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Research Article

Ecological adaptation of Algal communities in the Swat Valley, (Hindu cush mountains, Pakistan) to altitude

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Abstract

The problem of algal species diversity distribution and their relationships with altitude of aquatic habitats is studied on the Hindu Cush Mountain communities of the Swat River Valley. The present study was conducted to explore 20 different localities for algal flora and check their variation with respect to some ecological parameters such as seasonal variation in temperature and pH, and altitudes from 1000 to 2000 m a.s.l. Altogether, 149 species and infraspecies belonging to four taxonomical divisions were taken from 77 algological samples during 2005-2008. For the analysis methods of bio-indication, comparative floristic, and species-area relationships with the help of statistical programs were used. Bio-indication analysis showed that algal species in studied communities inhabit water and soil and preferred temperate, intermediate organically enriched, slow streaming, low-alkaline, and low-saline water. Photosynthetic activity of algal communities is rather high. Correlation between species richness and major climatic condition variables calculated with statistic programs show that algal species richness in Swat Valley decreased with altitude, formed communities with cyanobacteria and greens prevailing in the valley and diatoms, and greens in the mountains, which are regulated by temperature higher than 19 C° and altitude about 1800 m a.s.l. The mean water temperature is important but algal communities are most impacted by the altitudes of their habitat.

Keywords: Algae, Diversity, Ecology, Distribution, Altitude, Bio-indication, Hindu Cush Mountains, Pakistan

1.Introduction

The biodiversity of algal communities in the Hindu Cush Mountains areas was formed under natural climatic and anthropogenic impacts. The algal diversity research in the rivers of the southern Hindu Cush region still remains in the initial stage. In Pakistan, our knowledge of regional algal diversity is far from exhaustive, whereas the algal communities of some rivers and parks are better but are still sporadically studied [1-39]. The Swat River Valley is located in an inaccessible mountainous area and therefore has been insufficiently studied.

Elevation plays a large role in regulating plant species richness patterns. The altitudinal studies of high-plant diversity distribution are very extensive, especially for rare species. But from a standpoint of factors regulating distribution, studies of common species are the most important [40]. The diversity-temperature relationship for high plants is well-known [41]. Altitude-diversity correlation was studied for vascular plants, bryophytes, and lichens [42], whereas for freshwater algal communities, it is still not clear.

Our last experience for algal diversity and altitude relationships [43-44] shows a complex correlation of species richness and divisional content in freshwater habitats of the Georgia Mountains. Nevertheless, the main trend of algal diversity in altitudes of habitats higher than 1000 m a.s.l. is the increase in species richness.

Methods used to reveal environmental impacts with the help of ecological indicators are: the community structure fluctuation analysis, bio-indication of major impacting factors, calculations of integral density-diversity indices, and statistical approaches linking the community structural and functional aspects with environmental fluctuation [45].Therefore, this work was aimed at taking inventory of the algal diversity in this area and to compare species content in respect to the habitats' altitude. We have assumed that a comparison of species diversity of aquatic habitats will help in revealing trends of algal diversity under climatic impacts.

2. Study area description

The Swat Valley has been divided in two administrative units: Tehsil Swat and Tehsil Matta. Both have their separate councils. Matta tehsil is located at 35° 5' 37" North, 72° 18' 47" East and has an altitude of 1,120 meters. The area of Tehsil Matta is called Bar Swat (Upper Swat) in local vernacular. The total area of Tehsil Matta is about 683 square kilometer [46]. The surrounding geographical position of Tehsil Matta is: Swat Tehsil surrounds Tehsil Matta on 3 sides: east, north, and south; the Lower Dir District is found to the west.

