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Water quality assessment of the Sinchun stream based on epilithic diatom communities

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Abstract

Water quality was assessed 11 sites on the Sinchun Stream, in the region of Daegu City (South Korea), from May 2007 to March 2008 using Diatom Assemblage Index to Organic Water Pollution (DAIpo) and Trophic Diatom Index (TDI). The reference sites were unaffected by effluent from a closed mine or treated sewage and had, epilithic diatom communities that were dominated by saproxenous taxa such as *Achnanthes convergens* and *Cocconeis placentula* var. *lineata*. The water quality of these sites had DAIpo values ranging between 77.5-93.8 and TDI values between 51.3-67.6, indicating β−oligosaprobic and mesotrophic environments, respectively. Study sites affected by effluent from the closed mine had epilithic diatom communities that were dominated by acidobiontic diatoms, such as *Eunotia exigua* and *Achnanthidium minutissimum*. The water quality of these sites had DAIpo values of 45.9-70.8, indicating β-mesosaprobic to α-oligosaprobic environments, whereas TDI ranged between 1.7-66.9, indicating an oligotrophic to mesotrophic environment. Downstream sites affected by the influx of mine effluent and treated sewage had many species and a high percentage of saprophilous taxa, including *Fragilaria construens* var. *venter* and *Nitzschia amphibia*. The water quality of these regions had DAIpo values ranging between 21.8-33.1 and TDI values between 67.5-76.7, indicating α-mesosaprobic and eutrophic environments, respectively.

Key words

Epilithic diatom communities, DAIpo, TDI, Sinchun Stream, Water quality

Introduction

Biological assessment of water quality of rivers and streams has several advantages over physical and chemical analysis of water quality (Bate *et al.*, 2004). In particular, the use of biological communities for stream monitoring provides integrated information on the interaction between water quality and integrity of the biological communities (Hill *et al.*, 2000). Many biological water quality assessment systems have been developed, based on the assessment of benthic diatoms, benthic macroinvertebrates and fishes (Resh and Jackson, 1993; Kelly and Whitton, 1995; Whitton and Kelly, 1995; Hill *et al.*, 2000; Ramos *et al.*, 2012). Assessment systems based on benthic macroinvertebrates and fishes have some disadvantages, because these organisms can migrate and often do not have strong or rapid response to some environmental changes, such as eutrophication, acidification, and metal contamination.

Diatoms have long been used as reliable indicators of environmental changes in water quality as they have rapid immigration and replication rates and respond, quickly to changes in the aquatic environment they have short life cycles and rapid reproduction, identification to the species level is usually easy taxa differ in their sensitivity to changes of specific environmental parameters, they can be used for long-term evaluations because they do not migrate (Dixit and Smol, 1994; Pan *et al.*, 1996; Winter and Duthie,2000; Schneider *et al.*, 2013). During the last two decades, several water quality assessment systems have been developed based on epilithic diatom communities in Asia (Watanabe, 2005), Europe (Prygiel and Coste, 1993; Kelly and Whitton, 1995), North America (Lowe and Pan, 1996; Stevenson and Pan, 1999) and Australia (John, 1998; Chessman *et al.*, 1999). The diatom assemblage index to organic water pollution (DAIpo), proposed by Asai and Watanabe (1995) is the most widely used indices in Asia, and the Trophic Diatom

Index (TDI) was designed to study the effect of inorganic nutrients by Kelly and Whitton (1995) is the official index in UK and Ireland.

In the present study, DAIpo and TDI index, based on epilithic diatom communities, were used to evaluate the water quality of regions of the Sinchun Stream in Daegu City (South Korea), and examined the response of epilithic diatom community to drainage from a closed mine and treated sewage discharge.

Materials and Methods

Study site : Sinchun stream is about 27 km long and passes through the center of Daegu City, located is in southeast of South Korea and has 2.5 million residents (Fig. 1). This stream serves as a source of potable water and as a recreational region to many of the nearby inhabitants. In 1978, a dam was constructed in the upper reaches of the stream to supply drinking water, and this dramatically reduced the quantity of water flow downstream. In addition, effluent from a closed tungsten mine in the upper part of stream increased the pollution of this stream. Since February 1997, treated sewage has been discharged into the lower part of this stream.

