# Applicability of Diatom-Based Water Quality Assessment Indices in Dari Stream, Isparta-Turkey

Hasan Kalyoncu and Burcu Şerbetci

***Abstract*—**Diatoms are an important group of aquatic ecosystems and diatom-based indices are increasingly becoming important tools for the assessment of ecological conditions in lotic systems. Although the studies are very limited about Turkish rivers, diatom indices were used for monitoring rivers in different basins. In the present study, we used OMNIDIA program for estimation of stream quality. Some indices have less sensitive (IDP, WAT, LOBO, GENRE, TID, CEE, PT), intermediate sensitivities (IDSE, DESCY, IPS, DI-CH, SLA, IDAP), the others higher sensitivities (SID, IBD, SHE, EPI-D). Among the investigated diatom communities, only a few taxa indicated alfa-mesosaprobity and polysaprobity. Most of the sites were characterized by a great relative contribution of eutraphent and tolerant ones as well as oligosaprobic and betamesosaprobic diatoms. In general, SID and IBD indices gave the best results. This study suggests that the structure of benthic diatom communities and diatom indices, especially SID, can be applied for monitoring rivers in Southern Turkey.

***Keywords*—**Diatom, Darı stream, OMNIDIA, Turkey, Water quality.

## I. Introduction

CLASSICALLY, physical and chemical monitoring reflects instantaneous measurements while biotic parameters provide better evaluation of environmental changes. Because community development integrates a period of time reflecting conditions that might not be any longer present at the time of sampling and analysis [1]. Diatoms have been used for the assessment of short- and long-term environmental change [2]. Diatoms are widely used in bioassessments, and a substantial number of diatom indices have been developed for estimation of water quality in various geographic areas. The first studies of diatoms and river pollution were carried out 60 years ago, and the suitability of these micro-algae as bioassessment indicators for monitoring river quality was quickly demonstrated. These studies demonstrated the potential and robustness of diatoms that could enable their use to monitor river quality. After these first approaches, benthic diatoms in rivers became an obligatory bioindicator for use in several European and American countries in the late 90s.

The overall objective of this report is to describe the studies performed in the first ten years of the twenty-first century [3]. Numerous studies focusing on the application of standardized methods based on diatom assemblages for water quality assessment have been carried out, especially in the northern hemisphere and in particular in European countries [4]-[6].

Several diatom-based indices have been developed most of which are based on the weighted average equation of Zelinka & Marvan [7] and are general pollution indices. There are as many indices as the number of researchers working in the field [8]-[11].

In Turkey, the first studies on the use of epilithic diatom for monitoring of the pollution levels of lotic systems were carried out in Isparta stream [12], [13]. First used index was Saprobi index for Turkey and the index gave good results, but this topic is still new in Turkey [14], [15]; Isparta [16] and Aksu [17] streams were investigated by using Saprobity Index [7]. Gürbüz and Kıvrak [18] practised firstly three different indices [TDI, SI and IDG] on Karasu River [Erzurum] while, OMNIDIA software program was firstly used for Akçay stream [Muğla] in Turkey [19]. Kalyoncu et al. [20] used saprobi index in Darıören stream in Isparta and compared saprobi index with diversity and species richness. Also, Kalyoncu et al. [21] compared the performance of three types of benthic diatom indices**:** (Swiss Diatom Index (DI-CH), Trophic Index (TI) and Saprobic Index (SI)) in Isparta stream and they concluded that in these rivers, DI-CH and TI could be more useful than SI. On Aksu river catchment area was used several indices and compared macrozoobenthic index and diversity [17]. Also, the diversity and ecology of diatoms from Felent Creek was investigated by Omnidia software [22].

The aims of this study are to test the use of epilithic diatoms as indicators and the use of diatom indices as a tool for estimating the creek water quality. This study presents the relationship between measured water quality variables in the Darı stream and diatom index scores. Diatom index scores were calculated and correlated to concurrent physical and chemical water quality data. The results of these correlation analyses were compared to results obtained in similar studies.

## II. Material and Methods

Six sites were monthly established between June 2009 and May 2010 along the Darı stream and its tributaries: four sites (1st, 2nd, 3rd and 4th) in the relatively less impacted agricultural and forested headwaters to act as reference sites; site 5 in the relatively moderately polluted urban area; and site 6 in highly polluted downstream area after the urban area (Fig. 1).

Assoc. Prof. Dr. Hasan Kalyoncu is with the Süleyman Demirel University, Isparta/Turkey (Phone: +905326776615, e-mail: hasankalyoncu@sdu.edu.tr).
Burcu Serbetci is with the SGS Antalya Food Control Laboratory, Antalya/Turkey (e-mail: burcuserbetci@gmail.com).

Sampling points 1, 2 and 3 were chosen on the springs on southern side of Akdağ Mountain, Darı village (1200 m. alt.) where there was no urban waste water connection. Sampling point 4 is in the halfway of the stream, sampling point 5 is before the meeting point of the Darıören stream and Isparta stream. Sample point 6 is after the meeting point of Isparta stream and Darı stream (Fig. 1). When choosing the sampling points on the stream, we took into consideration all kinds of effected the stream water quality, such as tributaries and mixing points of waste-water discharge.

