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Primary Production Dynamics of Two Dominant Macrophytes in Wular Lake, a Ramsar Site in Kashmir Himalaya

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Abstract. Growing season changes in the organic matter, organic carbon and chlorophyll content of the two dominant macrophytes, *Nymphoides peltatum* and *Ceratophyllum demersum* of Wular Lake, a Ramsar Site in Kashmir Himalaya were analysed during March- November 2011. The content of organic matter and organic carbon for *Nymphoides peltatum* were 114.1 g m^{-2} and 53.1 g C m^{-2} and *Ceratophyllum demersum* were 57.0 g m^{-2} and 26.4 g C m^{-2}. Chlorophyll A (Chl a) and chlorophyll A+B (Chl a+b) pigments ranged from 1.75 mg g^{-1} (Chl a) and 2.1mg g^{-1} (Chl a+b) in *Nymphoides peltatum to* 4.41 mg g^{-1} (Chl a) and 5.69 mg g^{-1} (Chl a+b) in *Ceratophyllum demersum*. In full leaf out, the latter aquatic plants exceeded 15-20% coverage of the open water surface.*Ceratophyllum demersum* and *Nymphoides peltatum* achieved maximum growth in June and August respectively, but significant differences in their growth dynamics was observed. At the end of the vegetation period, these plants sink to the bottom and decompose.

Keywords: aquatic macrophytes, organic matter, organic carbon, chlorophyll.

Introduction

Macrophytes, as a component of freshwater ecosystems have diverse roles to play in the structure and functioning of these ecosystems (PANDIT, 1984; WETZEL, 2001). Water plants, including macrophytes are universally recognized as important participants in the natural processes of water self-purification (GAYEVSKAYA, 1966; DEMBITSKY *et al*., 1992). The occurrence and distribution of aquatic vascular macrophytes depends on water depth, transparency, regime, chemical composition, pH and salinity (MADSEN *et al*., 2006; VIS *et al*., 2007). The presence of certain macrophytic species in aquatic ecosystems also depends on composition and properties of sediments (DAWSON & KRYSZTOF, 1999; HEEGARD *et al*., 2001; BARENDREGT BIO, 2003; MAKELA *et al*., 2004). Owing to their high rate of biomass production, macrophytes have primarily been characterized as an important food resource for aquatic organisms, providing both living (grazing food webs) and dead organic matter (detritivorous food webs). Macrophytes being excellent indicators of lake condition also act as "nutrient source" and "nutrient pumps" (PANDIT, 1984; STRIVASTAVA *et al*., 2008). On the other hand, the process of eutrophication may get accelerated due to high productivity of aquatic macrophytes creating large

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problems, particularly at the time of decomposition of their biomass (NIKOLIC *et al.*, 2007). It is therefore important to monitor aquatic ecosystems for growth and development of macrophytes with high biomass production, thus protecting the ecological balance in these ecosystems.

Shallow freshwater ecosystems are characterized by high productivity. Phytoplankton and emergent, floating and submerged macrophytes are principal primary producers, which differ in productivity, utilization of different sources of carbon dioxide, nutrients and light energy (HORNE & GOLDMAN, 1994). In general, it can be stated that macrophytes are dominant and principal primary producers in shallow freshwater aquatic ecosystems (WETZEL, 2001). The aim of the present study was to analyze the primary production dynamics of the two dominant macrophytes by monitoring their levels of organic matter and organic carbon and estimating their photosynthetic potential *via* the total chlorophyll content.

Study area. The work underlying this paper was carried out in the largest freshwater lake of Indian Sub-continent, Wular Lake, a Ramsar site in Kashmir Himalaya in the course of the 2011 vegetation period. The lake, is a shallow one (open water area 24 Km^2), located 34 Km north-west of Srinagar city on the Kashmir valley between 34^0 16′ -34^0 20′ N latitude and 74^0 33′ – 74^0 44′ E longitude. Its altitude is 1580 m and its depth, on average, 3.6 m throughout length, reaching 5.8 m at its deepest point (Watlab). The major inflows to Lake Wular are Jhelum, Madumati and Erin. The location of Lake Wular has a mean annual temperature of 10.7°C and 17.5°C for the vegetation period. The amplitude difference of the mean monthly temperatures is 21.9°C, the temperatures ranging from 0.8°C in January to 21.1°C in July. The survey and analysis of the present lake was carried out at monthly intervals from March to November, 2011. For detailed study and investigation, the lake was divided into nine sampling sites (Fig. 1).

