Science and Technology

RMUTT Journal

Vol.10 No.1 (2020) : 245-260

www.sci.rmutt.ac.th/stj

Online ISSN2229-1547

Diversity of Freshwater Green Macroalgae in Phu Wua Wildlife Sanctuary

Thanitsara Inthasotti[1*] and Sorrachat Thiamdao[1]

Department of Biology, Faculty of Science, Udon Thani Rajabhat University,

Meaung, UdonThani 41000, Thailand

*E-mail: Thanitsara_bew@hotmail.com

Abstract

Green freshwater macroalgae are known as primary producers in aquatic ecosystems. They are also used as a traditional food in various parts of Thailand. However, knowledge of their taxonomy, especially their morphological data are rare. Therefore, this study was aimed to investigate the diversity and specific morphology of green macroalgae from Phu Wua Wildlife Sanctuary. Specimens were collected from five waterfalls, Ched Sii, Tham Fhun, Cha Nan, Tad Nok Khian and Tham Phra Waterfalls. Six genera consisting of eighteen species were found. The most diverse genus was *Spirogyra*. The next most common were *Mougeotia* and *Oedogonium*. Ched Sii Waterfall revealed the highest diversity of macroalgae, with nine species. *Zygnema ralfsii* (Hassall) de Bary was a common species found at the sampling sites. Alternatively, *Draparnaldia mutabilis* (Roth) Cedergren was a rare species as it was found only at Tham Fhun Waterfall. This report is the first description of the characteristics of freshwater green macroalgae from Phu Wua Wildlife Sanctuary.

Keywords: macroalgae, Phu Wua, *Spirogyra*, *Draparnaldia*

Received: November 13, 2018

Revised: January 29, 2020

Accepted: June 29, 2020

1. Introduction

Algae are important and well known primary producers in aquatic ecosystems. Their photosynthetic activities absorb carbondioxide and generate oxygen. These are important functions of algae as primary producers [1]. Macroalgae are a group of algae that can be viewed in the field without the need for magnification. They form slimy filamentous colonies and mats of various colours. Some macroalgae have well developed structures that are similar to those of higher plants [2]. Most freshwater macroalgae are usually found attached to substrates, e.g., cobble stones, gravel, tree branches and roots [3].

Phu Wua Wildlife Sanctuary was established in 1975 by the Forestry Department with an area of 186.5 km^2. It is situated in northeastern Thailand. Its geography is considered a sandstone mountain. During the wet season, there are many streams flowing down from mountain that form five waterfalls [4]. However, during the dry season, these streams and waterfalls are mostly dry. These extreme conditions form the habitat of some very interesting macroalgae.

Green freshwater macroalgae have been reported in various parts of Thailand and they are widely used for purposes such as traditional foods, supplementary foods and as medicinal products [5-6]. However, their taxonomy has not been reported. Only some specimens have been identified on the basis of specific morphology since reference data is inadequate [7-17]. Therefore, this study aimed to investigate the diversity of green macroalgae and describe their specific morphology and the characters of vegetative cells including the reproductive structures of each species. This report provides helpful data that will be useful in future research. Moreover, this is the first report of algae in Phu Wua Wildlife Sanctuary.

2. Materials and Experiments

2.1 Study sites

Specimens were collected from five waterfalls, Ched Sii (18°09'37.37"N 103°56'56.44"E), Tham Fhun (18°15'53.57"N 103°53'49.37"E), Cha Nan (18°13'30.2"N 103°53'32.9"E), Tad Nok Khian (18°09'53.43"N 103°54'14.00"E) and Tham Phra Waterfalls (18°08'13.68"N 103°59'32.81"E). All sampling sites werein Phu Wua Wildlife Sanctuary, Bung Khla District, Bueng Kan Province (Figure 1). The sample collection was done between June and October 2015.

2.2 Macroalgae collection and investigation

Green macroalgae samples were individually collected from free flowing water and substrates, i.e., rocks, cobblestones, and tree branches found immersed in the water and from the banks of the streams in the study area. All specimens were divided into two subsamples, fresh samples for identification and a second specimen that was preserved with 2.0% glutaraldehyde. Both subsamples were kept in plastic boxes at low

temperature (0-4˚C) during transport. All specimens were imaged to record their characteristic filaments using an Olympus CX21 microscope. The width and the length of individual cells, branch patterns, the form of their chloroplasts and the size of their zygotes were recorded.

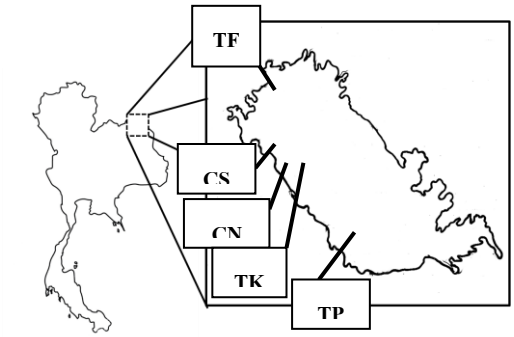

Figure 1 The study sites in the area of Phu Wua Wildlife Sanctuary, TF: Tham Fhun Waterfall, CS: Ched Sii Waterfall, CN: Cha Nan Waterfall, TK: Tad Nok Khian Waterfall, and TP: Tham Phra Waterfall

3. Results and Discussion

Green macroalgae from Phu Wua Wildlife Sanctuary were collected and indentified. Six genera, comprising eighteen taxa were discovered. The most diverse genus was *Spirogyra* which accounted for 39% of all taxa. The next most common were *Mougeotia* (28%) and *Oedogonium* (17%). A single species each of *Bulbochaete*, *Draparnaldia* and *Zygnema* were found which comprised 5% of material collected during this study. The sampling site that revealed the highest species diversity was Ched Sii Waterfall, where nine species were found (Table 1). The descriptions of the discovered taxa are as follows.