Sample collection, treatment and enumeration : Samples from the Sinchun Stream were collected from 11 sites, at an interval of one or two month, from May 2007 to March 2008. Three sites (R1, R2, R3) were designated as reference sites as they were unaffected by the effluent from the closed mine. Eight study sites

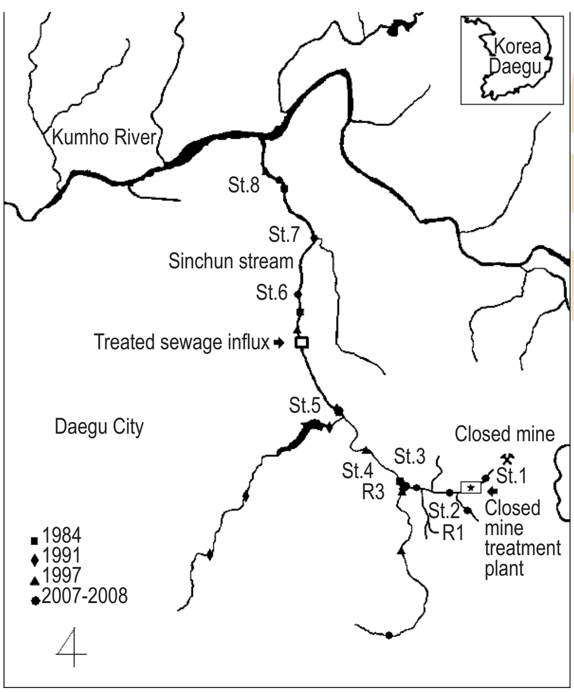

Fig. 1 : Sampling sites on Sinchun Stream. The inset map shows the location of the Sinchun Stream in southeastern Korea

(St. 1-8) downstream of the mine effluent, and three of these sites (St. 6-8) were also downstream of the treated sewage (Fig. 1).

Epilithic diatoms were scraped from three submerged stones (about 10 cm diameter) with a stiff brush and specimens for taxonomic analyses were cleaned by the permanganate method (Hendey, 1974). Permanent slides were prepared using Pleurax mounting medium. Valves or frustules were examined under light microscopy (Zeiss Axioskop 2) at 1,000 X, and identified using microscopic photographs at 1,000-2,000 X. The taxonomic and autecological analysis, including division of diatoms into groups with respect to organic pollution, was performed as described by Hustedt (1937-1939), Patrick and Reimer (1966), Krammer and Lange-Bertalot (1986-1991), Watanabe (2005) and Guiry and Guiry (2014). Abundance of each epilithic diatom species was determined by counting over 500 frustules at each sampling. The most abundant organism in each community was considered as dominant species, and other organisms that accounted for at least 10% of the total population were considered subdominant species. Water temperature, pH, and electrical conductivity of the sampling sites were measured at the time of sampling, using a HI8314 membrane pH meter and a WTW-LF91 membrane EC meter. The concentrations of heavy metal ions in the water were measured with an inductively coupled plasma optical emission spectrometer (Perkin-Elmer 4300DV). Total phosphorus (TP) and total nitrogen (TN) concentrations were measured by standard methods (APHA, 2005). Diatom Assemblage Index (DAIpo) was calculated as described by Watanabe (2005). Trophic Diatom Index (TDI) was calculated as described by Kelly (1998). Shannon-Weaver index (1963) was used for the relative abundance and species diversity, while Simpson index (1949) was applied to calculate the relative degree of dominance of the community. The data of all sities were subjected to one-way ANOVA and Pearson correlation analysis. All statistical analysis was conducted with SPSS 12.0 (2000 Apache Software Foundation).