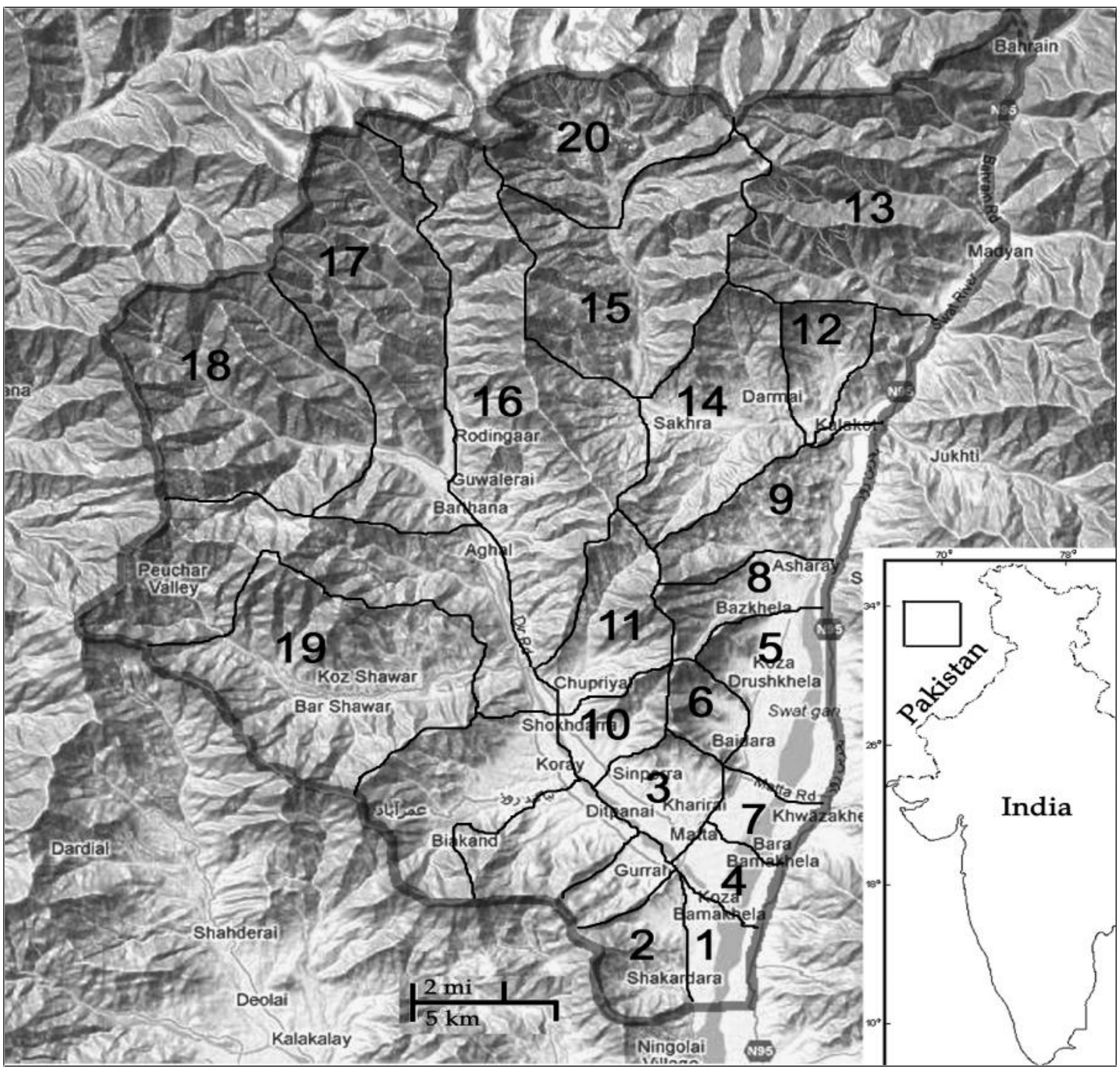


Figure 1. Site of sampling in the Swat district, Pakistan

Matta Town is the trading center as well as the administration headquarters, located some 22 miles away from Mingora City. The total population of the upper swat is 251,368 according to the 1998 census report. The annual population growth rate is 3.04%. Matta City, having more than 10,000 inhabitants, is one of the largest settlements of the District of Swat, Pakistan located near the north junction of the Haronai River and Swat River. The Swat River is a river in Khyber-Pakhtunkhwa, Pakistan. Its source is in the Hindu Kush Mountains, from where it flows through the Kalam Valley passing from Tehsil Matta and the Swat District. It then skirts around the Lower Dir District and flows through Malakand District to enter the Kabul River at Charsadda in the Peshawar Valley. Upper Swat (Tehsil Matta) consists of two main valleys: Sakhra and Rodingar. The Arnwai stream irrigates The Rodingar valley up to the Totkai, while the Bawrai stream irrigates the Sakhra valley up to the Baghderai. The Shawarai stream irrigates the narrow valley of Shawar. The elevation of the Swat River Valley, at the southern boundaries of the District is over 6,000 meters and rises rapidly toward the North. The summer season is short and moderate. It is warm in the lower Swat Valley but cool in the upper northern part. The hottest month is June, which means maximum and minimum temperatures are about 33°C and 16°C, respectively. The coldest month is January, which has maximum and minimum mean temperatures of 11°C and -2°C, respectively. Winter is long from November to March. The highest rain fall recorded during the month of March is about 242 mm [46].

The geography of Tehsil Matta is divided into mountain and plain ranges. Mountain ranges consist of high mountains and hills spreading in western and northern directions. These mountains are covered with snow in winter seasons, but in summer seasons the snow gradually decreases. The western direction contains mountains of Shawar and Biha and the northwest direction is defined by the mountains of Sakhra and Lalko. The area of Tehsil Matta started from Shakardara Valley along the Swat River at one side and reaches to the Lalko Valley, and on other side, towards the west from Matta, it reaches to the Biha Valley and at the junction of the Chuprial Valley it separates, reaching up to the Shawar Valley and its surrounding localities. The plain area of Tehsil Matta is a narrow range starting from Shakardara valley and runs along the Swat River to the Ashary Valley. Most of the area consists of hills and mountains. On the whole, Swat is located in the temperate zone, where the climate is controlled by various factors including latitude, altitude, the Indian Summer Monsoon in the summer and the Cyclonic current, coming in from the Mediterranean Sea in winter. The average annual precipitation in the Swat district ranges from 1000 mm to 1200 mm, distributed among three rainy seasons (table 1) [46]:

Winter Rains

These begin in the month of December and last until the end of February, typically occurring in 1-2 week-long continuous rainfall, called Jarai (the local name). Snowfalls occur from mid-January to the end of February in the plains areas, and from the beginning of December to the end of March in the mountainous areas.

Spring Rains

These begin from March to May, accompanied by thunderstorms, hail, and with larger raindrops than those that fall during the winter.

Summer Rains

These rains begin after the dry month of June, starting from the month of July till the end of September. Precipitation in this season is sporadic and is sometimes followed by thunderstorms and by sudden hailstorms that cause damage to crops and fruits.

Tehsil Matta has diverse flora (Algae, bryophytes, pteridophytes, angiosperms, and gymnosperms) from a small herbaceous plant to large coniferous forests with plants of great medicinal value. Tehsil Matta is a lush green area with fertile soil, and the best irrigation and agricultural resources. Fruit orchards are the main cash crops; the famous Swat Apples are cultivated and produced here. Besides its physical beauty, Tehsil Matta is well known for certain fruits and nuts that are produced within the area. Peaches, apples, apricots, walnuts, almonds, and persimmons are consumed locally as well as exported and provide the main source of income [47].

.Table 1. Mean monthly air temperature of the year [46].

Month	Air temperature	
	Maximum	Minimum
January	11.2	-2.39
February	12.07	-1.28
March	16.23	3.09
April	22.41	7.67
May	27.59	11.56
June	32.52	15.67
July	31.38	19.29
August	30.24	18.54
September	29.04	13.60
October	25.05	7.62
November	19.94	2.55
December	13.83	-0.86

3.Materials and Methods

A collection of algae was made from 20 different localities of the Tehsil Matta, District Swat. These localities are Lalko, Gharai, Sakhra, Darmai, Baghderi, Ashary, Bazkhela, Drushkhela, Baidara, Bamakhela, Pirkaly, Sherpalam, Shakardara, Shawar, Biha, Rorengar, Aghal, Chuprial, Senpura, and Kharirai.

For the purpose of collection, preservation, and the study of some ecological aspects, the necessary equipments were carried to the research site. These equipments were a portable pH meter, a Celsius scale, and an Altimeter. The collection was carried out with the help of a plankton net, knife, by picking large algae with hands, tooth brush, etc. The algae were scratched from stones in running water, stagnant water, springs water, rice fields, etc. with the help of knives and tooth brushes. Free-floating large planktons or colonies of planktons were collected directly from water surfaces and placed in the collecting bottles. The algae were also collected from moist soil surfaces. The epiphytic algae were collected by separating it from aquatic plants with the help of forceps. The filamentous large algae were collected by hand-picking. The collected algae were put in the bottles and preserved on the spot by the addition of formalin at a rate of 3%.

The pH of water was taken on the spot because it changes with time. The parameters used for examining physical properties on the research spot were temperature (which was measured with Celsius scale), pH (with a portable pH meter) and altitude (taken with the help of an altimeter). The collected samples of algae were carried to the laboratory of phycology and were identified with the help of a microscope, according to G.W. Prescott [48], L.H. Tiffany, M.E. Britton [49], T.V. Desikachary [50], E.N. Transeau [51], E.G. Bellinger, and D.C. Sigee [52] and other available literature and experts.