Materials and methods

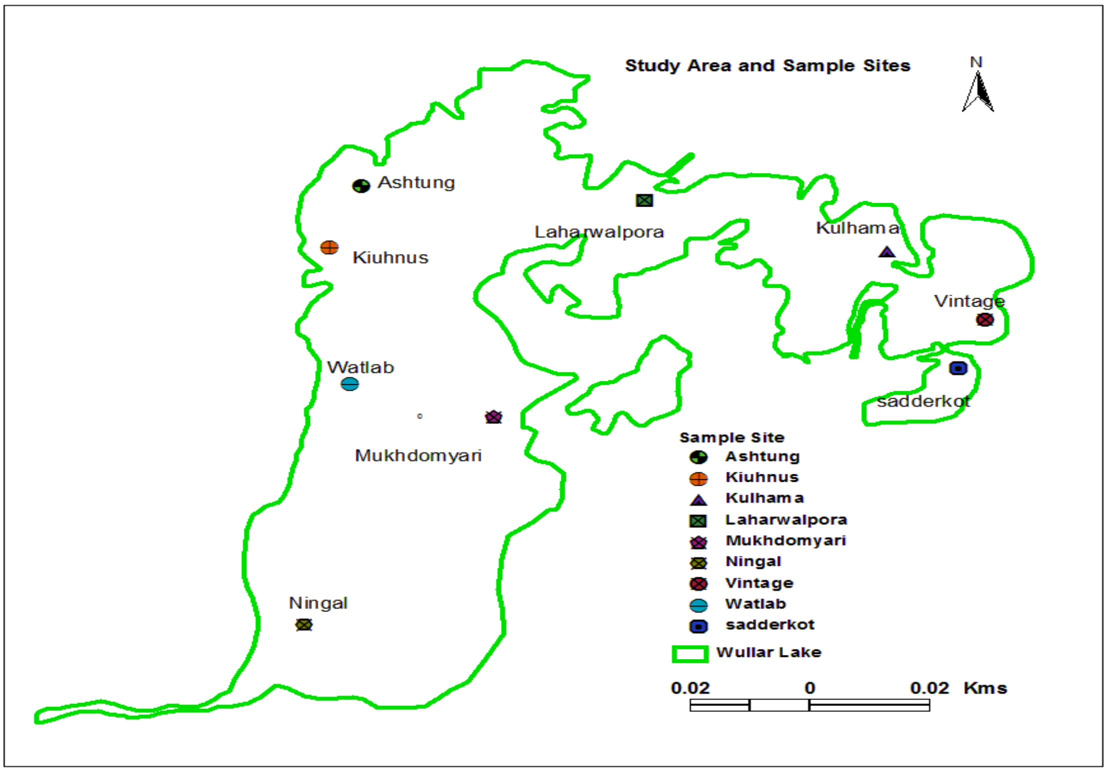

Fig. 1. Study area and sampling sites.

*Methods.*Organic matter, organic carbon and chlorophyll contents were measured according to standard methods (APHA, 1998). Vascular aquatic macrophytes were collected from a boat, using a 0.5 m^2 wooden frame and a 0.25 m^2 Ekman dredge (WELCH, 1948). Macrophytes were sampled in three replications, from nine spots (sampling sites), throughout the growing season in one year. Whole plants were taken from sample areas of 0.5 m^2 or 0.25 m^2. Plant material was labeled and taken to laboratory where it was rinsed, wrung out and weighed. Samples were dried at 105°C for 30 hours *i.e.*, until a constant weight was reached. Plant material was ground and burnt for as long as it emitted gases. The residue was incinerated at 550 °C for 6 hours. After cooling in a desiccator, the residue was weighed to calculate the content of organic matter, which was expressed in g m^{-2}. As most of the higher plants contain 46-48% of carbon in dry weight, organic carbon content was calculated using the factor 46.5% and expressed in g C m^{-2}. Chlorophyll content (Chlorophyll A, Chl a and chlorophyll A+B, Chl a+b) was determined spectrophoto-metrically, in acetone extracts from fresh samples (LICHTENTALER & WELLBURN, 1983). Descriptive statistics were calculated for content of organic matter and organic carbon (Table 1) using StatSoft Statistica 7.0 statistics software.

