Invertebrate Zoology, 2025, 22(3): 447–467

Species composition of Cladocera (Crustacea: Branchiopoda) in the water bodies of Sakaerat Biosphere Reserve, Northeast Thailand in relation to environmental factors

N. Plangklang[1,2], C. Boonyanusith[3], S. Waengsothorn[4], S. Athibai[1,2*]

[1] *Department of Biology, Faculty of Science, Khon Kaen University, Khon Kaen, Thailand 40002.*
[2] *Applied Taxonomic Research Center, Faculty of Science, Khon Kaen University, Khon Kaen, Thailand 40002.*
[3] *School of Biology, Faculty of Science and Technology, Nakhon Ratchasima Rajabhat University, Nakhon Ratchasima, Thailand 30000.*
[4] *Sakaerat Environmental Research Station, Thailand Institute of Scientific and Technological Research, Wang Nam Khieo District, Nakhon Ratchasima, Thailand 30370.*
** Corresponding author*
Nattaporn Plangklang: pk.nattaporn@kkumail.com ORCID https://orcid.org/0000-0002-5602-7259
Chaichat Boonyanusith: chaichat.b@nrru.ac.th ORCID https://orcid.org/0000-0003-1487-2160
Surachit Waengsothorn: surachit@tistr.or.th ORCID https://orcid.org/0000-0002-8847-7975
Sujeephon Athibai: sujiat@kku.ac.th https://orcid.org/ORCID 0000-0002-0900-1216

ABSTRACT: The Sakaerat Biosphere Reserve (SBR), located in Northeast Thailand, has a high biodiversity of invertebrates, but there is no records of the water fleas (Crustacea: Cladocera) in this area. We investigated the cladoceran fauna, as well as the relationship between physicochemical variables of water and the cladoceran abundances in this reserve. Thirty-three species of the cladocerans were recorded. The greatest species richness was detected in a reservoir with 29 species (accounting for 87.9% of the total number of species), while the lowest number of species was noted from a pond, with four species. PCA result indicated that the variations in physicochemical parameters of water were associated with different seasons. Moreover, the CCA results showed that orthophosphate, dissolved oxygen, electrical conductivity, total dissolved solid and ammonia seem to be environmental factors influencing cladoceran composition in SBR water bodies. Information on the characters, distribution, and ecology of four rare cladoceran species is also provided.
How to cite this article: Plangklang N., Boonyanusith C., Waengsothorn S., Athibai S. 2025. Species composition of Cladocera (Crustacea: Branchiopoda) in the water bodies of Sakaerat Biosphere Reserve, Northeast Thailand in relation to environmental factors // Invert. Zool. Vol.22. No.3. P.447–467. doi: 10.15298/invertzool.22.3.06

KEY WORDS: conservation area, diversity, seasonal variation, zooplankton

Видовой состав Cladocera (Crustacea: Branchiopoda) водоемов Биосферного заповедника Сакаэрат (северо-восток Таиланда) и его зависимость от условий окружающей среды

Н. Плангкланг[1,2], С. Бунианусит[3], С. Венгсозорн[4], С. Атибай[1,2*]

[1] *Department of Biology, Faculty of Science, Khon Kaen University, Khon Kaen, Thailand 40002.*
[2] *Applied Taxonomic Research Center, Faculty of Science, Khon Kaen University, Khon Kaen, Thailand 40002.*

[3] *School of Biology, Faculty of Science and Technology, Nakhon Ratchasima Rajabhat University, Nakhon Ratchasima, Thailand 30000.*
[4] *Sakaerat Environmental Research Station, Thailand Institute of Scientific and Technological Research, Wang Nam Khieo District, Nakhon Ratchasima, Thailand 30370.*
* *Ответственный за переписку: sujiat@kku.ac.th*

РЕЗЮМЕ: Биосферный заповедник Сакаэрат (СБЗ), расположенный в северо-востчном Таиланде, отличается высоким разнообразием беспозвоночных, однако по этому району нет никаких данных о ветвистоусых ракообразных (Crustacea: Cladocera). Мы исследовали фауну кладоцер, а также связь между физико-химическими параметрами воды и численностью видов в этом заповеднике. Всего было найдено 33 вида Cladocera. Наибольшее видовое богатство было обнаружено в водохранилище — 29 видов (87,9% от общего числа видов), в то время как наименьшее число видов было отмечено в пруду — всего четыре вида. Результаты канонического корреляционного анализа показали, что вариации физико-химических параметров воды связаны с разными сезонами. Результаты анализа главных компонент показали, что содержание ортофосфатов, растворенного кислорода, электропроводность, общее количество растворенного твердого вещества и содержание ионов аммония являются факторами среды, влияющими на состав кладоцер в водоемах СБЗ. Представлена информация о морфологических признаках, распространении и экологии четырех редких видов ветвистоусых ракообразных.

Как цитировать эту статью: Plangklang N., Boonyanusith C., Waengsothorn S., Athibai S. 2025. Species composition of Cladocera (Crustacea: Branchiopoda) in the water bodies of Sakaerat Biosphere Reserve, Northeast Thailand in relation to environmental factors // Invert. Zool. Vol.22. No.3. P.447–467. doi: 10.15298/invertzool.22.3.06

КЛЮЧЕВЫЕ СЛОВА: природоохранная зона, разнообразие, сезонная изменчивость, зоопланктон.

Introduction

Biosphere reserves are sites for testing interdisciplinary approaches for understanding interactions between social and ecological systems (UNESCO, 2021). There are five biosphere reserves in Thailand: Sakaerat Biosphere Reserve, Hauy Tak Teak Biosphere Reserve, Mae Sa-Kog Ma Biosphere Reserve, Ranong Biosphere Reserve, and Doi Chiang Dao Biosphere Reserve (UNESCO, 2021).

The Sakaerat Biosphere Reserve (SBR) is a conservation area that plays an important role in promoting long-term ecological research for the protection of biodiversity, sustainable resource use, and ecosystem conservation (Sutthivanich, Ongsomwang, 2015). The area of SBR is known as a biodiversity hotspot in Thailand. At present, 533 invertebrate species are known from this area. New species and new records are still being discovered (UNESCO, 2021). The SBR contains various types of water bodies, e.g., intermittent streams, reservoirs, and ponds (Plangklang *et al.*, 2019). A new species of cyclopoid copepods, *Metacyclops sakaeratensis* Athibai, Wongkamhaeng et Boonyanusith, 2022 was found there, and a freshwater sponge, *Umborotula bogorensis* (Weber, 1890), was also discovered recently (Ruengsawang *et al.*, 2017; Athibai *et al.*, 2022). These findings confirmed the opinion that the SBR is a biodiversity hotspot in Thailand.

Water fleas (Class Branchiopoda: Superorder Cladocera) in general, are speciose in freshwater ecosystems, they have a high diversity, frequency, and biomass. They comprise more than 800 species worldwide (Kotov *et al.*, 2013a). In continental inland waters, they are found in the pelagic, littoral, and benthic areas of different types of freshwater habitats (e.g. lakes, ponds, rivers, and swamps) (Dodson *et al.*, 2009). The diversity, distribution, and taxonomy of cladocerans in Thailand has been intensively investigated, throughout surface waterbodies, since 1998 (Sanoamuang, 1998). To date, 125 species of cladocerans have been found in this country (Tiang-nga *et al.*, 2020; Sinev *et al.*, 2023).

Although the SBR is known to be rich in biodiversity, there is still a dearth of information on the cladoceran diversity. The previous study of Sinev, Korovchinsky (2013) pointed out that investigations in protected areas have importance for the comprehensive evaluation of microcrustacean richness.

Thus, the objectives of this research were: (i) to make an inventory of the cladoceran fauna in the SBR, and (ii) to explore seasonal variations in the species richness and abundance of the cladoceran taxa, as well as (iii) to assess the relationship between physicochemical variables of water and abundance of the cladoceran species.

Material and methods

STUDY AREA. The Sakaerat Biosphere Reserve (SBR) is situated on the southwest edge of the Korat Plateau (c.a 14°31′N, 101°55′E) in Wang Nam Khieo and Pak Thong Chai Districts, Nakhon Ratchasima Province, northeastern part of Thailand (Petersen *et al.*, 2019). The total area of the SBR is 1632.48 km^2, with altitude ranging from 250 to 762 m above sea level. The SBR comprises three types of management zones: core, buffer, and transition. The core area contains protected forest, while a buffer zone is an area of reforestation and plantations. Transitional areas are mainly composed of agricultural land (Ongsomwang, Sutthivanich, 2013).

CLADOCERAN SAMPLING AND IDENTIFICATION. Cladocerans were collected from these eight sites at three sampling locations per site in three different seasons (rainy, winter and summer) between September 2013 and May 2014 (Fig. 1). The S1 and S8 water bodies are located in dry evergreen forest, while the S2 and S6 are situated in dry dipterocarp forest. The S3, S4, and S7 water bodies are located in areas of plantation, but S5 is in grassland. The details of sampling sites are shown in Table 1.

For four sites (S1, S3, S4 and S7), cladocerans were collected in all three seasons (rainy, winter and summer). For the other four sites, cladocerans could only be collected in specific seasons because the water bodies were dried during other seasons (S2: winter, S5: rainy and winter, S6: summer, S8: winter and summer). Thus, we collected 108 samples: 54 qualitative ones and 54 quantitative ones. The qualitative samples were collected using a 60 μm mesh plankton net. For quantitative sampling, 20 L of water samples were taken using a Schindler-Patalas plankton trap, and then filtered through a 22 μm mesh plankton net. The specimens were then immediately preserved with a 4% formaldehyde solution. We sorted out the cladocerans specimens, identified them to the species level, and counted using an Olympus CH30 compound light microscope. The identification keys of Goulden, 1968; Korovchinsky, 1992; Smirnov, 1992; Lieder, 1996; Smirnov, 1996; Orlova-Bienkowskaja, 2001; Kotov, Štifter, 2006 and particular research papers e.g., Sinev, 2016 were used.

ENVIRONMENTAL FACTORS MEASUREMENT. Eight physicochemical parameters were measured from the eight sites at three sampling points per site before collecting cladocerans: water temperature (°C), pH, electrical conductivity (EC, μS/cm), and total dissolved solids (TDS, mg/L) were detected with a multi–parameter, Hanna HI98129; dissolved oxygen (DO, mg/L) was determined by using a DO meter, "Oxy-Check" Hanna HI9147. Orthophosphate (PO_4^{3-}, mg/L), nitrate (NO_3^-, mg/L), and ammonia (NH_3, mg/L) were determined by the colorimetric methods with a spectrophotometer, Hach DR/2400 following the ascorbic acid method, cadmium reduction method and salicylate method, respectively.

DATA ANALYSIS. The Shannon-Wiener diversity index (H′) (Shannon, Weaver 1949) and Pielou's evenness index (J) (Krebs, 1999) were applied to estimate species diversity, and species-abundance distributions of cladocerans in each habitat. The Sørensen-Dice index (Cs) (Magurran, 2004) was applied to express the similarity in the species occurrence of cladocerans between two sampling localities. The dominant species of zooplankton were determined based on the dominance index of each species ($Y \geq 0.02$) (Gao *et al.,* 2008). The Shapiro–Wilk normality test was applied to evaluate normal distribution in data of species richness, abundance of cladocerans, and water quality variables. Data were transformed root squared to achieve normal distribution (Zar, 1999). The differences in number of species and abundance of cladocerans, as well as the physicochemical parameters of water among three seasons (rainy, winter, summer) and four habitat types (intermittent stream, stream, pond, reservoir) were analyzed using one-way analysis of variance; (one-way ANOVA) followed by Duncan's multiple range test in IBM SPSS Statistics for Windows (version 28.0; IBM Corp., Armonk, NY, USA).

In addition, Chao1, Chao2, Jackknife1, Jackknife2, and Bootstrap estimators (Colwell, Coddington, 1994) were used to estimate the number of species in each water habitat. The calculations were performed with R studio version 3.6.1.

