbicula* clams (total and 0-10 mm density; inds•m^{-2}) and various environmental factors of the Ubolratana reservoir from April to November 2019.

Factors	Water temperature (°C)	DO (mg·L^{-1})	pH	TSS (mg·L^{-1})	WC (%)	TOM (%)	AVS (mg·g dw^{-1})
Density$_{(Total)}$	-0.232^{ns}	0.354^{ns}	0.265^{ns}	-0.349^{ns}	-0.287^{ns}	-0.312^{ns}	0.323^{ns}
Density$_{(0-10\ mm)}$	-0.683*	0.009^{ns}	-0.524^{ns}	-0.030^{ns}	-0.156^{ns}	-0.703*	-0.070^{ns}

Note: *ns* = no significant difference; * Significant difference ($p<0.05$) from 0

Table 4. Correlation coefficient between density of small (0-10 mm) *Corbicula* clams (inds·m^{-2}) and meteorological and hydrological factors from the prior five months ($_{p-5}$) and their relative changes during the prior 4-5 months ($_{Dif}$) during 2018-2019.

Factors	$Rainfall_{p-5}$ (mm)	$Rainfall_{Dif}$ (mm)	$Inflow_{p-5}$ (million tonne)	$Inflow_{Dif}$ (million tonne)	Water $storage_{p-5}$ (million tonne)	Water $storage_{Dif}$ (million tonne)
$Density_{(0-10\ mm)}$	0.767*	-0.849*	0.703*	0.703*	-0.703*	0.703*

Note: * Significant difference (p<0.05) from 0

Results indicated that the number of small (0-10 mm) *Corbicula* clams had positive relationships ($p<0.05$) with rainfall, inflow, relative changes of the inflow, and relative changes of water storage during the prior five months (Table 4). Thus, these meteorological and hydrological factors are important for this species. Accordingly, drought conditions (low rainfall and inflow) will potentially have negative effects on the clam's sustainability.

During 2019, densities of clams were very low throughout the year. The previous report of Nahok *et al*. (2017) indicated densities of 6-243 inds·m^{-2}, much higher than those found in this study. Such low densities were probably due to the restriction of water inflows into the reservoir during 2019 (Table 1). Normally, *Corbicula* clams have the potential to reproduce twice yearly (Darrigran, 2002; Mouthon and Parghentanian, 2004). The increased water inflow into the ecosystem has been shown to decrease water temperature and stimulate the reproduction of this genus. Mouthon (2001) suggested that *Corbicula* spp. can reproduce during the early rainy season. The population usually begins to settle into the sediment during mid rainy season (Hornbach, 1992). The amount of water inflow and related factors (water velocity and temperature) have been reported to be important influencing factors on reproduction and growth of the *Corbicula* clam (Strayer, 1999; Cooper *et al*., 2005; Nahok *et al*., 2017).

Overall, our results imply the importance of inflow pulse and related factors (i.e., water storage and water temperature) for the *Corbicula* population of the reservoir ecosystem. In the study year, the impacts of global warming, the decrease of rainfall and related severe drought conditions in the ecosystem (Jeppesen *et al*., 2009) were pronounced. In this study, the water storage level became lower than the "minimum storage level" determined for the reservoir's sustainability (Electricity Generation Authority of Thailand, 2019). Such conditions can further affect the living and fertility of *Corbicula* clams and other benthic organisms (Thanasomwang, 2013). According to the study of Nahok *et al*. (2017), low precipitation and low velocity of water inflows can cause a decline in the clam resources in the reservoir ecosystem. Mackie (2007) similarly reported that many reservoirs are affected by the increase in temperature and decrease in water storage levels that impact the survival of aquatic species. In the Ubolratana reservoir, severe drought conditions have been clearly evident since 2018 (Thai Meteorological Department, 2019). The results showing very low densities of the *Corbicula* population are therefore not unexpected.

CONCLUSION

Our study on changes in the *Corbicula* clam population of the Ubolratana reservoir considered meteorological and hydrological conditions, and related water and sediment parameters in 2019. During the study, the reservoir faced severe drought conditions with drastically low inflows and low storage volumes. Sampling revealed that both sites, Tha Lat and Nong Muad Ae, had comparatively low population densities (4-140 inds·m^{-2}) throughout the year. Out of five sampling periods, no new-born *Corbicula* clams were found, except in November. In that period, the settled young clams (with the median size of 6-10 mm) would have likely come from the spawning of parent stocks during June to July 2019. The density of young clams (0-10 mm) had a negative relationship ($p<0.05$) with water temperature and sedimentary organic matter. In addition, the density of young clams had positive relationships ($p<0.05$) with rainfall, inflow, relative change of inflow, and relative change of water storage during the prior five months. Thus, the increasing pulses of rainfall, inflow, and the decrease of water temperature during the early- to mid-rainy seasons of the year are considered to be the most important factors stimulating the reproduction of *Corbicula* clams in the reservoir ecosystem.

It can also be concluded that the *Corbicula* population in the Ubolratana reservoir were in a deteriorated status during ongoing drought conditions in 2019. It was rare to find any young clams in the population. Such a phenomenon suggests future problems for the sustainable utilization of *Corbicula* clam resources in the reservoir ecosystem. Thus, management approaches should be conservative and carefully considered. Development of protection areas for parent stock and/or extension of clam nursery areas in suitable reservoir habitats is needed.

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