The ecological characteristics of algal species were obtained from the database compiled for freshwater algae of the world from multiple analyses of algal biodiversity by S.S. Barinova et al. [53], with additions of C. Ter Braak [54] and H. van Dam [55], according to substrate preference, temperature, oxygenation, pH, salinity, organic enrichments, N-uptake metabolism, and trophic states. The ecological groups were separately assessed according to their significance for bio-indications. Species that respond predictably to environmental conditions were used as bio-indicators for particular variables of aquatic ecosystems, the dynamics of which are related to environmental changes.

For species diversity and ecological analysis, we applied the bio-indication methods frequently used in European countries under Framework Directive [56]. Our database for indicator species is published in S.S. Barinova et al. [53].

The statistical methods are those recommended by V. Heywood [57] for the development of floristic and taxonomic studies, namely, the GRAPHS program [58] for comparative floristic, the Statistica 7.0 Program for Stepwise regression analysis, and Distance Weighted Least Squares calculation.

4.Results and Discussion

In the first step of our analysis we outline the catchment basins for each habitat of the sample collection. Therefore, we can see 20 districts (figure 1) on the Swat Valley basin. These catchment basins reflect the ecoregions, which are homogenous according to their landscape and natural environment.

The water temperature is dependent for climatic seasons of the sampling habitats (figure 2). Winter temperature fluctuated between 9 C° and 17 C°. Highest temperature was found in summer, which fluctuated between 21 C° and 27 C°. In figure 2 it can be seen that water temperature decreased with altitude increases all year.

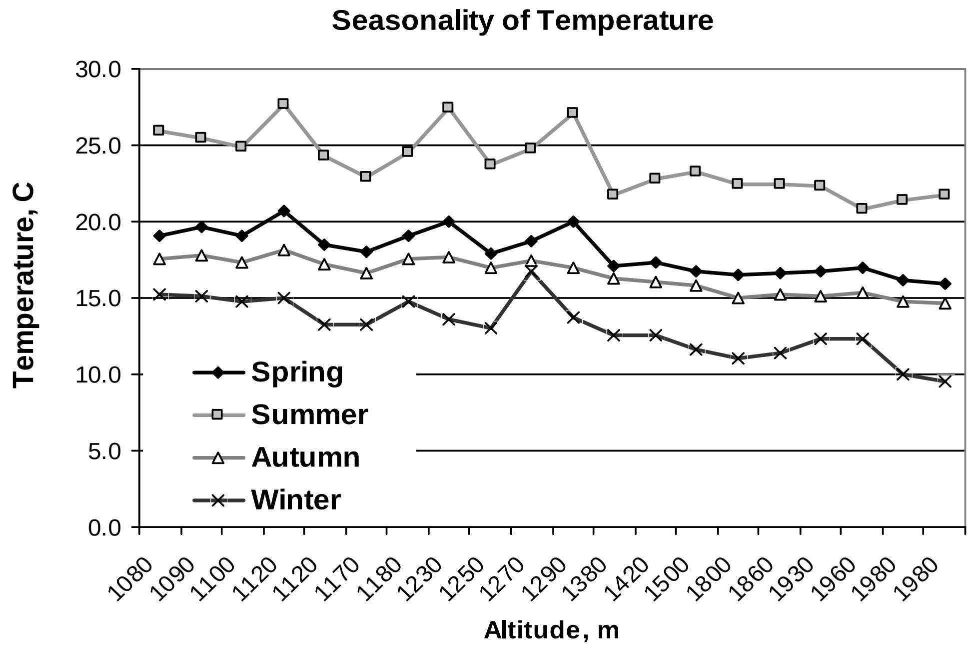
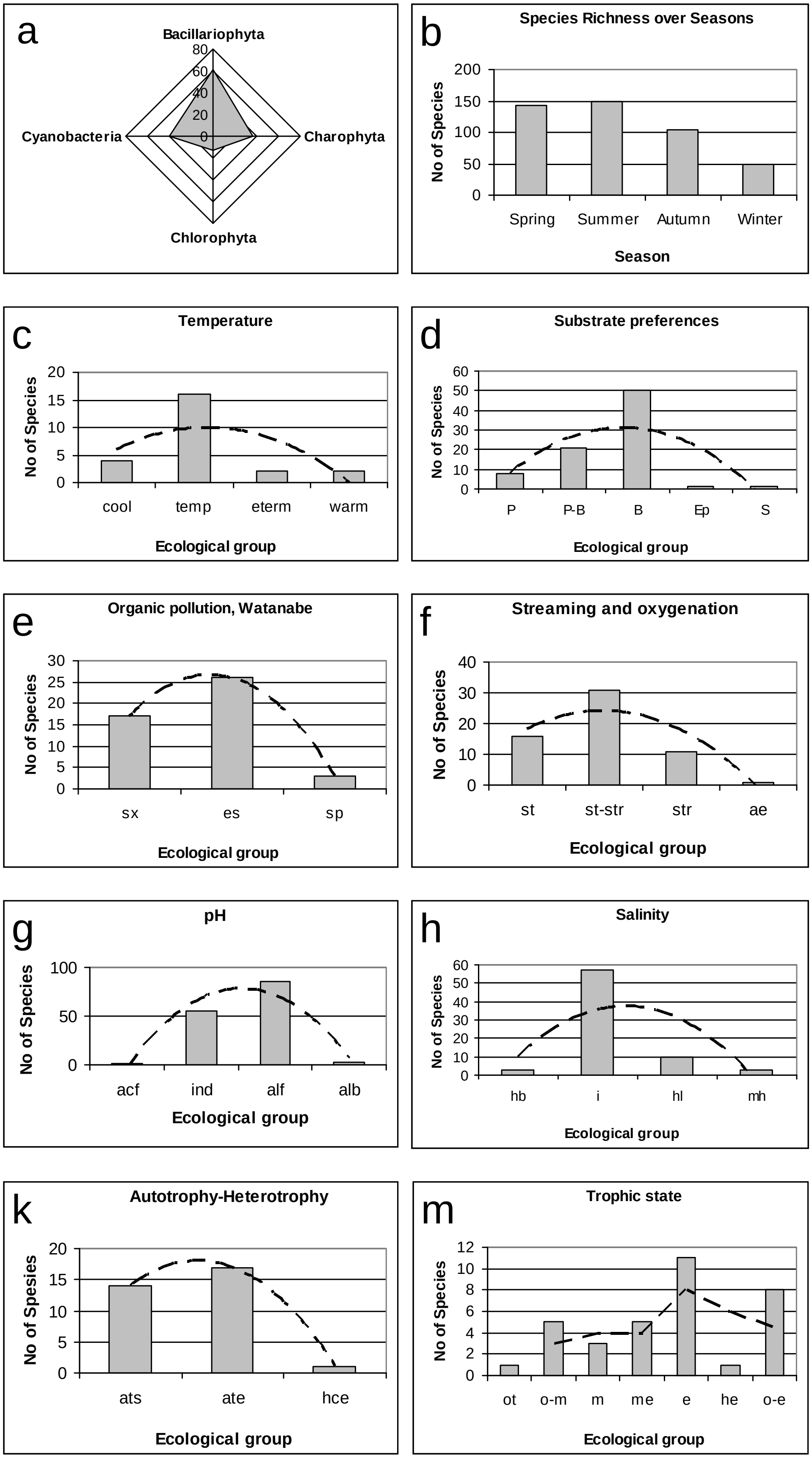