Bulbochaete quadrata Wittrock ex Hirn 1900

Filaments consisted of rich of branches with non-wavy edges of vegetative cells. Each cell hada long hair with abulbous base. Chloroplasts were parietal and net-like. Cells were 14-25 µm wide and 54 µm long, 2.2-3.8 times as long as wide (Figure 2; 1).

Bulbochaete was reported in several parts of the world including Thailand. This taxon was found in the central and north part of the country [9], [24]. The current study is the first report of *Bulbochaete* in northeastern Thailand, particularly in Phu Wua Wildlife Sanctuary.

Draparnaldrai Bory 1808 is well known for its uniseriate filaments with a soft mucilagenous envelope. Barrel-shaped or cylindrical cells are aligned along the main axes. Secondary branches are laterally placed on the main axes. *Draparnaldrai* is classified into the order Chaetophorales, and family Chaetophoraceae [18],]22]. In this sanctuary, only one specimen of *Draparnaldria* was collected and identified as *D. mutabilis* (Roth) Cedergren 1920. This taxon was reported in several parts of the world [18], [25]. However, in Thailand, this genus has rarely been reported. Our finding expands the biogeography of this rare taxon toThailand. Moreover, we described the characteristics at thespecies level as follows.

Draparnaldrai mutabilis (Roth) Cedergren 1920

The thalli were bright green and slippery with a mucilaginousenvelope. The main axes consisted of cylindrical cells in which the width was greater than the length, 36-47 wide and 16-20 long. A single parietal chloroplast laid transversely along the main axes. The primary branches formed in an opposing manner. Cylindrical and barrel-shape cells were found in primary branches. The secondary branches were narrow and formed a lance-like outline. The cells of secondary branches were 5-7 µm wide and 25-30 µm long (Figure 2; 2).

Three *Oedogonales* species were found, *Oedogonium calcareum* Cleve et Wittrock 1870, *O.* cf. *curtum* Wittrock et Lundell in Wittrock 1870, and *Oedogonium* sp.1. *Oedogonium calaceum* was found at two waterfalls, Cha Nan and Tad Nok Khian. *Oedogonium* sp.1 was also found at two waterfalls, Ched Sii and Tham Fhun. *Oedogonium* cf. *curtum* was found only at Tham Fhun Waterfall. However, *Oedigonium*was not found at Tham Phra Waterfall. The vegetative cells of *Oedogonium* sp.1 are cylindrical shape, 24-38 µm wideand 42-175 µm long. Sexual reproduction of *Oedogonium* sp.1 was not observed (Figure 2; 11). The characteristics of each taxa are as follows.

Oedogonium cf. *curtum* Wittrock et Lundell in Wittrock 1870

Vegetative cells were distinctly swollen at the distal ends. There was a row of puncta at the end of cells without spiral orientation. Cells were 15-24 µm wide and 78-91 µm long (Figure 2; 10).

Oedogonium calareum Cleve et Wittrock 1870

Cylindrical cells were 11 µm wide and 31 µm long. Cells were not swollen at distinct ends. Oospores were depressed-spherical, 24 µm wide and 20 µm long. The spore walls were smooth. The suffultory cells were similar to adjacent vegetative cells (Figure 1; 9). *Oedogonium calareum* has been reported in Africa, Asia, New Zealand and various parts of Europe [26].

The genus *Oedogonium* was reported invarious parts of Thailand. A single species of *Oedogonium* was reported at Mae Ngat Somboonchol Dam Reservoir [9], Pra Wiharn National Park [16], Huai Kha Khang Wildlife Sanctuary [7]. Additionally, six species of *Oedogonium* were reported in the Thong PhaPhum District of Southern Thailand [10], but their reported taxa were *Oedogonium* sp.1-6. Neither oospores nor any sexual reproduction details were described.

Table 1 Distribution of green macroalgae in Phu Wua Wildlife Sanctuary

Taxa	Ched Sii	Tham Fhun	Cha Nan	Tad Nok Khian	Tham Phra
Bulbochaete quadrata Wittrock	-	-	+	+	-
Draparnaldia mutabilis (Roth) Cedergren	-	+	-	-	-
Mougeotia parvula Hassall	+	+	+	+	-
Mougeotia levis (Kutzing)W Archer	-	-	-	-	+
Mougeotia sp.1	+	-	-	-	-
Mougeotia sp.2	-	-	+	-	-
Mougeotia sp.3	-	-	+	-	-
Oedogonium calareum Cleve et Wittrock	-	-	+	+	-
Oedogonium cf. *curtum*	-	+	-	-	-
Oedogonium sp.2	+	+	-	-	-
Spirogyra dubia Kutzing	-	+	+	+	-
Spirogyra cf. inflata (Vaucher) Kützing	+	+	+	-	+
Spirogyra grossii Schmiddle	-	+	-	-	-
Spirogyra schmidtii West&West	+	-	-	-	-
Spirogyra shantungensis Li	+	-	-	+	-
Spirogyrarhizobranchialis Jao	+	-	-	-	-
Spirogyra sp.	+	-	-	-	-
Zygnema ralfsii (Hassall) de Bary	+	+	+	+	+

- : not found, + : found

The genus, *Mougeotia,* is uniseriate unbranched filaments with mucilaginous layers at the outer wall containing a single plate-like chloroplast with an axial row of pyrenoids. *Mougeotia* was classified into the order Zygnematales andfamily Zygnemaceae [18], [22]. From this study, five morphological types of *Mougeotia* were found, *Mougeotia laevis* (Kutzing) W. Archer 1867, *M. parvula* Hassall 1847 and *Mougeotia* sp. 1-3. Unfortunately, the sexual reproduction of *Mougeotia* sp.1-3 wasnot observed. However, these taxa revealed obviously differences in morphology, such as in their cell width, cell length and length/width ratio (Figure 2; 3-8 and Table 2).