Results

During the investigated period, the macrophytes *Nymphoides peltatum*, and *Ceratophyllum demersum* dominated Lake Wular waters along with other 10 macrophytes. In full vegetation, the two dominant aquatic plants flourished and overgrew 15-20 % of the open water surface, while the surface of the deepest part of the lake remains free of aquatic vegetation.

Nymphoides peltatum and *Ceratophyllum demersum* were analyzed for organic matter, organic carbon and chlorophyll pigment contents, *i.e.*, for indicators of biomass production in the investigated aquatic ecosystem.

Nymphoides peltatum occurred in the course of March. They reached maximum growth in summer and they persisted until late fall, when some plants were still in flower. *Nymphoides peltatum* plants inhabited the shallower parts of the lake, growing at the depths between 1.5 and 5 m. The average annual contents of organic matter and organic carbon in *Nymphoides peltatum* plants were 114.1 g m^{-2} and 53.1 g C m^{-2}, respectively (Table 1).

In the investigation period, *Ceratophyllum demersum* occurred in late March. They occupied limited areas at the depths between 2 and 5.6 m of the lake. The average annual contents of organic matter and organic carbon in *Ceratophyllum demersum* plants were 63.75 g m^{-2} and 29.75 g C m^{-2}, respectively (Table 1). The analyzed parameters (content of organic matter and content of organic Carbon) showed relatively high variation coefficients and variation (Table 1). The average values of chlorophyll pigment content ranged from 1.75 mg g^{-1} (Chl a) and 2.1 mg g^{-1} (Chl a+b) in *Nymphoides peltatum in* the month of November to 4.41 mg g^{-1} (Chl a) and 5.69 mg g^{-1} (Chl a+b) in *Ceratophyllum demersum* in June (Table 2). Our results show species specificity in the seasonal dynamics of pigment content (Table 2). *Nymphoides peltatum* and *Ceratophyllum demersum* exhibited significant differences in chloro-phyll content between the seasons in a single vegetation period. Seasonal variation in chlorophyll content may provide indirect indication of the dynamics of bioproduction by the analyzed plant species. The species *Nymphoides peltatum* has the longest vege-tation period and is distinguished for largest and longest photosynthetic activity, which results in the largest organic production and thus impact on the eutrophication process. We also show that the two species differed significantly in chlorophyll content.

Discussion

It has been emphasized that there is a direct relationship between the primary production dynamics of macrophytes and light regime, temperature, water depth, sediment composition and the amount of available nutrients (SHILLA & DATIVA, 2008; ZHU *et al.*, 2008). In our study we also show that these ecological factors affected the primary production in Wular Lake.

Different macrophyte species may exhibit seasonally variable growth patterns (WETZEL, 2001). In our study, the floating, rooted, species *Nymphoides peltatum*, characterized by a long flowering period and high biomass productivity achieved maximum growth in summer and persisted till late fall, when individual plants could still be found in flower. The contents of organic matter (around 71% in relation to dry matter) and organic carbon (33% in relation to dry matter) in *Nymphoides peltatum* were somewhat lower than those found in literature (RICH *et al.*, 1971).

Table 1. Growing season changes in organic matter• and organic carbon content• for the two aquatic plant species in Wular Lake.

Plant species	Biomass*	March	April	May	June	July	August	September	October	November	Mean	SD±	V	I
Ceratophyllum demersum	OM	18	45	95	110	105	70	30	25	15	57	38.6	1488.5	67.7
	OC	8	21	44	51	49	32	14	12	7	26.4	17.9	320.3	67.7
Nymphoides peltatum	OM	66	85	135	210	190	230	45	36	30	114.1	79	6241.9	69.2
	OC	31	39	63	98	88	107	21	17	14	53.1	36.7	1348.4	69.1

*Legend: OM-organic matter (g m^{-2}); OC-organic carbon (g C m^{-2}); SD-standard deviation; V-variation coefficient; I-variation.
•Average results based on independent analyses from nine sites.

Table 2. Growing season changes in chlorophyll A• and A+B• (mg g^{-1} dry matter) for the two aquatic plant species in Wular Lake.

