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# Diversity of freshwater red algae at Khao Luang National Park, southern Thailand

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Freshwater red algal diversity and the relationship with water conditions in 22 stream segments in the area around Khao Luang National Park, Nakhon Si Thammarat province, southern Thailand, were studied during a period of twelve months (May 2014 to April 2015). Sixteen species of freshwater red algae, belonging to eight genera (*Audouinella*, *Balliopsis*, *Batrachospermum*, *Caloglossa*, *Compsopogon*, *Kumanoa*, *Sirodotia*, and *Thorea*) were identified, which were all reported earlier for the country. *Thorea clavata* (Thoreaceae) was the most common species occurring in eight stream segments. *Caloglossa beccarii sensu lato* (Delesseriaceae) and *Sirodotia huillensis* Skuja (Batrachospermaceae) had the highest percent cover with up to 40% and 20% per stream segment, respectively. The water quality showed most sites to be unpolluted or ultra-oligotrophic to oligotrophic. Canonical Correspondence Analysis revealed some trends in occurrence of individual species with stream environmental variables: *Batrachospermum* sp. with strong current velocity; *Kumanoa Hirosei* with high turbidity, total dissolved solid and alkalinity; *Caloglossa beccarii* with high conductivity; *Kumanoa tabagatenensis* with high ammonia-nitrogen and *Thorea siamensis* with high calcium and magnesium. In view of the scarce studies on the stream ecology of freshwater red algae in Philippines and neighbouring countries, it is expected that the data presented here would be helpful in more critical further studies in south-east Asia in general.

**Key Words:** *Audouinella*; *Balliopsis*; *Batrachospermum*; biodiversity; *Caloglossa*; *Compsopogon*; environmental factors; *Kumanoa*; *Sirodotia*; *Thorea*

## INTRODUCTION

Freshwater red algae constitute only about 3.4% of the total number of members of the division Rhodophyta, while the remaining more than 96.6% are exclusively marine (Sheath 1984, Guiry and Guiry 2017). The envi-

ronmental physical and chemical conditions are considerably different spatially and temporally from those of the marine environment (Necchi et al. 1999). Red algal diversity and ecology in characteristics in freshwaters are



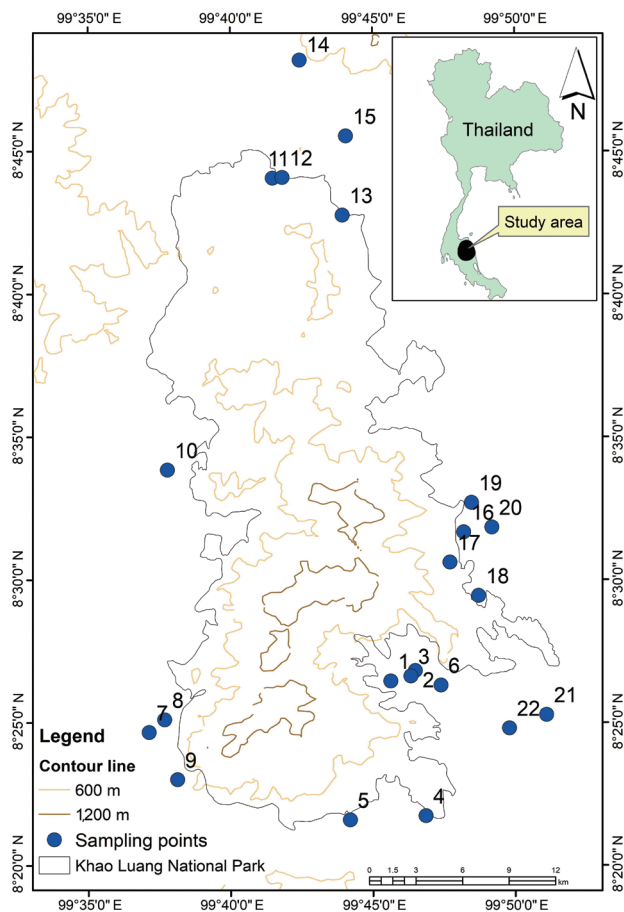
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**Fig. 1.** Map of Thailand showing the location of the study areas around Khao Luang National Park, Nakhon Si Thammarat province, Thailand.