We performed the principal component analysis (PCA) to investigate the variation of environmental variables by season. The variables from the four sampling sites (S1, S3, S4, and S7) where cladocerans could be collected from all seasons were analyzed. The environmental variables were averaged from three sampling points at each site. Prior to analysis, all variables were log-transformed except for pH to skew distribution (Yang *et al.*, 2005). The relationship between environmental variables and species abundances was determined using canonical correspondence analysis (CCA). In the data matrix of species abundance, species present in more than 1% of samples were included (Yang *et al.*, 2005). These two multivariate analyses were conducted by PC-ORD, version 5.0 (McCune, Mefford 2006).

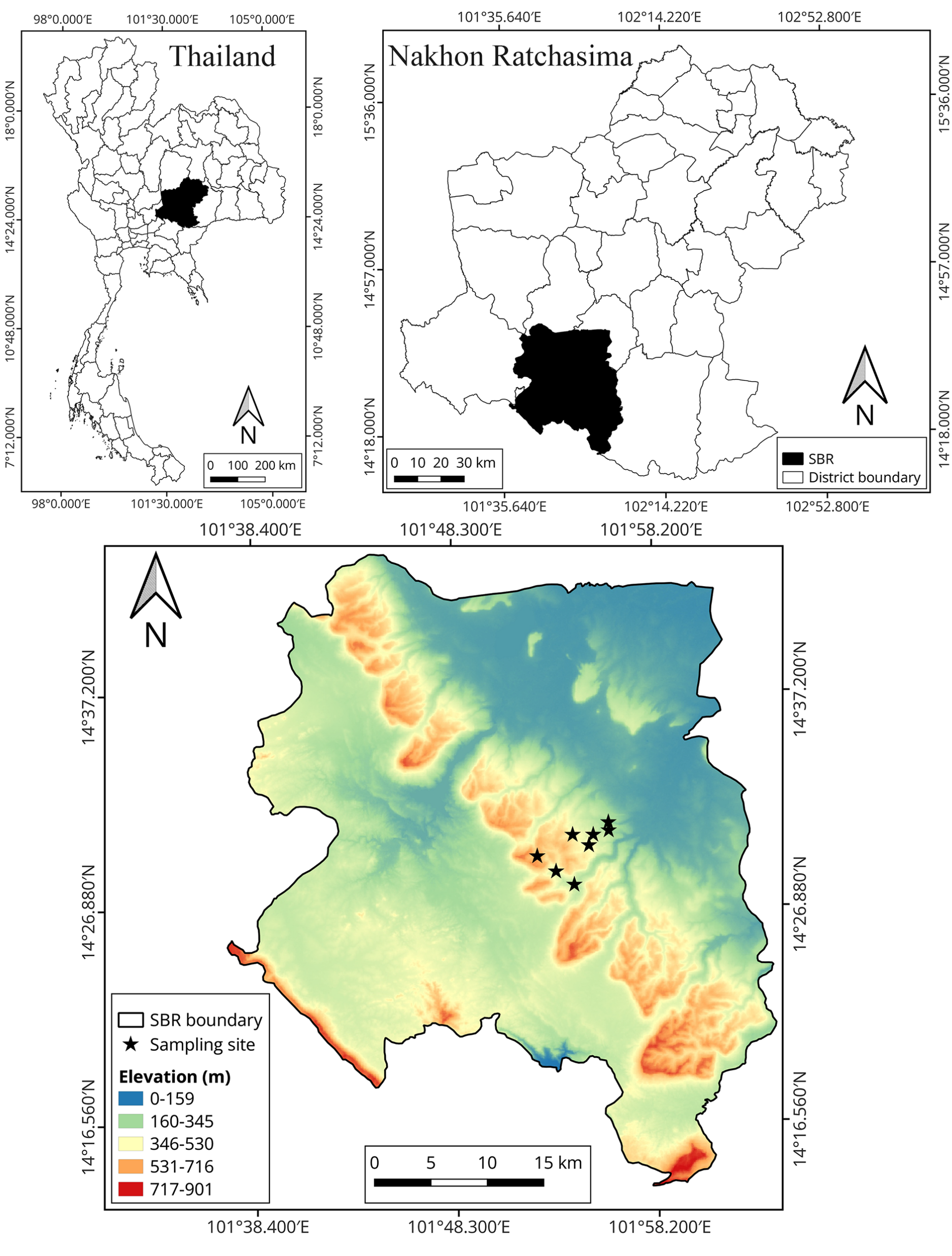

Fig. 1. Map of the Sakaerat Biosphere Reserve (SBR), Northeast Thailand, showing the distribution of the eight sampling sites. Photographs demonstrate eight water bodies: A — Tham Chong-ang (S1); B — Khang Pa Pa Kao (S2); C — Huai Tho Khat (S3); D — Ton Krathin (S4); E — Ton Wha (S5); F — Bho Kop (S6); G — Ban Huai Namkhem (S7); H — Khuean Bon (S8).

Рис. 1. Карта биосферного заповедника Сакаэрат (SBR), Северо-Восточный Таиланд, на которой показано распределение восьми локаций отбора проб. Фотографии демонстрируют восемь водных объектов: A — Tham Chong-ang (S1); B — Khang Pa Pa Kao (S2); C — Huai Tho Khat (S3); D — Ton Krathin (S4); E — Ton Wha (S5); F — Bho Kop (S6); G — Ban Huai Namkhem (S7); H — Khuean Bon (S8).

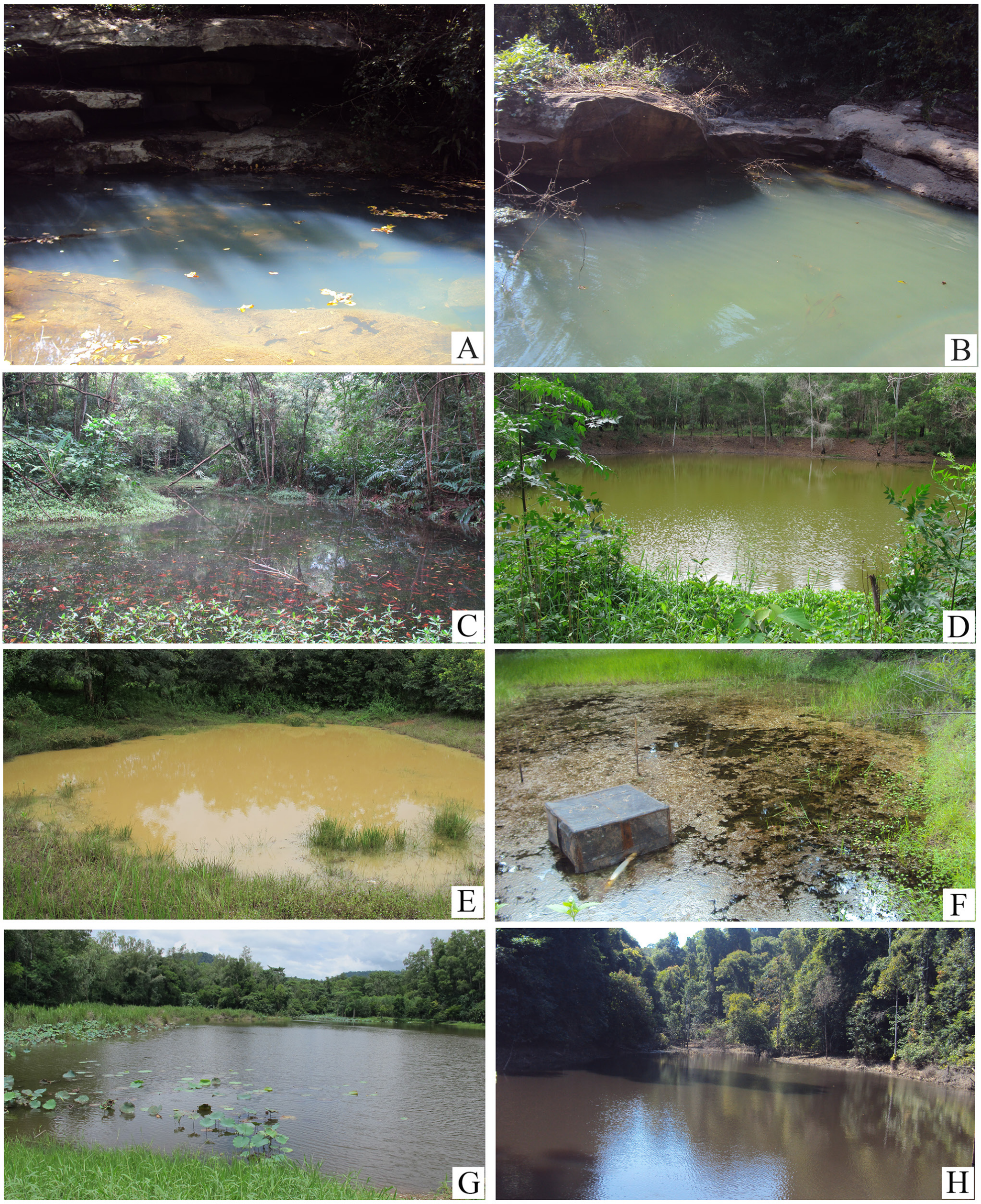

Fig. 1 (continued).
Рис. 1 (продолжение).

Results

SPECIES RICHNESS AND COMPOSITION. In total, 33 cladoceran species belonging to 27 genera and 7 families were recorded (Table 2). Chydoridae was the most diverse family (20 species, 60.61%), followed by Sididae (4 species, 12.12%), Daphnidae (3 species, 9.09%), Macrothricidae (2 species, 6.06%), and Moinidae (2 species, 6.06%) respectively. By contrast, only a single species was noted from Bosminidae and Ilyocryptidae (3.03%) (Fig.

Table 1. General characteristics and geographical coordinates of the eight sampling localities in the Sakaerat Biosphere Reserve.
Таблица 1. Общая характеристика и географические координаты восьми мест отбора проб в Биосферном заповеднике Сакаэрат.

Sampling site name	Code	Habitat type	Latitude (N)	Longitude (E)	Altitude (m)
Tham Chong-ang	S1	intermittent stream	14°30′20.22″	101°55′09.36″	422
Khang Pa Pa Kao	S2	stream	14°30′55.62″	101°55′54.60″	330
Huai Tho Khat	S3	stream	14°28′35.64″	101°53′17.94″	370
Ton Krathin	S4	pond	14°30′20.80″	101°54′08.30″	560
Ton Wha	S5	pond	14°29′20.10″	101°52′22.80″	692
Bho Kop	S6	pond	14°30′32.10″	101°55′55.38″	385
Ban Huai Namkhem	S7	reservoir	14°27′56.88″	101°54′11.70″	392
Khuean Bon	S8	reservoir	14°29′50.00″	101°54′56.30″	478

2). The most frequently occurring species were *Diaphanosoma excisum* (100.00% of the sampling sites), followed by *Chydorus eurynotus* (87.50%), and *Coronatella acuticostata*, *Ilyocryptus spinifer* and *Simocephalus serrulatus* (75.00%). Sixteen species were found in only a single water habitat. In addition, *Ceriodaphnia cornuta* and *D. excisum* were dominant species in the study, representing high values of degree of dominance (Y), with 0.21 and 0.09, respectively (Table 2).

Ban Huai Namkhem reservoir was the most diverse habitat containing 29 species. By contrast, Ton Wha pond had the lowest species richness (4 species only). The greatest species richness was reported during the rainy season (25 species), followed by summer (21 species), and winter (18 species). There was a statistically significant difference in species richness between habitat types $F_{3,47} = 11.950$, $p < 0.001$). The reservoir showed an elevated number of species, with 8.27 ± 5.16 (range between 3–19 species), while the lowest average species richness was recorded in pond which was 2.71 ± 1.16 (range between 1–5 species) (Fig. 3A).