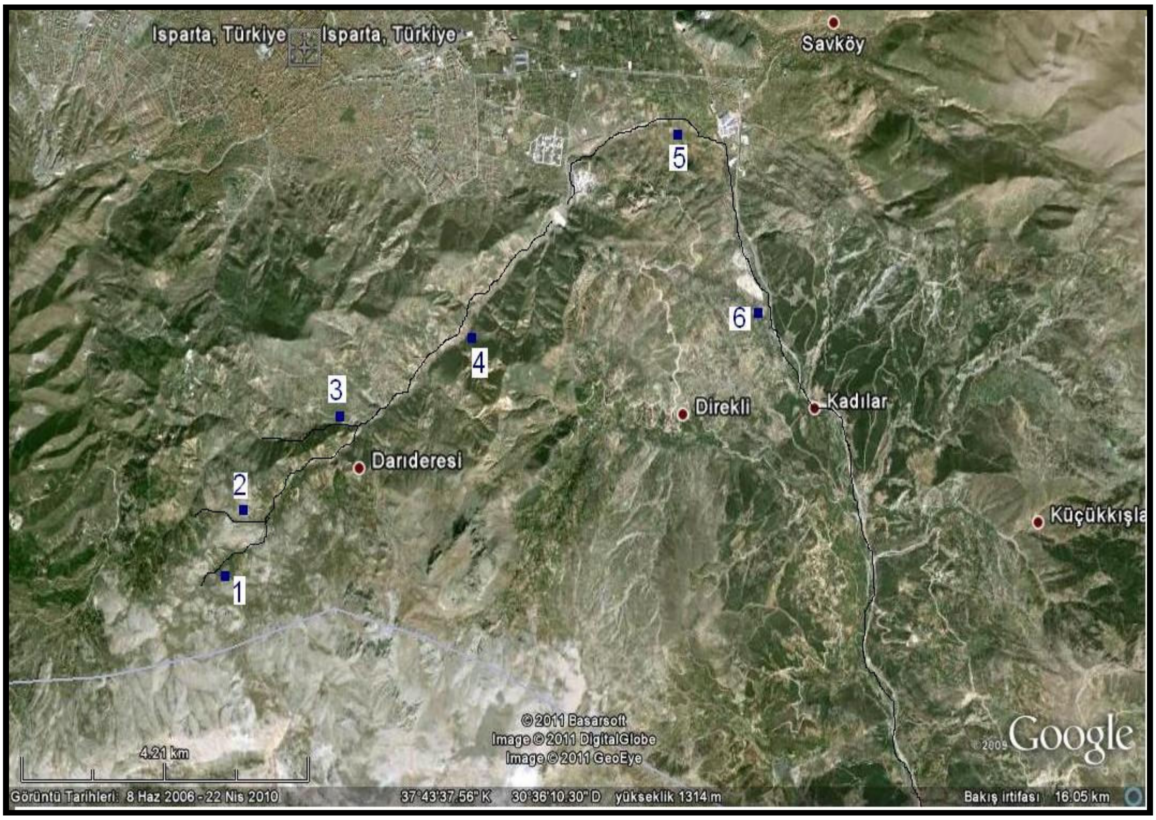


Fig. 1 Location of sampling sites in the study area

*A. Environmental Variables*

At the same time of sampling diatoms, water samples were seasonally taken and analyzed for the following parameters: $NH_4$-N mgL−1, $NO_2$ -N mgL−1, $NO_3$ -N mgL−1, $PO_4$-P mgL−1, biological oxygen demand ($BOD_5$ mgL−1), chemical oxygen demand (COD mgL−1) and chloride (Cl- mgL−1). All analyses were done in accordance to national standards [23]. Water temperature (C0), pH, dissolved oxygen (DO mgL−1) and electrical conductivity (EC µScm−1) were measured in the field by portable equipments.

*B. Biological Elements*

The samples were monthly collected between June, 2009 and May 2010. During the study period, samples were taken on the middle of months except rainy days to avoid transient effects of the flood. The diatoms were sampled by scraping the 25cm$^2$ upper surface of the epilithon, with a stiff toothbrush and collected in 250ml sample bottle. The collected samples were transferred to the laboratory in an icebox. The composition and relative abundance of diatoms was estimated at 1000x magnification from acid-cleaned sub-samples, counted separately.

Cleaned frustules were mounted on permanent slides using Naphrax resin. Sampling was done during the dry season to avoid variable effects of rainy season such as great variations in water level and velocity, floods and inundations. These factors affect diatom development, especially growth rates and relative abundance of different species [24].

Identification and nomenclature were based on Krammer and Lange-Bertalot [25]-[28], Round et al. [29], Hartley et al. [30]. Three slides were prepared from each side and approximately 250-600 valves were enumerated in each slide to determine the relative abundance of each taxon.

The diatom species counts were entered into the diatom database and index calculation tool OMNIDIA version 5.3 [31] and the following indices were calculated and tested: the Artois-Picardie Diatom Index (IDAP); the Eutrophication/Pollution Index (EPI-D); the Biological Diatom Index (BDI); Schiefele and Schreiner's index (SHE); the Saprobic Index (SID); the Trophic Index (TID); the Watanabe index (WAT); the Specific Pollution Sensitivity Index (SPI); the Sla`decˇek's Index (SLA); Descy's Pollution Index (DESCY); Leclerq (IDSE); the Generic Diatom Index (GENRE); the Commission of Economical Community Index (CEC); the Trophic Diatom Index (TDI) and the Pampean

Diatom Index (IDP); LOBO index (LOBO). All these indices, except CEC, SHE, TDI and WAT, are based on the formula of Zelinka & Marvan [7]. The percentage of species used in calculation of the indices, as indicated by the OMNIDIA, was also recorded. The correlation analysis was done according to Pearson and statistical analyses were carried out on Statistical Package for the Social Sciences [32].

## III. Results

### A. Physico-Chemical Variables

The values of physical and chemical variables measured in the study area during the study period were shown in Table I. The pH increased slightly down acidic at site 4 and alkaline at 1, 2, 3 and 5 sites, and slightly neutral site 6. On the other hand, the values of conductivity, $NO_2$-N, $NO_3$-N, $NH_4$-N, $PO_4$-P, Cl and $BOD_5$ increased significantly downstream, while DO decreased significantly downstream (site 6).

TABLE I
The Mean (n = 66) Values of Physical and Chemical Variables Measured at 6 Sites during 11 Sampling Periods and Water Quality Levels

| | DO | Temp. | pH | E.C | NO3 - N | NH4 - N | NO2 - N | PO4 - P | Cl | BOI | Klee |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 7,25 | 10,58 | 7,96 | 573,5 | 1,33 | 0,12 | 0 | 0 | 2,05 | 2,74 | I |
| **2** | 7 | 12,37 | 7,75 | 495,21 | 1,33 | 0,09 | 0 | 0,17 | 1,92 | 2,48 | I |
| **3** | 6,32 | 15,56 | 7,95 | 587,11 | 1,6 | 0,18 | 0 | 0,47 | 3,21 | 1,48 | I |
| **4** | 5,97 | 12,2 | 6,62 | 373,6 | 1,1 | 0,09 | 0 | 0,09 | 2,3 | 0,13 | I |
| **5** | 6,06 | 16,41 | 7,88 | 310,10 | 1,75 | 0,10 | 0,02 | 0,30 | 2,17 | 1,64 | I |
| **6** | 5,11 | 18,53 | 7,4 | 1069,37 | 1,8 | 29,15 | 0,13 | 2,66 | 116,47 | 187,95 | III |

### B. Community Composition

A total of 70 diatom species belonging to 27 genera were identified and also, species richness, diversity and evenness differed significantly ($P<0.05$) among sampling sites, tending to be higher in upstream, relatively unpolluted were compared to downstream polluted mainly urban site 6. Site 6 was subject to some form of pollution (urban); hence, species distribution was strongly different from other stations. The highest number of species was determined at site 3 (34), while the lowest at site 6 (24). In addition, the highest values of diversity and evennes were determined at site 5 and the lowest values at site 6 (Fig. 2).

