Predicting the Effects of water temperature, pH, nitrogen and Phosphorus on the abundance of Melosira in Jebel Aulia Reservoir – Sudan, using Multiple Regression model

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Abstract: This study attempt to envisage the effects of water temperature, pH and availability of nitrogen and phosphorus on the phytoplankton Melosira in Jebel Aulia Reservoir in Khartoum, Sudan. The study took a complete year from January 2003-December 2003 during which selected physicochemical variables such as water temperature, pH, nitrate and phosphate concentrations were measured at the time of plankton collection. The effects of the four physicochemical variables on the Melosira abundance were predicted by the development of seven models using the Multiple Regression Analysis of STATVIEW 5.0. The annual means of water temperature, pH, nitrate, phosphate and the Melosira abundance were in the order of 25.19 ±1.10^{o}C, 7.99± 0.30 μgl-l, 3858.50 ±1087.37 μgl^{-1} and 340.83 ±12.44 μgl^{-1} and 1650.99±2386.90 cell L^{-1}. The highest Melosira density of 9111.5 cells L^{-1} occurred in March at the temperature of 21.8^{o}C, pH 8μgl^{-1}, nitrate and phosphate concentrations of 3800 and 280 μgl^{-1}. The lowest density of 442 cells L^{-1} occurred in June at the temperature of 28.8^{o}C, pH 7.60μgl^{-1} and at the nitrate and phosphate concentrations of 4100 and 360μgl^{-1}. The actual population density and the population density of Melosira predicted by the estimated regression model were compared using t-Test analysis and the result indicated a non-significant difference at P ≤ 0.05 (t-Value = 0.26, DF=11, P-Value =0.80) between the means of the two.

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1. Introduction

The purpose of Jebel Aulia reservoir is to store water during the flood season in order to be used in down-stream areas during the dry season, but the economic importance of reservoirs on fish production is often ignored or not fully understood. Nevertheless, reservoirs play a great role in plankton development. Plankton in aquatic environment, ever since, has been recognized and its demand expanded with the growing industry of aquaculture [1].

Optimum temperature for phytoplankton photosynthetic activities is generally between 20 – 24oC and temperature lower than 16oC will slow down the growth of phytoplankton whereas those higher than 35oC are lethal for a number of species [2]. Failure of plankton to develop beyond a certain level in Jebel Aulia reservoir was attributed to depletion of nitrate [3]. However, on the other hand, there is positive correlation between plankton and nitrate concentration for example, the peak of Melosira, drop when the concentration of nitrate fell to10 – 20 mgl-1(1000-20000μgl-1), where as the concentrations of phosphate and nitrate necessary for phytoplankton growth are at least, 15μgL-1 and 300μgL-1, respectively[4][5].

Algae normally grow in alkaline medium of 7-9 with an optimum range between 8.2–8.7 and pH value exceeding 9.2 could inhibit the photosynthetic activity of phytoplankton [6].

Because seasonal phytoplankton dynamics are controlled by biotic and chemical and physical factors, it is important that these factors be well understood in order to study phytoplankton seasonal dynamics and abundance with an understanding of the effects of these factors on them [7]. Unfortunately, due to complete lack of long terms data sets on the most basic physical and chemical parameters and inadequacy of knowledge about the dynamic of particular phytoplankton species in African aquatic systems [8] and particular in Sudan, it is therefore not exempted from this knowledge deficiency mentioned above. This study is therefore important in availing some facts on the effects of certain physicochemical parameters on Melosira abundance in Jebel Aulia reservoir.

2. Material and Methods

2.1 Description of the Study Area

Jebel Aulia dam is situated 42 Km south of Khartoum (latitude of 15°N and longitude of 32°E), built in 1937, to improve the natural storage of the White Nile waters. At its highest level, its reservoir covers an area of about 600 Km2. Its width varies between 1 – 1.5 Km and has a maximum depth of 12.5m. There are series of seasonal drainage which drain into the reservoir from the eastern bank.