diverse. Sheath (1984) and Sheath and Hambrook (1990) evaluated on large scale (biomes and continent), the biology, ecology, and taxonomy of freshwater red algae. Primary studies of the ecology, distribution and diversity of freshwater red algae have been conducted in Rhode Island, USA by Burkholder and Sheath (1985), Sheath and Burkholder (1985), Sheath et al. (1986), in Brazil by Nec-

chi (1993), Necchi et al. (1999), and in Europe by Eloranta and Kwandrans (1996, 2004). Malaysia has high red algal diversity with many endemic taxa, (Johnston et al. 2014). Only a few investigations of freshwater macroalgal ecology have been published in South East Asia. In Thailand, ecological studies have been conducted on water quality and its effects on the distribution and diversity of phytoplankton and benthic algae in Doi Suthep-Pui National Park (Peerapornpisal et al. 2000). Studies were performed to determine phytoplankton bio-indicators in Ang-Kaew reservoir by Peerapornpisal et al. (2004) and macroalgal / phytoplankton diversity as bio-monitors of water quality by Suphan and Peerapornpisal (2003, 2007). Red algal diversity and ecology have been investigated by Chankaew et al. (2013, 2015), Peerapornpisal et al. (2006), Traichaiyaporn et al. (2004, 2005, 2007), and Naulcharoen et al. (2007). More recently, Chankaew et al. (2016) evaluated the importance of two freshwater red algae (*Caloglossa ogasawarensis* and *Compsopogon caeruleus* as *C. aeruginosus*) as potential candidates for development of antioxidants. The aims of the present study are to describe the diversity and abundance of freshwater red algae and their relation to environmental factors in stream segments around an important area in southern Thailand, the Khao Luang National Park. The data presented here will be a useful source of information for further studies on the ecology of the freshwater red algae in lotic water bodies of other are of Thailand and the Southeast Asian region.

**MATERIALS AND METHODS**

**Area of study**

Khao Luang National Park (Nakhon Si Thammarat province) (Fig. 1), is an important watershed region for the surrounding farms and villages, located between the following geographic coordinates: 08°30' N, 99°44' E. Cov-

**Table 1.** Sampling stations from districts, around Khao Luang National Park, Nakhon Si Thammarat province, Thailand

Station	Location
K1-K6	LanSaKa district; Wangbaipat, Klong Toog, Lumnga, Nongkaew, Cheesuk and Wangpai streams
K7-K8	ChangKlang district; Klongtow and Klongpeeg streams
K9	Phipoon district; Nannokan stream
K10	Chawang district; Suanei stream
K11-K15	Nopphitum district; Pakklong, Krungching, Klongyan, Klongka and Klonggun streams
K16-K20	Promkhiri district; Huaytaykaw, Plauyoen, Plauynam, Promlok and Noga streams
K21-K22	Mueang district; Huaymoo and Huayhang streams

See Fig. 1 for location of each station.

ering an area of approximately 570 km<sup>2</sup>, it is mountainous with many tall peaks and has forests, wildlife, rivers and waterfalls (National Park, Wildlife and Plant Conservation Department 2006). Due to its unique location on the peninsula, it receives heavy monsoon rains throughout the year from both the east and the west coasts. The climate is tropical, with well-demarcated rainy and dry seasons. We selected 22 stream segments accessible by car around community areas of seven different districts of Nakhon Si Thammarat province in Khao Luang National Park (designated K1 to K22) (Table 1).

### Environmental (physical and chemical) water variables and red algal sampling

Physical and chemical stream variables were measured and two replicates of each alga were collected at each site in each of three seasons over a period of 12 months (May 2014 to April 2015): the early rainy season (July-August 2014, SW monsoon), the heavy rainy (November-December 2014, NE monsoon), and the dry season (March-April 2015). Species exploring were conducted along a transect line marked by permanent plots. A long-transect length surveyed is 100 m per sampling site. In each of the 22 sites, a permanent plot 10 m in length along the stream margin was used as the sampling area were chosen at random (modified from Necchi 1993, Necchi et al. 1999). Along this 10 m long transect, divided into 10 at equal intervals, red algal occurrence (presence and percent cover) was estimated visually on the stream bottom and abundance was averaged over the entire stream segment according to the following scale (modified from Necchi 1993): 0, absent; 1, <10%; 2, 11-20%; 3, 21-30%; 4, 31-40%; 5, >40%. This procedure was followed in two replicates in each site and data were computed as the average for the sampling site.

