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Full Length Research Paper

Study on productivity of epilithic algae in Urumqi River Basin in Northwest China

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The primary objective of this study was to make a deep investigation on the concentration of chlorophyll a and ash-free dry mass (AFDM) estimates for algae growing on stones in Urumqi River located in an arid region of northwest China. The study was conducted on three sites. A highly improved method for measuring primary productivity *in situ* was used to estimate the primary production of algae growing on rocks (or algae epilithic) deposited in surface water. The results showed a low biomass with mean chlorophyll a content that was estimated at 5.9 mg/m ^{2} in the Urumqi River. Of the three sites studied, the mean gross primary productivity of periphyton was 394.89 mgC/m^2 day and AFDM 344.75 mg/m^2. The analysis of correlation between chlorophyll a and altitude was found to be a curve of anti- hyperbola. Total phosphorus and chlorophyll a was in equilibrium with that between chlorophyll a and total nitrogen.

Key words: Epilithic algae, phytoplankton productivity, chlorophyll a, ash-free dry mass (AFDM).

INTRODUCTION

Aquatic plants absorb nutrients from surrounding zones. Normally, they live in freshwater habitats along the edges, in streams, rivers, at the surface water, and lakes. They are innumerable and belonging to several thousands of species. They are numerous in areas with low flooding and wet. Their way of life is that they manage to take root in the soil waterlogged and along natural drainage system, while others are piled on the stones in water. Studies showed that the high phosphorus but low nitrogen environment in the headstream of the river did not cause eutrophication. The impacts have been deeply recorded for lacustrine phytoplankton. It was revealed that the impact of nutrient enrichment on the biotic of lotic ecosystem is important in the distribution of algae communities (Whitton and Crisp, 1984; Peterson et al., 1990; Padisak et al., 1993; Reynolds et al., 1993). In aquatic systems, the utilization of the nutrients in water leading to the proliferation of algae and increase of primary productivity of water abnormally where both nutrients and grazers usually have important effects on the productivity of phytoplankton and their stratification facilitates loss of particulate nutrients through sedimentation, as well as chemical transformations across a sharp reduction–oxidation gradient in the metalimnion (Kilham and Kilham, 1990; Hillebrand, 2002; Liess and Hillebrand, 2004). Several studies indicated that primary productivity by periphyton is a useful proxy in determining stream water quality because these organisms respond rapidly to environmental change (Hecky and Fee, 1981; Lowe and Laliberte, 1996). Studies have indicated that nutrient limitation of primary productivity in most parts of the World varies through space and time, most likely as a function of upwelling and they have indicated that other nutrients like iron and coppers may limit or colimit algal growth than nitrogen and phosphorus (Plisnier, 2002; Guildford et al., 2003; Langenberg et al., 2003; Descy et al., 2005; Chale, 2004). On the other hand, studies have revealed that the autotrophic index is indicative of the proportions of the community composed of heterotrophic and autotrophic organisms. It is said that autotrophic index values between 50 and 100 are characteristic of

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non-polluted conditions with little organic detritus and the values that are greater than 400 indicate the communities affected by organic pollution (Chale, 2004; Descy et al., 2005). In China like elsewhere in whole world, several studies related to the aquatic plants have been discussed with a remarkable lack of productivity of epilithic algae investigations. All authors focused their force in geological origin of the release of phosphorus. Other several studies concerned the plants in the lakes. The arid regions were totally forgotten due to their inaccessibility that makes work difficult for achievement. The main objectives of this study were not only to understand the species diversity, chlorophyll a, biomass and primary productivity of epilithic algae for arid region of Northwest China, but also their quantification in this arid zone and to compare their growth within two opposite periods (winter and summer) in order to assess the effects of climate change for their nutrients distribution.