Figure 2. Seasonal fluctuation of water temperature over altitude of sampling site

A total of 149 species of algae were identified in the studied river systems of Swat Valley (table 2). The taxonomic structure of algal communities is represented in table 2. The Swat Valley algal flora belongs to four taxonomic divisions (figure 3a) from which diatoms prevail (40%), followed by Cyanobacteria (27%), then Charophyta (24%), and greens (9%). It is remarkable that Charophyta algae represent about a quarter of the algal flora and the most diverse of all was *Spirogyra* with 24 species. Species richness of the Swat Valley fluctuated over climatic seasons and was richer in summer and spring with about 150 species (figure 3b).

Bio-indication of major environmental variables (table 3, figure 3c-m) show that algal species inhabit water and soil (figure 3d) with diverse environmental variables and prefer temperate (figure 3c), intermediate organically enriched (figure 3e), slow streaming (figure 3f), alkaline (figure 3g), and low saline (figure 3h) water. Algal communities are represented by active photosynthetic nitrogen-autotrophic taxa, tolerant of organic pollution (figure 3k) and reflect diversity of trophic state ecosystems in which eutrophic prevail (figure 3m). Our measurements of water pH help us to enrich ecological speciation of more than ten species of algae and to find pH ecological ranges for others (table 3).


a
Bacillariophyta
80
60
40
20
0
Cyanobacteria
Charophyta
Chlorophyta
b
Species Richness over Seasons
No of Species
200
150
100
50
0
Spring
Summer
Autumn
Winter
Season
c
Temperature
No of Species
20
15
10
5
0
cool
temp
eterm
warm
Ecological group
d
Substrate preferences
No of Species
60
50
40
30
20
10
0
P
P-B
B
Ep
S
Ecological group
e
Organic pollution, Watanabe
No of Species
30
25
20
15
10
5
0
sx
es
sp
Ecological group
f
Streaming and oxygenation
No of Species
40
30
20
10
0
st
st-str
str
ae
Ecological group
g
pH
No of Species
100
50
0
acf
ind
alf
alb
Ecological group
h
Salinity
No of Species
60
50
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30
20
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Autotrophy-Heterotrophy
No of Spesies
20
15
10
5
0
ats
ate
hce
Ecological group
m
Trophic state
No of Species
12
10
8
6
4
2
0
ot
o-m
m
me
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he
o-e
Ecological group

Figure 3. Bio-indication of major environmental variables by the algal floras of Swat Valley. (a) Species richness of taxonomic divisions; (b) Species richness in climatic seasons; (c) cool = cool-water, temp = temperate, eterm = eurythermic, warm = warm-water; (d) P = planktonic, P-B = plankto-benthic, B = benthic, Ep = epiphyte, S = soil; (e) sx = saproxenes, es = eurysaprobes, sp = saprophiles; (f) st = standing water, str = streaming water, st-str = low streaming water, ae = aerophiles; (g) alb = alkalibiontes, alf = alkaliphiles, ind = indifferents, acf = acidophiles; (h) hb = oligohalobes-halophobes, i = oligohalobes-indifferent, mh = mesohalobes, hl = halophiles; (k) ats = nitrogen-autotrophic taxa, tolerating very small concentrations of organically bound nitrogen, ate = nitrogen-autotrophic taxa, tolerating elevated concentrations of organically bound nitrogen, hce = obligately nitrogen-heterotrophic taxa, needing continuously elevated concentrations of organically bound nitrogen; (m) ot = oligotraphentic, o-m = oligo-mesotraphentic, m = mesotraphentic, me = meso-eutraphentic, e = eutraphentic, he = hypereutraphentic, o-e = oligo- to eutraphentic (hypereutraphentic).Diagrams c-m are organized according to indicator groups with increases in variables from left to right.

Fluctuation of species richness over altitude of eco-regions is represented in figure 4. It can be seen that summer communities are richest compared to winters but both seasons reflect the stability of environmental variables whereas spring and autumn communities fluctuate (figure 4). Distribution of species richness over altitude of habitats shows a negative correlation when the most diverse are communities of the lowermost habitats.

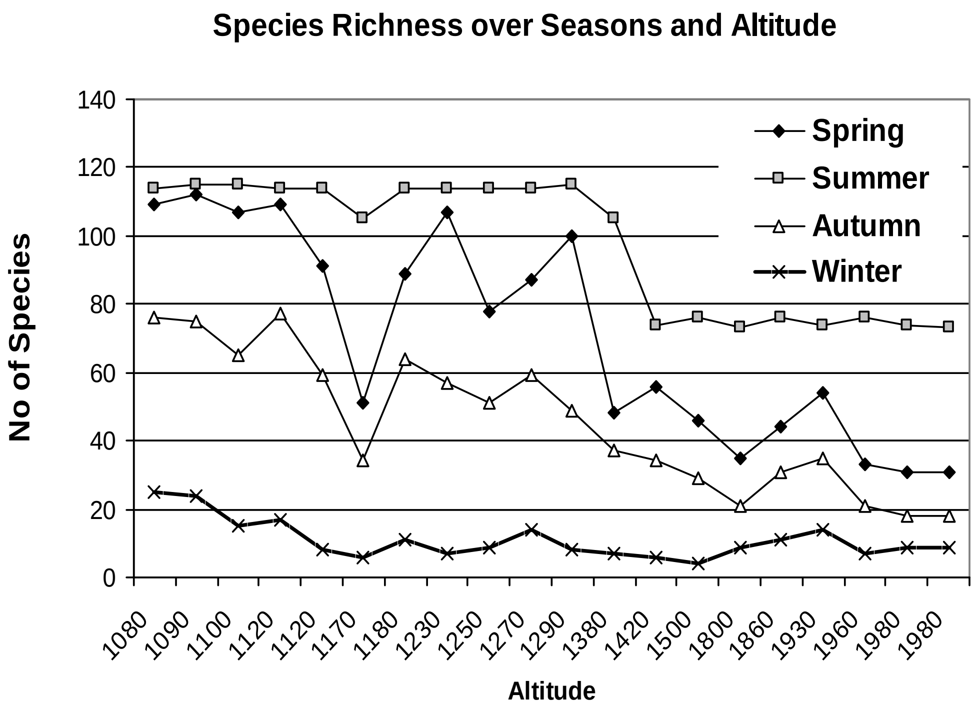

Figure 4. Seasonal fluctuation of algal species richness over altitude of sampling site

As can be seen in figure 5, species richness appears to be correlated with water temperature. The critical altitude for both species richness and temperature is about 1400 m a.s.l. Communities of the Darmai region and those in the highest communities till the Lalko high mountain region have lower species diversity.