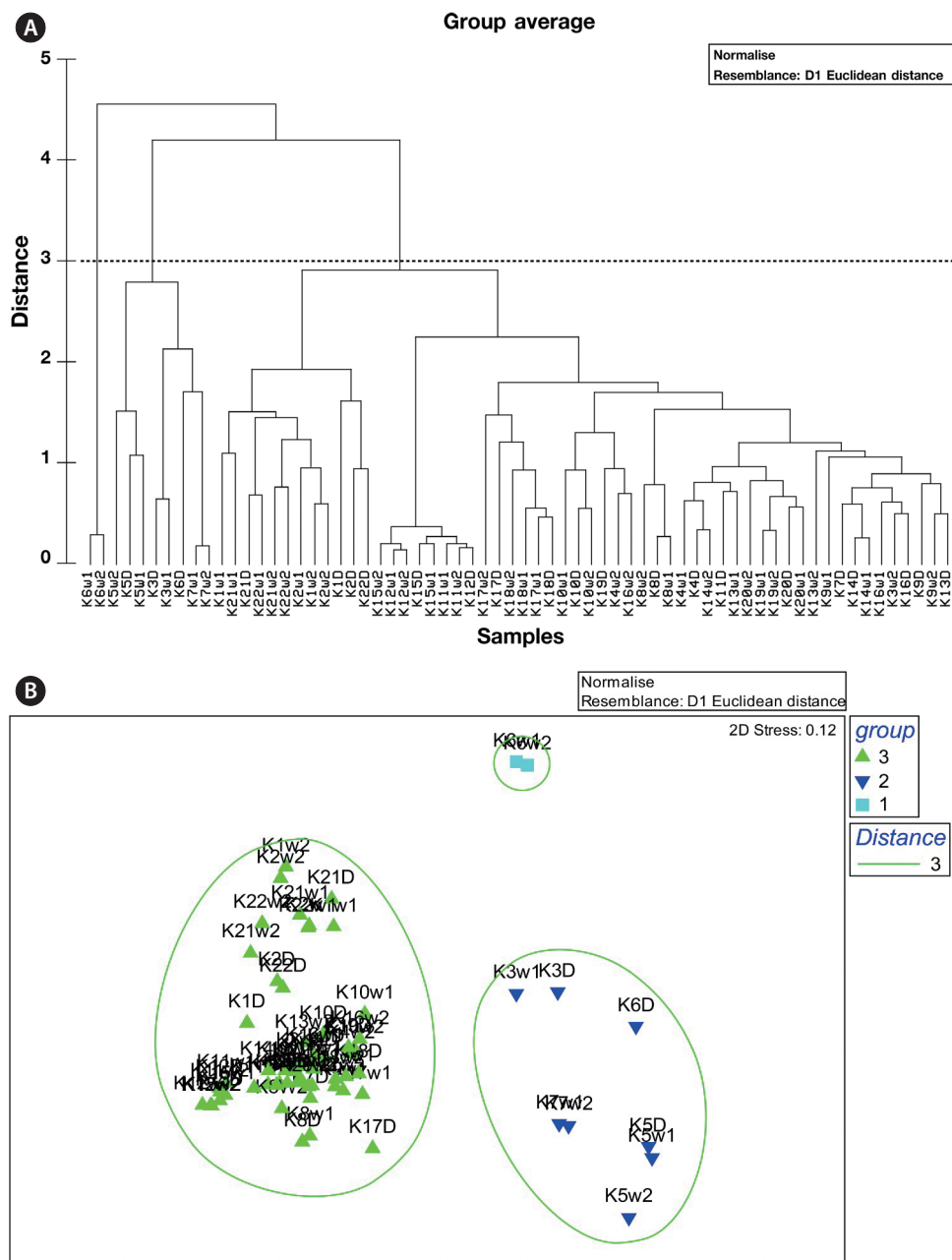
In each study site, water samples were collected for measurement according to American Public Health Association, American Water Works Association, and Water Pollution Control Pact standards (Eaton et al. 1995). Temperature, water depth, current velocity, conductivity, total dissolved solid, dissolved oxygen (DO), and pH values were measured in the field using standard portable instruments (Portable Multi Parameter Photometer, MD600; Lovibond, Dortmund, Germany). Nutrients, ammonium-nitrogen (NH<sub>3</sub>-N), nitrate-nitrogen (NO<sub>3</sub>-N), and orthophosphate (PO<sub>4</sub>-P), acidity, alkalinity, and hardness were analyzed in the laboratory by standard methods (Eaton et al. 1995) from water samples kept at 4°C until analysis. The trophic status was evaluated us-

ing the Applied Algal Research Laboratory Physical and Chemical score (AARL-PC score) (Peerapornpisal et al. 2004). This composite index defines water quality categories using dissolved oxygen, conductivity, nitrate-nitrogen, ammonia-nitrogen, and soluble reactive phosphorus (SRP).

Algal specimens were preserved in 2% glutaraldehyde in the field. Species were identified using morphological characters according to Jose and Patel (1990), Kumano (2002), Traichaiyaporn et al. (2007, 2012), Necchi and Vis (2012), and Necchi (2016). The community structure was evaluated using the Shannon-Wiener diversity index ( $H'$ ) and Pielou's evenness index ( $J'$ ) (Brower et al. 1997). These indices were calculated from the annual average scores of red algal species records. Shannon-Wiener diversity  $-\sum_{i=1}^n pi \log_2 pi$  with  $i$  proportion of each algal species (percent cover) to the total abundance, Pielou's evenness =  $H' / H_{max}$ , where  $H'$  = Shannon-Wiener diversity index,  $pi$  = the proportion of individual average scores of the species  $i^{th}$  species expressed as a proportion of total abundance,  $H_{max} = \log_2 S$ , where  $S$  = the total number of species.