MATERIALS AND METHODS

Description of the study area location

Located in Xinjiang Uygur autonomous region, the Urumqi River Basin (URB) is one of the experimental river basins in the Northwest China. The Urumqi River (43°06'N, 86°49'E) is originating from Tianger Peak at 4486 m above sea level. The river crosses the western part of Urumqi City, the capital of Xinjiang Uygur Autonomous Region, China and disappears in the desert. It is 53 km long and its average slope is 48.5%. There are a total of 14 precipitation stations and nine hydrometric stations in the basin. Data from these stations show that it is experiencing the rainfall around 420.0 mm. The URB has an annual snowfall estimated to about 54% of the total precipitation. Its potential evaporation is decreasing with the increase of the altitude. According the study held by Lanzhou Institute of Glaciology and Geocryology (1991), the steep-sided rock outcrops, debris cones and talus slopes surround the moraines and the main valley floor. In this arid region, Tundra vegetation is found only on the lower elevations, and peaty soil that supports grasses and sedges has developed on the valley bottom. The lithology is primarily Siluric crystalline schist, with liberal amounts of gneiss, gabbro, granodiorite, granite, and quartzite (Woo et al., 1994). Like whole China, the URB experiences long winter period from the end of October every year to the end of March the following year; a spring period from April to end of May and the summer period from June to October. The mean annual Temperature is estimated to be 5.4°C, with below 0°C mean temperature occurring between September and May (Yang et al., 1989; Woo et al., 1994) (Figure 1)

Field methods

Chlorophyll a

Samples were taken from the rocks that were removed from water to collect algae in a plastic tray using a small steel brush during summer (June-October 2009 and 2010) and end of winter (February to March 2010 and 2011) for a total period of 22 months; two times with high air temperature conditions that may be favorable for biomass growing each season. At each sampling site, 2 sub-samples were taken and rock scrubbing samples were then diluted to 250 ml and shaken well before each filtration to avoid any appearance of stranger elements that can disturb the assessment of epilithic algae. Two replicates for each sample were filtered for chlorophyll a and carotenoid pigment analyses and placed in 15 ml centrifuge tubes and frozen. Samples were kept Lugol filtered through membrane filters, offset, and analyzed for algal composition (Fahnenstgiel et al., 1998). ADFM was used for the extraction of chlorophyll filters, while the fluorometer was used for analysis (Fahnenstgiel et al., 2000).

Dissolved nutrients

Water temperature (the dissolved oxygen meter, JPB-607), pH (pH meter, PHB-1-S, Anhui), DO (dissolved oxygen concentration), conductivity (conductivity meter, HANNA HI 8733), NO_3 (cadmium reduction, 0.07 mmol L21 N), and total dissolved P (TDP: High-temperature persulfate digestion and molybdenum blue, 0.03 mmol L21 P), soluble reactive phosphorus (SRP; molybdenum blue, 0.02 mmol L21 P), total dissolved N (TDN; high-temperature persulfate digestion and cadmium reduction, 0.7 mmol L21 N) were filtered through prerinsed. Serial glass-fiber (Gelman A/E) and membrane (Osmonics PCTE 0.2 mm in 2001, Osmonics Cameo 0.22 mm in 2002) were analyzed using standard colorimetric methods (method and minimum detection limit in parentheses). During collection, more than 100 ml epilithon samples were filtered by glass microfiber filters (Whatman GF/C, 1.2 m pore size) for ash-free dry mass (AFDM) measurement and about 120 ml epilithon samples were filtered by glass microfiber filters for chlorophyll a extraction.

In situ primary productivity

Primary productivity was measured by gently sliding rock with black and white bottle of 250 ml each bottle in which was put rocks with at least 3 cm in diameter and Carbon-14 was then added. These bottles were totally covered by water to ensure that air from outside cannot enter into the bottle. To analyze the concentration of the dissolved oxygen in the river, water was measured through the bottles that were placed close to the original location of the rocks during 24 h of incubation (this operation was possible only during summer, while during winter, it could not be possible due to heavy snow cover). The stones were removed from the bottles after this incubation period. According to the study done by Fahnenstgiel et al. (2000), the filters that counted by liquid scintillation counting were decontaminated and incubation period in a photosynthetron was estimated to 45 min where the contents from each scintillation bottle were filtered onto membrane filters. Total CO and total C-14 activity were determined from water samples of each bottle that was placed under water. Photosynthesis-irradiance of the epilithic algae determined by phytoplankton integral primary production using Winkler, honest reading and the Great Lakes Production Model (Lang and Fahnenstgiel, 1995) was used to determine the amounts of oxygen