Mougeotia laevis, with long cylindrical cells (8.9 L/W ratio), showed an oospore in the middle of a short conjugation tube. The oospores

of this taxonwere ellipsoidal with shallow depressions or scrobiculate. Oospores of *M. parvula* were almost spherical and formed wholly in very shot conjugation tubes (Figure 2; 8).

Mougeotia were cosmopolitan, mostly found at the margins of the small ponds and lakes [18]. In Thailand, this genus was reported (in 1979) in a rice field in thenortheastern part of the country [27]. Additional, *Mougeotia* were continuously reported in various parts of the country, such as Na Thap River, Songkhla Province [15], Khao Pra Wiharn National Park, Srisaket Province [16], the area of the Golden Jubilee Thong Pha Phum Project, Thong Pha Phum District, Kanchanaburi Province [10] and Huay Kha Khang Wildlife Sanctuary [7]. However, the details of *Mougeotia* were described only at thegenus level. The sexual reproduction and oospore characters of this taxa in Thailand are ambiguous. In the present study, we described the sexual reproduction and oospore characteristics of *M. parvula* and *M. laevis*.

Spirogyra Link 1820 consists of unbranched long filaments, cylindricalcells with an outer mucilage and is the largest genus among Zygnemaceae. Their major characteristics are spiral chloroplasts and scalariform conjugation. In this investigation, *Spirogyra* was the most diverse taxa, as seven species were found. *Spirogyra* cf. *inflata* (Vaucher) Kützing was a common species, found in four of the five waterfalls (Table 1). The next most common was *Spirogyra dubia* Kutzing, which was found in three waterfalls. The highest species diversity (fives pecies) of this genus was at the Ched Sii Waterfall. The description of each taxonisas follows.

Spirogyra dubia Kutzing

Thallus were filamentous, unbranched and uniseriated. Cells were cylindrical, 43 µm wide and 286 µm long, with a 6.65 L/W ratio. There were three cholroplasts with some pyrenoids along the chloroplast bands. Each chloroplast made 2.5 turns in a cell. Sexual reproduction by conjugation forms as scaliform. Zygospores were ellipsoidal, 69 µm wide and 83 µm long, with a 1.2 L/W ratio (Figure 2; 13).

Spirogyra cf. *inflata* (Vaucher) Kützing 1843

Cells were cylindrical, 15-22 µm wide and 128-192 µm long, with a 5.8-12.8 L/W ratio. A single chloroplast with some pyrenoids made six turns in a cell. The end walls were ring-like or infolded (replicate). Sexual reproduction was not observed (Figure 2; 14.-15).

Table 2 Characteristics of *Mougeotia* in Phu Wua Wildlife Sanctuary

Taxa	Vegetative cells			Oospores		
	Width (μm)	Length (μm)	L/W	Width (μm)	Length (μm)	L/W
Mougeotia parvula Hassall	11	123-151	11.1-13.7	29	31	1.1
Mougeotia levis (Kutzing)W Archer	20	117-178	5.8-8.9	33	47	1.42
Mougeotia sp.1	22	277	12.6	*	*	*
Mougeotia sp.2	30	225	7.5	*	*	*
Mougeotia sp.3	23	102-108	4.43-4.69	*	*	*

* : not found

Spirogyra grossii Schmiddle

Cells were cylindrical, 45 μm wide and 118 μm long, with a 2.62 L/W ratio. There were three cholroplasts with globular pyrenoids along the chloroplast bands. Each chloroplast made 2.5-3 turns in a cell. Sexual reproduction by conjugation formed as scaliform. The conjugation tubes were formed by both gametangia, male and female gametes. Sterile cells were slightly swollen. Zygospores were ellipsoidal, 50 μm wide and 70 μm long, with a 1.4 L/W ratio (Figure 2; 16).

Spirogyra schmidtii West&West

Cells were cylindrical, 26 μm wide and 173 μm long, with a 6.65 L/W ratio. There were three cholroplasts with some pyrenoids along the chloroplast bands. Each chloroplast made 2-2.5 turns in a cell. Sexual reproduction by conjugation formed as scaliform. The conjugation tubes were formed by both male and female gametangia. The tubes were 16.7 μm wide and 11μm long. Sterile cells were slightly swollen. Zygospores were long ellipsoids, 34 μm wide and 61 μm long, with a 1.8 L/Wratio (Figure 2; 19-20).

Spirogyra shantungensis Li

Cells were cylindrical, 67 μm wide and 125 μm long, with a 1.87 L/W ratio. There were three cholroplasts with globular pyrenoids along the chloroplast bands. Each chloroplast made 2-2.5 turns in a cell. Sexual reproduction by conjugation formed as scaliform. The conjugation tubes were formed by both gametangia. Sterile cells were swollen and contained ellipsoid zygospores that were51 μm wide and 80 μm long, with a 1.6 L/W ratio (Figure 2; 21-22).