ABUNDANCE. The total abundance of cladocerans was the greatest during the rainy season, followed by the summer and winter, respectively. In the rainy season, the highest quantity of cladocerans were found in Tham Chong-ang intermittent stream,. By contrast, the lowest number corresponded to Ton Krathin pond. In addition to winter, Ton Wha pond showed an elevated number of cladocerans; whereas Tham Chong-ang had only a few individuals. During summer, the greatest abundance was reported in Huai Tho Khat. The lowest cladoceran abundance occurred in Tham Chong-ang, with only few individuals (Table 3). There was a significant difference in abundance of cladocerans among habitat types $F_{3,47} = 8.674$, $p < 0.001$). Intermittent stream showed the greatest number of cladocerans with 2,109.71 ± 1,009.17 individuals. By contrast, the lowest abundance was reported in pond, with was 53.17 ± 12.18 individuals (Fig. 3B).

Seven species had the largest contribution to the community structure (Fig. 4). *Ceriodaphnia cornuta* was the most abundant species recorded in Tham Chong-ang stream during the rainy season and dominated in Huai Tho Khat stream in the summer. Additionally, *Diaphanosoma excisum* not only had high abundance in Tham Chong-ang stream in the rainy season along with *C. cornuta*, but it also exhibited an elevated number of individuals in Ton Wha pond during the same season, and Khuean Bon reservoir in the summer. *Chydorus eurynotus* had a great abundance in both Huai Tho Khat stream and Ban Huai Namkhem reservoir in the rainy season, with *Ephemeroporus barroisi* as well. Only *Ilyocryptus spinifer* dominated during winter in Ton Wha Pond. Regarding summer, *Anthalona harti harti* and *Simocephalus serrulatus* had high abundance in Bho Kop pond and Huai Tho Khat stream.

ESTIMATED DIVERSITY, DIVERSITY AND SIMILARITY INDEX. The estimated numbers from rarefaction analysis of five estimators (Chao1, Chao2, Jackknife1, Jackknife2, and Bootstrap) (Fig. 5) were somewhat higher

Table 2. Species list and the degree of dominance (Y) of cladocerans recorded in eight waterbodies of the Sakaerat Biosphere Reserve in three seasons.
Таблица 2. Список видов и степень доминирования (Y) ветвистоусых ракообразных, зарегистрированных в восьми водоемах Биосферного Заповедника Сакаэрат в течение трех сезонов. сезон.

Taxa	S1			S2	S3			S4			S5		S6	S7			S8		*Y*
	R	W	S	W	R	W	S	R	W	S	R	W	S	R	W	S	W	S	
Family Bosminidae																			
1. *Bosminopsis deitersi* Richard, 1895	–	–	–	–	–	–	–	+	–	–	–	–	–	+	+	+	–	–	< 0.02
Family Chydoridae																			
2. *Alona kotovi* Sinev, 2012	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	< 0.02
3. *Alonella excisa* (Fischer, 1854)	–	–	–	–	–	+	–	–	–	–	–	–	–	+	+	+	–	–	< 0.02
4. *Anthalona harti harti* Van Damme, Sinev et Dumont, 2011	–	–	–	–	–	–	–	+	–	–	–	–	+	+	+	+	–	–	< 0.02
5. *Camptocercus uncinatus* Smirnov, 1971	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	< 0.02
6. *Camptocercus vietnamensis* Thanh, 1980	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	< 0.02
7. *Chydorus eurynotus* Sars, 1901	–	+	–	+	+	+	+	–	+	–	–	–	+	+	+	+	+	–	< 0.02
8. *Chydorus opacus* Frey, 1987	–	–	–	–	+	–	+	–	–	–	–	–	–	+	+	+	–	–	< 0.02
9. *Chydorus reticulatus* Daday, 1898	–	–	–	+	+	+	–	–	–	–	–	–	–	+	+	+	–	–	< 0.02
10. *Coronatella acuticostata* (Sars, 1903)	–	+	–	+	–	+	–	+	+	+	+	+	–	+	–	+	–	–	< 0.02
11. *Dadaya macrops* (Daday, 1898)	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	< 0.02
12. *Ephemeroporus barroisi* (Richard, 1894)	–	–	–	–	+	–	–	–	–	–	–	–	–	+	+	+	–	–	< 0.02
13. *Euryalona orientalis* (Daday, 1898)	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	< 0.02
14. *Karualona fatimae* Sinev et Semenyuk, 2023	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	< 0.02
15. *Leydigia ciliata* Gauthier, 1939	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	< 0.02
16. *Ovalona cambouei* (Guerne et Richard, 1983)	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	< 0.02
17. *Oxyurella singalensis* (Daday, 1898)	–	–	–	–	+	+	–	–	–	–	–	–	–	–	+	–	–	–	< 0.02
18. *Pleuroxus laevis* (Sars, 1862)	–	+	–	–	+	+	–	–	–	–	–	–	–	+	–	–	–	–	< 0.02

Table 2 (continued).
Таблица 2 (окончание).

Taxa	S1			S2	S3			S4			S5		S6	S7			S8		Y
	R	W	S	W	R	W	S	R	W	S	R	W	S	R	W	S	W	S	
Family Chydoridae																			
19. *Pleuroxus quasidenticulatus* (Smirnov, 1996)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	< 0.02
20. *Prendalona guttata* (Sars, 1862)	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	< 0.02
21. *Pseudochydorus bopingi* Sinev, Garibian et Gu, 2016	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	< 0.02
Family Daphniidae																			
22. *Ceriodaphnia cornuta* Sars, 1885	+	–	–	–	+	–	+	–	–	–	–	–	–	+	–	+	+	+	**0.21**
23. *Scapholeberis kingi* Sars, 1888	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	< 0.02
24. *Simocephalus serrulatus* (Koch, 1841)	–	–	+	+	+	–	+	–	–	–	–	–	+	+	+	+	+	–	< 0.02
Family Ilyocryptidae																			
25. *Ilyocryptus spinifer* Herrick, 1882	–	+	–	–	–	+	+	–	–	–	+	+	+	+	+	+	+	+	< 0.02
Family Macrothricidae																			
26. *Macrothrix spinosa* King, 1853	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	+	–	–	< 0.02
27. *Macrothrix triserialis* Brady, 1886	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	+	–	–	< 0.02
Family Moinidae																			
28. *Moina micrura* Kurz, 1875	–	–	–	–	–	–	–	–	–	+	–	+	–	+	–	–	–	–	< 0.02
29. *Moinodaphnia macleayi* (King, 1853)	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	< 0.02
Family Sididae																			
30. *Diaphanosoma dubium* Manujlova, 1964	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	< 0.02
31. *Diaphanosoma excisum* Sars, 1885	+	–	+	–	+	–	–	+	+	–	+	+	+	+	–	+	+	+	0.09
32. *Latonopsis australis* Sars, 1888	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	< 0.02
33. *Pseudosida szalayi* (Daday, 1898)	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	< 0.02

Abbreviations: + present; — absent; R — rainy season; W — winter season; S — summer season.

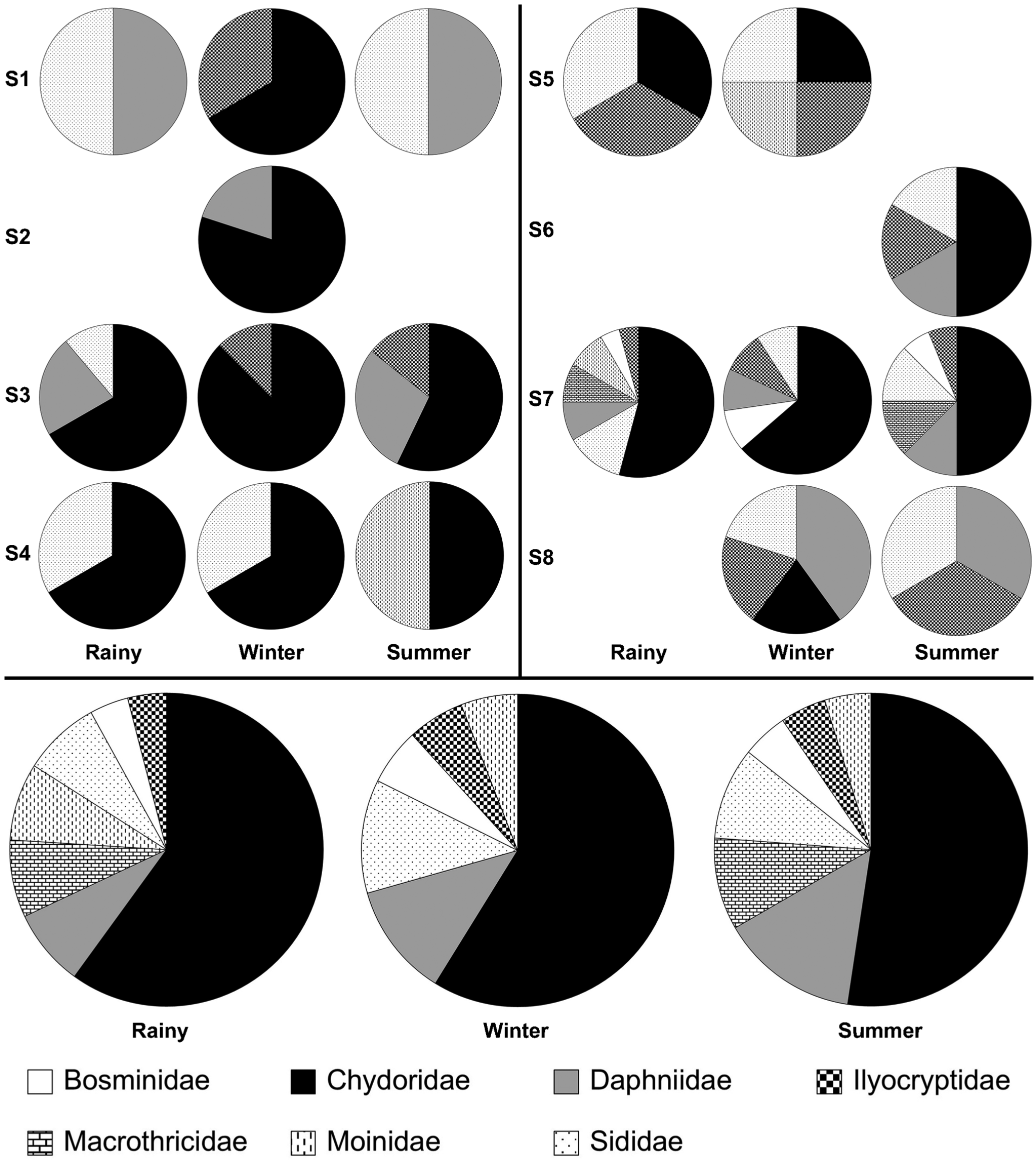

Fig. 2. The proportion of species richness of cladocerans families in sampling sites at three seasons.
Рис. 2. Соотношение видового богатства семейств ветвистоусых ракообразных в точках отбора проб в три сезона.

than the number of observed species (33 species) (Table 4). This result indicated that there were some unseen species which could be found in the study areas.

The highest Shannon-Wiener diversity index (H´) was reported in Ban Huai Namkhem reservoir in the summer, while the greatest value of Pielou's evenness index was recorded from Tham Chong-ang intermittent stream (Table 3). Tham Chong-ang stream and Khuean Bon reservoir demonstrated the highest similarity value, followed by Ton Krathin and Ton Wha ponds, and Bho Kop pond and Khuean Bon reservoir. In contrast, the lowest similarity was recorded for Ton Wha pond and Ban Huai Namkhem reservoir (Table 5).