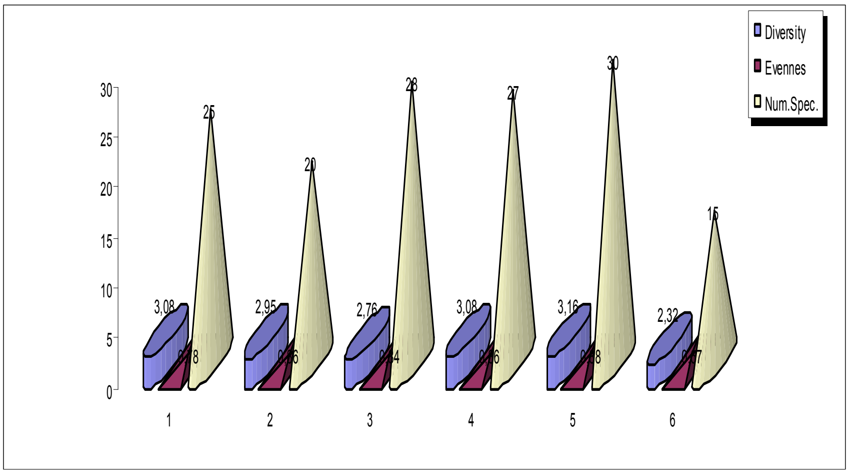


Fig. 2 Diversity, Evennnes and Number of species in Darı stream

Sites 1, 2, 3, 4 and 5 with mean good water quality were associated with such species as *Achnanthidium minutissimum*, *Fragilaria capucina var amphicephala, Diatoma mesedon, Navicula radiosa, Meridion circulare, Melosiria varians, Gomphonema olivaceum, Cocconeis pediculus and C. placentula.* At sites 1, 2, 3 and 4 was dominant taxa *F. capucina var amphicephala* while *D. mesedon* at site 5.

Downstream site [6], with very bad water quality, was associated with such species as *Craticula accomoda, Nitzschia palea, Mayamae atomus, Gomphonema parvulum.* These species have been reported to be pollution tolerant. The most dominant taxon was *Caraticula accomoda* in this site.

According to Pearsen correlation, positive significant correlation was determined between EC, $NH_4$-N, $NO_2$-N, $PO_4$-P, Cl, $BOD_5$ ($p<0,01$), negative pH ($p<0,05$) and *Navicula spp.*, positive significant correlation between $NH_4$-N, $NO_2$-N, $PO_4$-P, Cl, $BOD_5$ ($p<0,01$), temperature, conductivity ($p<0,05$), negative DO ($p<0,05$) and *Nitzschia spp. Cymbella spp.* and *Achnanthidium minitissimum* showed positive significant correlation with DO, negative teperature and *Fragilaria* spp. showed significant correlation ($p<0,05$) with pH. No considerable correlation was determined neither between these taxa and other parameters nor between other species and ecological parameters (Table II).

TABLE II
PEARSON CORRELATION COEFFICIENTS BETWEEN MEASURED ENVIRONMENTAL VARIABLES AND DIATOM GENUS GENERATED FOR SITES IN THE DARI STREAM

| Genus | DO | T | pH | EC | N03-N | NH4-N | NO2-N | PO4-P | Cl | BOD5 |
|---|---|---|---|---|---|---|---|---|---|---|
| *Caraticula* | ,601 | -,725 | ,270 | -,400 | -,700 | -,403 | -,403 | -,418 | -,406 | -,398 |
| *Achnanthidium* | ,867* | -,827* | ,665 | -,248 | -,659 | -,464 | -,464 | -,474 | -,465 | -,462 |
| *Cocconeis* | ,915* | -,940** | ,611 | -,343 | -,819* | -,510 | -,510 | -,524 | -,513 | -,507 |
| *Cymbella* | ,158 | -,211 | ,308 | -,673 | -,100 | -,511 | -,511 | -,511 | -,511 | -,510 |
| *Diatoma* | -,221 | ,201 | ,062 | -,550 | ,732 | -,344 | -,343 | -,338 | -,345 | -,345 |
| *Gomphonema* | -,324 | ,349 | -,012 | -,198 | ,179 | -,062 | -,062 | -,051 | -,059 | -,064 |
| *Melosira* | -,328 | ,268 | -,103 | -,448 | ,773 | -,202 | -,200 | -,198 | -,203 | -,202 |
| *Meridion* | ,629 | -,558 | ,663 | -,300 | -,405 | -,429 | -,429 | -,434 | -,430 | -,430 |
| *Navicula* | -,795 | ,749 | -,912* | ,952** | ,344 | ,999** | ,999** | ,999** | ,999** | ,999** |
| *Nitzschia* | -,820* | ,824* | -,798 | ,891* | ,493 | ,933** | ,933** | ,937** | ,934** | ,931** |
| *Pinnularia* | -,035 | -,062 | -,022 | -,517 | ,528 | -,336 | -,334 | -,339 | -,339 | -,334 |
| *Rhopalodia* | ,036 | ,200 | ,409 | -,003 | ,036 | -,199 | -,200 | -,179 | -,193 | -,204 |
| *Surirella* | ,236 | -,200 | ,545 | -,792 | ,297 | -,689 | -,688 | -,684 | -,689 | -,691 |
| *Fragilaria* | ,784 | -,649 | ,853* | -,388 | -,780 | -,620 | -,621 | -,617 | -,617 | -,621 |

*C. Indices*

SLA, DESCY, IDSE, SHE, IPS, IBD, EPI-D, DICH and SID diatom index scores showed significant correlations ($P<0.05$, $P<0,01$) to DO, Temperature, Conductivity, $NH_4$-N, $NO_2$-N, $PO_4$-P, Cl and $BOD_5$. There was no correlation between all indices and pH and $NO_3$-N. %PT was not significantly correlated with DO, temperature, $NO_2$-N, GENRE, IDP, LOBO, TID and IDAP with $NO_2$-N, CEE with DO and $NO_2$-N (Table III). Correlation coefficients between the calculated index scores and the measured water quality variables differed significantly ($P<0.05$) among different indices.