Spirogyra rhizobranchialis Jao

Cells were 53 μm wide and 225 μm long with a 4.24 L/W ratio. There were five chloroplasts with small pyrenoids along the chloroplast bands. Each chloroplast made 2.5 turns in a cell. Sexual reproduction by conjugation formed as scaliform. The conjugation tubes were formed by both gametangia. Fertilized cells were cylindrical.

Zygospores were long-ellipsoid, 50 µm wide and 100 µm long, with a 2.0 L/W ratio. The attached part formed a rhizoid-like shape (Figure 2; 17-18).

Spirogyra sp.

Cells were 54 µm wide and 223 µm long with a 4.13 L/W ratio. There were three chloroplasts with some pyrenoids along the chloroplast bands. Each chloroplast made1.5-2 turns in a cell. Sexual reproduction by conjugation formed as scaliform. The conjugation tubes were formed by male gametangia. Male gametangia were flat, while the female gametangia were swollen. Fertilized cells were inflated. Zygospores were ellipsoidal, 46 µm wide and 76 µm long, with a 1.65 L/W ratio. The outer walls of zygospores were thick and clear (Figure 2; 23.-24). Although sexual reproduction characteristics were observed, there were no previous reports of this. Consequently, identification at the species level and molecular studies are still needed.

Spirogyra were studied and reported from various parts of the world. More than a hundred species were described in the USA since 1986 [28-30]. In the Netherlands, 82 species were discovered and characterised [31-32]. In Thailand, *Spirogyra* has been reported from various parts of the country, including Mae Cheam Stream, Chiang Mai Province, the area of the Golden Jubilee Thong Pha Phum Project, Thong Pha Phum District, Kanchanaburi Province, the Ping and Nan Rivers, the Kham Watershed, Chiang Rai Province, Na Ku Ha Village, Phrae Province, the Kok River, Chiang Rai Province, the Huerng River, Leoi Province, Songkram River and Nakhon Phanom Province [8-12], [14]. However, all of these studies recorded data and described morphology only at the genus level. Additionally, Thiamdao [17] reported 11 species from various places around Thailand, seven of which were newly recorded in the country. However, the sexual reproduction characteristics were not clearly described. From our investigation, up to seven characteristics of both sexual reproduction and zygospores are described.

Zygnema, forms unbranched filaments, but occasionally revealsan attachment forming a rhizoid-like structure. Thalli are slimy, often surrounded by mucilage. Star-shape chloroplasts, 2 or up to 4, are contained in a cell. Conjugation tubes are developed by sexual reproduction in which the zygospores are developed in the conjugation tubes [18]. This genus is classified into the order Zygnematales and family Zygnemaceae [18], [22]. In our investigation, a single species of *Zygnema* was