Other laboratory and statistical analysis

A combination of AFDM (1 g/ sample) = [(W1 - W2) × sample volume]/ [volume of filtered sub-sample] and analysis of variance (ANOVA) was used to determine differences in productivity (GPP: Gross primary productivity and NPP: Net primary productivity) per exposed rock area (mg O_2 h^{-1} cm^{-2}) and the sub-samples was dried (filter + sample) for 4 to 5 h at 100 to 120°C. Autotrophic index was calculated by the equation: AI = AFDM (mg/m^2) / chlorophyll a (mg/m^2).

The ANOVA was used to test the differences in chlorophyll a and carotenoid concentrations measured for chlorophyll a at 663 and

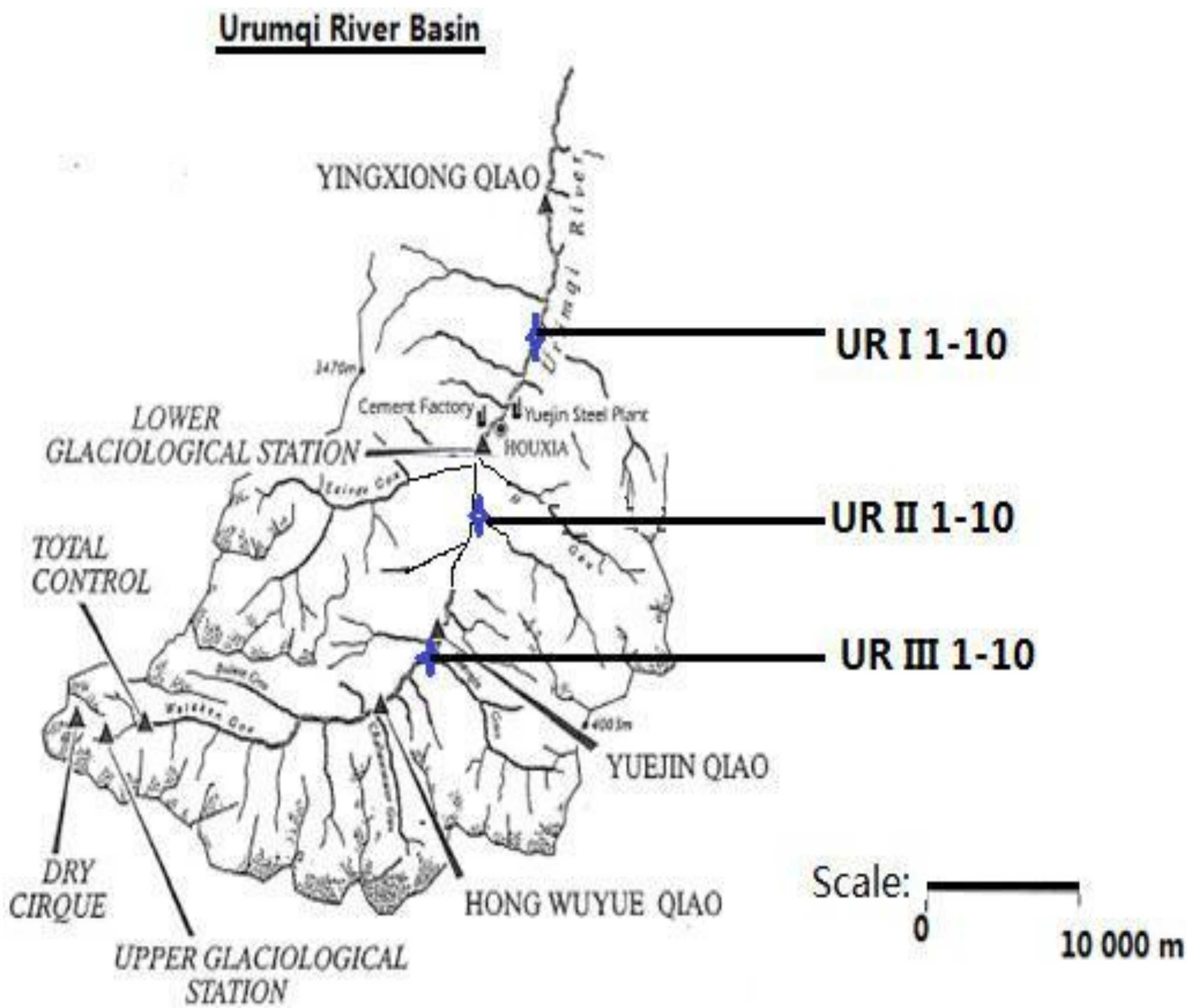

Figure 1. Study area location.

645 and 630 and 750 nm wavelength with a spectrophotometer (mg cm^{-2}) between watershed types and streams. Four nutrient treatments were tried and compared: P (phosphorus added), NP (nitrogen and phosphorus added), N (nitrogen added) that was added to agar as equal parts NO_3- N ($NaNO_3$) and NH_4-N (NH_4Cl) to achieve a concentration of 1.0 mol N and C (no nutrients added). N. P was added as Na_2HPO_4 to achieve a concentration 0.1 mol P. National Standards (SEPA, 2002) ware used as instruments for water quality analysis

RESULTS AND DISCUSSION

Analysis of biomass and primary productivity

Table 1 describes the distribution of AFDM, and chlorophyll a, the primary productivity of the epilithic algae, autotrophic index, consumed carbon by respiration (R), in the study area (Table 1).