2.2 Sampling the phytoplankton

The phytoplankton was collected by towing plankton nylon net from a boat moving against the current for ten minutes. Five hauling were taken at two minutes interval; Contents were kept in a plastic bottle with capacity of a liter. Immediately 4% formalin was added and the sample was left to stand for 24 hours. When the suspension settled down, the supernatant water was siphoned off leaving sediment varying between 5– 25 ml in volume, according to the richness of the catch. Ten slides from the sample were first thoroughly examined under the lower power of the microscope (×10) before counting it under the high power (×40). Five transects, selected at random, and from each slide samples were examined under the high power. All the phytoplankton encountered in these transects counted and were identified to genera level using identification criteria [9].

2.3 Measuring physicochemical Variables

Water for chemical analyses was collected from a depth of about 20 cm. The sample was filtered on the site immediately after collection through filter paper (Whatman GF/C No. 42), except water for pH and dissolved oxygen. Water surface temperatures were recorded at the start, using an ordinary centigrade thermometer and the chemical analyses were completed on the same day of collection. Phosphate was determined using Atkin's modification of Denges' method (1925).[10] and results were expressed as µg PO4 L-1 and nitrate concentration was determined by phenol disulphonic acid method as described by the author above were expressed as µg NO3 L-1 and pH was determined on arrival to the laboratory using a digital pH meter (Huck).

2.4 Data Analysis

All tables were constructed using Statview 5.0 software for Windows and all graphs in this work were drawn using Microsoft Excel 2007. In this study, multiple regression models were formulated using an organized data-set. Multiple regression models are often used in many study areas, because it can be easily modeled using simple assumptions. This model is composed of independent and dependent variables, and is easily verified, based on three viewpoints. The first is the correctness of the values predicted by the model. The second is the multi-collinearity between independent factors, and the third is whether the errors in the model have normality or not.The other good thing with the regression model is that the sensitivities of the variables are estimated according to the coefficient values for them [12].

2.5 Multiple regression models

The multiple regression models is often used in many study because it can be easily modeled using simple assumptions. This model is composed of independent and dependent variables and is easily verified based on four viewpoints. The first is the correctness of the values predicted by the model. The second is the multi-co linearity between independent factors and the third is whether the errors in the model have normality or not. Moreover, the sensitivities of the variables are estimated according to the coefficient values for them (Goldberg et al., 2003).

$$Y = C + a1X1 + a2X2 + a3X3 + a4X4$$

Where Y= Melosira density (cell L-1), X1 = water temperature (0C), X2 = water pH, X3= nitrate concentration (µgl-1), X4 = phosphate concentration (µgl-1), a1= coefficient of X1, a2 = coefficient of X2, a3 = coefficient of X3 , a4 = coefficient of X4 and C = intercept.

Generally, the coefficient of each variable represents the capacity or sensitivity of the variable. Therefore, the coefficients for two variables must show positive values in the multiple regression models.

3. Results

Table1 shows, the mean water temperature, the mean pH and the mean abundance of Melosira (Cells L-1) with their minimum and maximum values from January to December 2003. Water temperature varied between 19.60°C in January and 30°C in September and October during the research period and water temperature annual mean was 25.18±2.00°C. pH was mostly neutral and measured between 7.40 in May and 8.50 in September, and had annual mean of 7.99±0.09. The annual mean of phosphate concentration was 340.83 ±12.44 µgl-1 and varied from 280 µgl-1 in March to 420 µgl-1 in August .The highest and lowest concentrations of NO3 were 600 µgl-1 in November and 15002 µgl-1 in September, respectively and had an annual mean of 3858.50 ±1087.37µgl-1 .