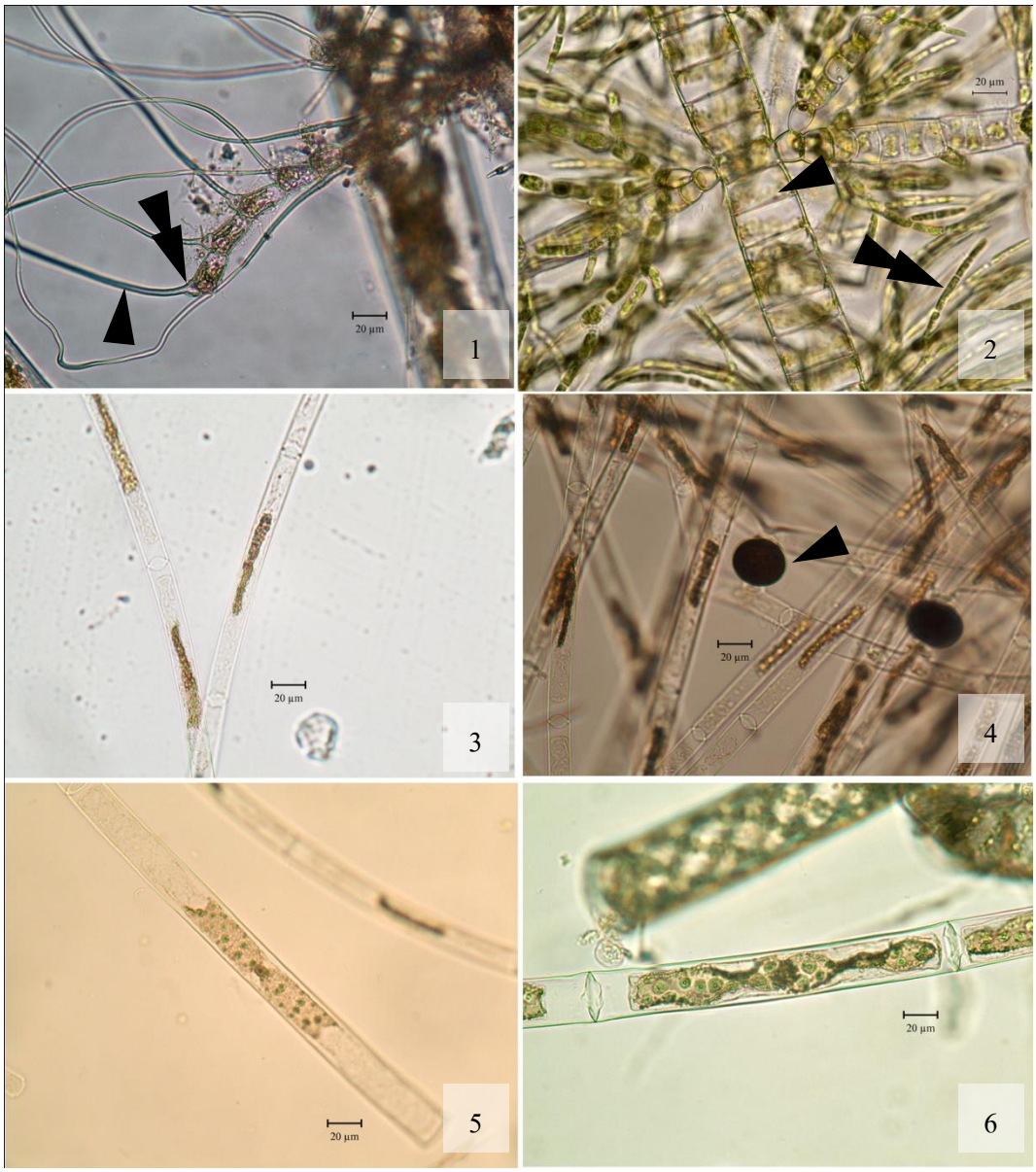

Figure 2 Macroalgae in Phu Wua Wildlife Sanctuary

1. *Bulbochaete quadrata*, long hair projected from each cell (arrowhead) with bulbous base (double arrowhead)
2. *Draparnaldrai mutabilis*, a single chloroplast laid transversely in main axes cells (arrowhead), secondary branches were narrow (double arrowhead)

3-4. *Mougeotia parvula*, zygospore formed in the conjugation tube (arrowhead)

5. *Mougeotia* sp.1

6. *Mougeotia* sp.2

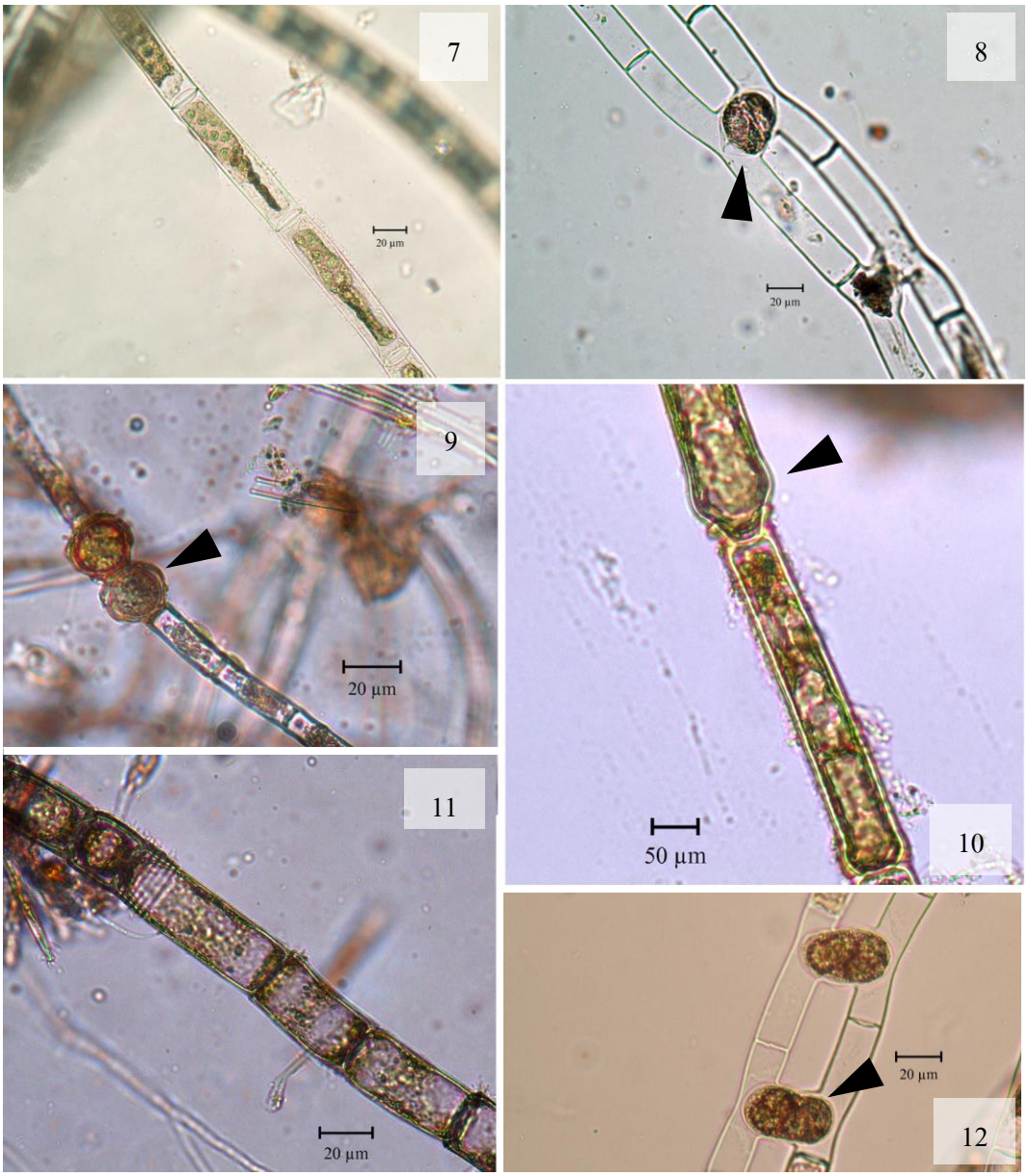

Figure 2 Macroalgae in Phu Wua Wildlife Sanctuary (continued)