Results and Discussion

Analysis of physico-chemical properties revealed that water temperature ranged 0.7°C to 30.8°C, mean pH ranged from 4.6 to 8.0, and the mean electrical conductivity (EC) ranged from 71.2 to 1340 μScm^{-1} respectively. The pH and EC values varied significantly among different sampling periods and sites. In particular, St. 1 had high acidity (pH 3.0-6.3) and conductivity (872-2500 μScm^{-1}). Downstream regions had decreased concentrations of heavy metals and EC, although there were notable increase in EC and heavy metal concentrations at St.1 (near the closed mine) and in EC at St. 6 (near the treated sewage discharge). The three sites downstream of the treated sewage (St. 6-8), had elevated concentrations of TN (4.47-10.58 mg l^{-1}) and TP (0.394-1.418 mg l^{-1}), indicating hyper trophication (Table 1).

Table 1 : Mean water temperature (WT), electrical conductivity (EC), pH, and concentrations of total nitrogen (TN), total phosphorus (TP), and selected heavy metal ions (mg l^{-1}) at each sampling site

	WT (°C)	EC (μScm^{-1})	pH	TN (mg l^{-1})	TP (mg l^{-1})	Cu (mg l^{-1})	Fe (mg l^{-1})	Mn (mg l^{-1})	Zn(mg l^{-1})	Al (mg l^{-1})
R1	14.8±8.1	121.3±51.0	7.9±0.6	0.766±0.186	0.012±0.005	0.005±0.001	0.166±0.145	0.024±0.032	0.030±0.032	0.137±0.087
R2	14.3±7.2	71.2±11.4	8.0±0.4	0.594±0.290	0.013±0.010	0.002	0.090±0.049	0.021±0.034	0.026±0.034	0.138±0.111
R3	16.9±9.2	238.8±35.2	7.4±0.7	1.459±0.649	0.035±0.019	0	0.055±0.031	0.005±0.005	0.019±0.006	0.150±0.105
St.1	12.8±7.6	1340.1±679.2	4.6±1.4	1.359±0.455	0.011±0.008	1.516±1.403	0.824±1.545	7.126±2.856	1.071±0.923	2.454±2.824
St.2	15±8.3	341.9±119.9	7.2±0.5	1.078±0.428	0.044±0.038	0.043±0.040	0.242±0.246	1.872±1.093	0.269±0.223	0.320±0.228
St.3	14.9±8.1	359.1±35.1	6.8±0.4	1.200±0.476	0.023±0.011	0.033±0.024	0.086±0.074	0.546±0.429	0.118±0.087	0.177±0.137
St.4	16.5±9.0	269.7±21.1	7.1±0.3	1.721±0.619	0.034±0.011	0.005±0.008	0.101±0.061	0.033±0.022	0.035±0.012	0.170±0.123
St.5	17.9±9.6	253.9±25.6	7.4±0.6	1.781±0.528	0.041±0.010	0.003±0.003	0.071±0.026	0.023±0.009	0.023±0.015	0.134±0.076
St.6	16±8.1	623.9±92.6	7.2±0.5	8.623±1.360	0.846±0.354	0.001	0.105±0.078	0.013±0.007	0.04±0.017	0.192±0.157
St.7	16.1±8.3	603.4±83.8	7.3±0.4	6.726±1.766	0.905±0.299	0.001	0.075±0.053	0.008±0.006	0.032±0.019	0.135±0.136
St.8	16.9±7.9	620.1±97.4	7.5±0.6	7.552±1.750	0.810±0.311	0.002±0.001	0.133±0.079	0.017±0.014	0.038±0.015	0.192±0.107

(R1, R2, R3: reference sites, St. 1 - St. 5: metal polluted sites, St. 6 - St. 8: metal and sewage polluted sites, ± value: standard deviations)

A total of 131 diatom taxa belonging 35 genera were identified in the epilithic diatom communities of Sinchun Stream (Table 2). The mean number of species (range: 39-86 taxa) varied according to the sampling site and collection time (Table 4).