Table 1. Annual Means of melosira of the selected physicochemical variables

Variable/Organism	Mean ±SE	Minimum	Maximum
Water temperature(oC)	25.19 ±1.10	19.6	30
pH(µgl-l-1)	7.99±0.09	7.4	8.5
Phosphate (µgl-1)	340.83 ±12.44	280	420
Nitrate(µgl-1)	3858.50 ±1087.37	600	15002

SE, standard error of the means

Figure 1 shows the fluctuation of Melosira abundance with water temperature and pH during the study. Melosira density showed one maximum peak of 9.1115 X 103 cells L-1 in March then droped to a density of 1.587 X 103 cells L-1 in April and continued to decline through May and reached its lowest density of 0.442 X 103 cells L-1 in June. After June, there was again a gradual rise in density through July; August and September where the density started to decline again and finally shot up to 0.707 X 103 cells L-1 in December. Water temperature started to rise as from February through March, April May then June where it reached 30oC. From June it droped to 26 and 25 in July and August then rose to its maximum of 28.5^{0}C in September and 30^{0}C in October. The pH was observed to drop from January and continued through February; April reached its minimum value 7.4 in May then started to rise from June, July and slightly dropped in August then gave rise to its maximum value 8.5 in September that are in agreement with the pH of most natural waters that ranges between 6.0 and 8.5 (Chapman, 1992). From September a decline in the pH was observed through October and November then finally rose up in December.

It is apparent from figure1b that Phosphate concentration showed a uniform trend throughout the year, while nitrate concentration was high from January to September; dropped to a concentration of 1x103 µgl-1 in October to 0.6x103µgl-1 in November then rose finally to 0.7 x 103 µgl-1 in December. The minimum Melosira density was obtained in June when the water temperature recorded was 41^{o}C, pH 7.6 and phosphate and nitrate concentrations were 4.1x103 and 0.36x103 µgl-1 respectively. The maximum density on the other hand was recorded in March at the water temperature of 21.8 oC, pH 8 and phosphate and nitrate concentrations of 3.8 x 103 and 0.28 x 103µgl-1 respectively.

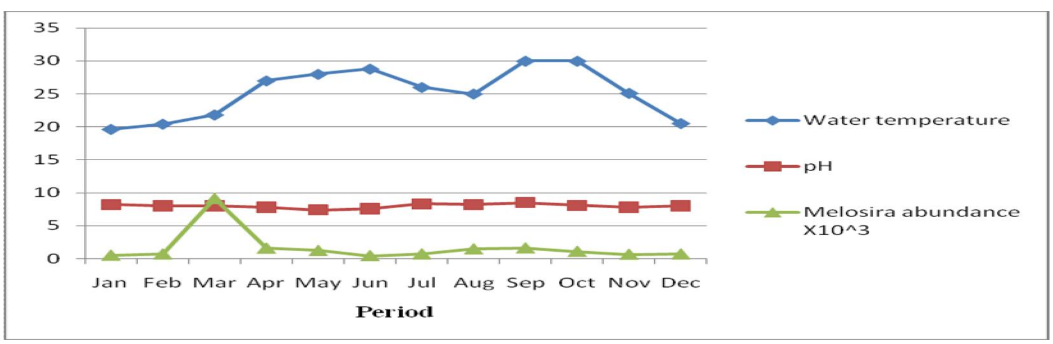

Figure 1a. Fluctuation of Melosira with the physicochemical variables.

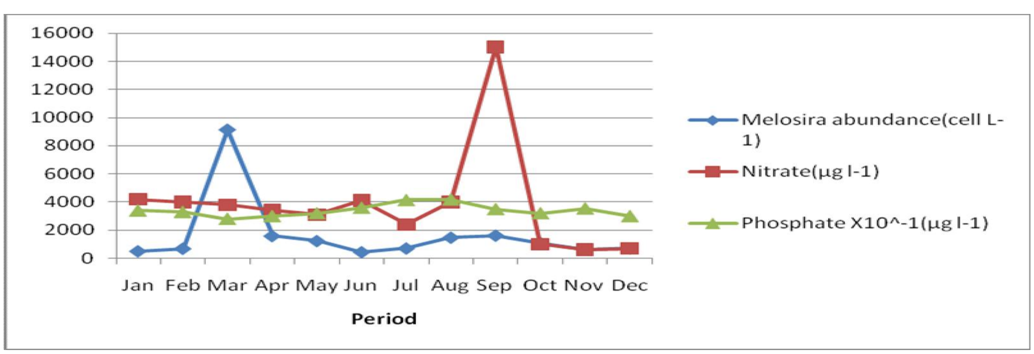

Figure 1b. Fluctuation of Melosira with the physicochemical variables.