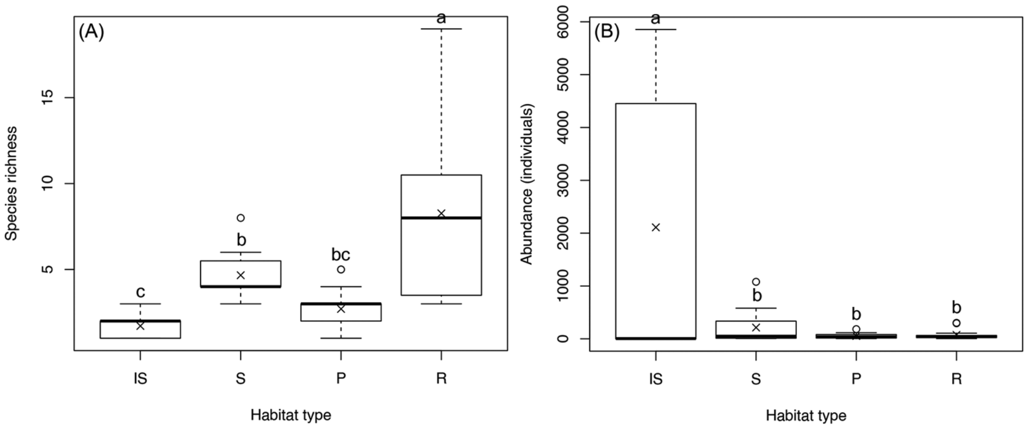

Fig. 3. Boxplots show the differences in species richness (A) and abundance (B) of cladocerans in four habitat types, including intermittent stream (IS), stream (S), pond (P) and reservoir (R). Different letters indicate significant differences ($p < 0.05$). A cross (×) on the boxplot indicates the mean value.
Рис. 3. Боксплоты показывают различия в видовом богатстве (A) и численности (B) ветвистоусых ракообразных в четырех типах местообитаний, включая периодически существующий ручей (IS), ручей (S), пруд (P) и водохранилище (R). Буквы обозначают достоверные различия ($p < 0,05$). Крестиком (×) обозначены средние значения.

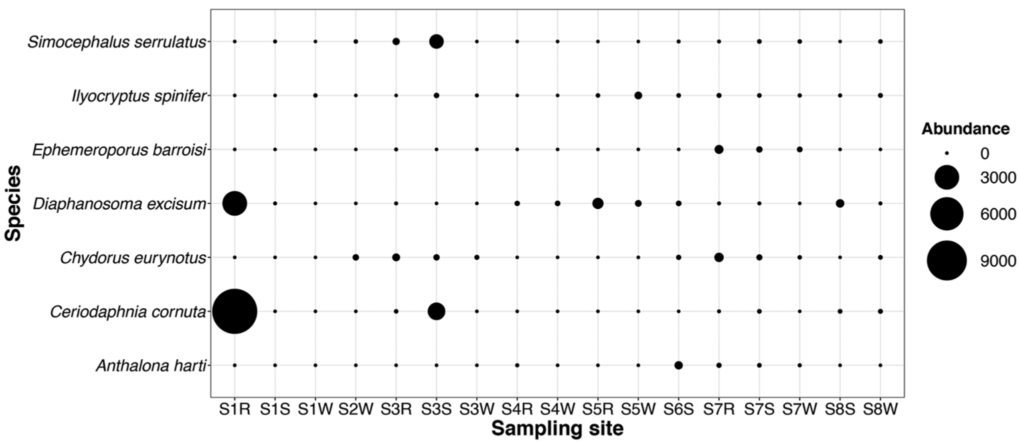

Fig. 4. Bubble plots show a total abundance of seven dominant cladocerans in each sampling site.
Abbreviations: R — rainy season; W — winter season; S — summer season.
Рис. 4. Пузырьковые диаграммы показывают общее обилие семи доминирующих видов ветвистоусых ракообразных в каждой точке отбора проб.
Сокращения: R — сезон дождей; W — зимний сезон; S — летний сезон.

Notes on distribution and ecology of rare species

Alona kotovi Sinev, 2012
Fig. 6A–C.

DIAGNOSIS. *A. kotovi* belongs to *Alona* s.str. (“the *quadrangularis*-group”). It differs from the other species by morphology of its labrum, thoracic limbs and postabdomen (see Fig. 6A, B). For detailed description see Sinev, 2012.

DISTRIBUTION AND ECOLOGY. *A. kotovi* was first described from Vietnam (Sinev, 2012), recently known only in the Oriental Region (Choedchim, Maiphae, 2023). The species was found in a small forest stream, Cat Tien National Park, and a roadside ditch in Dong Nai National Park, Dong Nai Province, Vietnam (Sinev, 2012). *A. kotovi* was also recorded in several localities in other counties of Asia, including

Table 3. Species richness, abundance, and diversity indices of cladoceran community at eight sampling localities in three seasons.
Таблица 3. Видовое богатство, численность и индексы разнообразия сообщества ветвистоусых ракообразных в восьми точках отбора проб в течение трех сезонов.

Sampling site	Season	Species richness	Abundance	H′	*J*
S1	Rainy	2	14,760	0.51	0.73
	Winter	4	7	0.87	0.79
	Summer	2	2	0.69	1.00
	Total	7	14,768	0.51	0.28
S2	Winter	5	72	0.80	0.50
S3	Rainy	10	246	1.17	0.53
	Winter	8	29	1.44	0.69
	Summer	7	2,217	0.82	0.42
	Total	16	2,491	1.04	0.38
S4	Rainy	4	26	0.55	0.50
	Winter	3	61	0.85	0.77
	Summer	2	13	0.54	0.78
	Total	6	99	1.13	0.70
S5	Rainy	3	399	0.11	0.10
	Winter	4	192	0.90	0.65
	Total	5	591	0.63	0.45
S6	Summer	6	214	0.99	0.56
S7	Rainy	24	638	1.90	0.60
	Winter	11	69	1.77	0.73
	Summer	18	209	2.18	0.79
	Total	29	916	2.11	0.64
S8	Winter	5	40	1.42	0.88
	Summer	3	170	0.27	0.25
	Total	6	210	0.85	0.53

Table 4. Species richness estimates (± SE) for cladocerans in the SBR in three seasons.
Таблица 4. Оценки видового богатства (± SE) ветвистоусых ракообразных в водоемах Биосферного заповедника Сакаэрат в течение трех сезонов.

Estimator	Rainy	Winter	Summer	Total taxa
Observed species richness	25	18	21	33
Chao1	25.52 ± 1.01	17.06 ± 0.30	32.56 ± 13.15	42.46 ± 10.27
Chao2	25.31 ± 0.72	17.00 ± 0.05	27.61 ± 6.75	38.87 ± 6.54
Jackknife1	27.80 ± 2.12	17.95 ± 0.95	27.61 ± 3.16	39.85 ± 3.41
Jackknife2	23.96	12.84	32.16	44.72
Bootstrap	27.18 ± 3.20	18.31 ± 1.38	23.95 ± 2.22	35.52 ± 2.41

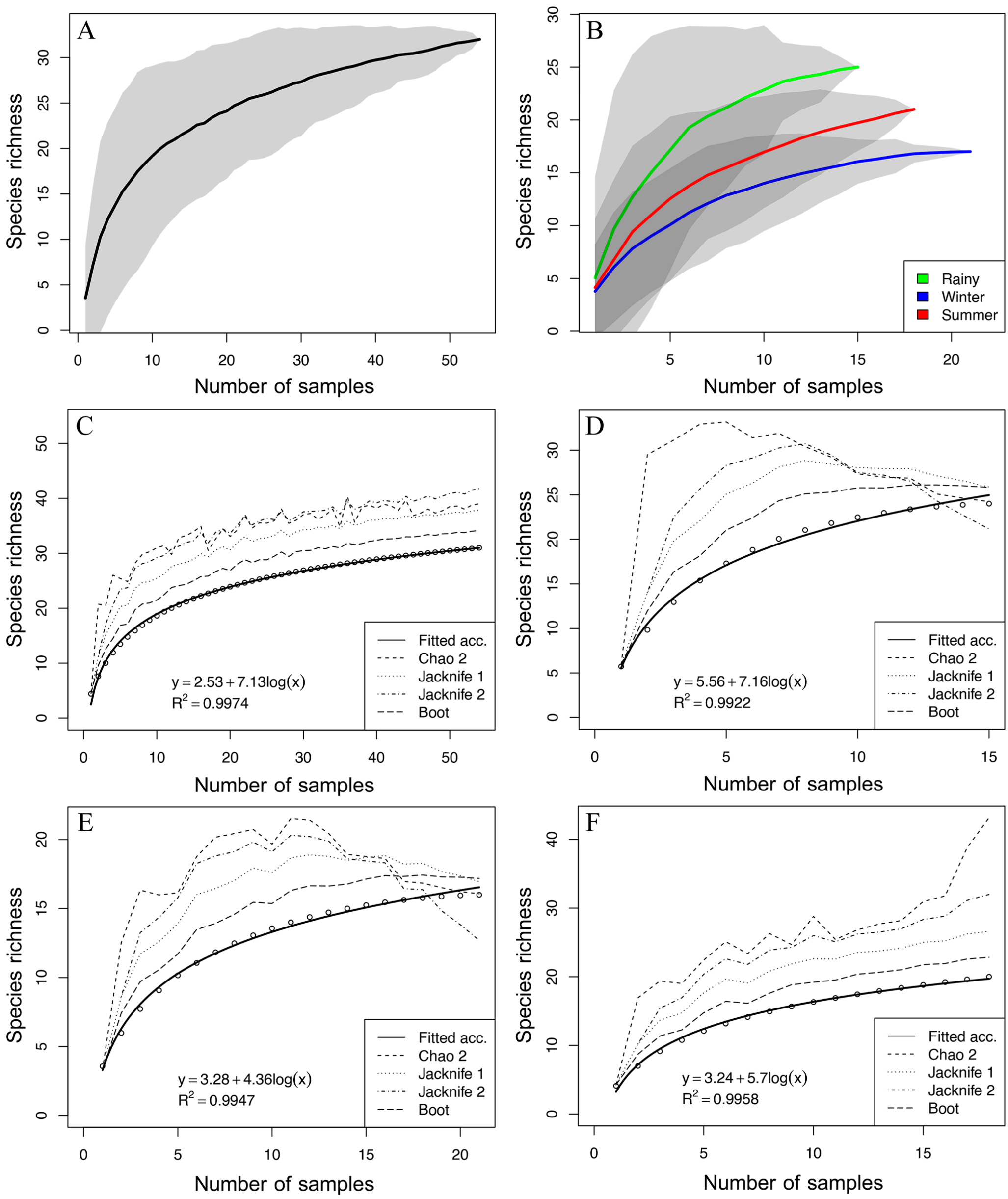

Fig. 5. Species accumulation and estimation curves of cladocerans observed at the Sakaerat Biosphere Reserve. A — species accumulation curve of all seasons; B — species accumulation curves of three seasons; C — species estimation curve of all seasons; D — species estimation curve for rainy season, E — same, winter season, F — same, summer season.

Рис. 5. Кривые накопления и модельные кривые для видов ветвистоусых ракообразных, встреченных в Биосферном заповеднике Сакаэрат. A — кривая накопления видов за все сезоны; B — сравнение кривых накопления видов за три сезона; C — кривая оценки биоразнообразия за все сезоны; D — то же, в сезон дождей; E — то же, в зимний сезон; F — то же, в летний период.

Table 5. Summary of similarity index for cladoceran community among eight water bodies.
Таблица 5. Обобщение информации по индексам сходства сообществ ветвистоусых ракообразных в восьми водоемах.