In thirty sample sites taken in the URB, the results indicated the variation of biomass founded to be a chlorophyll a content. The highest was 13.2 mg/m^2 and the lowest was 3.2 mg/m^2 with an average of 5.3 mg/m^2. The average AFDM obtained was 344.75 mg/m^2 with the highest being 489.15 mg/m^2 and the lowest being 204.07 mg/m^2. From the results shown in Table 1, *in situ* primary productivity measurement revealed that the growing of biomass in the region is very limit. The highest gross productivity was 647.1 mgC/m^2 day and the lowest was 173.3 mgC/m^2 day with an average of 349.89 mgC/m^2 day. The mean net primary productivity was 108.78

Table 1. Distribution of biomass and primary productivity in Urumqi River Basin.

Site	AFDM (mg/m^2)	Autotrophic index	Chlorophyll *a* (mg/m^2)	Primary productivity (mgC/m^2 day)	R (mgC/m^2 day)	P/R
URI01	540.42	96.5	5.6	204.1	9.3	21.9
URI02	394.24	70.4	5.6	461.7	89.9	5.1
URI03	287.41	48.7	5.9	288.1	81.3	3.5
URI04	489.15	135.9	3.6	356.4	146.7	2.4
URI05	204.07	35.8	5.7	612.3	118.1	5.2
URI06	461.83	82.5	5.6	647.1	89.7	7.2
URI07	288.21	51.5	5.6	614.3	118.2	5.2
URI08	260.89	19.8	13.2	409.4	89.2	4.6
GF09	287.41	33.0	8.7	287.4	166.1	1.7
URI10	489.15	152.9	3.2	492.2	137.5	3.6
URII01	204.07	37.1	5.5	205.6	178.5	1.4
URII02	461.83	115.5	4	463.1	161.3	2.9
URII03	288.21	45.7	6.3	173.3	130.6	1.3
URII04	260.89	30.1	8.7	846.5	87.2	9.7
URII05	287.41	30.0	3.2	287.3	174.2	1.8
URII06	489.15	89.0	5.5	499.1	63.6	7.2
URII07	204.07	51.0	4	204.7	27.7	7.4
URII08	461.83	73.3	6.3	461.3	118.1	3.9
URII09	288.21	80.1	3.6	286.2	89	3.2
URII10	260.89	45.8	5.7	260.9	166.6	1.6
URIII01	287.41	51.3	5.6	182.3	118.1	1.5
URIII02	489.15	87.3	5.6	269.9	86.9	3.1
URIII03	204.07	15.5	13.2	311.7	79.8	3.9
URIII04	461.83	53.1	8.7	263.1	89.9	3.1
URIII05	288.21	90.1	3.2	301.8	81.1	3.6
URIII06	260.89	47.4	5.5	187.5	146.7	1.3
URIII07	287.41	81.9	4	611.2	118.8	5.1
URIII08	489.15	77.6	6.3	641.6	89.4	2.2
URIII09	204.07	23.5	8.7	614	118.9	5.1
URIII10	461.83	144.3	3.2	402.6	91.2	3.3
Mean	344.75	66.6	5.98	394.89	108.78	4.43