The epilithic diatom communities exhibited considerable differences among the upper-, mid-, and downstream regions (Table 4 and Fig. 5). In particular, the epilithic diatom communities of St. R1-3 were characterized by high composition of pollution-sensitive taxa (62-89%) and were dominated by the pollution-sensitive taxa such as *Cocconeis placentula* var. *lineata* (Ehrenb.) and *Achnanthes convergens* H. Kobayasi, *A. subhudsonis* Hustedt and *Gomphoneis okunoi* Tuji. Although the species identified at St. R3 were similar to those at R1 and R2, the diatom community of R3 was dominated by different taxa, including pollution-sensitive taxa *Reimeria sinuata* (Greg.) Kociolek and Stoermer and *Cocconeis pediculus* Ehrenberg, and the indifferent taxon *Nitzschia fonticola* Grunow in Van Heurck. Pollution−tolerant and indifferent taxa accounted for a higher percentage of species at R3 than R1-2.

The epilithic diatom community at St. 1 (just below the closed mine) had low TDI, high EC, high concentration of heavy metals and a low pH. This site also, had small number of species (range: 4-27 taxa) (Table 4) and very high percentage of indifferent taxa (96.8%), dominated by *Eunotia exigua* (Breb. ex Kütz.) Rabenhorst (85.7-98.8%).

The communities of St. 2 and 3 were dominated by *Achnanthidium minutissimum* (Kütz.) Czarnecki throughout the study period, except during May and July, when it was dominated by *Fragilaria construens* var. *venter* (Ehrenb.) Grunow and *Eolimna minima* (Grunow) Lange-Bertalot and W. Schiller. These sites also had abundances of indifferent taxa (76.7-82.4%). In general, diatom communities of St. 1-3 had very low species diversity because of high dominance of these dominant taxa (46.9-98.8%) (Fig. 3).

The epilithic diatom communities at St. 4 and 5 had greater diversity and lower dominance index (Fig. 3), presumably due to the influx of a tributary. These sites were dominated by

Table 2 : Diatom genera and number of taxa identified in the Sinchun Stream during the study period

Genus	No. of taxa	Genus	No. of taxa
Achnanthes	8	*Hannaea*	1
Achnanthidium	1	*Hantzschia*	1
Amphora	4	*Hydrosera*	1
Asterionella	1	*Meridion*	1
Aulacoseira	3	*Melosira*	1
Caloneis	3	*Navicula*	27
Cocconeis	3	*Nitzschia*	11
Cyclostephanos	1	*Pinnularia*	7
Cyclotella	4	*Pleurosira*	1
Cymbella	7	*Punctastriata*	1
Diatoma	2	*Reimeria*	1
Eolimna	1	*Rhoicosphenia*	1
Epithemia	1	*Stephanodiscus*	1
Eunotia	3	*Surirella*	3
Fragilaria	8	*Synedra*	6
Gomphoneis	1	*Tabularia*	1
Gomphonema	11	*Thalassiosira*	2
Gyrosigma	2	Total number of taxa	131

Table 3 : Pearson correlation coefficients of diatom-based pollution indices (DAIpo and TDI) with electrical conductivity (EC), total nitrogen (TN) and total phosphorus (TP)

0	T-N	T-P	DAIpo	TDI
EC	0.854	0.842	-0.865	0.456
T-N		0.864	-0.72	0.579
T-P			-0.684	0.541
DAIpo				-0.333

N = 70, p<0.05

Table 4 : Seasonal changes of the speices number, DAIpo and TDI at sampling sites during the study period