Based on forward stepwise multiple regression analysis performed to determine the SID, IBD, SHE, EPI-D, IDSE, DESCY, IPS, DI-CH, SLA, IDAP and TDI indices that gave best reflection of water quality, measured water quality variables significantly ($P<0.05$) account for the variation in SID, IBD, SHE, EPI-D, IDSE, DESCY, IPS, DI-CH, SLA, IDAP and TDI scores (Table III).

IDP, WAT, LOBO, GENRE, TID, CEE and %PT didn't have significant correlation with environmental variables. Physico-chemical parameters were determined with the lowest correlation between %PT while the highest correlation with SID index (R2 0,815). In general, indices have been in a highly significant relationship between each other. However, a significant correlation between the CEE and GENRE, IDSE and DESCY, EPI-D and IBD, DI-CH and CEE, LOBO and CEE, DESCY, SID and IBD, WAT and GENRE, TDI, PT and TDI and EPI-D, TID were not determined. TID show significant correlation with GENRE, LOBO ($p< 0.01$), IDP ($p<0.05$) while not significant correlation other indices. PT shows significant correlation with DESCY, IDSE, SHE, CEE, IDAP, TID, IDP and LOBO while significant correlation with other indices (Table IV). This situation has been clearly established by multivaryet regression analysis. Adjusted R2 values ranged from 1% (PT%) to 81% (SID) and SID, IBD, SHE, EPI-D, IDSE, DESCY, IPS, DI-CH, SLA and IDAP more than 50% (Fig. 3).

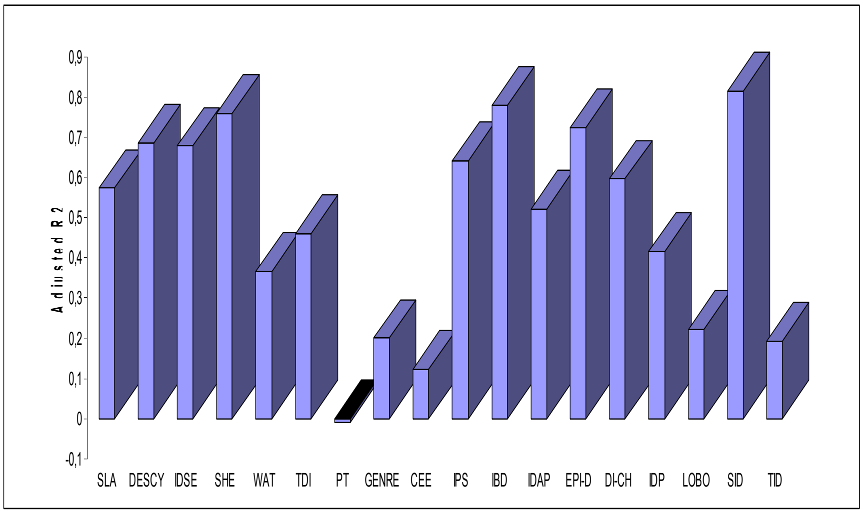


Fig. 3 Adjusted R2 values obtained from forward stepwise multiple regression analysis performed on index scores and measured water quality variables

TABLE III
PEARSON CORRELATION COEFFICIENTS BETWEEN MEASURED ENVIRONMENTAL VARIABLES AND DIATOM INDEX SCORES GENERATED FOR SITES IN THE DARI STREAM

| | DO | T | pH | EC | NO3 - N | NH4 – N | NO2 - N | PO4 - P | Cl | BOD5 |
|---|---|---|---|---|---|---|---|---|---|---|
| **SLA** | -,400** | ,473** | -,121 | ,770** | -,053 | ,788** | ,319* | ,770** | ,720** | ,776** |
| **DESCY** | ,488** | -,529** | ,027 | -,754** | ,116 | -,798** | -,331* | -,786** | -,705** | -,781** |
| **IDSE** | ,503** | -,537** | -,030 | -,766** | ,196 | -,793** | -,320* | -,769** | -,724** | -,780** |
| **SHE** | ,349* | -,486** | ,040 | -,755** | -,030 | -,784** | -,318* | -,768** | -,709** | -,770** |
| **WAT** | ,420** | -,487** | -,020 | -,599** | ,115 | -,619** | -,264 | -,614** | -,559** | -,614** |
| **TDI** | -,310* | ,333* | -,111 | ,690** | -,203 | ,702** | ,282 | ,671** | ,643** | ,690** |
| **PT** | -,186 | ,167 | -,089 | ,432** | -,064 | ,391** | ,156 | ,408** | ,438** | ,406** |
| **GENRE** | ,393** | -,330* | ,174 | -,543** | -,060 | -,499** | -,192 | -,482** | -,572** | -,518** |
| **CEE** | ,222 | -,488** | -,135 | -,365* | ,068 | -,349* | -,154 | -,352* | -,329* | -,356* |
| **IPS** | ,450** | -,476** | ,114 | -,780** | ,155 | -,810** | -,328* | -,785** | -,749** | -,802** |
| **IBD** | ,469** | -,536** | ,089 | -,805** | ,245 | -,850** | -,348* | -,829** | -,757** | -,834** |
| **IDAP** | ,451** | -,550** | -,069 | -,708** | ,173 | -,706** | -,277 | -,694** | -,674** | -,702** |
| **EPI-D** | -,463** | ,484** | -,096 | ,793** | -,246 | ,829** | ,336* | ,803** | ,754** | ,815** |
| **DI-CH** | -,411** | ,407** | -,082 | ,731** | -,249 | ,769** | ,309* | ,750** | ,709** | ,761** |
| **IDP** | -,461** | ,467** | -,048 | ,659** | -,121 | ,658** | ,262 | ,649** | ,621** | ,653** |
| **LOBO** | -,348* | ,209 | -,217 | ,488** | ,062 | ,455** | ,243 | ,500** | ,494** | ,479** |
| **SID** | -,423** | ,529** | -,127 | ,816** | -,188 | ,857** | ,358* | ,840** | ,759** | ,841** |
| **TID** | -,343* | ,471** | ,024 | ,502** | -,251 | ,487** | ,203 | ,490** | ,486** | ,500** |