mgC/m^2 day and the average net primary productivity was 4.4 gC/m^2 month. However, the highest autotrophic index was 152.9; the lowest was 23.5 with an average of 66.6.

Statement of sample sites characteristics

In order to provide an environmental basis for explaining biological patterns, Table 2 summarizes the most important physicochemical data of all sampling sites (Table 2)

This study was conducted at an average altitude of 880.2 m above sea level with an average latitude of 43033'N, and the longitude of 88o47' W. The results presented in Table 2 report that the pH varied between 7.1 and 7.3 with an average of 7.2. The highest conductivity was 416 S/cm and the lowest was 381 S/cm with an average of 393.9 S/cm. In all sample sites, the total phosphorous was very low. The highest total phosphorus concentration was 0.91 mg/L, the lowest was 0.03 mg/ml and the average was 0.27 mg/L only. On the other hand, the average total nitrogen concentration was 1.09 mg/L where the highest concentration was 1.22 mg/L and the lowest concentration was 0.98 mg/L.

Impact of physicochemical characteristics for the distribution of biomass in arid zone

Chlorophyll a and altitude

The analysis of correlation between chlorophyll a and altitude as indicated in Figure 2 was found to be a curve of anti- hyperbola. The URB is located at an average altitude of 880.2 m and the distribution of chlorophylla ranged between 3.6 and 13.2 mg/m^2. The climatic

Table 2. Analysis of characteristics of the sample sites in Urumqi River Basin.

Site sample	Altitude (m)	Conductivity (S/cm)	pH	Total phosphorus (mg/L)	Total nitrogen (mg/L)	Latitude (^{0})	Longitude (^{0})
URI01	886	386	7.1	0.04	0.99	43.3	88.3
URI02	884	416	7.3	0.19	1.22	43.4	88.5
URI03	857	399	7.3	0.18	1.14	43.5	88.1
URI04	870	389	7.1	0.18	1.06	43.5	88.1
URI05	880	387	7.2	0.56	1.01	43.2	88.5
URI06	879	402	7.3	0.91	1.17	43.1	88.5
URI07	892	402	7	0.049	1.11	43.3	88.5
URI08	885	392	7.1	0.04	1.06	43.5	88.5
GF09	874	394	7.3	0.038	0.99	42.5	88.5
URI10	881	397	7.1	0.073	1.22	43.3	88.5
URII01	893	390	7.3	0.04	1.14	43.5	88.1
URII02	884	381	7.1	0.19	1.06	43.5	88.5
URII03	857	401	7.1	0.18	1.01	43.5	88.5
URII04	870	384	7.3	0.56	1.17	43.5	88.5
URII05	880	396	7.2	0.91	1.11	43.3	88.5
URII06	879	389	7.2	0.038	1.06	43.1	88.4
URII07	892	387	7.3	0.04	0.98	43.3	88.5
URII08	885	402	7.1	0.19	0.99	43.1	88.4
URII09	885	402	7.2	0.18	1.22	43.5	88.5
URII10	874	392	7.3	0.56	1.14	43.2	88.5
URIII01	881	397	7.1	0.91	1.06	43.5	88.5
URIII02	893	390	7.1	0.049	1.01	43.4	88.5
URIII03	884	381	7.1	0.04	1.17	43.5	88.5
URIII04	870	401	7.1	0.03	1.11	43.5	88.5
URIII05	880	384	7.2	0.07	1.06	43.3	88.5
URIII06	879	396	7.3	0.04	0.98	43.1	88.5
URIII07	892	389	7.1	0.19	1.39	43.3	88.5
URIII08	885	387	7.2	0.18	1.02	43.1	88.5
URIII09	874	402	7.3	0.56	1.1	43.2	88.5
URIII10	881	402	7.1	0.91	0.99	43.1	88.5
Mean	880.2	393.9	7.2	0.27	1.09	43.33	88.47