7. *Mougeotia* sp.3
8. *Mougeotialevis*, ellipsoid oospore with shallow depressions laid into the middleof the conjugation tube (arrowhead)
9. *Oedogonium calaceum*, depressed-spherical oospores (arrowhead)
10. *Oedogonium* cf. *curtum*, vegetative cells with distinctly swollen at the distalends (arrowhead)
11. *Oedogonium* sp.1
12. *Zygnema ralfsii*, yellow-brown median spore wall formed in conjugation tubes(arrowhead)

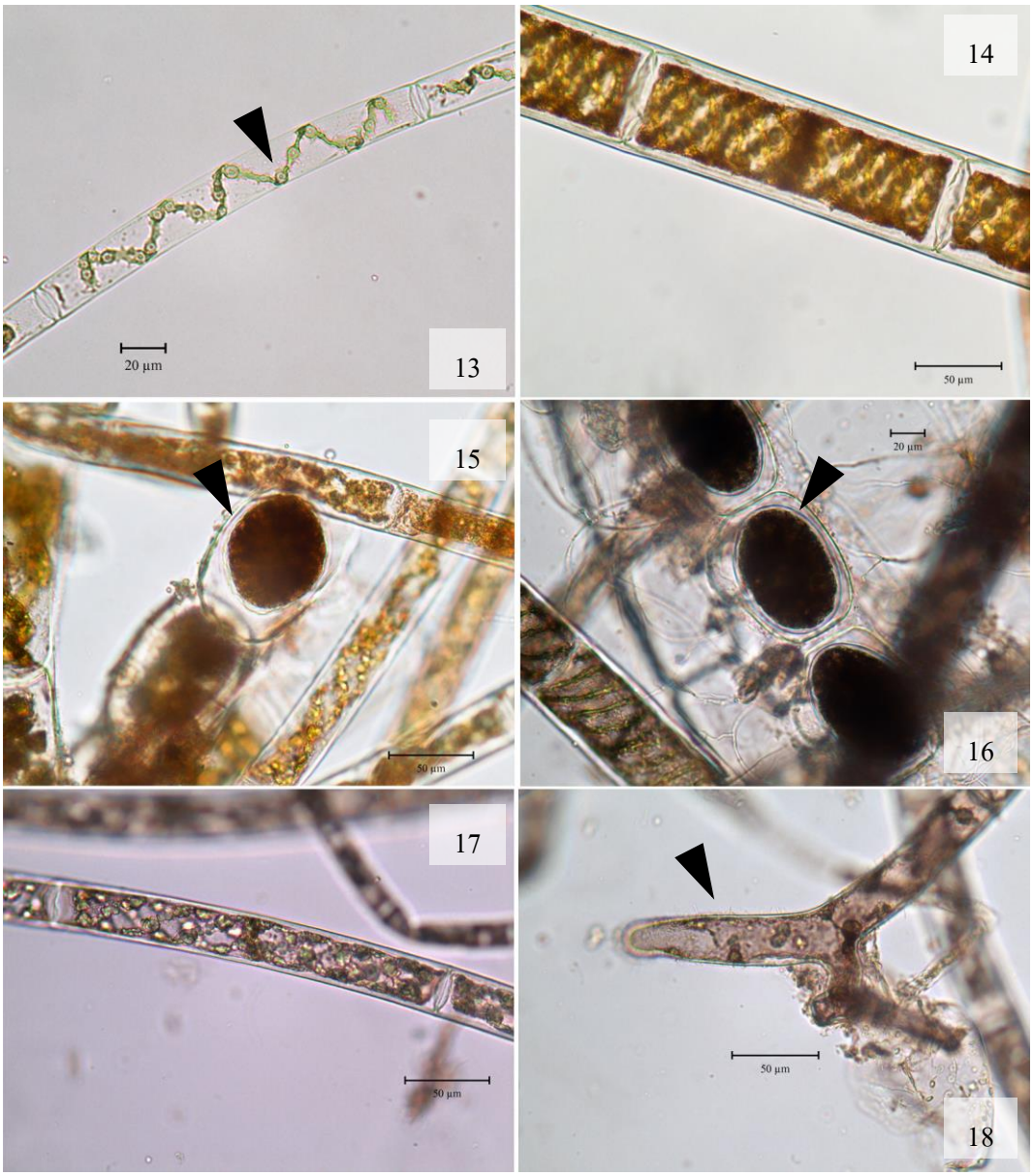

Figure 2 Macroalgae in Phu Wua Wildlife Sanctuary (continued)

13. *Spirogyra* cf. *inflata*, the single chloroplast in a cell (arrowhead)

14-15. *Spirogyra dubia*, ellipsoid zygospore (arrowhead)

16. *Spirogyra grossii*, ellipsoid zygospore in slightly swollen cell (arrowhead)

17-18. *Spirogyra rhizobranchialis*, rhizoid-like shape of attached part (arrowhead)

Figure 2 Macroalgae in Phu Wua Wildlife Sanctuary (continued)

19-20. *Spirogyra schmidtii*, slightly swollen sterile cells with long-ellipsoid zygospore (arrowhead), conjugation tubes formed by both gametangia (double arrowhead)

21-22. *Spirogyra shantungensis*, ellipsoid zygospores in swollen sterile cells(arrowhead)

23-24. *Spirogyra* sp., conjugation tubes formed by male gametangia (arrowhead), thick and clear outer wall of zygospores (double arrowhead)

found. Particularly, sexual reproduction was observed and identified as *Zygnema ralfsii* (Hassall) de Bary. This taxon is considered a common species and was found in all the waterfalls of the Phu Wua Wildlife Sanctuary.