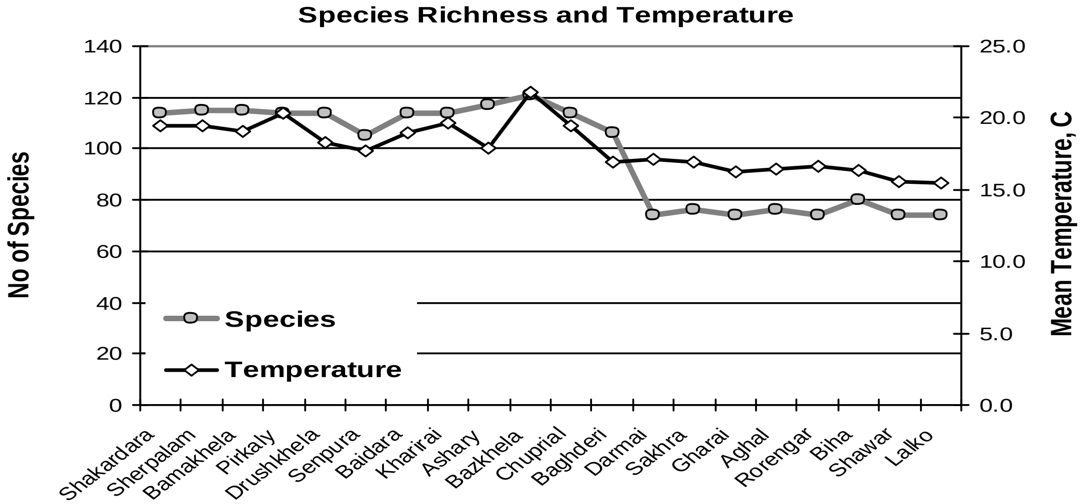

Figure 5. Fluctuation of mean water temperature and maximal algal species richness over altitude of sampling site

4.1. A Comparative Floristic Approach

Because algal communities of studied habitats are rather rich, we used several statistical approaches to reveal species and their environment relationships. A comparative floristic approach provides the grouping of freshwater floras of studied Swat valley areas in respect to their taxonomic similarity and phytogeographic affinities. This approach helps determine diversity and climatic variable relationships in algal species located in the Caucasian Mountains, Kazakhstan, Turkey, India, and Israel [43,44,59-61].

A similarity tree of floristic composition is constructed in the GRAPHS program [58] for the Swat Valley eco-regions (figure 6), showing four species diversity clusters at the similarity level 50%. Cluster 1 includes the richest lower altitude floras; Cluster 2 includes two floras of anthropogenically impacted areas; Cluster 3 comprises the floras of piedmonts, and Cluster 4 includes high mountain floras. Therefore, we can see that algal communities are most similar in similar environments and altitudes of habitats.

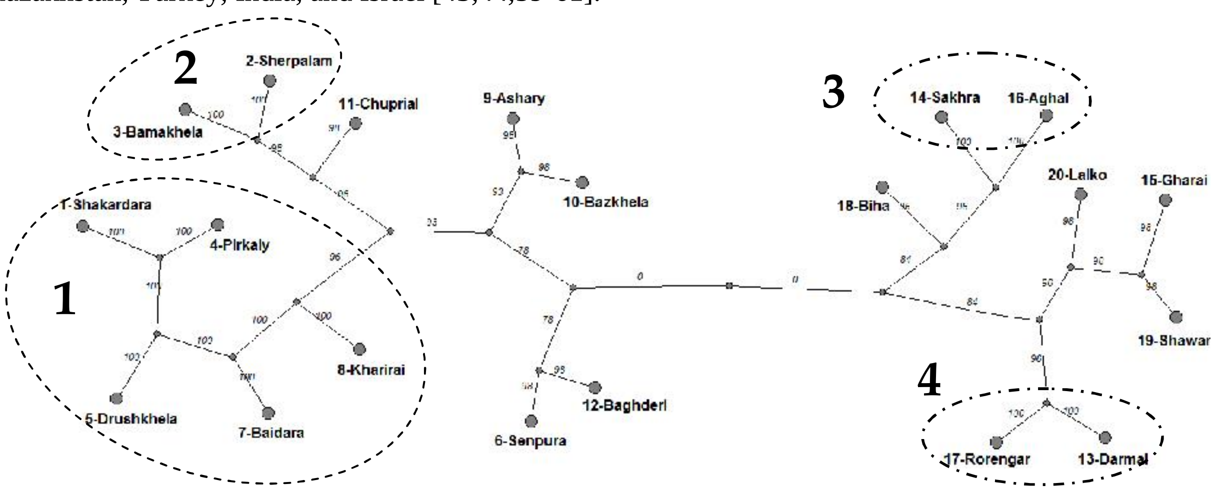

Figure 6. Dendrite of comparative floristic approach of algal communities in Swat district sampling sites based on Euclidean Distance and Ward methods. The four groups of highest similarity are marked 1-4.

The dendrite of taxonomic overlap in the GRAPHS program [58] (figure 7) shows that the algal flora of the Shakardara region shares species with many other floras (about 90%) and is therefore placed in the center of the left part of the dendrite and is called the Shakardara floristic core. The Shakardara region is located in the Swat River Valley at the lower altitude of the study site. This region is affected not only by agricultural activities but also by settlements. Shakardara algal flora is most similar to floras of lower altitude regions of the study site. The floras with minimal overlap are placed on the right side of the dendrite (Gharai core, cut off by dashed line), included lower species-rich communities of piedmonts and high mountains. Therefore, we can conclude that a comparative floristic analysis reveals not only the climatic but also the anthropogenic impact on the algal communities of the Swat Valley.