0	R1	R2	R3	St.1	St.2	St.3	St.4	St.5	St.6	St.7	St.8
Species number											
May 07	53	25	32	6	42	40	42	39	23	29	30
Jul. 07	29	29	39	11	47	40	47	48	38	32	37
Sep. 07	14	16	19	19	41	20	30	37	43	38	45
Oct. 07	44	21	30	27	33	33	39	37	50	37	47
Dec. 07	21	19	33	4	12	22	28	28	29	35	32
Jan. 08	37	17	36	7	7	31	38	30	36	39	39
Mar. 08	30	28	34	8	10	21	34	30	27	30	32
Total	81	59	66	39	85	72	74	78	86	72	80
DAIpo											
May 07	92.2	96.8	75.3	35.4	45.6	52.4	69.8	55.1	21.1	18.1	15.3
Jul. 07	89.7	97.1	67.3	35.6	58.8	52.5	50.9	62.3	31.1	13.1	11.8
Sep. 07	96.8	85.4	89.4	38.7	49.2	50.3	29.2	52.3	35.0	38.9	37.7
Oct. 07	87.0	89.3	89.1	36.8	49.6	48.8	60.5	84.2	23.5	29.5	26.3
Dec. 07	95.3	96.2	70.0	35.4	50.1	48.4	70.9	71.5	49.4	17.1	11.3
Jan. 08	90.0	97.2	82.1	35.7	50.2	39.7	61.3	79.8	38.6	23.6	10.4
Mar. 08	86.1	95.1	69.8	35.5	50.3	44.8	53.2	74.7	33.2	27.6	39.6
Mean	91.0	93.9	77.6	36.2	50.5	48.1	56.6	68.6	33.1	24.0	21.8
TDI											
May 07	50.6	51.5	70.1	0.2	63.6	39.7	63.9	44.4	76.1	88.0	65.5
Jul. 07	58.1	50.3	72.7	1.2	79.4	40.5	78.1	48.6	62.7	59.1	51.1
Sep. 07	51.2	49.6	73.8	6.0	39.1	36.6	79.3	70.2	80.7	67.5	62.8
Oct. 07	57.0	49.8	64.9	3.3	32.2	31.5	59.6	54.4	77.1	83.6	65.3
Dec. 07	48.8	53.4	59.8	0.2	26.4	29.9	56.9	52.4	73.0	86.5	86.8
Jan. 08	62.4	51.4	65.8	0.2	27.1	37.9	60.1	44.6	77.4	72.7	64.1
Mar. 08	57.0	53.4	66.0	0.3	28.0	38.0	70.3	57.2	79.2	79.6	77.1
Mean	55.0	51.3	67.6	1.7	42.3	36.3	66.9	53.1	75.2	76.7	67.5

variable taxa, such as pollution sensitive taxa *Achnanthes atomus* Hustedt, *Cocconeis placentula* var. *lineata*, and *Reimeria sinuata,* the pollution tolerant taxon *Nitzschia palea* (Kütz.) W. Smith, and indifferent taxa such as *Achnanthidium minutissimum, Melosira varians* Agardh*, Navicula decussis* Østrup and *Nitzschia fonticola*. These two sites also had higher percentage of pollution sensitive taxa than St. 1-3. The species richness and species diversity gradually increased from St. 1 to St. 5 (Fig. 3).

St. 6 to 8, which were affected by the influx of treated sewage and had high level of nutrients and EC, had similar epilithic diatom communities as St. 2 to 5. These diatom communities had a high percentage of pollution-tolerant taxa and a low percentage of pollution−sensitive taxa (Fig. 5), and were dominated by pollution-tolerant taxa such as *Fragilaria construens* var. *venter*, *Navicula atomus*, *Nitzschia amphibia* Grunow, and *Nitzschia palea*, and some indifferent taxa such as *Nitzschia fonticola*, *Nitzschia inconspicua* Grunow, and *Navicula decussis*, except for St. 6 in December, which was dominated by the pollution−sensitive taxon *Achnanthes subhudsonis* Hustedt.