Zygnema ralfsii (Hassall) de Bary

Vegetative cells were 17 µm wide and 55-75 µm long. There were 2 star-shape chloroplasts in a cell. The median spore wall was yellow-brown. Zygospores were formed in conjugation tubes. Nevertheless, in most of *Zygnema*'s species, the zygospores were formed in gametangia [18]. The zygospores of Z. *ralfsii* were 26 µm wide and 42 µm long (Figure 2; 12).

From previous reports, one morphotype of *Zygnema* was found in Pra Wiharn National Park [16]. Suphan and Peerapornpisal [10] reported three mophotypes of *Zygnema* from Thong Pha Phum District, in Southern Thailand. Although only one such species was found in thepresent study, its sexual reproduction, especially its zygospore characteristics, are described.

The characteristics of green macroalgae, mentioned above, were the first morphological descriptions from this region. Particularly, the sexual reproduction structures, which are the most important details for identification at the species level, were also shown. These results can be used as reference data for the future studies.

4. Conclusions

From our investigation, 18 species classified into six genera were found and described. *Spirogyra* was the most diverse genus, with seven species. *Mougeotia* and *Oedogonium* were found the next most common, with five and three species, respectively. A single species of *Bulbochaete*, *Draparnaldia* and *Zygnema* were each found. The most common species of this study, found in all sampling sites, was *Zygnema ralfsii* (Hassall) de Bary. *Draparnaldia mutabilis* (Roth) Cedergren was considered a rare species since this genus was found and described infrequently, especially in Thailand.

Ched Sii Waterfall showed the highest diversity of macroalgae as nine species were found. Eight species were found in Tham Fhun Waterfall. Seven and six species were found at Cha Nan and Tad Nok Khian Waterfalls, respectively. At Tham Phra Waterfall, only three species of green macroalgae were observed.

Characteristics of each taxa described above were categorized into two groups, branched and unbranched filamentous marcoalgae. The branched filamentous groups were *Bulbochete* and *Drapanaldia*. *Bulbochete*s howing long hairs with a bulbous base. *Drapanaldia* were bright green and slippery. The thallus of this genus consisted of main, primary and secondary branches. In the unbranched filamentous group, the characteristics

of each genus revealed an obvious difference in the chloroplast pattern. A plate-like or twisted-plate chloroplast characterised *Mougeotia*. Algae with a spiral ribbon-like chloroplast were *Spirogyra*. Perforate net-like chloroplasts indicated the genus *Oedogonium*. Stellate or star-shape chloroplasts were characteristic of *Zygnema*.

Identification of some specimens were incomplete by the reason of their unobserved sexual reproduction. However, *Spirogyra* sp. was a specimen that showed a conjugation tube including a characteristic of zygospore. Unfortunately, the data of the current study did not match any previous descriptions. A molecular approach will be needed to clarify the morphological plasticity of green macroalgae in this tropical zone.

5. Acknowledgements

This study was financially supported by National Research Council of Thailand (NRCT). The authors are deeply grateful to Department of National Parks, Wildlife and Plant Conservation forall of their assistance.

6. References

[1] Brown, L.M. and Zeiler, K.G. Aquatic biomass and carbon dioxide trapping. *Energy Conversion and Management*. 2003. 34 : 9-11.

[2] Sheath, R.G. and Cole, K.M. Biogeography of stream macroalgae in North America. *Journal of Phycologia.* 1992. 28 : 448-460.

[3] Entwisle, M.J. Phenology of the *Cladophora - Stigeoclonium* community in two urban creeks of Melbourne, Australia. *Australian Journal of Marine and Freshwater Research*. 1989. 40 : 236-248.

[4] Royal gazette No. 92 chapter 87 (Thai only) : 11-13.

[5] Surayot, U., Wang, J., Ju Hun, L., Khanongnuch, C., Peerapornpisal, Y., You, S.G. Characterization and immunomodulatory activities of polysaccharides from Spirogyra neglecta (Hassall) Kützing. *Bioscience, Biotechnology, and Biochemistry*. 79(10) : 1644-1653.

[6] Surayot, U., Ju Hun, L., Khanongnuch, C., Peerapornpisal, Y., Park, W.J., You, S.G. Structural characterization of sulfated arabinans extracted from *Cladophora glomerata* Kützing and their macrophage activation. *Bioscience, Biotechnology, and Biochemistry*, 80:5, 972-982

[7] Chonudomkul, D., Yongmanitchai, W., Sookpreedee, C., Yongmanitchai P., Arunpairojana W., and Prasart, K. Diversity of blue-green algae and green algae in the deciduous dipterocarp forest at Huai Kha Khang Wildlife Sanctuary. *Kasetsart Journal* (Nat. Sci.). 1998. 32 : 339-346.

[8] Wannathong, P. 2002. *Species Investigation, Ecology of Blue Green Algae in Some Watershed of Northern Thailand and its Cultivation*. M.Sc. thesis. Biology

Department, Faculty of Science, Chiang Mai University. Chiang Mai. Thailand.