### Statistical analysis

Univariate analysis, using the mean and standard deviation, was applied to describe and evaluate the water quality among sampling sites and seasons. Multivariate indices analysis, cluster and ordination multi-dimensional scaling (MDS) analyses were used to classify similarity of water quality parameters among seasons and sites. The cluster and MDS analyses aimed to find grouping of similarities of samples among different sites and season that samples within a group are more similar to each other than samples in different groups. The resulting cluster was shown in tree-like diagram called a dendrogram and MDS was shown as biplot. The correspondence of the ordination to the distances shown as a stress value, where a value less than 0.05 is an excellent fit, a value less than 0.10 is a good fit, a value less than 0.20 is a potential fit and a value greater than 0.30 is an arbitrary fit. Both the clustering dendrogram and map were constructed using a standardized Euclidean distances matrix for the water variables. Analysis of similarity (ANOSIM) was also performed to determine significant differences in the different groups of water parameters. The similarity percentages (SIMPER) was used to test the parameters within groups. All analysis procedures used were based on Clark and Warwick (1994) using PRIMER program (ver. 5 for Windows; Bourne Press Limited, Bournemouth,



**Fig. 2.** Normalized Euclidean cluster diagram (A) and multi-dimensional scaling analyses (B) according to sampling sites of physico-chemical variable in all seasons.

UK). The relationships between red algae assemblages and environment variables were explored by Canonical Correspondence Analysis (CCA) using MVSP (MultiVariate Statistical Package) for Windows ver. 3.22. The result was shown by CCA plot.

In addition, the trophic status of water was evaluated from the main parameters such as dissolved oxygen, conductivity, ammonia-nitrogen, nitrate-nitrogen and SRP by AARL-PC score, based on Peerapornpisal et al. (2004).

## RESULTS AND DISCUSSION

### Environmental factors

Most stream segments (20 of 22) were slightly acidic (pH  $6.3 \pm 0.2$  to  $6.7 \pm 0.6$ ) while two stream segment (K5 and K9) were slightly basic (pH  $7.4 \pm 0.5$  and  $7.1 \pm 1.2$ ), with high DO content ( $3.51 \pm 1.5$  to  $7.8 \pm 0.7$  mg L<sup>-1</sup>) and conductivity levels ( $12.4 \pm 10.1$  to  $128.3 \pm 24.4$   $\mu$ s cm<sup>-1</sup>). All

stream sites had clear water with low turbidity (except K6 site) and relatively high water temperature (varied from  $24.5 \pm 0.4$  to  $26.5 \pm 0.6^\circ\text{C}$ ). The current velocity was highly variable, ranging from  $2.0 \pm 0.1$  to  $116.5 \pm 22.2 \text{ cm s}^{-1}$ . The turbidity ranged from  $1.0 \pm 0.1$  to  $116.5 \pm 22.2$  nephelometric turbidity unit. Total dissolved solids (TDS) ranged from  $6.4 \pm 1.1$  to  $58.4 \pm 20.2 \text{ mg L}^{-1}$ . In acid samples  $\text{CaCO}_3$  varied from  $2.3 \pm 0.3$  to  $19.8 \pm 4.4 \text{ mg L}^{-1}$ . In alkaline samples alkalinity is accurately expressed as  $\text{CaCO}_3$ , which was  $4.3 \pm 1.5$  to  $81.3 \pm 0.8 \text{ mg L}^{-1}$ . In a wide range of samples hardness as  $\text{CaCO}_3$  varied from  $5.1 \pm 0.8$  to  $130.8 \pm 59.6 \text{ mg L}^{-1}$ . Ammonia-nitrogen values varied from  $<0.02 \pm 0.0$  to  $0.22 \pm 0.1 \text{ mg L}^{-1}$  (Table 2).

Most species occurred in slightly acidic water, which is consistent with data from Sheath and Hambrook (1990), who reported freshwater red algae occurring mostly in mildly acidic streams ranging between pH 6.0 and 7.0. The AARL-PC showed most sites within the range of ultra-oligotrophic to oligotrophic status, and few in the oligo-mesotrophic (Table 3). Most of the sampling sites showed similar trophic status throughout the year and were classified to clean to very clean. This finding is probably due to geographical proximity of the preserved area of Khao Luang National Park. However, the sampling sites K2, K4, K5, K14, and K22 located in the downstream area showed moderate contamination levels by the agriculture activities, evidenced by oligo-mesotrophic status (clean to moderate clean). These characteristics were similar to those described in eight National parks of five provinces in northern Thailand (Traichaiyaporn et al. 2005).