TABLE IV
PEARSON CORRELATION COEFFICIENTS BETWEEN DIATOM INDEX SCORES GENERATED FOR SITES IN THE DARI STREAM

| | SLA | DESCY | IDSE | SHE | GENRE | CEE | IPS | IBD | IDAP | EPI-D | DI-CH | IDP | LOBO | SID | TID | PT | WAT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **SLA** | 1 | | | | | | | | | | | | | | | | |
| **DESCY** | -,976** | 1 | | | | | | | | | | | | | | | |
| **IDSE** | -,984** | ,994** | 1 | | | | | | | | | | | | | | |
| **SHE** | -,941** | ,962** | ,972** | 1 | | | | | | | | | | | | | |
| **GENRE** | -,894* | ,832* | ,867* | ,823* | 1 | | | | | | | | | | | | |
| **CEE** | -,922** | ,892* | ,919** | ,917* | ,752 | 1 | | | | | | | | | | | |
| **IPS** | -,975** | ,977** | ,985** | ,960** | ,924** | ,861* | 1 | | | | | | | | | | |
| **IBD** | -,956** | ,982** | ,967** | ,943** | ,836* | ,818* | ,974** | 1 | | | | | | | | | |
| **IDAP** | -,973** | ,961** | ,984** | ,952** | ,883* | ,951** | ,962** | ,909* | 1 | | | | | | | | |
| **EPI-D** | ,959** | -,983** | -,972** | -,939** | -,863* | -,813* | -,984** | -,997** | -,921** | 1 | | | | | | | |
| **DI-CH** | ,894* | -,945** | -,912* | -,872* | -,763 | -,706 | -,925** | -,981** | -,828* | ,978** | 1 | | | | | | |
| **IDP** | ,974** | -,934** | -,964** | -,935** | -,950** | -,917** | -,970** | -,904* | -,982** | ,918** | ,816* | 1 | | | | | |
| **LOBO** | ,874* | -,787 | -,828* | -,845* | -,937** | -,811 | -,876* | -,796 | -,850* | ,802 | ,685 | ,927** | 1 | | | | |
| **SID** | ,963** | -,974** | -,968** | -,956** | -,872* | -,833* | -,984** | -,994** | -,919** | ,992** | ,960** | ,928** | ,852* | 1 | | | |
| **TID** | ,783 | -,670 | -,717 | -,708 | -,943** | -,664 | -,797 | -,697 | -,746 | ,715 | ,597 | ,858* | ,967** | ,760 | 1 | | |
| **PT** | ,834* | -,790 | -,776 | -,707 | -,864* | -,569 | -,850* | -,865* | -,716 | ,871* | ,869* | ,791 | ,797 | ,876* | ,817* | 1 | |
| **WAT** | -,943** | ,973** | ,972** | ,923** | ,757 | ,918** | ,921** | ,915* | ,963** | -,921** | -,870* | -,903* | -,696 | -,897* | -,560 | -,660 | 1 |
| **TDI** | ,989** | -,993** | -,993** | -,954** | -,889* | -,884* | -,991** | -,982** | -,967** | ,988** | ,939** | ,961** | ,840* | ,983** | ,748 | ,842* | -,953** |

## IV. DISCUSSION

Nutrient concentration, particularly phosphorus, increases with urban development, associated with storm water run-off and is caused by other catchment activities such as agriculture [33]. Studies of streams draining urban centers with mixed storm water and sewage impacts have shown declines in diatom species richness associated with high loads of organic pollution [34].

In this study, both taxa richness and diversity in the site 6 declined due to a mixture of waste water to stream. All of the taxa determined in this site are tolerant of pollution. These taxa are *N. palea* (Kützing) W. Smith, *G. parvulum* (Kützing) H.F. Van Heurck, *Mayamaea atomus* (Kützing) Lange-Bertalot, *Navicula cryptocephala* Kützing, *Craticula accomoda* Hustedt and *C. halophila* (Grunow) D.G.Mann. [35]-[41]. Lobo et al. [42] described *N. palea* as a medium pollution-tolerant species. In this study, however, this species had high relative abundance (around 90%) at alfamesosaprobic site 6 with critically polluted water quality, an indication that it is tolerant of high pollution. According to Lobo et al. [43], *G. parvulum* is a relatively abundant species at downstream eutrophic sites with high organic pollution as alfamesosaprobic. This taxon represented quality class III-IV [16]. Kobayasi & Mayama [44] and Lobo et al. [45] classified *G. parvulum* as highly tolerant to organic pollution in agreement with the results of the current study. Similarly, Kelly & Whitton [5], working in rivers of UK described this species as highly tolerant to eutrophication in their calculation of the Trophic Diatom index (TDI). *G. parvulum* is known to be tolerant to several forms of pollution and indicates disturbed conditions [11], then it was added to list of pollution tolerant species by Cholnoky [46]. To Cox [37] it is a taxon tolerant to pollution in general and sometimes can be seen in polisaprobic and alfamesosaprobic conditions. It is also reported to be seen in oligosaprobic conditions *Navicula radiosa* Kützing, *Achnanthidium minutissimum* Kützing, *Meridion circulare* (Greville) C. Agardh, *Cocconeis pediculus* Ehrenberg, *F. capucina* var. *amphicephala* (Kützing) Lange-Bertalot ex Bukhtiyarova were dominant taxa in station 1, and *Navicula lanceolata* C. Agardh Ehrenberg, *N. radiosa* Kützing and *Diatoma mesodon* (Ehrenberg) Kützing, *A. minutissimum, F. capucina* var. *amphicephala* in station 2, *Gomphonema olivaceum* (Hornemann) Brébisson, *Cymbella affinis* Kützing, *Rhopalodia gibba* (Ehrenberg) Otto Müler, *A. minutissimum F. capucina var. amphicephala* in station 3, *N. lanceolata, C. affinis, G.. olivaceum, N. radiosa, Gomphonema lateripunctatum* Reichardt, *F. capucina var. amphicephala* in satation 4, *C. affinis, G. olivaceum, Ulnaria ulna, Diatoma mesodon* in station 5. *A. minutissimum, M. circulare, C. pediculus F. capucina* var. *amphicephala, R. gibba, Navicula lanceolata, C. affinis, G. lateripunctatum, M. circulare, D. mesodon* were not found in station 6. However, these taxa were especially found in oligosaprob regions.