[9] Tularak, P., Traichaiyaporn, S. and Rojanapibul, A. 2001. Influence of Environmental Factor on Distribution of Green Algae (Chlorophyta) in MaeNgat Somboonchol Dam Reservoir. 27th Congress on Science & Technology of Thailand.

[10] Suphan, S. 2004. *Diversity of macroalgae and benthic diatoms in the area of Golden Jubilee Thong Pha Phum Project, Thong Pha Phum District, Kanchanaburi Province.* M.S. thesis. Biology Department, Faculty of Science, Chiang Mai University. Chiang Mai. Thailand.

[11] Kunpradid, T. 2005. *Diversity of Macroalgae and Benthic Diatoms and Their Relationship with Nutrient Compounds in Ping and Nan Rivers*. Ph.D. thesis. Biology Department, Faculty of Science, Chiang Mai University. Chiang Mai. Thailand.

[12] Inthasotti, T. 2006. *Diversity of Macroalgae and Benthic Diatoms in Kham Watershed, Chiang Rai Province*. M.Sc. thesis. Biology Department, Faculty of Science, Chiang Mai University. Chiang Mai. Thailand.

[13] Suphan, S. and Peerapornpisal, Y. 2003. Used of Macro algae and Benthic Diatoms to MonitorWater Quality in the Area of the Golden Jubilee Thong Pha Phum Project, Thong Pha Phum district, Kanchanaburi Province, Thailand. *Proceeding on 2003 International Symposium on Environmental Management: Policy, Research and Education*, 6-9 November 2003, Chiang Mai, Thailand.

[14] Yana, E. and Peerapornpisal, Y. Diversity of benthic algae and water quality in tributaries of the Mekong River passing Thailand and some parts of Lao PDR, *KKU Science Journal*. 2009. 37: 30-41.

[15] Lueangthuwapranit, C., Sampantarak, U., and Wongsai, S. Distribution and abundance of phytoplankton: influence of salinity and turbidity gradients in the Na Thap River, Songkhla Province, Thailand. *Journal of Coastal Research*. 2011. 27(3) : 585-594.

[16] Nawagawong, S. and Sangpun, N. Aquatic ecology and biodiversity around Khao Pra Wiharn National Park, Thailand. *Environment and Natural Resources Journal*. 2011. 9(3) : 41-52.

[17] Thiamdao, S. 2011. Diversity of Edible Freshwater Macroalgae in Thailand During 2007-2008. Ph.D. thesis. Biology Department, Faculty of Science, Chiang Mai University. Chiang Mai. Thailand.

[18] John, D. M., Whitton, B. A. and Brook, A. J. 2002. *The Freshwater Algal Flora of the British Isles: an identification guide to freshwater and terrestrial algae*. Cambridge: Cambridge University Press.

[19] Kim, J.H., Kim, Y.H. and Lee, I.K. Morphotaxonomy of the genus *Spirogyra* (Zygnemataceae, Chlorophyta) in Korea. *Algae*. 2004. 19(2) : 91-115.

[20] Hainza, R., Wöbera, C. and Schagerl, M. The relationship between *Spirogyra* (Zygnematophyceae, Streptophyta) filament type groups and environmental conditions in Central Europe. *Aquatic Botany*. 2009. 91(3) : 173-180.

[21] Hoshaw, R.W. and McCourt, R.M. The Zygnemataceae (Chlorophyta): a twenty-year update of research. *Phycologia*. 1988. 27 : 511-548.

[22] Guiry, M.D. & Guiry, G.M. 2016. AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org; searched on 04 April 2016.

[23] Keshri, J.P. The genus Bulbochaete C.A. Agardh (Chlorophyta Oedogoniales) in West Bengal, India. *Bibliotheca Phycologica.* 2008. 114 : 1-103.

[24] Catling, D. 1999. *Rice in Deep Water*. London: Palgrave Macmillan UK.

[25] Sarma, P. The freshwater Chaetophorales of New Zealand. *Nova Hedwigia, Beiheft.* 1986. 58 : 1-169.

[26] West, W. and West, G.S. Notes on freshwater algae. I. *Journal of Botany*. 1900. 38 : 289-299.

[27] Heckman, C.W. 1979. *Rice Field Ecology in Northeastern Thailand: The effect of wet and dry seasons on a cultivated aquatic ecosystem. Springer-Science Business Media*. Doedrecht.

[28] McCourt, R.M., Hoshaw, R.W., Wang, J.C. Distribution, morphological diversity and evidence for polyploidy in North American Zygnemataceae (Chlorophyta). *Journal of Phycology*. 1986. 22 : 307–313.

[29] Berry, H.A. and Lembi, C.A. Effects of temperature and irradiance on the seasonal variation of a *Spirogyra* (Chlorophyta) population in a Midwestern lake (U.S.A.). *Journal of Phycology*. 2000. 36(5) : 841-851.

[30] Nanda, R.P., Alison, R.S. and Morgan, L.V. Macroalgae from 23 stream segments in the Hawaiian islands. *Pacific Science*. 2003. 57(4) : 421-431.

[31] Simons, J. Spirogyra species and accompanying algae from dune waters in the Netherlands. *Acta Botanica Neerlandica.* 1987. 36 : 13–31.

[32] Simons, J. and van Beem, A.P. *Spirogyra* species and accompanying algae from pools and ditches in the Netherlands. *Aquatic Botany*. 1990. 37: 247-269.