Cluster and MDS analyses of water quality parameter variations among seasons and sites showed three groups. The three groups (70% similarity and ANOSIM test results of  $R = 0.977$ ,  $p < 0.01$ ) were group 1—K6W1 and K2W2, group 2—K3D, K3W1, K5D, K5W1, K5W2, K6D, K7W1, and K7W2, and group 3 composed of the rest of the sampling dates (56 variables) (Fig. 2A & B). One parameter indicated similarity within each groups: turbidity contributed greater than 15% similarity in the first group; TDS, hardness and velocity in the second group; TDS and conductivity in the third group. The status of Khao Luang National Park water quality is similar to the results of Thiemdoea et al. (2007) in other areas of northern and southern Thailand with mostly clean waters.

### Species composition and distribution

A total of 16 red algal species were identified (Table 4), belonging to eight genera *Audouinella*, *Balliopsis*, *Batrachospermum*, *Caloglossa*, *Compsopogon*, *Kumanoa*,

*Sirodotia*, and *Thorea*) that are distributed among the families Acrochaetiaceae, Batrachospermaceae, Compsopogonaceae, Delesseriaceae, and Thoreaceae, and occurred in all collecting sites sampled (Table 3). In 16 sites only one species was found, whereas site K5 had the highest species richness with four species (Table 3). The most species-rich genera recorded was *Kumanoa* (four species), followed by *Sirodotia* (three species), and *Thorea* (two species). *Audouinella*, *Balliopsis*, *Caloglossa*, and *Compsopogon* has only one species. *Thorea clavata* Seto & Rathanasabapathy occurred most frequently in eight sites in both seasons, while most appeared rarely (only 1 site). During this study, maximum algal abundance was observed in April 2015 at the Klonggun site (K15), in which the dominant species was *Caloglossa beccarii* (Zanardini) De Toni *sensu lato*. The lowest algal abundance was found in Klongtow site (K7), in which *Audouinella subtilis* Jao occurred in both seasons. The highest species richness was at the Klongwangpai site (K6) with four species, while at 11 sites only one species was found. Among the 16 species sampled, *T. clavata* and *C. beccarii sensu lato* were dominant with greatest abundance and maximum density, respectively. In contrast, some species were found only in particular sites, for instance, *A. subtilis* occurred only at Klongtow (K7), *Thorea siamensis* was observed only at the Huaycheesuk (K5) and *Kumanoa gibberosa* occurred only at the Huaytrankaew (K16) (Table 3). Our results show the streams around Khao Luang National Park have a high diversity of red algae compared to studies of other regions of the world (Necchi et al. 1999, Eloranta et al. 2016). This area is well-preserved and has relatively rich red algal communities, when compared with some neighbouring countries like Philippines (Liao 2010), Malaysia and Indonesia (Johnston et al. 2014).

It is also important to point out that the alga we have identified tentatively as *C. beccarii sensu lato* as occurring in Thailand, well in the morphological characteristics of *Caloglossa fluviatilis*, a species described from Panama and also reported from India (Kamiya and West 2014). However, molecular characterization of the Thailand specimens are under study to confirm our tentative identification.

### Comparison of dry and rainy seasons

Table 3 shows some differences in diversity of study sites and seasons. Of the 22 sites surveyed, eight species were found in all seasons. The highest values (16) of species richness were observed in the period of dry and wet

**Table 2.** Mean and standard deviation for physico-chemical parameters of stream around Khao Luang National Park, Thailand