Sampling site	S1	S2	S3	S4	S5	S6	S7
S2	0.46						
S3	0.61	0.54					
S4	0.46	0.50	0.27				
S5	0.50	0.36	0.28	0.73			
S6	0.62	0.50	0.36	0.50	0.36		
S7	0.39	0.29	0.62	0.34	0.23	0.28	
S8	0.77	0.45	0.45	0.33	0.54	0.67	0.34

a swamp in Viengkham District, Vientiane Province, Laos (Kotov *et al.*, 2013b), wetlands of Majuli, India (Sharma, Sharma, 2014), a reservoir in South Korea (Jeong *et al.*, 2015), ponds, reservoirs, and rivers of Hainan Island (Sinev *et al.*, 2015), and Dali Bai Autonomous Prefecture, Yunnan Province, China (Sinev *et al.*, 2020). In Thailand, *A. kotovi* was encountered in Thale-Noi, Phatthalung Province (Choedchim *et al.*, 2017), and rivers in Bueng Kan Province (Tiang-nga, 2019). In this study, this species was found only in Ban Huai Namkhem reservoir during the rainy season. It occurred in littoral zone and is associated with macrophytes. Environmental variables of the localities where *A. kotovi* occurred were the following: water temperature 29.8–30.5°C, pH 6.58–6.74, dissolved oxygen 4.5–5.5 mg/L, electrical conductivity 37–40 μS/cm, total dissolved solids 18–20 mg/L, nitrate 1.2–1.4 mg/L, orthophosphate 0.05–0.07 mg/L, and ammonia 0.01–0.02 mg/L.

Camptocercus uncinatus Smirnov, 1971
Fig. 6D–F.

DIAGNOSIS. *C. uncinatus* is subovoid in lateral view. Valves with prominent diagonal lines. Labrum with moderately acute apex (Fig. 6E). Postabdomen very long and narrow. Preanal margin convex. Postanal margin with 11–13 single, triangular denticles, with serrated anterior margin (Fig. 6F). For detailed description see Sinev, 2014.

DISTRIBUTION AND ECOLOGY. *C. uncinatus* was first described from Transbaikalia in Russia (Smirnov, 1971). It is known from Afrotropical, Neotropical, Oriental, and Palearctic Regions (Choedchim, Maiphae, 2023). This species has been reported in Russia, Israel, Iraq, Egypt, Ethiopia, the Rift Valley of Africa, South-West, and East Siberia (Smirnov, 1998; Sinev, 2016; Garibian *et al.*, 2019). In Asia, *C. uncinatus* has been reported from the lakes in South Korea (Kotov *et al.*, 2012; Jeong *et al.*, 2015), reservoirs and rivers of Hainan Island (Sinev *et al.*, 2015), lakes and small reservoirs in Yunnan Province, China (Sinev *et al.*, 2020). In Thailand, *C. uncinatus* was found in different water bodies, including lakes, rivers, and artificial reservoirs in the southern, north-eastern, and western part of the country (Pholpunthin, 1997; Sanoamuang, 1998; Wongrat, Pipatcharoenchai 2003). In this study, it was encountered only in Khang Pa Pa Kao stream in winter, namely, in a pool on the stream rich of green filamentous algae *Spirogyra* sp. Environmental variables of the locality where *C. uncinatus* occurred were the following: water temperature 23.7–25.7°C, pH 5.55–5.63, dissolved oxygen 5.2–5.4 mg/L, electrical conductivity 40–57 μS/cm, total dissolved solids 22–30 mg/L, nitrate 0.4–0.7 mg/L, orthophosphate 0.00–0.08 mg/L, and ammonia 0.00–0.02 mg/L.

Camptocercus vietnamensis Thanh, 1980
Fig. 6G–I.

DIAGNOSIS. *C. vietnamensis* is egg-shaped in lateral view. Valves with prominent sculptures of diagonal shape. Labrum with subtriangular keel. Apex of keel rounded. Postero-ventral valve margin with denticle (Fig. 6H). Postabdomen very long and narrow. Postanal margin of postabdomen provided with 13–15 small triangular denticles (Fig. 6I). For detailed description see Sinev, 2011.

DISTRIBUTION AND ECOLOGY. *C. vietnamensis* was first described from Vietnam (Thanh *et al.*, 1980) and redescribed by Sinev, 2011. This species appeared to be widely distributed in Pacific Asia (Kotov *et al.*, 2012). It inhabits running water bodies, such as streams and rivers in northern and southern parts of Vietnam (Thanh *et al.*, 1980; Sinev, 2011; Sinev, Korovchinsky, 2013). Although *C. vietnamensis* is a predominantly rheophylic species (Sinev, 2011), it was found also in some lentic water bodies, including a rice field in Seberang, Malaysia (Idris, 1983), a pond, a roadside ditch and a swamp in Vientiane Province, Laos (Kotov *et al.*, 2013b), a reservoir in Hainan Island,

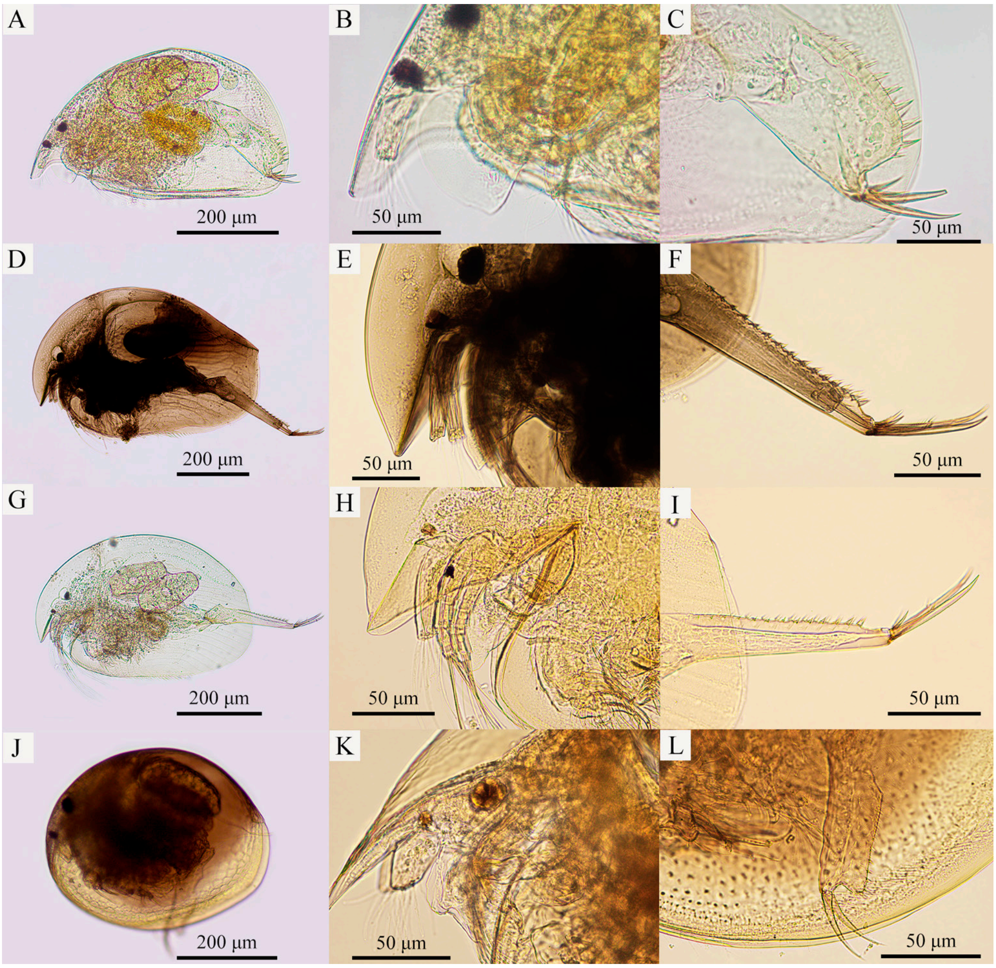

Fig. 6. Rare cladoceran in the the Sakaerat Biosphere Reserve. A–C — *Alona kotovi* Sinev, 2012; D–F — *Camptocercus uncinatus* Smirnov, 1971; G–I — *C. vietnamensis* Thanh, 1980; J–L, *Pseudochydorus bopingi* Sinev, Garibian et Gu, 2016. A, D, G, J — lateral view. B, E, H, K — labrum C; F, I, L — postabdomen.
Рис. 6. Редкие кладоцеры в Биосферном заповеднике Сакаэрат. A–C — *Alona kotovi* Sinev, 2012; D–F — *Camptocercus uncinatus* Smirnov, 1971; G–I — *C. vietnamensis* Thanh, 1980.; J–L — *Pseudochydorus bopingi* Sinev, Garibian et Gu, 2016. A, D, G, J — вид сбоку. B, E, H, K — лабрум C; F, I, L — постабдомен.

China (Sinev *et al.*, 2015), and an oxbow lake and a swamp in South Korea (Kotov *et al.*, 2012; Jeong *et al.*, 2015). In Thailand, *C. vietnamensis* was found only in Bueng Kan Province, occurring in several types of water habitats, including a temporary pond, a reservoir, a swamp, and a river (Tiang-nga, 2019). In the present work, *C. vietnamensis* was recorded only from Huai Tho Khat stream in winter together with *Alonella excisa* and *Oxyurella singalensis*. During our sampling time, the water body became stagnant, had a greater density of *Hydrilla* sp. as compared to the summer. Water variables of the locality where *C. vietnamensis* occurred were the following: water temperature 19.0–19.5°C, pH 5.87–5.99, dissolved oxygen 2.9–3.9 mg/L, electrical conductivity 27–32 μS/cm, total dissolved solids 14–15 mg/L, nitrate 0.3–1.6 mg/L, orthophosphate 0.13–0.18 mg/L, and ammonia 0.02–0.13 mg/L.

Pseudochydorus bopingi Sinev, Garibian et Gu, 2016
Fig. 6J–L.

DIAGNOSIS. *P. bopingi* differs from *P. globosus* by a smaller size, well-developed flattened flange along

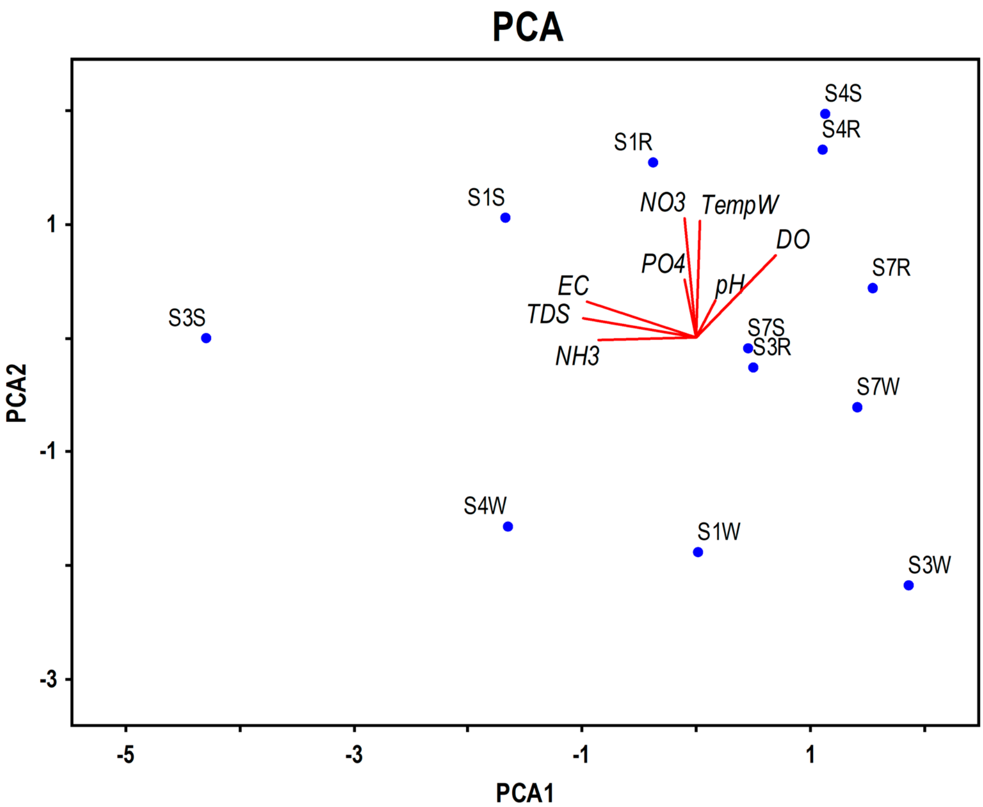

Fig. 7. Results of Principal components analysis (PCA) with a correlation bi-plot projecting observations of the environmental variables from sampling sites where cladocerans could be collected in all seasons. The letters R, W, and S refer to the rainy, winter and summer seasons, respectively.
Abbreviations: NH3 — ammonia, TDS — total dissolved solids, EC — electrical conductivity, NO3 — nitrate, WT — water temperature, PO4 — orthophosphate, DO — dissolved oxygen.
Рис. 7. Результаты анализа главных компонент (PCA) с биплотом, визуализирующим значения экологических переменных из локаций, в которых ветвистоусые ракообразные были собраны во все сезоны. Аббревиатуры R, W и S означают дождливый, зимний и летний сезоны соответственно.
Сокращения: NH3 — аммоний, TDS — общая концентрация растворенных твердых веществ, EC — электропроводность, NO3 — нитраты, WT — температура воды, PO4 —ортофосфаты, DO — растворенный кислород.

the posterior margin of the valves, shorter rostrum, smaller ocellus (Fig. 6K), and morphology of antenna and thoracic limb. Postabdomen is long and narrow, in postanal portion with parallel margins. Postanal margin bearing about 15 sharp denticles, decreasing in size basally (Fig. 6L). For detailed description see Sinev *et al.* (2016).