According to European Guidance Standard *D. mesodon, M. circulare, G. olivaceum* represents excellent quality class, *F. capucina* var. *amphicephala, A. minutissimum, G. olivaceum, N. lanceolata, C. affinis* good quality class, *C. pediculus, G. parvulum* moderate quality class, *N. palea* poor quality class. *N. accommoda, N. atomus* bad quality class [11]. Lange-Bertalot [35], Klee [47] and Kalyoncu [12] classified that *C. pediculus* is betamesosaprobic organism. To Cox [37] it is present in waters of high electroit. Lange-Bertalot [35], [36] states that *G. olivaceum* is the characteristic organism of quality classes II and III and that it develops parallel to the recovery of water quality. Steinberg ve Schiefele [48] points out that this species develops in rich food conditions. Also, to Klee [47] and Kalyoncu [12], it is of quality classes II-III. Cox thinks it is a wide species and is widest in oligotrophic waters and eutrophic rivers. *M. circulare,* to Barlas [49], Klee [47] and Kalyoncu [12], is one of the diatoms representing the quality class I. Cox [37] says that it is present in sources of abundant calcerous and in streams, especially in cold source waters.

*F. capucina* is widely found in oligotrophic waters. N. lanceolata is wide from source waters to salty waters in oligotrophic, beta-alfa mesosaprophic conditions, but often in low temperatures. R. gibb is wide in waters running slowly, especially source waters [37]. Bertalot [35], [36] and Barlas [49] say that *A. minutissimum* is an organism of quality I. However, most of these species are known to be tolerant of eutrophication and organic pollution [50]. In this study, *F. capucina* var. *amphicephala* was dominant takson in stations 1, 2, 3 and 4, *D. mesedon* in station 5, *C. accomoda* in station 6.

SID was determined to be in harmony with physico-chemical parameters. It was followed by IBD, SHE and EPI-D and Adjusted R2 values were higher than 0.7. These indices were followed by DESCY, IPS (over $p>0.6$), DI-CH, SLA, IDAP ($p<0.5$). Adjusted R2 values of the other indices were below 0.5. The lowest relation with ecological parameters was with %PT and it was followed by CEE and TID (Fig. 3). Trofi-based indices didn't give good results in Darı Stream, and saprobe-based indices gave better results. All of the indices showed the change of water quality in station 6. However, differences were determined in quality levels. In unpolluted areas, too, there were differences by classification of indices. All through the study, SLA, DESCY, SHE, TDI, CEE, CEE, IBD, EPI-D, DI-CH, SID and TID used more than 90% of the species in index calculations. GENRE and IPS used 100% of the species in calculations. IDSE and PT used 80.95%, IDAP and IDP 42.67%, and LOBO 28.57%. However, while, in 6th station, the rates were LOBO 50%, WAT 33%, IDAP and IDP 66.67%, CEE and DESCY 83.33%, the other indices used 100%. For this reason, the presence of taxa whose ecological characteristics are well-known and that are tolerated to pollution in this station. Of the indices of high correlation values with ecological variables, only IDP used 42% of the species, and the all the others used more than 90%. Although CEE (90%) and %PT (80%) used a big majority of the species in index calculations, they were in lowest relation with the ecological parameters.

The diatom indices gave similar responses to those obtained for both slow-flowing rivers in France [51] and faster-flowing ones in England [52]. In Poland streams IPS [53] and in southern Poland IPS and GDI gave the best results [54]. All OMNIDIA indices were applicable to the study area in streams around Sa˜o Carlos-SP, Brazil [55]. EPI-D, TDI, %PT, IPS and IDG were significantly correlated to nutrient contents in wetlands in central Italy [56]. Diatom indices responded differently to the selected criteria of the studied typologies. The size of the watercourse and flow velocity did not affect significantly any of the studied indices, while bedrock type and water temperature sometimes played a noteworthy role. Although stream size is an important factor in the formation of benthic diatom assemblages, the diatom indices were not notably dependent on it. Some indices (SLA, L-M, CEC) were quite sensitive to the character of the riverbed; however, at the same time, they did not respond to the concentration of organic matter in the water [57]. In our study, SID, IBD, SHE and EPI-D seemed to give the best results. Diatom indicator methods can be successfully used as criteria for rivers classification system. These methods can indicate many kinds of human impacts and permit estimations from different types of water and, different geographical regions to be compared [9], [58].

According to all these results, the indices in OMNIDIA program yield results applicable for Turkey. However, due to the fact that geo-geographic characteristics are different, saprobity and trophy values of organisms must be modified for Turkey conditions and their indication weights must be accounted again.

## V. Conclusions

There is a need for better water quality indicator for rivers and streams for Turkey. Simple metrics are often used but commonly do not work well over wide geographic scales and types of side. Understanding ecological characteristics of the diatom taxa is very important for Turkey because there are different geographic conditions and ecological variables. One of the best approaches for obtaining ecological information is the development of calibration sets, for indices are fixed and modified worldwide according to geographic and ecological conditions or a different index is developed (e.g. [59]-[62]. Geo-geographic scales and habitat types should be determined, ecological variables should be measured and a common system with Europe should be established in extraction, assessment and counting. No common understanding of method is present in Turkey. For the integration with Europe, extraction and counting methods in Europe should be used in Turkey, too.

## Acknowledgments

This research has been supported by Unit of Scientific Research Projects, Süleyman Demirel University (Project No: SDÜBAP 1919-YL-09). We are deeply grateful to them for their financial support.

## References

[1] Salomoni SE., Rocha O., Callegaro VL & Lobo EA. (2006). Epilithic diatoms as indicators of water quality in the Gravataı´ river, Rio Grande do Sul, Brazil. *Hydrobiologia*, 559: 233–246.

[2] Dixit SS., Dixit AS & Smol JP. (1992). Assessment of changes in lake water chemistry in Sudbury area lakes since preindustrial times. *Can. J. Fish. Aquat. Sci.* 49(Suppl. 1):8–16.

[3] Rimet F. (2012). Recent views on river pollution and diatoms. *Hydrobiologia,* 683:1–24.

[4] Descy JP & Coste M (1991). A test of methods for assessing water quality based on diatoms. *Verhandlungen der Internationalen Vereinigung fu¨r Theoretische und Angewandte Limnologie* 24: 2112–2116.

[5] Kelly, MG. & Whitton, BA. (1995). The trophic diatom index: a new index for monitoring eutrophication in rivers. *Journal of Applied Phycology* 7: 433–444.

[6] Prygiel J., Whitton BA & Bukowska J. (1999). Use of Algae for Monitoring Rivers III. *Agence de L'Eau Artois-Picardie*, Douai: 271 pp.