Plant species	Chlorophyll	March	April	May	June	July	August	September	October	November	Mean	SD ±	V	I
Ceratophyllum demersum	A	3.7	4	4.3	4.41	4.12	3.8	3.3	3.2	2.6	3.7	0.6	0.3	15.8
	A+B	4.83	5.28	5.5	5.69	5.34	4.94	4.22	4.36	3.38	4.8	0.7	0.5	15.3
Nymphoides peltatum	A	1.86	1.92	2.1	2.51	3.21	3.56	2.42	2.11	1.75	2.4	0.6	0.4	26.3
	A+B	2.1	2.22	2.52	3.11	4.01	4.68	2.93	2.41	2.15	2.9	0.9	0.8	31.0

Legend: SD-standard deviation; V-variation coefficient; I-variation.
• Average results based on independent analyses from nine sites.

Still lower biomass values were registered for *Nymphoides* (KELLY, 1989; NIKOLIC *et al.*, 2009), they pointed out that water chemistry had an exceptionally high effect on macrophytic species and their bioproduction. On the other side, KAUL (1971) registered higher biomass values for *Nymphoides peltatum* at the peak of the vegetation period. In case of species with large leaf area such as *Nymphoides peltatum*, the biomass production dynamics is significantly affected by the rate of colonization by epiphytic organisms (HOPSON & ZIMBA, 1993). The submerged, unrooted species *Ceratophyllum demersum,* which occurs at all depths and in all regions and seasons (KUNII & MAEDA, 1982), was found in Wular Lake on a limited area, near the bottom of this aquatic ecosystem, where it did not form large biomass. This might be due to *Ceratophyllum* and its high requirements for nitrogen and nitrogen containing substances, which are moderately abundant in Wular Lake. NIKOLIC *et al*. (2009) reported this observation in case of *Ceratophyllum demersum* in Lake Provala (Serbia). Compared with the N. *peltatum, Ceratophyllum demersum* had lower values of the organic matter and organic carbon, which were somewhat lower than those found in literature (VIS *et al.,* 2007). The obtained data are a good illustration of the primary production dynamics of *Ceratophyllum demersum* in Wular Lake, and they also showed lowest variations. Overall *Ceratophyllum demersum* grew and produced biomass fairly uniformly through the vegetation period, with an exception in June when it reached a peak of the vegetation growth. The average values of organic matter were about 75 %, in agreement with the available literature (WESTLAKE, 1965, 1971, 1975; NIKOLIC *et al*., 2009). The values of organic carbon we obtained for the analyzed species were slightly higher than those reported by WESTLAKE, (1975)), while other authors (RICH *et al.,* 1971; VIS *et al*., 2007) recorded considerably higher average values.

The analysis of chlorophyll A and B in the two macrophytes indicated the presence of species specificity as well as of seasonal dynamics of these pigments. The content of chlorophyll A has a wide range of variation in aquatic plants, which speaks in favour of plant adaptation to different ecological conditions, in the first place light and temperature (SCHAGERL & PICHLER, 2000). In Wular Lake, the floating species *Nymphoides peltatum* and the submerged species *Ceratophyllum demersum* exhibited significant differences in chlorophyll content among the dates of measurement throughout the vegetation period. The results of pigment content for the analyzed macrophytic species were in agreement with the available literature.

The seasonal variation in pigment content was an indication of bioproduction dynamics with *Nymphoides peltatum* having the longest period of bioproduction. Consequently, due to the decay and decomposition of its biomass after the end of the vegetation period, which significantly bolster the eutrophication process, this species had the highest effect on the process of secondary pollution of the lake (NIKOLIC & BILJNI, 2005).

Conclusions

It may be concluded from the above that the investigated aquatic ecosystem is dominated by macrophytes, one floating (*Nymphoides peltatum*) and another *submerged* (*Ceratophyllum demersum*). These plant species are characterized by uneven biomass during the vegetation period, which is brought about by the ambient climatic conditions and the trophic state of the investigated aquatic ecosystem. The enormous biomass which they form by the end of the vegetation period causes secondary pollution of the lake, which directly affects the trophic level of the ecosystem by accelerating the eutrophication process in this lake. Therefore it is necessary to monitor and control their growth and development. The results of the present study have implications for efficient eco-restoration of the lake ecosystem through scientific management of macrophytic vegetation**.**

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