Site <sup>a</sup>	Temp. (°C)	Turbidity (NTU)	Velocity (m s <sup>-1</sup> )	Cond. (µS cm <sup>-1</sup> )	TDS (mg L <sup>-1</sup> )	Acidity (mg L <sup>-1</sup> )	Alkalinity (mg L <sup>-1</sup> )	Hardness (mg L <sup>-1</sup> )	pH	DO (mg L <sup>-1</sup> )	NH <sub>3</sub> (mg L <sup>-1</sup> )	NO <sub>3</sub> (mg L <sup>-1</sup> )	SRP (mg L <sup>-1</sup> )
K1	24.9 ± 0.9	13.1 ± 4.3	18.7 ± 27.9	46.7 ± 14.3	53.0 ± 28.1	4.1 ± 0.3	21.2 ± 1.4	10.7 ± 0.2	6.4 ± 0.2	6.1 ± 0.3	0.02 ± 0.0	0.08 ± 0.0	0.00 ± 0.0
K2	24.6 ± 0.6	13.2 ± 25.3	21.8 ± 26.3	36.9 ± 8.9	53.0 ± 28.4	3.5 ± 1.2	16.0 ± 1.8	8.8 ± 0.3	6.4 ± 0.1	5.1 ± 1.6	0.04 ± 0.1	0.03 ± 0.0	0.03 ± 0.0
K3	25.2 ± 0.5	6.3 ± 4.8	7.9 ± 1.9	31.8 ± 9.5	37.5 ± 24.5	3.7 ± 1.0	9.0 ± 2.6	50.3 ± 40.0	6.7 ± 0.6	6.2 ± 1.3	0.22 ± 0.1	0.02 ± 0.0	0.03 ± 0.0
K4	24.8 ± 0.2	1.0 ± 0.1	11.3 ± 3.3	32.5 ± 12.8	10.3 ± 0.9	3.1 ± 0.4	6.2 ± 2.4	7.2 ± 2.7	6.3 ± 0.2	5.3 ± 0.4	0.03 ± 0.0	0.01 ± 0.0	0.07 ± 0.0
K5	24.5 ± 0.4	2.2 ± 1.0	116.5 ± 22.2	12.4 ± 10.1	12.5 ± 1.2	3.2 ± 0.5	81.3 ± 0.8	130.8 ± 59.6	7.4 ± 0.5	4.1 ± 1.2	0.11 ± 0.0	0.00 ± 0.0	0.01 ± 0.0
K6	25.1 ± 0.3	83.3 ± 22.8	8.3 ± 1.1	23.3 ± 8.7	11.7 ± 0.6	3.0 ± 0.8	5.1 ± 1.6	34.5 ± 65.5	6.4 ± 0.7	5.2 ± 0.6	0.03 ± 0.0	0.04 ± 0.0	0.03 ± 0.0
K7	25.2 ± 0.1	6.1 ± 0.2	17.0 ± 6.4	28.9 ± 0.6	6.4 ± 1.1	5.0 ± 1.1	4.3 ± 0.7	49.7 ± 43.4	6.6 ± 0.4	7.8 ± 0.7	0.04 ± 0.0	0.03 ± 0.0	0.04 ± 0.1
K8	25.4 ± 0.2	6.4 ± 0.8	2.6 ± 0.6	36.5 ± 6.8	7.8 ± 2.4	6.8 ± 1.5	5.0 ± 1.0	7.0 ± 1.2	6.5 ± 0.4	5.3 ± 0.1	0.05 ± 0.1	0.09 ± 0.1	0.03 ± 0.0
K9	26.0 ± 0.4	6.7 ± 0.7	9.3 ± 0.7	25.4 ± 3.5	9.4 ± 2.0	9.0 ± 1.0	5.3 ± 0.4	8.8 ± 0.8	7.1 ± 1.2	5.7 ± 0.5	0.09 ± 0.1	0.04 ± 0.0	0.04 ± 0.1
K10	24.9 ± 0.2	2.7 ± 0.4	2.0 ± 0.1	20.7 ± 4.7	12.5 ± 1.3	4.1 ± 0.9	6.1 ± 0.8	10.9 ± 1.4	6.7 ± 0.0	4.9 ± 0.5	0.05 ± 0.0	0.01 ± 0.0	0.02 ± 0.0
K11	25.6 ± 0.3	4.6 ± 1.6	9.8 ± 0.4	87.1 ± 24.6	11.6 ± 2.4	2.3 ± 0.3	5.8 ± 0.9	6.7 ± 1.7	6.4 ± 0.6	5.8 ± 0.8	0.06 ± 0.0	0.02 ± 0.0	0.03 ± 0.0
K12	25.4 ± 0.2	7.2 ± 1.8	10.7 ± 0.7	45.2 ± 42.0	10.5 ± 2.8	3.2 ± 0.1	5.0 ± 0.8	5.1 ± 0.8	6.7 ± 0.3	6.3 ± 0.5	0.04 ± 0.0	0.07 ± 0.0	0.01 ± 0.0
K13	24.9 ± 0.5	8.1 ± 0.3	9.9 ± 0.2	33.1 ± 6.9	9.8 ± 2.9	5.1 ± 2.6	9.3 ± 4.7	8.3 ± 1.3	6.6 ± 0.1	6.7 ± 0.9	0.08 ± 0.0	0.03 ± 0.0	0.01 ± 0.0
K14	26.5 ± 0.6	5.8 ± 3.4	10.7 ± 0.9	34.4 ± 8.9	11.8 ± 0.8	3.7 ± 1.4	5.1 ± 0.5	8.4 ± 2.6	6.2 ± 0.3	4.9 ± 1.5	0.12 ± 0.0	0.04 ± 0.0	0.09 ± 0.0
K15	25.2 ± 0.4	2.0 ± 1.3	12.6 ± 2.2	128.3 ± 24.4	10.9 ± 0.8	4.3 ± 0.3	4.8 ± 2.6	7.3 ± 1.7	6.5 ± 0.9	4.0 ± 1.3	0.10 ± 0.0	0.03 ± 0.0	0.04 ± 0.0
K16	25.1 ± 0.5	3.8 ± 1.1	12.7 ± 0.5	25.4 ± 5.9	13.0 ± 1.1	3.8 ± 1.1	6.3 ± 0.5	8.9 ± 2.2	6.7 ± 0.2	4.7 ± 1.9	0.03 ± 0.0	0.02 ± 0.0	0.01 ± 0.0
K17	26.1 ± 0.3	3.4 ± 0.4	10.2 ± 0.5	26.8 ± 2.2	13.5 ± 0.1	19.8 ± 4.4	4.3 ± 7.8	13.4 ± 1.0	6.5 ± 0.6	6.1 ± 0.5	0.09 ± 0.0	0.04 ± 0.0	0.01 ± 0.0
K18	26.0 ± 0.3	4.6 ± 0.5	8.8 ± 2.9	25.1 ± 1.3	13.3 ± 0.8	15.2 ± 1.5	5.4 ± 1.8	10.7 ± 0.7	6.5 ± 1.8	4.7 ± 2.4	0.02 ± 0.0	0.09 ± 0.0	0.03 ± 0.1
K19	26.1 ± 0.7	2.3 ± 0.2	12.6 ± 0.4	36.9 ± 10.5	13.8 ± 1.6	3.8 ± 1.4	4.4 ± 0.4	14.0 ± 0.9	6.6 ± 0.2	3.5 ± 0.9	0.03 ± 0.0	0.25 ± 0.0	0.04 ± 0.0
K20	25.2 ± 0.5	4.2 ± 1.5	13.7 ± 1.3	38.8 ± 5.2	13.0 ± 0.4	10.8 ± 0.7	5.0 ± 2.9	11.5 ± 1.5	6.4 ± 1.4	3.5 ± 1.5	0.10 ± 0.0	0.03 ± 0.0	0.05 ± 0.0
K21	25.6 ± 0.6	13.0 ± 6.5	8.9 ± 15.6	40.2 ± 32.5	58.4 ± 20.2	5.8 ± 1.6	11.2 ± 9.4	10.4 ± 0.4	6.7 ± 0.1	5.3 ± 1.7	0.05 ± 0.0	0.17 ± 0.0	0.00 ± 0.0
K22	25.4 ± 0.8	12.7 ± 1.8	8.7 ± 11.2	39.9 ± 14.4	49.7 ± 23.6	3.4 ± 0.8	4.3 ± 1.5	8.6 ± 0.6	6.3 ± 0.1	5.5 ± 1.9	0.03 ± 0.0	0.07 ± 0.0	0.02 ± 0.0