conditions with temperature of below 0°C during whole winter period from the end of October every year to the end of March of the following year may be the main cause that limits algae growth (Figure 2).

Chlorophylla and chemical composition

The mean chlorophylla of epilithic algae, total phosphorus and total nitrogen concentrations from all sampling sites of the URB were 5.98 mg/m^2, 0.27 mg/L and 1.09 mg/L, respectively. However, the relationship between chlorophylla and water temperature was significantly positive due to the conductivity that varied 386 to 416 S/cm with an average of 393.9 S/cm. These results confirm the hypothesis that in most cases, the proliferation rate of algae increased with increasing temperature (Kilham and Kilham, 1990; Caraco et al., 1992). The relationship between chlorophyll a and total phosphorus was below 1 at all sampling sites. The growth and metabolism of epilithic algae absorbed large amounts of phosphorus, and destruction of the phosphorus balance due to the highly lack of supplementary phosphorus leaded to TP concentration decreasing, and thus there was no significant correlation between chlorophyll a and total phosphorus. The relative abundance of dissolved organic N and P (Figure 3) indicates that access to organic nutrients by either direct assimilation or some mineralization might be a critical control on biomass productivity in the URB. Reference to some studies on primary productivity and biomass-specific phytoplankton productivity that assessed the rapid recycling of organic

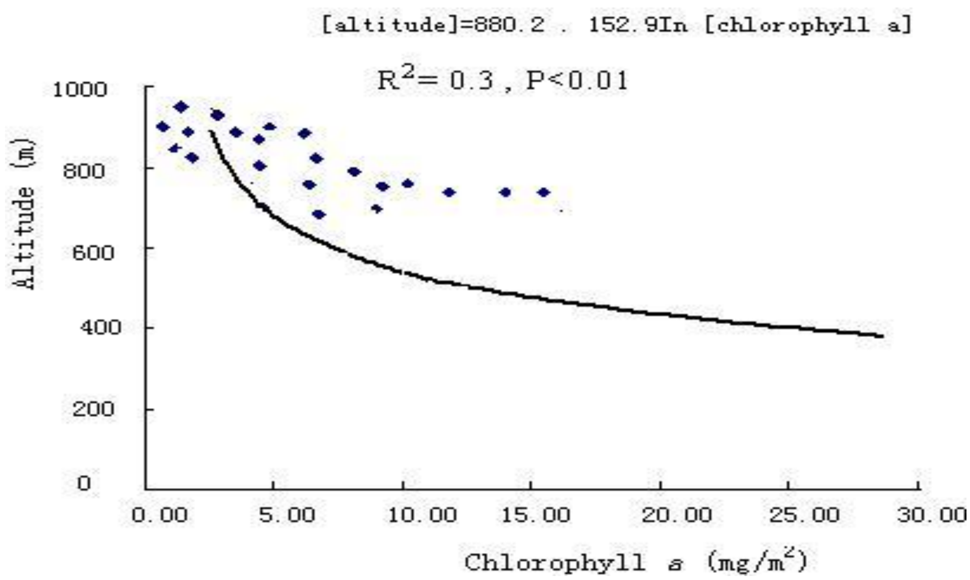

Figure 2. Analysis of correlation between chlorophyll a and altitude in Urumqi River Basin.