[7] Zelinka M. & Marvan P. (1961). Zur prasisiering der biologischen klassifikation der reinheot fliessender gewa¨sser. *Archive Hydrobiologia* 57: 389–407.

[8] Stevenson RJ., Pan Y. (1999). *Assessing environmental conditions in rivers and streams with diatoms.* In: The Diatoms. Applications for the Environmental and Earth Sciences (Eds: EF STOERMER & JP SMOL). - pp. 11-40 Cambridge Univ. Press, Cambridge.

[9] Stevenson RJ., Pan Y. (1999). *Assessing environmental conditions in rivers and streams with diatoms.* In: The Diatoms. Applications for the Environmental and Earth Sciences (Eds: EF STOERMER & JP SMOL). - pp. 11-40 Cambridge Univ. Press, Cambridge.

[10] Eloranta P., Soininen J. (2002). *Ecological Status of some Finnish rivers evaluated using diatom communities*, Journal of Applied Phycology 14, 1-7.

[11] Rimet F., Cauchie HM., Hoffmann L & Ector L. (2005). Response of diatom indices to simulated water quality improvements in a river. *Journal of Applied Phycology* 17: 119–128.

[12] Harding WR., Archibald CGM & Taylor JC. (2005). The relevance of diatoms for water quality assessment in South Africa: a position paper. *Water SA* 31: 41–46.

[13] Kalyoncu H., Barlas M. (1997). Isparta Deresinde Yoğun Olarak Belirlenen Epilitik Diatomların Su Kalitesine Bağlı Olarak Mevsimsel Değişimleri. *IX. Ulusal Su Ürünleri Sempozyum Kitabı*, 17-19 Eylül 1997. Eğirdir/Isparta. 310-324.

[14] Kalyoncu H., Barlas M., Ertan OÖ., Gülboy H. (2004). Ağlasun Deresi'nin Su Kalitesinin Fizikokimyasal Parametrelere ve Epilitik Alglere Göre Belirlenmesi. *Eğirdir Su Ürünleri Fakültesi Dergisi,* 2(7): 7-14.

[15] Solak CN & Ács É (2011). Water qualıty monıtorıng ın European and Turkısh rıvers usıng dıatoms. *Turkish Journal of Fisheries and Aquatic Sciences* 11(2): 329-337.

[16] Solak CN, Ector L., Wojtal AZ., Ács É. & Morales EA (2012). A review of investigations on diatoms (Bacillariophyta) in Turkish inland waters. *Nova Hedwigia Beiheft* 141: 431-462.

[17] Kalyoncu H. (2006). Isparta Deresi Su kalitesinin Fizikokimyasal Parametrelere ve Epilitik Diyatomelere Göre Belirlenmesi. *SDU Fen Edebiyat Fakültesi Fen Dergisi (E-Dergi)*,1(1): 14-25.

[18] Kalyoncu H., Barlas M., Ertan Ö.O. (2009c). Aksu Çayı'nın Su Kalitesinin Biotik İndekslere (Diyatomlara ve Omurgasızlara Göre) ve Fizikokimyasal Parametrelere Göre İncelenmesi, Organizmaların Su Kalitesi ile İlişkileri. *Türk Bilim Dergisi*, 2(1): 46-57.

[19] Gürbüz H, Kıvrak E (2002). Use of epilithic diatoms to evaluate water quality in the Karasu River of Turkey. *J Environ Biol.* 23(3):239-46.

[20] Solak CN., Fehér G., Barlas M and Pabuçcu K. (2007). Use of epilithic diatoms to evaluate water quality of Akçay Stream (Büyük Menderes River) in Mugla/Turkey. *Archiv Für Hydrobiologie Suppl*., 161 (3-4), Large Rivers, 17(3-4): 327-338.

[21] Kalyoncu, H., Çiçek, N. L., Akköz, C and Yorulmaz, B. (2009b). Comparative performance of diatom indices in aquatic pollution assesment. *African Journal of Agricultural Research*, Vol. 4 (10), pp. 1032-1040.

[22] Solak CN., Barinova S., Acs E & Dayıoğlu H. (2012a). Diversity and ecology of diatoms from Felent Creek (Sakarya river basin), Turkey. *Turk J Bot*, 36.

[23] American Public Health Association (APHA) (1998). Standard methods for examination of water and wastewater. Washington, D.C.: American Water Works Association and Water Pollution Control Federation.

[24] Round FE., 1991. Diatoms in river water-monitoring studies. *Journal of Applied Phycology* 3: 129–145.

[25] Krammer K & Lange-Bertalot H (1986) *Bacillariophyceae*. 1. Teil: Naviculaceae. *Süßwasser von mitteleuropa*. Gustav Fischer Verlag, Band 2-1, Stuttgart.

[26] Krammer K & Lange-Bertalot H (1988) *Bacillariophyceae*. 2. Teil: Bacillariophyceae, Epithemiaceae, Surirellaceae. *Süßwasser von mitteleuropa*. Gustav Fischer Verlag, Band 2-2, Stuttgart.

[27] Krammer K & Lange-Bertalot H (1991a) *Bacillariophyceae.* 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. *Süßwasser von mitteleuropa*. Gustav Fischer Verlag, Band 2-3, Stuttgart.

[28] Krammer K & Lange-Bertalot H (1991b) *Bacillariophyceae.* 4. Teil: Achnantheceae, Kritische Erg舁zungen zu Navicula (Lincolatae) und Gomphonema. Cesamptliteraturverzeichnis . *Süßwasser von mitteleuropa*. Gustav Fischer Verlag, Band 2-4, Stuttgart.

[29] Round FE., Crawford RM and Mann DG. (1990). *The diatoms: biology and morphology of the genera.* Cambridge University Press: London, UK., 747 pp.

[30] Hartley B., Barber HG., Carter JR & Sims PA. (1996). *An atlas of British Diatoms*. Biopress Limited, Bristol.

[31] Lecointe C., Coste M & Prygiel J (1993). ‘‘Omnidia’’: software for taxonomy, calculation of diatom indices and inventories management. *Hydrobiology* 269 (270): 509–513.

[32] SPSS INC (2004). SPSS Proffessional Statistics 13.0 SPSSINC,Chicago.

[33] Sonneman JA., Walsh CJ., Breen PF & Sharpe AK. (2001). Effects of urbanization on streams of the Melbourne region, Victoria, Australia. II. Benthic diatom communities. *Freshwater Biology* 46: 553–565.