Values are presented as mean ± standard error (n = 6).

Temp., temperature; NTU, nephelometric turbidity unit; Cond., specific conductance; TDS, total dissolved solids; DO, dissolved oxygen; SRP, soluble reactive phosphorus.

<sup>a</sup>See Table 1 for abbreviations.

**Table 3.** Species number, Shannon-Wiener index, Simpson index, and Pielou evenness and water quality by trophic status for the different sampling sites

Site <sup>a</sup> / Diversity index	No. of species			Trophic status		
	W1	W2	D	W1	W2	D
K1	1	1	1	UO	UO	O
K2	1	1	1	UO	O	OM
K3	0	1	1	UO	UO	O
K4	1	1	1	UO	O	OM
K5	4	3	1	O	O	OM
K6	3	2	1	UO	UO	O
K7	2	2	1	UO	UO	O
K8	1	1	2	UO	O	O
K9	1	1	1	UO	UO	O
K10	1	0	1	UO	O	O
K11	3	3	2	UO	UO	O
K12	1	1	1	O	O	O
K13	1	1	-	UO	UO	O
K14	1	0	1	UO	O	OM
K15	1	1	1	UO	UO	O
K16	2	2	1	UO	UO	O
K17	1	1	1	UO	UO	O
K18	2	1	2	UO	UO	O
K19	1	0	1	UO	UO	O
K20	1	1	1	UO	O	O
K21	1	0	1	O	O	O
K22	1	1	2	OM	OM	OM
Shanon-Wiener index	3.793	3.010	3.797	-	-	-
Simpson index	0.915	0.875	0.916	-	-	-
Pielou evenness	0.945	1.0	0.946	-	-	-

W1, wet season (SW); W2, wet season (NE); D, dry season; UO, ultraoligotrophic; O, oligotrophic; OM, oligotrophic-mesotrophic.

<sup>a</sup>See Table 1 for abbreviations.

**Table 4.** List of stream red algae, site distribution and abundance (%) in stream around KhaoLuang National Park, Nakhon Si Thammarat province