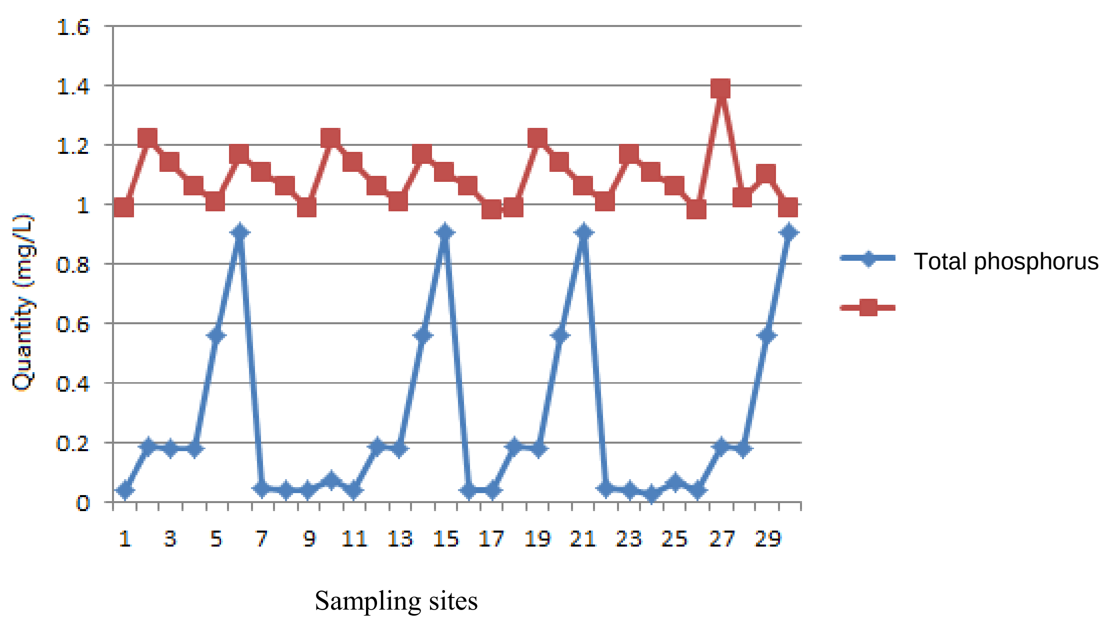

Figure 3. Variation of total phosphorus and total nitrogen in Urumqi River Basin.

nutrients in temperate (Caraco et al., 1992; Salonen et al., 1999; Hudson et al., 2000; Mitchell and Baldwin, 2005) with this analysis, it might be said that organic N and P is probably vital for supporting the nutrient demands of phytoplankton, periphyton and other aquatic plants in many region–and this study supports that this hypothesis of nutrient recycling is also critical in arid zones in order to sustain high productivity despite low inorganic nutrient concentrations (Kilham and Kilham, 1990). In most of sample sites, it was found that total phosphorus was one of the main limited factors for epilithic algae growth; this was regular in the winter period with high amount of sediment that belongs to snowcover. During winter period, a large mining phosphate rock plant in all sampling sites was exposed on the surface and eroded sediments by the precipitation and river. On the other hand, the relationship between chlorophyll a and total nitrogen was also positive in all sampling sites in the URB. Moreover; the relationship between chlorophyll a and dissolved oxygen was not significant. These results could be explained by the dissolved oxygen of all sampling sites been measured at