DISTRIBUTION AND ECOLOGY. *P. bopingi* was first described from China (Sinev *et al.*, 2016). It is considered an Oriental species, based on its distribution (Chiang, Du, 1979; Tiang-nga *et al.*, 2020). It occurs in various freshwater habitats in China, including a roadside pond and a lake in Hunan Province, a small reservoir at Hainan Island (Sinev *et al.*, 2016), Donghu Lake in Wuhan city, Hubei Province (Chiang, Du, 1979) and Dali Bai Autonomous Prefecture in Yunnan Province (Sinev *et al.*, 2020). It also was found in the Bau Sau lake in Cat Tien National Park, South Vietnam (Sinev, Korovchinsky, 2013). In Thailand, *P. bopingi* is a rare species, found only in Lake Kud-Thing in northeast Thailand (Tiang-nga *et al.*, 2020). In the present study, *P. bopingi* occurred only in a Huai Tho Khat stream during summer with *Leydigia ciliata*. This site was represented by a small forest stream; the bottom was covered by muddy sediment and leaf litter. In summer, the water body became stagnant and covered with lightly submerged vegetation (*Hydrilla* sp.). Environmental variables of the locality where the following: water temperature 25.8–27.3°C, pH 5.99–6.62, dissolved oxygen 0.7–1.5 mg/L, electri-

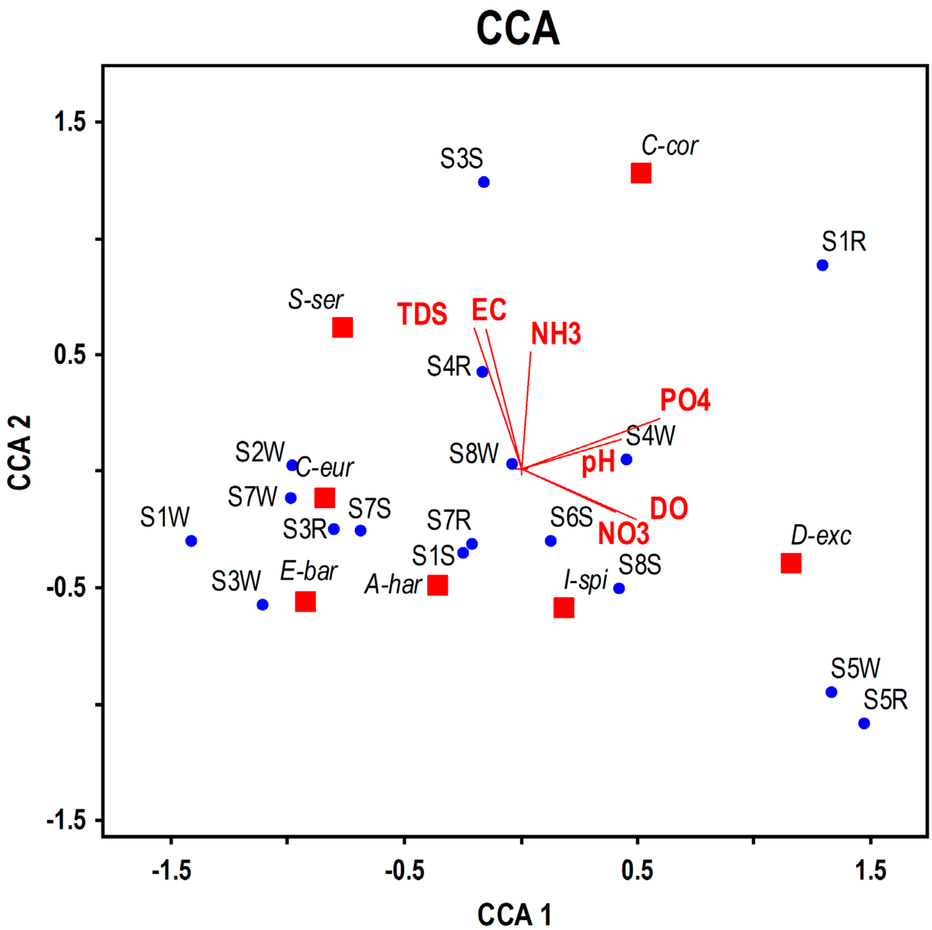

Fig. 8. Canonical correspondence analysis (CCA) triplot of seven cladoceran species with a relative abundance of more than 1% and physicochemical parameters of water.
Abbreviations: A-har — *Anthalona harti harti*; C-eur — *Chydorus eurynotus*; C-cor — *Ceriodaphnia cornuta*; D-exc — *Diaphanosoma excisum*; E-bar — *Ephemeroporus barroisi*; I-spi — *Ilyocryptus spinifer*; S-ser — *Simocephalus serrulatus*. The S1, S2, S3, S4, S5, S6, S7, and S8 indicate the sampling site numbers, and the letters R, W and S refer to seasons. The abbreviations of environmental factors are the same as in Fig. 7.

Рис. 8. Результат канонического анализа соответствия (CCA) семи видов Cladocera с относительной численностью более 1% и физико-химических параметров воды.
Сокращения: A-har — *Anthalona harti harti*; C-eur — *Chydorus eurynotus*; C-cor — *Ceriodaphnia cornuta*; D-exc — *Diaphanosoma excisum*; E-bar — *Ephemeroporus barroisi*; I-spi — *Ilyocryptus spinifer*; S-ser — *Simocephalus serrulatus*. S1, S2, S3, S4, S5, S6, S7 и S8 обозначают номера точек отбора проб, а буквы R, W и S — сезоны. Сокращения экологических факторов те же, что и на рис. 7.

cal conductivity 73–85 µS/cm, total dissolved solids 36–48 mg/L, nitrate 0.9–2.8 mg/L, orthophosphate 0.18–0.31 mg/L, and ammonia 1.56–1.96 mg/L.

ENVIRONMENTAL FACTORS. The PCA of the eight environmental variables accounted for 59.0% of the variation, with PC axes 1 and 2 accounting for 36.4 and 22.6% of the variation, respectively (Fig. 7). Principal component 1 (PC1) was associated with EC, TDS, and NH_3, while principal component 2 (PC2) related to water temperature, DO, NO_3^-, PO_4^{3-} and pH (Fig. 7).

RELATIONSHIP BETWEEN ENVIRONMENTAL VARIABLES AND CLADOCERAN COMMUNITY STRUCTURE. The first CCA axis (CCA1) accounted for the highest explained variance, with 29.5%, while the second axis

(CCA2) accounted for 14.2% (Fig. 8). *Chydorus eurynotus*, *Ephemeroporus barroisi* and *Simocephalus serrulatus* densities showed a negative correlation with PO_4^{3-} and DO. During all three seasons, they were common in the Huai Tho Khat stream (S3) and the Ban Huai Namkhem reservoir (S7). The average level of orthophosphate was 4.51 mg/L, and the average level of dissolved oxygen was 0.05 mg/L. On the other hand, *Diaphanosoma excisum* density was positively associated with PO_4^{3-} and DO. It exhibited the highest abundance in Ton Wha pond during the rainy season (S5R), where the highest values of PO_4^{3-} (13.37 mg/L) and DO (9.07 mg/L) were recorded. *Ceriodaphnia cornuta* density was positively associated with EC, TDS, and NH_3. During the summer season, we found many individuals of this species in the Huai Tho Khat stream, exhibiting the highest values of EC (80.33 μS/cm), TDS (42.67 mg/L), and NH_3 (1.81 mg/L). However, the Monte Carlo permutation test showed that the axis does not have any statistically significant relationship with any physicochemical values of the water.

Discussion

Typically, cladoceran fauna have a higher species richness in lentic habitats as compared to lotic water bodies (Sousa, Elmoor-Loureiro, 2012). Since our study was conducted in various types of freshwater habitats, we revealed a higher species richness as compared to other conservation areas: 28 species from Keoladeo Ghana National Park, India (Chandrasekhar, 2010) and 27 species from the Sempre Vivas National Park, Brazil (Sousa, Elmoor-Loureiro, 2013). However, the number of species of cladocerans in this study (33 species) is lower than that in Cat Tien National Park, South Vietnam (53 species), with 56.47% similarity with the latter (Sinev, Korovchinsky, 2013). Difference in the cladoceran species occurrence between two National Parks could be explained by differences in environmental, spatial, and geographic variables (Dallas, Drake, 2014).

In local scale, Ban Huai Namkhem reservoir (S7) had the highest species richness of cladocerans (29 species), whereas other sampling sites showed a low diversity. Macrophytes seem to be attective microhabitats for most species of cladocerans, providing habitat, shelter, breeding area, and sites of food production for various aquatic animals as well as cladocerans in aquatic ecosystems (Ali *et al.*, 2007). The S7 site contains many species of aquatic macrophytes in the littoral zone throughout three sampling occasions, that probably leads to the higher diversity of cladocerans.

Based on Sørensen-Dice similarity index, Tham Chong-ang intermittent stream (S1) and Khuean Bon reservoir (S8) revealed the highest similarity coefficient (0.77). One possible reason that can explain this case is the connectivity between them. Both sampling sites connect to each other in certain seasons because S1 and S8 are in the same watershed. Therefore, the species occurrence in S1 is relatively like species recorded in S8.

Five estimators predicted a total diversity of 34–40 species, few unseen cladoceran taxa were likely present in the study area, and the total number of species recorded within the SBR seemed to lie within the estimation range. The rarefaction curve in our investigation indicated that 60 samples would be enough to record approximately 80% of the total species richness (33 species). The diversity of cladocerans within the SBR is 33 species representing 26.40% of total number of freshwater cladocerans in Thailand (125 species) (Tiang-nga *et al.*, 2020; Sinev *et al.*, 2023).