Table 2. Regression Models for Melosira density and the selected physicochemical parameters.

General Model	Y= Cn + a1X1 +a2X2 +…..+ anXn
Estimated Model	Y=-13807.99+ 143.54X1+3982.61X2-0.133X3-57.65X4

The table above shows seven regression models generated based on the general regression formula to predict the effect of water temperature, pH and nitrate and phosphate concentrations on abundance of Melosira.

In the estimated model developed in this study, Y stands for Melosira density; X1 for water temperature; X2 for water pH; X3 and X4 for nitrate and phosphate concentrations consecutively. The estimated Model developed predicted the synergistic effects of water temperature, water pH and nitrate and phosphate concentrations on Melosira abundance.

Table 3. Melosira abundance (cell L-1) generated from the seven regression models.

Month	Water temperature	Water pH	Nitrate	Phosphate	Melosira (cell L-1)	Melosira (cell L-1) Predicted by the Model
JAN	19.7	8.2	4200	340	510.33	1517.6
FEB	20.4	8	4000	330	691.5	1424.6
MAR	21.8	8	3800	280	9111.5	4534.7
APR	26.8	7.8	3400	300	1587	3356
MAY	28	7.4	3100	320	1230	822.14
JUN	30	7.6	4100	360	442	533.3
JUL	26	8.3	2400	415	708	1264
AUG	25	8.2	4000	420	1473.5	2304
SEP	28.5	8.5	15002	350	1619	1962.3
OCT	30	8.1	1000	320	1090.5	4176.4
NOV	26	7.8	600	355	641.5	442.86
DEC	20	8	700	300	707	3535.6

It is clear from the above table that the value of Y(Melosira abundance) generated by the Model in March is higher (4535 cell L-1) than the one the model generated in the month of June (1046 cell L-1). It is also clear from the same table that the density of melosira obtained by following the density fluctuation as a function of the selected physicochemical variables was 9111.50 (cell L-1)in March higher than the predicted one in the same month. However, the trend analysis of the fluctuation of Melosira density recorded a density of 442 (cell L-1) in June lower than the predicted abundance for the same month(June).

Table 4 Difference between the predicted Melosira abundance and the actual one

	Mean Difference	DF	t-Value	P-Value
Predicted/Real	178.69	11	0.26	0.80NS

NS: non-significant

From the table above, there is no statistically significant difference (P=0.45) between the means of the density of Melosira predicted by the model and the one obtained from the trend fluctuation study.

3.1 Discussion

In the present study, water temperature and nitrate and pH were important physicochemical variables in explaining the total abundance of Melosira. Phytoplankton generally have an optimum temperature range for photosynthesis that lies between 20 – 24°C and temperature lower than 16°C will slow down the growth of phytoplankton whereas those higher than 35°C are lethal for a number of species. Based on this, the highest density attained by Melosira in March was reached at the temperature of 21.8°C. The present study however, obtained an optimum temperature range of (19.6-30°C). Therefore, the temperature at which Melosira peaked up in March is within the optimum temperature obtained by the present study (19.6-30°C). Effect of temperature on Melosira abundance was eminent in this study and might have been responsible for the drop of Melosira density to its minimum in June (at the temperature of 30°C). Another important physicochemical variable that determines Melosira abundance is the water pH. In March during the highest density of Melosira the pH measured was 8 and the optimum pH range in the present study was 7.99±0.30. Looking at the pH value measured in March it is apparent that it fits well within the optimum range for Melosira physiological activities. This is in agreement with Lavans B et al