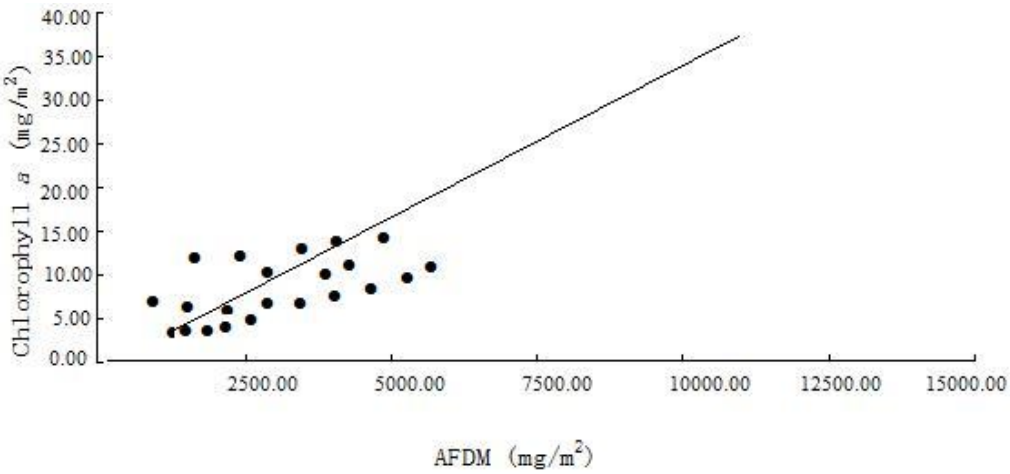

Figure 4. Analysis of linear correlation between Chlorophyll a and AFDM in Urumqi River Basin.

different time (Figure 3).

Biomass and primary productivity

AFDM and chlorophyll a

The total amount of autotrophic organisms in the sample was a good factor (or index) to determine the significant presence of chlorophyll a. The AFDM is defined as a measurement of the total amount of organic material in the sample including the presences of autotrophic concentrations. The correlation of AFDM and chlorophyll a is indicated in Figure 4.

Due to the physicochemical characterization of the URB, the analysis of linear relationship between Chlorophyll a and AFDM could not determine wether AFDM or chlorophyll a is good indicator of the distribution of the epilithic alga biomass in this arid zone. These results may guide to conclude that the high and low biomass are possible closely related to total phosphorous and total nitrogen. However, chlorophyll a and AFDM can be combined to form an informative autotrophic index. The results of this study indicate that the mean of autotrophic index from all sampling sites in the URB was 66.6, the highest amount was 152.9 and the lowest was 23.5.

Primary productivity

The gross primary productivity has been discussed in many studies (Putz and Redford, 2010; Putz, 1997; Allen, 1971; Sheldon and Boylen, 1975) with different results. It was revealed that the respiration is far more than productivity in the sewage. It had been found that when both items decrease in the clean water area, P/R value is generally close to 1. P/R value is less than 1 in sewage area and it is more than 1 in the recovery area (Odum, 1956). This was found little different according to the results of this study as indicated in Table 1, where P/R ranged between 1.3 and 21.9 with an average of 4.43 implying that the respiration was less than primary productivity. The results show that the respiration ranges between 9.3 and 178.5 mgC/m^2 day while the primary productivity ranges between 173.3 and 647.1 mgC/m^2 day. The long winter period with high amount of snowcover and temperature decrease in the URB led to death of most of the algae which would take a long time to recovery in spring and summer. The high amount of P/R in the URB may be due to water pollution by sedimentation, sewage and other anthropogenic activities**.**

Conclusions

This study demonstrates that climate change and anthropogenic activities are the main factors that influence the distribution of epilethic algae biomass and primary productivity in the phosphorus-rich river in arid zone. The high biomass was obtained in summer. However, the results of the study indicated that the growth of epilithic algae was very limited during winter where temperature was below 0°C due to high amount of snowcover that freezes the soil and water; these conditions cannot facilitate the photosynthesis system which is important for development of plants. The distribution of epilithic algae was influenced more by the total nitrogen than total phosphorus.

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