Our result clearly shows that habitat heterogeneity and season influences the diversity of cladocerans (Takahashi *et al.*, 2005; Choi *et al.*, 2016). Season fluctuations in environmental factors are accompanied by the fluctuations in the abundances of phytoplankton and zooplankton (Kondowe *et al.*, 2022). In addition, seasonal succession of macrophyte vegetation leads to change in habitat complexity, being a remarkable factor in determining microcrustacean assemblages (Vad *et al.*, 2012). Space-size heterogeneity is the number of discrete sizes of interstitial spaces for macrophyte species, being an important contributor to taxonomic richness (St. Pierre, Kovalenko, 2014). As a result, seasonal fluctuation of physicochemical variables influence particularly the abundances of littoral-benthic species, such as *Chydorus eurynotus*, *Ephemeroporus barroisi* and *Simocephalus serrulatus*. Abundances of these species, whose abundance was high in Khang Pa Pa Kao stream (S2), Huai Tho Khat stream

(S3), and Ban Huai Namkhem reservoir (S7), showed a negative relation to orthophosphate and dissolved oxygen concentrations. *C. eurynotus* contributed 75, 48.97 and 51.72% of the total abundance of cladocerans in Khang Pa Pa Kao stream (S2) in the winter, Huai Tho Khat stream (S3) in the rainy season and winter, respectively. The combination of abundances of *C. eurynotus* and *E. barroisi* took the large proportion of total cladoceran abundance in Ban Huai Namkhem reservoir (S7) in the rainy season and summer, accounting for 65.36 and 44.49%. Change in the abundance of these two species would influence the community structure of cladocerans in the water body. In the rainy season, the mean values of dissolved oxygen (DO) and orthophosphate in S7 were 5.03 and 0.06 mg/L, being higher than those in the winter and summer.

The higher DO and orthophosphate values would be generated by aquatic macrophytes, seems to be a favorable condition for the high abundances of littoral cladoceranss (Ali *et al*., 2007). This would be a result why *C. eurynotus* and *E. barroisi* had the highest abundance in S7 in this season. In summer in which Huai Tho Khat stream (S3) presents anoxic conditions (1.20 mg/L of DO) and the water level is low, but the highest abundance of *S. serrulatus* together with *Ceriodaphnia cornuta* was recorded. This result indicated that these species could tolerate anoxic conditions. Smirnov (2017) reported that some species of genus *Simocephalus* can live in the oxygen-deficient water layer over mud. This would be an indirect effect of orthophosphate on the abundance of cladocerans.

Phosphorus is a limiting nutrient in many aquatic ecosystems. Orthophosphate is the only form of phosphorus that autotrophs, especially algae and cyanobacteria, can utilize (Correll, 1999). The major form of dissolved phosphorus releases from aquatic animals (Andersson *et al*., 1998) and decomposition of the submerged macrophytes (Wang *et al*., 2018). Since macrophytes generate in littoral areas, decomposition of macrophytes has occurred, resulting in the formation of carbonic acid from carbon dioxide (CO_2) and decreases in pH (Assunção *et al*., 2018).

The abundance of *A. harti harti* was high in Bho Kop pond (S6) during the summer with a moderate low pH (5.41), a low values of conductivity (32.33 µS/cm), but high-water temperature (33.13°C). Sa-ardrit, Beamish (2005) found that temperature is a significant factor which reveals positively associated with the abundance of several cladoceran species in Khayeng stream, western Thailand. *I. spinifer* showed the greatest quantity in Ton Wha pond (S5) during winter, with a moderate pH value of 6.59, and low electrical conductivity (10.33 µS/cm). This would be the characteristic of the species as Choedchim *et al.* (2017) reported that *I. spinifer* distributed in Thale-Noi, Phatthalung Province along the different pH gradient at acidic to neural between 3.58–8.48.

The pH is the most important factor determining of the presence and abundance of the cladocerans (Choedchim *et al*., 2017). In some species, salinity also has effects on survival rate, fecundity, net reproductive rate, and in some species, growth rate (Gökçe, Turhan, 2014), and the density of cladocerans in brackish lakes decreases with increasing of their conductivity (Green *et al*., 2005). Since electrical conductivity and total dissolved solids indicate indirect salinity levels of water (Rusydi, 2018), those variables could affect the density of cladocerans (Soto, De los Rios, 2006).

Conclusion

Orthophosphate, dissolved oxygen, electrical conductivity, total dissolved solid and ammonia seem to be main variables influencing cladoceran abundance in SBR. The presence of rare species in this biosphere reserve indicates that the protected areas in Thailand may contain interesting and unseen species, what is important for exploring the diversity and distribution of microscopic animals in future studies.

Compliance with ethical standards

This study was reviewed and approved by the Institutional Animal Care and Use Committee of Khon Kaen University, Thailand (No. IACUC-KKU (C) -111/66).

CONFLICTS OF INTEREST: The authors declare that they have no conflicts of interest.

Acknowledgements. The research was supported by the Fundamental Fund of Khon Kaen University, fiscal year 2024 and the Science Achievement Scholarship of Thailand (SAST). We would like to gratefully thank the former SERS director, Dr. T. Artchawakom, and the staff at the Sakaerat Environmental Research Station for facilitating this study. Our special thanks go to the members of the freshwater plankton laboratory at the Applied Taxonomic Research Center for their assistance in the field. The authors sincerely A.Y. Sinev for valuable comments on the earlier draft of the manuscript.

References

Ali M.M., Mageed A.A., Heikal M. 2007. Importance of aquatic macrophyte for invertebrate diversity in large subtropical reservoir // Limnologica Vol.37 No.2. P.155–169. https://doi.org/10.1016/j.limno.2006.12.001

Andersson G., Granéli W., Stenson J. 1998. The influence of animals on phosphorus cycling in lake ecosystems // Hydrobiologia Vol.170. P.267–284. http://dx.doi.org/10.1007/BF00024909

Assunção A.W.A., Souza B.P., Cunha-Santino M.B., Bianchini I. 2018. Formation and mineralization kinetics of dissolved humic substances from aquatic macrophytes decomposition // J. Soils Sed. Vol.18. P.1252–126. https://doi.org/10.1007/s11368-016-1519-x

Athibai S., Wongkamhaeng K., Boonyanusith C. 2022. Two new species of *Metacyclops* Kiefer, 1927 (Copepoda, Cyclopoida) from Thailand and an up-to-date key to the species recorded in Asia // Eur. J. Taxon. Vol.787. P.146–181. https://doi.org/10.5852/ejt.2021.787.1621

Chandrasekhar S.V.A. 2010. Zooplankton studies on Keoladeo Ghana National Park, Bharatpur, Rajasthan, with special reference to Rotifera and Cladocera // Rec. Zool. Surv. India. Vol.110. No.1. P.93−101. https://doi.org/10.26515/rzsi/v110/i1/2010/158965

Chiang S.C., Du N.S. 1979 Fauna Sinica: Crustacea: Freshwater Cladocera. Peking: Science Press. 297 p.

Choedchim W., Maiphae S. 2023. Diversity and distribution of the cladocerans (Crustacea, Branchiopoda) in Thailand // Biodivers. Data J. Vol.11. Art.e103553. https://doi.org/10.1051/limn/2017006

Choedchim W., Van Damme K., Maiphae, S. 2017. Spatial and temporal variation of Cladocera in a tropical shallow lake // Ann. Limnol. – Int. J. Limnol. Vol.53. P.233–252. https://doi.org/10.1051/limn/2017006

Choi J.-Y., Jeong K.-S., Kim S.-K., Joo G.-J. 2016. Impact of habitat heterogeneity on the biodiversity and density of the zooplankton community in shallow wetlands (Upo wetlands, South Korea) // Oceanol. Hydrobiol. Stud. Vol.45. No.4. P.485–492. https://doi.org/10.1515/ohs-2016-0041

Colwell R.K., Coddington J. 1994. Estimating terrestrial biodiversity through extrapolation // Philos. Trans. R. Soc. Lond. B. Biol. Sci. Vol.345. P.101–118. https://doi.org/10.1098/rstb.1994.0091

Correll D.L. 1999. Phosphorus: A rate limiting nutrient in surface waters // Poult. Sci. Vol.78. No.5. P.674–682. https://doi.org/10.1093/ps/78.5.674

Dallas T., Drake J.M. 2014. Relative importance of environmental, geographic, and spatial variables on zooplankton metacommunities // Ecosphere. Vol.5. No.9. P.1–13. https://doi.org/10.1890/ES14-00071.1

Dodson S.L., Cáceres C.E., Rogers D.C. 2009. Cladocera and other Branchiopoda // H.T. James, P.C. Alan (ed.). Ecology and Classification of North American Freshwater Invertebrates. London: Academic Press is an imprint of Elsevier. P.773–827. https://doi.org/10.1016/B978-0-12-374855-3.00020-0

Gao Q., Xu Z., Zhuang, P. 2008. The relation between distribution of zooplankton and salinity in the Changjiang Estuary // Chin. J. Oceanol. Limnol. Vol.26. No.2. P.178–185. https://doi.org/10.1007/s00343-008-0178-1

Garibian P.G., Chertoprud E.S., Sinev A.Yu., Korovchinsky N.M., Kotov A.A. 2019. Cladocera and Copepoda (Crustacea: Branchiopoda) of the Lake Bolon and its basin (Far East of Russia) // Arthropoda Sel. Vol.28. No.1. P.37–63. https://doi.org/10.15298/arthsel.28.1.05

Gökçe D., Turhan D.Ö. 2014. Effects of salinity tolerances on survival and life history of two cladocerans // Turk. J. Zool. Vol.38. No.3. P.347–353. https://doi.org/10.3906/zoo-1304-21

Goulden C.E. 1968. The systematics and evolution of the Moinidae // Trans. Amer. Philos. Soc. Vol.58. No.6. P.1−101.

Green A.J., Fuentes C., Moreno-Ostos E., Rodrigues da Silva S.L. 2005. Factors influencing cladoceran abundance and species richness in brackish lakes in Eastern Spain // Ann. Limnol. – Int. J. Limnol. Vol.41. No.2. P.73–81. https://doi.org/10.1051/limn/2005010

Idris B.A.G. 1983. Freshwater zooplankton of Malaysia (Crustacea: Cladocera). Pertanian: Perenbit University. 153 p.

Jeong H., Kotov A.A., Lee W., Jeong R., Cheon S. 2015. Diversity of freshwater cladoceran species (Crustacea: Branchiopoda) in South Korea // J. Ecol. Nat. Environ. Vol.38. No.3. P.361–366. http://dx.doi.org/10.5141/ecoenv.2015.037

Kondowe B.N., Masese F.O., Raburu P.O., Singini W., Sitati A., Walumona R.J. 2022. Seasonality in environmental conditions drive variation in plankton communities in a shallow tropical lake // Front. Water. Vol.4. Art.883767. https://doi.org/10.3389/frwa.2022.883767

Korovchinsky N.M. 1992. Sididae and Holopediidae (Crustacea: Daphniiformes) // Guides to the Identification of the Microinvertebrates of the Continental Waters of the World 3. The Hague: SPB Academic Publishing. 82 p.

Korovchinsky N.M. 2013. Cladocera (Crustacea: Branchiopoda) of South East Asia: History of exploration, taxon richness and notes on zoogeography // J. Limnol. Vol.72. No.s2. P.109–124. https://doi.org/10.4081/jlimnol.2013.s2.e7

Kotov A.A., Štifter P. 2006. Cladocera: Family Ilyocryptidae (Branchiopoda: Cladocera: Anomopoda) // Guides to the Identification of the Microinvertebrates of the Continental Waters of the World 22. Leiden: Backhuys Publishers. 172 p.

Kotov A.A., Jeong H.G., Lee W. 2012 Cladocera (Crustacea: Branchiopoda) of the south-east of the Korean Peninsula, with twenty new records for Korea // Zootaxa. Vol.3368. P.50–90. https://doi.org/10.11646/zootaxa.3368.1.4

Kotov A., Forró L., Korovchinsky N.M., Petrusek A. 2013a. World checklist of freshwater Cladocera species. Available from http://fada.biodiversity.be/ group/show/17

Kotov A.A., Van Damme K., Bekker E.I., Siboualipha S., Silva-Briano M., Ortiz A.A., De La Rosa R.G., Sanoamuang L. 2013b. Cladocera (Crustacea: Branchiopoda) of Vientiane province and municipality, Laos // J. Limnol. Vol.72. No.s2. P.81–108. https://doi.org/10.4081/jlimnol.2013.s2.e6

Krebs C. 1999. Ecological Methodology. 2nd ed. California: Addison-Wesley Educational Publishers. 620 p.