1996 who found a pH optimum range of 8.2 – 8.7 and Aleem A. A (1969) who pointed out that a pH value exceeding 9.2 could inhibit the photosynthetic activity of phytoplankton. The effect of pH on Melosira abundance was clearly seen in June when the pH value measured was 7.6. Comparing this pH value (7.6) with the optimum range above, there is no doubt that it is outside the optimum range needed to maintain physiological activities of phytoplankton. This might explain the occurrence of low Melosira density in this month.

However, nitrate and phosphate concentrations measured in March was (3800 µgl –l and 280 µgl–l) coincided with the highest density of Melosira. The study found nitrate and phosphate optimum ranges of 3858.50 ±1087.37 and 340.83 ±12.44µgl –l respectively. This result is in conformity with Andersen T. et al 1996 who found that at least, 15µgl-1 and 300 µgl-1 of phosphate and nitrate concentrations needed for phytoplankton growth. In Jebel Aulia Reservoir nutrient concentration did not seem to limit Melosira abundance. For example during the maximum abundance of Melosira in March, nitrate and phosphate concentrations were 3800 and 280µgl-1 and during the minimum abundance in June nitrate and phosphate concentration were 4100 and 360 µgl-1 respectively. However, in June in spite of the acceptable nitrate and phosphate concentrations, the population density was low due to low pH and high temperature values. The same result was obtained by NICO Salmaso et al 2010 who evidenced that nutrients did not appear to limit phytoplankton abundance in River Adige in Italy.

By looking at coefficients of the variables in the model, the last two variables(X3= nitrate concentration and X4= phosphate concentration) had negative coefficients that might contributed to Melosira abundance lower than the one obtain by the trend fluctuation especially in March which was the time in which the highest peak of Melosira density was recorded. However, in June the abundance of Melosira predicted by the model was higher than the one obtained by the trend fluctuation as a function of physicochemical variables despite the negative coefficient of both the nitrate and phosphate variables in the estimated model. The fact that the model predicted a higher Melosira abundance than the one obtained in the trend study despite the negative coefficients of both the nitrate and the phosphate variables is in conformity with the above finding of NICO Salmaso et al 2010 that phytoplankton abundance seemed not to be limited by nutrient availability.

The coefficients of the first two variables(X1=water temperature and X2= water pH) were both positive in the estimated regression model. From the study results, both the water temperature and pH were within the reasonable range for Melosira physiological activities and was responsible for the highest Melosira peak in March. However, as to the trend analysis, Melosira density was low in June due to the high temperature (300C) despite the acceptable pH range. This result obtained by the trend analysis of Melosira density fluctuation in June contradicted the prediction made by the model. That is to say, the density the model predicted was almost twice the one observed by trend analysis of Melosira density fluctuation in June.

The apparent difference in the means of Melosira density obtained by both the trend analysis and the predicted multiple regression did not differ statistically from each other. The estimated model has therefore predicted the effects of the environmental variables on the abundance of Melosira just as the trend analysis of Melosira density fluctuation during the study period.

4. Conclusion

In this paper nutrient concentrations did not appear to limit phytoplankton growth in Jebel Aulia reservoir. The most critical forcing factors in the reservoir were physical variables, mainly water temperature and pH. These factors acted positively by increasing Melosira density and negatively by decreasing Melosira abundance.

The estimated multiple regression Model had the same power of unveiling the effects of the selected physicochemical variables on the abundance of Melosira jus as the trend analysis of Melosira abundance did during the study area. Such a flexible model could slightly be adjusted to suit other studies such as predicting the effects of Phyto and zooplankton biotic interaction in water column and might provide aquatic ecologists, aquatic zoologists and limnologists with a valuable yard stick for quantifying and understanding the overall phyto and zooplankton interaction and its importance for aquaculture studies.

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