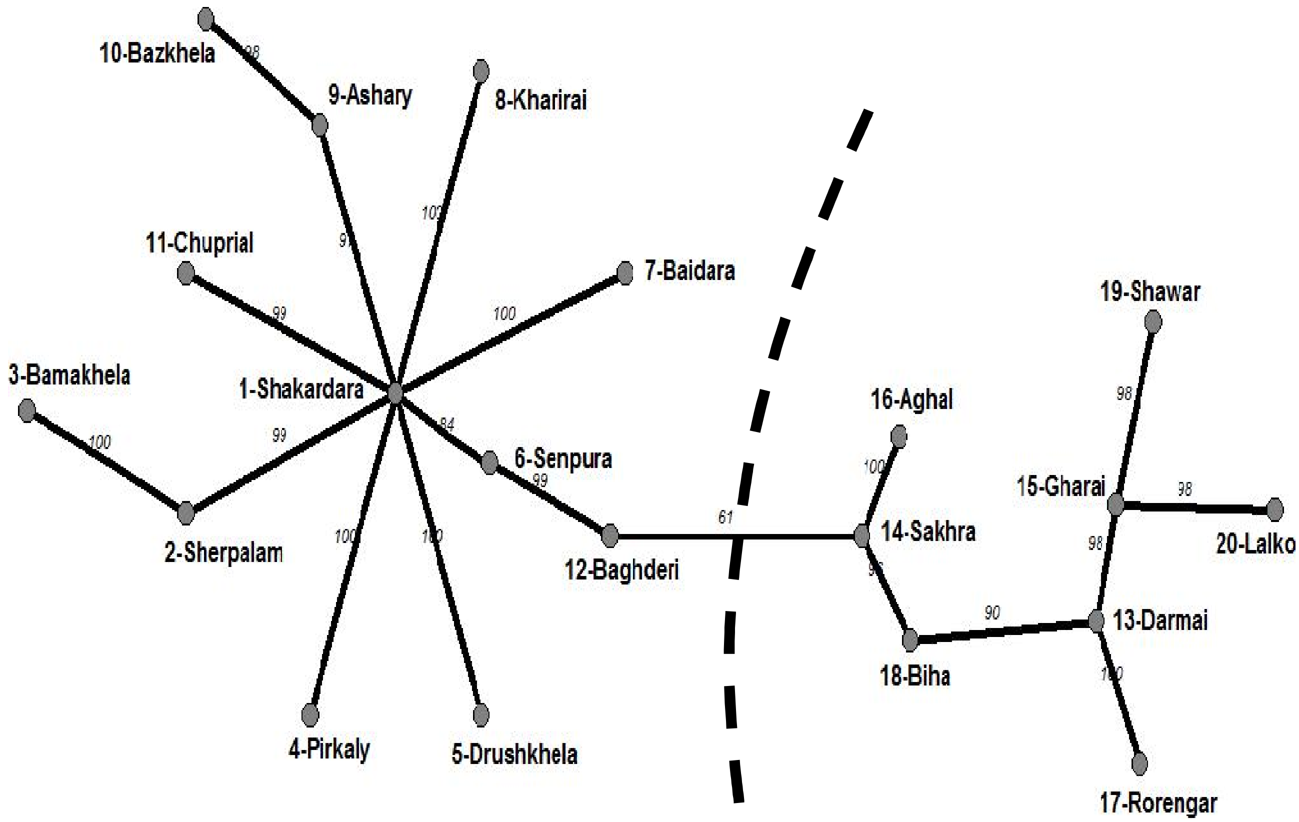

Figure 7. Dendrite of algal species lists comparing similarity levels of more than 50%.

To clarify this conclusion we toned clusters of statistical analysis of figure 7 on the Swat Valley regional map (figure 1). As can be seen in figure 8, toned eco-regions are related to the altitude of the sampling sites. Therefore, distribution of algal species diversity is strongly regulated by climatic conditions of their environment in which the water temperature is the major influence (figure 5).

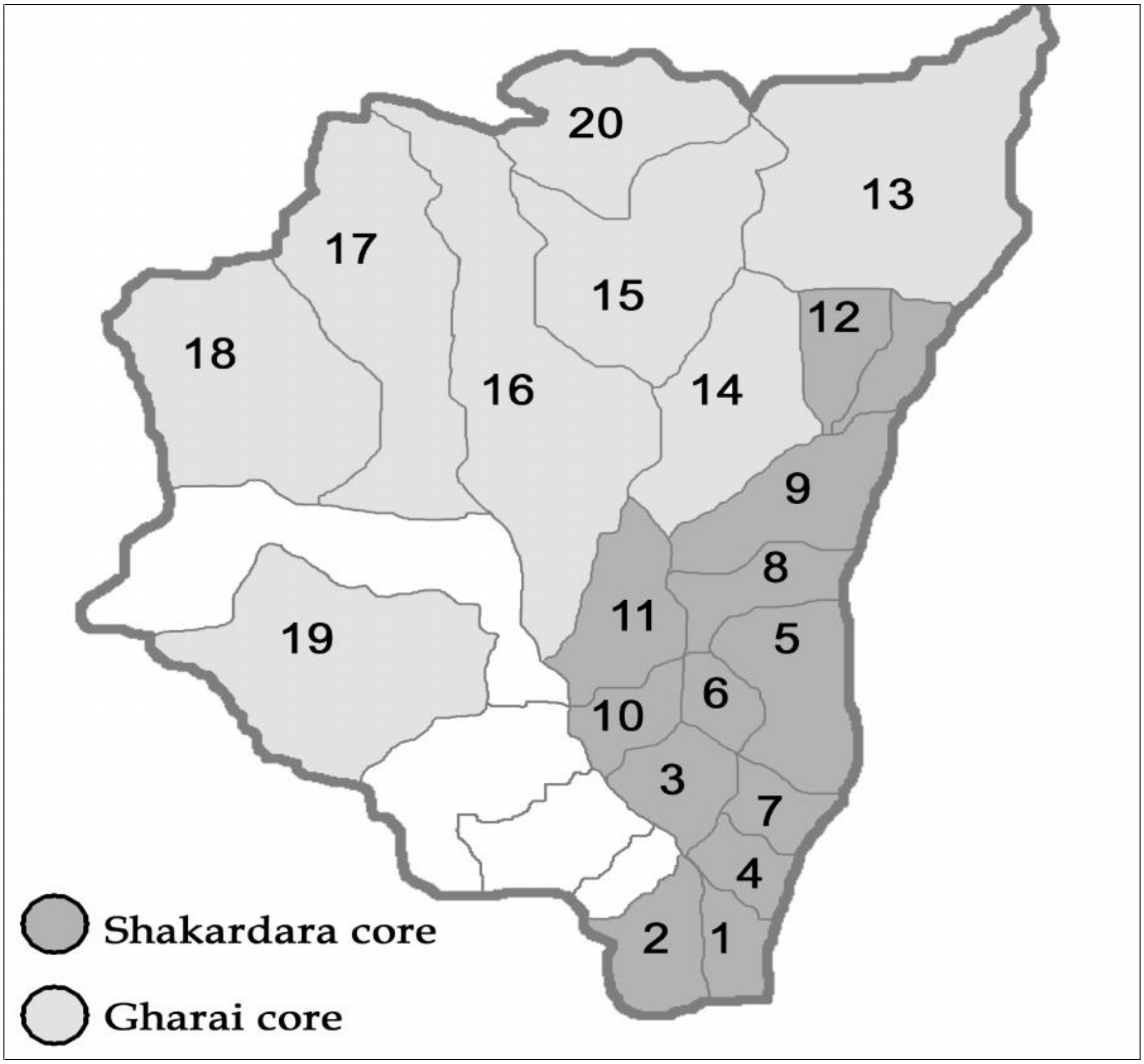

Figure 8. Floristic cores of algal communities in the Swat Valley sampling sites map- colored according to dendrite (figure 7) data.