Lieder U. 1996. Crustacea: Cladocera/Bosminidae // J. Schworbel, P. Zwick (Hrsg.). Süßwasserfauna von Mitteleuropa. Stuttgart: Gustav Fischer Verlag. S.1−80.

Lv J., Wu H., Chen M. 2011. Effects of nitrogen and phosphorus on phytoplankton composition and biomass in 15 subtropical, urban shallow lakes in Wuhan, China // Limnologica. Vol.41. No.1. P.48–56. https://doi.org/10.1016/j.limno.2010.03.003

Magurran A.E. 2004. Measuring Biological Diversity. Oxford: Blackwell Publishing. 256 p.

McCune B., Mefford M.J. 2006. PC-ORD: Multivariate Analysis of Ecological Data Version 5.0. Oregon: MjM Software Design, Gleneden Beach.

Ongsomwang S., Sutthivanich I. 2013. Integration of remotely sensed data and forest landscape pattern analysis in Sakaerat Biosphere Reserve // Suranaree J. Sci. Technol. Vol.21. No.3. P.233–248.

Orlova-Bienkowskaja M.Y. 2001. Cladocera: Anomopoda: Daphniidae: genus *Simocephalus* // H.J.F. Dumont (ed.). Guides to the Identification of the Microinvertebrates of the Continental Waters of the World 17. Leiden: Backhuys Publishers. 130 p.

Petersen W.J., Savini T., Steinmetz R., Ngoprasert D. 2019. Periodic resource scarcity and potential for interspecific competition influences distribution of small carnivores in a seasonally dry tropical forest fragment // Mamm. Biol. Vol.95. P.112–122. https://doi.org/10.1016/j.mambio.2018.11.001

Pholpunthin P. 1997. Freshwater zooplankton (Rotifera, Cladocera and Copepoda) from Thale-Noi, South Thailand // J. Sci. Soc. Thailand. Vol.23. P.23–34.

Plangklang N., Boonyanusith C., Athibai S. 2019. Species richness and abundance of monogonont rotifers in relation to environmental factors in the UNESCO Sakaerat Biosphere Reserve, Thailand // J. Threat. Taxa. Vol.11. No.9. P.14087–14100. https://doi.org/10.11609/jott.4721.11.9.14087-14100

Ruengsawang N., Sangpradub N., Artchawakom T., Pronzato R., Manconi R. 2017. Rare freshwater sponges of Australasia: new record of *Umborotula bogorensis* (Porifera: Spongillida: Spongillidae) from the Sakaerat Biosphere Reserve in Northeast Thailand // Eur. J. Taxon. Vol.260. P.1−24. https://doi.org/10.5852/ejt.2017.260

Rusydi A.F. 2018. Correlation between conductivity and total dissolved solid in various type of water: A review // OP Conf. Ser. Earth Environ. Sci. Vol.118. Art.012019. https://doi.org/10.1088/1755-1315/118/1/012019

Sa-ardrit P., Beamish F.W.H. 2005. Cladocera diversity, abundance and habitat in a Western Thailand Stream // Aquat. Ecol. Vol.39. P.353–365. https://doi.org/10.1007/s10452-005-0783-4

Sanoamuang L. 1998. Contributions to the knowledge of the Cladocera of north-east Thailand // Hydrobiologia Vol.362. P.45–53. https://doi.org/10.1023/A:1003111401684

Shannon C., Weaver W. 1949. The Mathematical Theory of Communication. Illinois: University of Illinois Press. 131 p.

Sharma B.K., Sharma S. 2014. Faunal diversity of Cladocera (Crustacea: Branchiopoda) in wetlands of Majuli (the largest river island), Assam, northeast India // Opusc. zool. Vol.45. No.1. P.83–94.

Sinev A.Y. 2011. Redescription of the rheophilous cladocera *Camptocercus vietnamensis* Than, 1980 (Cladocera: Anomopoda: Chydoridae) // Zootaxa. Vol.2934. P.53–60. https://doi.org/10.11646/zootaxa.2934.1.5

Sinev A.Y. 2012. *Alona kotovi* sp. nov., a new species of Aloninae (Cladocera: Anomopoda: Chydoridae) from South Vietnam // Zootaxa. Vol.3475. P.45–54. https://doi.org/10.11646/zootaxa.3475.1.4

Sinev A.Y. 2014. A comparative morphological analyses of four species of *Camptocercus* Baird, 1843 (Cladocera: Anomopoda: Chydoridae) // Zootaxa. Vol.3895. No.2. P.183–207. https://doi.org/10.11646/zootaxa.3895.2.3

Sinev A.Y. 2016. Key for identification of Cladocera of the subfamily Aloninae (Anomopoda: Chydoridae) from South-East Asia // Zootaxa. Vol.4200. No.4. P.451–486. https://doi.org/10.11646/zootaxa.4200.4.1

Sinev A.Y., Korovchinsky N.M. 2013. Cladocera (Crustacea: Branchiopoda) of Cat Tien National Park, South Vietnam // J. Limnol. Vol.70. No.2. P.125–141. https://doi.org/10.4081/jlimnol.2013.s2.e8

Sinev A.Y., Garibian P.G., Gu Y. 2016. A new species of *Pseudochydorus* Fryer, 1968 (Cladocera: Anomopoda: Chydoridae) from South-East Asia // Zootaxa. Vol.4079. No.1. P.129−139. https://doi.org/10.11646/zootaxa.4079.1.9

Sinev A.Y., Gu Y., Han B.P. 2015. Cladocera of Hainan Island, China // Zootaxa. Vol.4006. No.3. P.569–585. https://doi.org/10.11646/zootaxa.4006.3.9

Sinev A.Y., Gu Y., Han B.P. 2020. Winter-Spring fauna of Cladocera of Dali Bai Autonomous Prefecture, Yunnan Province // China. Limnetica. Vol.39. No.2. P.621–638. https://doi.org/10.23818/limn.39.40

Sinev A.Y., Semenyuk I.I. 2023 South-East Asian populations of *Karualona* cf. *karua* (King. 1853) (Crustacea: Cladocera: Chydoridae) belong to a separate species. // Zootaxa. Vol.5325. No.2. P.223–238. https://doi.org/10.11646/zootaxa.5325.2.4

Sinev, A.Y., Sousa F.D., Elmoor-Loureiro L.M. 2023. Revision of the guttata-group of *Alona* s. lato leads to its translocation to *Prendalona* Sousa, Elmoor-Loureiro & Santos, 2018 (Cladocera: Anomopoda: Chydoridae). // Zootaxa, Vol.5293. No.1. P.95–121. https://doi.org/10.11646/zootaxa.5293.1.4

Sinev A.Y., Tiang-nga S., Sanoamuang, L. 2023. *Anthalona vandammei* sp. nov. from Thailand, a sibling species of Neotropical *Anthalona brandorffi* (Sinev & Holwedell, 2002) (Cladocera: Anomopoda: Chydoridae) // Zootaxa. Vol.5230. No.1. P.67–78. https://doi.org/10.11646/zootaxa.5230.1.4

Smirnov N.N. 1971. [Chydoridae of the world fauna] // Fauna SSSR. Rakoobraznye. Vol.1. No.2. 531 p [in Russian].

Smirnov N.N. 1992. The Macrothricidae of the world // Guides to the Identification of the Microinvertebrates of the Continental Waters of the World 1. The Hague: SPB Academic Publishing. 143 p.

Smirnov N.N. 1996. Cladocera: The Chydorinae and Sayciinae (Chydoridae) of the World // H.J. Dumont (ed.). Guides to the Identification of the Microinvertebrates of the Continental Waters of the World 11. Amsterdam: SPB Academic Publishing. 197 p.

Smirnov N.N. 1998. A revision of the genus *Camptocercus* (Anomopoda, Chydoridae, Aloninae) // Hydrobiologia. Vol.386. P.63–83. https://doi.org/10.1023/A:1003524414799

Smirnov N.N. 2017. Physiology of the Cladocera. 2nd ed. London: Elsevier Inc. 402 p.

Soto D., De Los Rios P. 2006. Influence of trophic status and conductivity on zooplankton composition in lakes and ponds of Torres del Paine National Park (Chile) // Biologia. Vol.61. No.5. P.541–546. https://doi.org/10.2478/s11756-006-0088-7

Sousa F.D.R., Elmoor-Loureiro L.M.A. 2012. How many species of cladocerans (Crustacea, Branchiopoda) are found in Brazilian Federal District? // Acta Limnol. Bras. Vol.24. No.4. P.351–362.

Sousa F.D.R., Elmoor-Loureiro L.M.A. 2013. Cladocerans (Crustacea: Anomopoda and Ctenopoda) of the Sempre Vivas National Park, Espinhaço Range, Minas Gerais, Brazil // Check List. Vol.9. No.1. P.4–8. https://doi.org/10.15560/9.1.4

St. Pierre J.I., Kovalenko K.E. 2014. Effect of habitat complexity attributes on species richness // Ecosphere. Vol.5. No.2. P.1–10. https://doi.org/10.1890/ES13-00323.1

Sutthivanich I., Ongsomwang S. 2015. Evaluation on landscape change using remote sensing and landscape metrics: A case study of Sakaerat Biosphere Reserve (SBR), Thailand // Int. J. Environ. Sci. Dev. Vol.6. No.3. P.182−186.

Takahashi E.M., Lansac-Tôha F.A., Velho L.F.M., Bonecker C.C. 2005. Longitudinal distribution of cladocerans (Crustacea) in a Brazilian tropical reservoir // Acta Limnol. Bras. Vol.17. No.3. P.257–265.

Thanh D.N., Ray T.C., Mien F.V. 1980. Key to freshwater invertebrates of North Vietnam. Hanoi. 570 p. [In Vietnamese]

Tiang-nga S. 2019. [Cladoceran communities in Udon Thani and Bueng Kan provinces, with an updated checklist of cladocerans in Lake Kud-Thing, Bueng Kan Province]. [Thesis of Candidate (Ph.D.) of Biology Degree]. Kyiv: Khon Kaen University 218 p. [In Khon Kaen, with English and Thai summary].

Tiang-nga S., Sinev A.Y., Sanoamuang L. 2020. High diversity of Cladocera (Crustacea: Branchiopoda) in a Ramsar site Lake Kud-Thing, Northeast Thailand // Zootaxa. Vol.4780. No.2. P.275–290. https://doi.org/10.11646/zootaxa.4780.2.3

UNESCO. 2021. Sakaerat Biosphere Reserve, Thailand. Available from https://en.unesco.org/biosphere/aspac/sakaerat

Vad C.F., Horváth Z., Kiss K.T., Ács É., Török J.K., Forró L. 2012. Seasonal dynamics and composition of cladoceran and copepod assemblages in ponds of a Hungarian cutaway peatland // Int. Rev. Hydrobiol. Vol.97. No.5. P.420–434. https://doi.org/10.1002/iroh.201201441

Wang L., Liu Q., Hu C., Liang R., Qiu J., Wang Y. 2018. Phosphorus release during decomposition of the submerged macrophyte *Potamogeton crispus* // Limnology. Vol.19. P.355–366. https://doi.org/10.1007/s10201-018-0538-2

Wongrat L., Pipatcharoenchai W. 2003. Zooplankton of Kanchanaburi Province, Thailand // J. Fish. Environ. Vol.25. P.8–29. https://li01.tci-thaijo.org/index.php/JFE/article/view/96589

Yang X.D., Dong X.H., Gao G., Pan H.X., Wu J.L., Tian X.R. 2005. Relationship between surface sediment diatoms and summer water quality in shallow lakes of the middle and lower reaches of the Yangtze River // J. Integr. Plant Biol. Vol.47. No.2 P.153−164.

Zar J.H. 1999. Biostatistical Analysis. 4th ed. New Jersey: Prentice Hall. 663 p.

Responsible editor A.A. Kotov