[34] Lobo EA., Katoh K & Aruga Y. (1995). Response of epilithic diatom assemblages to water pollution in rivers in the Tokyo Metropolitan area. *Freshwater Biol.*, 34:191-204.

[35] Lange-Bertalot H. (1978). Diatomeen-Differantiallortenanstelle von Leitformen: ein geeigneteres Kriterium der Gewässerbelastung. Arch, Hydrobiol. Suppl. 51. *Algological Studies* 21. 393-427 pp. Suttutgard.

[36] Lange-Bertalot H. (1979a). Pollution tolerance of diatoms as acriterion for water quality estimation. *Nova Hedwigia* Beiheft 64: 285–304.

[37] Cox EJ. (1996). *Identification of Freshwater Diatoms From Live Material*. Chapman & Hall, London, 158 pp.

[38] Biggs BJF & Kilroy C. (2000). *Stream Periphyton Monitoring Manual*. NIWA, Christchurch, New Zealand.

[39] Potapova M & Charles DF. (2003). Distribution of benthic diatoms in U.S. rivers in relation to conductivity and ionic composition. *Freshwater Biology* 48: 1311–1328.

[40] Duong T., Coste M., Feurtet-mazel A., Dang D., Gold, C., Park, Y. (2006). Impact of urban pollution from the Hanoi area on benthic diatom communities collected from the Red, Nhue and Tolich Rivers (Vietnam). *Hydrobiologia* 563:201–216.

[41] Bere T., Tundisi JG. (2011a). Applicability of borrowed diatom-based water quality assessment indices in streams around Sa˜o Carlos-SP, Brazil. *Hydrobiologia,* 673:79–192.

[42] Lobo EA., Callegaro, VL., Hermany G., Bes D., Wetzel CE & Oliveira MA. (2004). Use of epilithic diatoms as bioindicator from lotic systems in southern Brazil, with special emphasis on eutrophication. *Acta Limnologica Brasiliensia* 16: 25–40.

[43] Lobo EA., Callegaro VL & Bender P. (2002). *Utilizac¸a˜o de algas diatoma´ceas epili´ticas como indicadoras da qualidade da a´gua em rios e arroios da Regia˜o Hidrogra´fica do Guaı´ba*, RS. EDUNISC, Santa Cruz do Sul, Brasil.

[44] Kobayasi H. & Mayama S. (1989). Most pollution-tolerant diatoms of severely polluted rivers in the vicinity of Tokyo. *Japanese Journal of Phycology* 30: 188–196.

[45] Lobo EA., Callegaro VLM, Oliveira MA, Salomoni SE., Schuler S & Asai K. (1996). Pollution tolerant diatoms from lotic systems in the Jacui Basin, Rio Grande do Sul, Brasil. *Iheringia Se´rie Bota^nica* 47: 45–72.

[46] Cholnoky BJ (1970) *Bacillariophyceae from the Bangweulu Swamps*. Cercle Hydrobiologique de Bruxelles, Brussels.

[47] Klee, O. (1991). *Angewandte Hydrobiologie*. G. Theieme Verlag, 2. neubearbeitete und erweiterte Auflage, Stuttgart-New York, 272 pp.

[48] Steinberg C. and Schiefele S. (1988). Biological indication of trophy and pollution of running waters. 2. *Wasser – Abwasser – Frosch*., 21: 227-234.

[49] Barlas M. (1988). *Limnologische untersuchungen ander Fulda unter besonderer berücksichtigung der fischparasiten, Ihrer Wirtsspektren und der Wassergüte.* Dissertation. PhD Thesis. Üniversität Kassel.

[50] Van Dam H., Mertens A & Sinkeldam J. (1994). A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. *Aquatic Ecology* 28: 117–133.

[51] Prygiel J., Coste M (1993) The assessment of water quality in the Artois-Picardie water basin (France) by the use of diatom indices*. Hydrobiol.* 269/279 343-349.

[52] Kelly, M. G., C. J. Penny, B. A. Whitton., 1995.Comparative performance of benthic diatom indicesused to assess river water quality. Hydrobiologia 302:179–188.

[53] Rakowska B., Szczepocka E. 2011. Demonstration of the Bzura River restoration using diatom indices. Biologia 66(3): 411–417.

[54] Kwandrans J., Eloranta P., Kawecka B & Kryzsysztof W. (1998). Use of benthic diatom communities to evaluate water quality in rivers of southern Poland. *Journal of Applied Phycology* 10: 193–201,

[55] Bere T & Tundisi JG. (2011b). Influence of land-use patterns on benthic diatom communities and water quality in the tropical Monjolinho hydrological basin, Sa˜o Carlos-SP, Brazil. *Water SA* 37: 93–102.

[56] Bella DV., Puccinelli C., Marcheggiani S., Mancini L. (2007). Benthic diatom communities and their relationship to water chemistry in wetlands of central Italy. *Ann. Limnol. - Int. J. Lim.*, 43 (2), 89-99.

[57] Vilbaste, S., Truu, J., Leisk, Ü. & Iital, A. 2007. Species composition and diatom indices in relation to environmental parameters in Estonian streams. *Arch. Hydrobiol. Suppl.*, 161(3.4), 307.326.

[58] Rott, E., Pipp, E. and Pfister, P., 2003. Diatom methods developed for river quality assessment in Austria and a cross-check against numerical trophic indication methods used in Europe. Algological studies, 110: 91–115.

[59] Watanabe T., Asai K & Houki A. (1986). Numerical estimation of organic pollution of flowing waters by using the epilithic diatom assemblage – Diatom Assemblage Index (DIApo). *Science of the Total Environment* 55: 209–218.

[60] Dell'Uomo A. (1996). *Assessment of water quality of an Apennine river as a pilot study*. In Whitton, B. A. & E. Rott (eds), Use of Algae for Monitoring Rivers II. Institut fu¨r Botanik, Universita¨t Innsbruck, Innsbruck: 65–73.

[61] Go´mez N. & Licursi M. (2001). The Pampean Diatom Index (IDP) for assessment of rivers and streams in Argentina. *Aquatic Ecology* 35: 173–181.

[62] Walley WJ., Grbovic J & Eroski , S. (2001). A Reappraisal Of Saprobic Values And Indicator Weights Based On Slovenian River Quality Data. *Wat. Res.* Vol. 35, No. 18, Pp. 4285–4292.