Relationships between higher/lower taxa ratios for vascular plants can characterize the floristic region. Diversity ratios in Asian floras parity are higher due to the temperate-tropical taxa [62]. The index of infraspecies variation in Swat Valley algal floras calculated on the basis of data from table 2 is rather low, less than 1.06, which means that only a few species from the total species list of each reserve are divided into taxonomic varieties. A calculated index is similar to others for closely related regions such as Turkey (1.09) and Israel (1.09). In the line of freshwater algal floras of Eurasia the Swat Valley flora index remains in the lower part of distribution [44]. Therefore, our calculation of variability for the Swat Valley algal communities confirms that the Index of infraspecies/species decreased from north to south. It can be related to climate changes and can be used also as criteria of determining future warming.

4.2. Species diversity-altitude relationships

We analyzed species diversity-altitude relationships on the divisional level for revealed taxa, which are more sensitive to altitudes. As can be seen in figure 9, close related are cyanobacteria and diatom taxa. When cyanobacteria species rate is decreased with increasing altitude, the diatom rate is increased and vice versa.

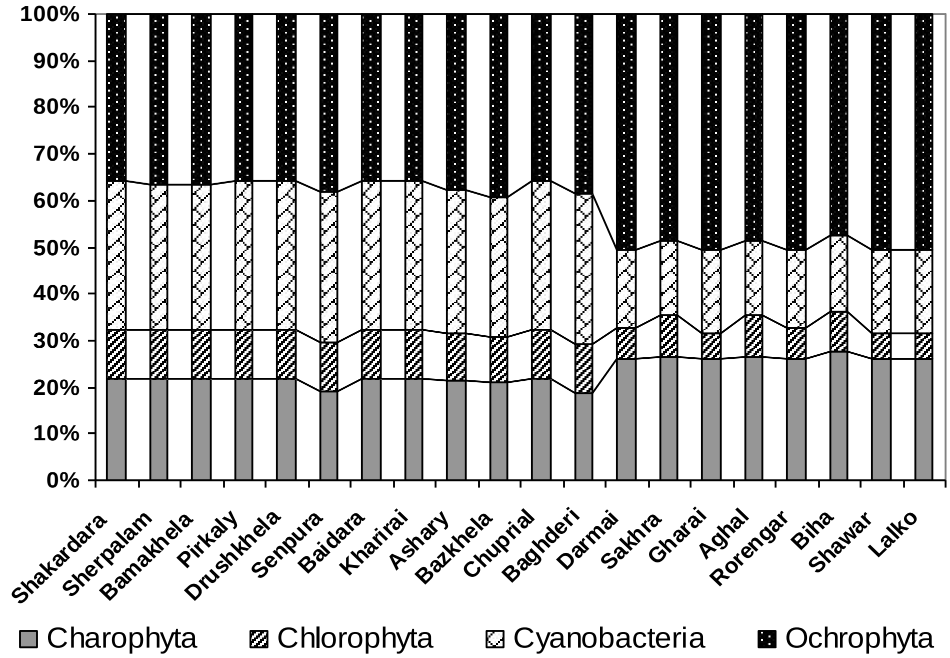

Figure 9. Distribution of algal taxonomic divisions in communities of Swat Valley sampling sites on the basis of table 3 data

The correlation between species richness and major climatic condition variables was calculated by Distance Weighted Least Squares in Statistica 7.0 Program. Figure 10 presents relationships of species richness, especially Chlorophyta numbers, and altitude of the studied territory. This plot confirms that species richness can increased with altitude with helps of Chlorophyta species number that was found for the Caucasian Mountains algal communities [43].

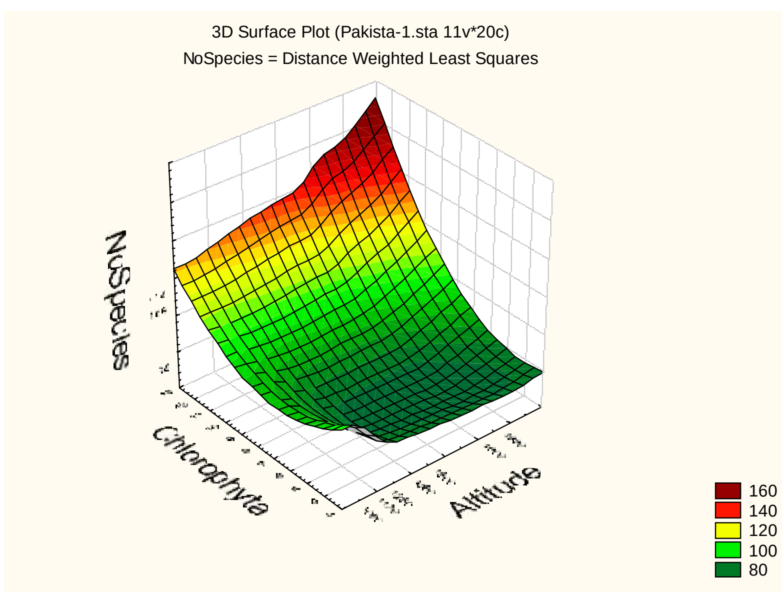

Figure 10. Correlation plot of species richness and number of Chlorophyta species in communities of the Swat valley with increasing altitude

As can be seen, species richness was dependent on altitude on the one hand, but altitude depended on water temperature on the other hand. Surface plot of this correlation in figure 11 shows two different types of communities with high species numbers, which are regulated by temperatures higher than 19 C° and divided on altitude about 1800 m a.s.l.