Order / Family	Genus / Species	Site distribution <sup>a</sup>	Abundance (%) <sup>b</sup>		
			W1	W2	D
Acrochaetiales / Acrochaetiaceae	<i>Audouinella subtilis</i> Jao <sup>c</sup>	K7	1	1	1
Batrachospermales / Batrachospermaceae	<i>Balliopsis prieurii</i> (Montagne) G. W. Saunders et Necchi	K9	1	1	1
	<i>Batrachospermum khaoluangensis</i> Chankaew, Peer- apornpisal et Kumano	K5	1	1	1
	<i>Batrachospermum gelatinosum</i> (L.) Roth	K19	1	0	1
	<i>Batrachospermum</i> sp.1	K8, 10	1	0	1
	<i>Kumanoa gibberosa</i> (Kumano) Necchi et M. L. Vis	K16	1	1	1
	<i>Kumanoa hirosei</i> (Kumano) Necchi et M. L. Vis	K6, 21	1	1	1
	<i>Kumanoa mahlacensis</i> (Kumano et W. A. Bowden- Kerby) M. L. Vis, Necchi, W. B. Chiasson et Entwisle	K11, 18	1	0	1
	<i>Kumanoa tabagatenensis</i> (Kumano et W. A. Bowden- Kerby) M. L. Vis, Necchi, W. B. Chiasson et Entwisle	K22	1	0	1
	<i>Sirodotia huillensis</i> (W. West et G. S. West) Skuja	K6	1	1	1
	<i>Sirodotia suecica</i> Kylin	K2, 4	1	0	1
	<i>Sirodotia</i> sp.1	K14	1	0	1
Compsopogonales / Compsopogonaceae	<i>Compsopogon caeruleus</i> (Balbis) Montagne	K5, 8, 17, 20	1	0	1
Ceramiales / Delesseriaceae	<i>Caloglossa beccarii</i> (Zanardina) De Toni <i>sensu lato</i> <sup>d</sup>	K11, 12, 15	2	1	2
Thoreaales / Thoreaceae	<i>Thorea clavata</i> Seto et Ratnas	K1, 3, 5, 6, 7, 11, 13, 18	4	1	4
	<i>Thorea siamensis</i> Kumano et Traichaiyaporn	K5	1	0	1

W1, wet season (SW); W2, wet season (NE); D, dry season.

<sup>a</sup>See Table 1 for abbreviations.

<sup>b</sup>0, absent; 1, <10%; 2, 11-20%; 3, 21-30%; 4, 31-40%.

<sup>c</sup>Possibly only a 'Chantransia' stage of Batrachospermumales.

<sup>d</sup>A complex of four species including *Caloglossa fluviatilis* Kraysky, Fredericq & J. N. Norris (see key in Sato and Akiyama 2001, Kamiya et al. 2016). We tentatively identify our specimens as *C. beccarii sensu lato*, pending critical morphological and molecular studies of the Thai populations.





## Relationship between red algal abundance and environmental variables by CCA

Many environmental variables can influence the growth of freshwater red algae. The substrate characteristics have a direct impact on the distribution of these algae (Sheath 1984), whereas other environmental factors affect stream condition and freshwater algal seasonality. In this study, water quality and trophic status were not particularly different among study sites and seasons. In a period of high turbidity, especially during the North-East monsoon, the nutrient concentration increased, water transparency decreased and species richness was lower (8 species). In this aspect, it is similar to a study made in Brazil (Necchi 1993), where algal abundance decreased with a higher nutrient levels, solar radiation, temperature and turbidity.

The relationship of red algae and water quality parameters provided by CCA plot (Fig. 3), indicated that the abundance of *Batrachospermum* sp. (Bsp) was positively correlated with current velocity (Vel) but it was negatively correlated with TDS, turbidity, and alkalinity. Thus, this species is more abundant in higher water velocity and lower TDS, turbidity, and alkalinity. *Caloglossa beccarii sensu lato* was more abundant in higher conductivity and temperature and lower pH. *Kumanoa tabagatenensis* was more abundant in high ammonia concentration and slightly acidic condition. *Kumanoa Hirosei* was more abundant in higher alkalinity, turbidity and TDS with lower DO and SRP. Although the dominant taxon, *C. beccarii sensu lato* occurred in three sites at all seasons under oligotrophic-mesotrophic status based on AARLPC score. The presence of rare species of *Batrachospermum* and *Kumanoa* at most sites could also be relate to oligotrophic condition. These findings corroborate previous studies in Thailand (Suphan and Peerapornpisal 2003, 2007, Suphan et al. 2004, Peerapornpisal et al. 2006). The present trophic water data can provide a good basis for water management in Khao Luang National Park. Also, this research provides more information on freshwater red algal ecology in tropical streams.

## CONCLUSION

A combined composition and ecological distribution study during a period of twelve months in 22 freshwater stream segments in southern Thailand resulted in the following conclusions: (1) sixteen species of freshwater red algae belonging to eight genera were identified show-

ing a fairly rich diversity of freshwater red algal species; (2) water quality showed that most sites to be unpolluted (ultra-oligotrophic to oligotrophic); and (3) trend of individual species to occur in stream segments with particular environmental characteristics was evident as shown in Canonical Correspondence Analysis: *Batrachospermum* sp. with high current velocity; *Kumanoa Hirosei* with high turbidity, total dissolved solids, and alkalinity; *Caloglossa beccarii* with high conductivity; *Kumanoa tabagatenensis* with high ammonia-nitrogen and *Thorea siamensis* with high calcium and magnesium.

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