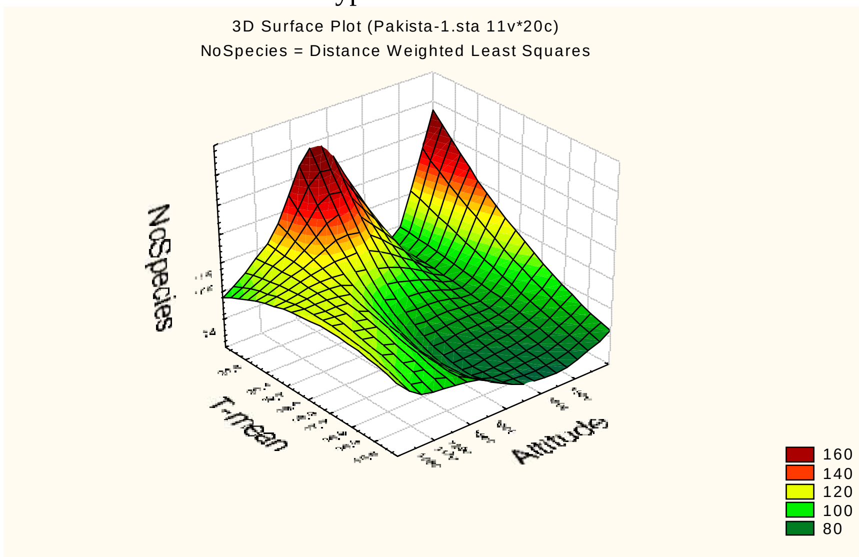

Figure 11. Surface plot of species richness in communities of the Swat Valley with increasing altitude and mean water temperature

Figure 12 reveals which temperature level is critical for these two types of communities dividing. The lower habitat communities are enriched by cyanobacteria and greens, whereas diatoms and greens prevail at the top of the mountains. As can be seen on the plot, the water temperature at about 16 C° in contour in the middle of the graph divided species richness with increasing altitude.

The analysis, thus, reveals a strong climatic control over the major diversity estimates in the Swat Valley district. The mean water temperature is shown to be the critical factor in particular for the high altitude algal communities and 16 C° is a critical temperature level.

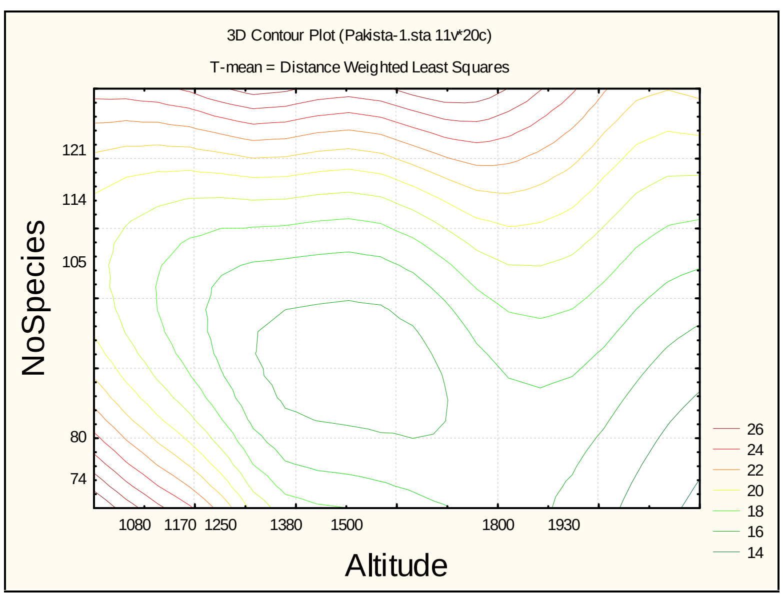

Figure 12. Correlation plot of species richness in communities of Swat Valley with increasing altitude and mean water temperature

4.3. Stepwise regression analysis

We tried to calculate what variables were most important for algal diversity in the Swat Valley environment with help from the Stepwise regression analysis in Statistica 7.0 Program. Table 4 represents the results of calculation where it can be seen that mean water temperature is important, but algal communities are most impacted by the altitude of their habitat.

Table 4. Multiple regression coefficients (R^2) relating diversity estimates as dependent variables to climatic factors, which are independent variables (abbreviations: Alt – Altitude, T_{Win} – Minimal Winter Water Temperature years averages, T_{Sum} – Maximal Summer Water Temperature years averages, T_{mean} – Mean Water Temperature years averages, N_{Sp} – Species richness).

Diversity Estimates	Stepwise Model by Climatic Factors			
	Step 1	Step 2	Step 3	Step 4
N_{Sp}, Species Richness	Alt 0.883***	Alt, T_{mean} 0.885***	Alt, T_{mean}, T_{Sum} 0.887***	T_{mean}, Alt,T_{Sum},T_{Win}, 0.892***

Note: *, **, *** = statistically significant at $p<0.05$, $p<0.01$, and $p<0.001$, respectively

5.Conclusion

As a result of our study during 2005-2008 in the Hindu Cush mountains habitats in the Swat district of Pakistan, we revealed 149 species of algae and Cyanobacteria from 77 algological samples. Species diversity was mostly enriched by diatoms. It is remarkable that Charophyta algae represent about a quarter of algal flora and the most diverse was *Spirogyra* with 24 species. Algal communities are most diverse in summer. Winter communities have the lowest species richness. Bio-indication analysis showed that algal species in studied communities inhabit water and soil and preferred temperate, intermediate organically enriched, slowly streaming, low-alkaline, and low-saline water. Photosynthetic activity of algal communities was rather high. Ecosystems were tolerant of organic pollution and reflected diversity of trophic states in which eutrophic conditions prevail.

In studied area algal species richness decreased with altitude and formed two different types of communities, which divided by the altitude. High altitude communities are enriched aided by the number of diatom, Charophyta and Chlorophyta species. In high mountain habitats in closely related regions such as Turkey [63-65], Georgia [43], and Israel [44,59] the algal floras are, as a whole, enriched by non-diatom algae but species richness increased with altitude, in contrast with our results found in the Swat valley.

A similarity tree of floristic composition shows four species diversity clusters related by similar environments and altitudes of habitats. The dendrite of taxonomic overlap shows that the algal flora of the Shakardara region shares species with many other floras and can be named as the Shakardara floristic core of the river valley. The Gharai core included lower species-rich communities of piedmonts and high mountains. The calculated index of infraspecies variation for Swat Valley is 1.06 and is similar to closely related regions, such as Turkey (1.09) and Israel (1.09). Index variation over latitude of Eurasia [44] is related to climate changes and can be used also as the criteria to determine future warming.

Correlation between species richness and major climatic condition variables calculated with statistic programs show that algal species richness in Swat Valley decreased with altitude, formed communities with cyanobacteria and greens prevailing in the valley and diatoms, and greens in the mountains, which are regulated by temperature higher than 19 C° and altitude about 1800 m a.s.l. Stepwise regression analysis shows that mean water temperature is important, but algal communities are most impacted by the altitudes of their habitat.

Therefore, our analysis reveals strong climatic control over the major diversity estimates in the Swat River Valley of Pakistan. The pattern of algal diversity distribution in Swat Valley depends on altitude and local climatic conditions in which the mean temperature of water is most important.

6.References

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