The characteristics of epilithic diatom communities of Sinchun Stream described in this study were similar to those previously described by Choi *et al*. (1998) in downstream regions, but considerably different from other descriptions of the same stream (Chung et al., 1985; Choi et al., 1998; Kim et al., 2008). For instance, the percentage of pollution−tolerant and pollution−sensitive taxa were similar to those in 1997 (Choi *et al*., 1998), but there were more pollution−tolerant taxa and fewer pollution−sensitive taxa in 2007 at downstream sites (Kim *et al*., 2008), presumably due to the effluent of treated sewage. In this study, five species of *Hydrosera whampoensis* (A.F. Schwarz) Deby, *Nitzschia nana* Grunow, *Pleurosira laevis* (Ehrenb.) Compère, *Thalassiosira bramaputrae* (Ehrenb.) Håkansson and Locker, and *T. weissflogii* (Grunow) G. Frywell and Hasle were only found at St. 6-8, which had a high nutrient concentration and high water temperature, as reported in previous study (Kim *et al*., 2008). Also, throughout the study period *Eunotia exigua* dominated at St. 1, had high level of heavy metals (Cu, Fe, Mn and Zn), high EC and low pH. This result is similar to that of a previous study (Kim *et al*., 2008), which reported that *Eunotia exigua* can be considered an indicator of heavy metal pollution. The results of the present study indicated that the effluent of a closed mine at an upstream site, agriculture runoff at midstream sites, and influx of treated sewage at a downstream site affected the water quality and epilithic diatom assemblages of the Sinchun Stream.

Finally, a dendrogram through cluster analysis was constructed to identify the overall similarities of the 11 sampled sities (Fig. 4). The results indicated five different types of epilithic diatom assemblages, which were designate as Type A to E. Type A (Site R1-2) was dominated by *Cocconeis placentula* var. *lineata* and *Achnanthes convergens*, and had a high percentage of pollution-sensitive taxa and a low percentage of pollution-tolerant taxa. Type B was dominated by various taxa (depending on sampling time) such the pollution-sensitive taxa *Reimeria sinuata* and *Cocconeis pediculus* Ehrenberg and the indifferent taxon *Nitzschia fonticola*, and had a high percentage of pollution-tolerant and indifferent taxa. Type C was dominated by pollution-tolerant taxa such as *Fragilaria construens* var. *venter*, *Navicula atomus*, *Nitzschia amphibia*, and *Nitzschia palea*. Type D was dominated by the indifferent taxon *Achnanthidium minutissimum* and had a high abundance of other indifferent taxa. Type E was dominated by *Eunotia exigua* and had a high percentage of indifferent taxa and a low percentage of pollution-sensitive and pollution-tolerant taxa. The cluster analysis supports the presence of five types of epilithic diatom assemblages in the Sinchun Stream, which could be identified by water quality characteristics due to effluent from a closed mine, agriculture and treated sewage.

Fig. 2 and 3 shows the mean DAIpo and TDI values in the Sinchun Stream. DAIpo values at three reference sites (mean: 77.6-93.9) were higher than at the other downstream study sites. TDI values were high at the reference sites (mean: 51.3−67.6), declined sharply at St. 1, and then gradually increased from St. 2-

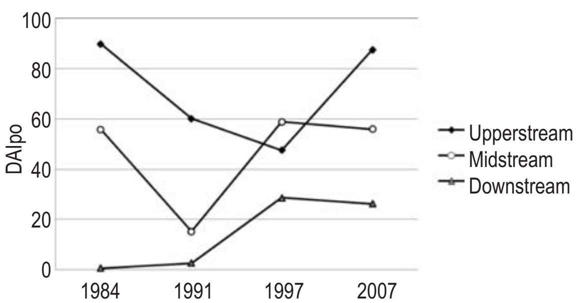

Fig. 2 : Long-term mean DAIpo values along the length of the Sinchun Stream

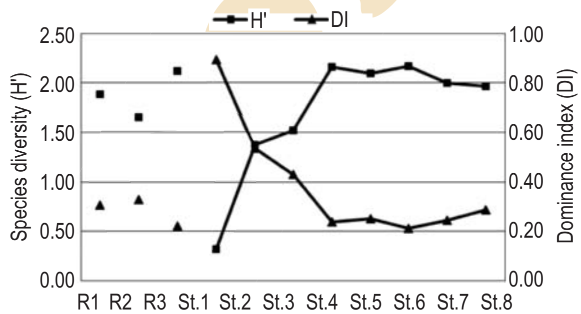

Fig. 3 : Mean species diversity (H´) and dominant index (DI) of the epilithic diatom communities at each sampling sites

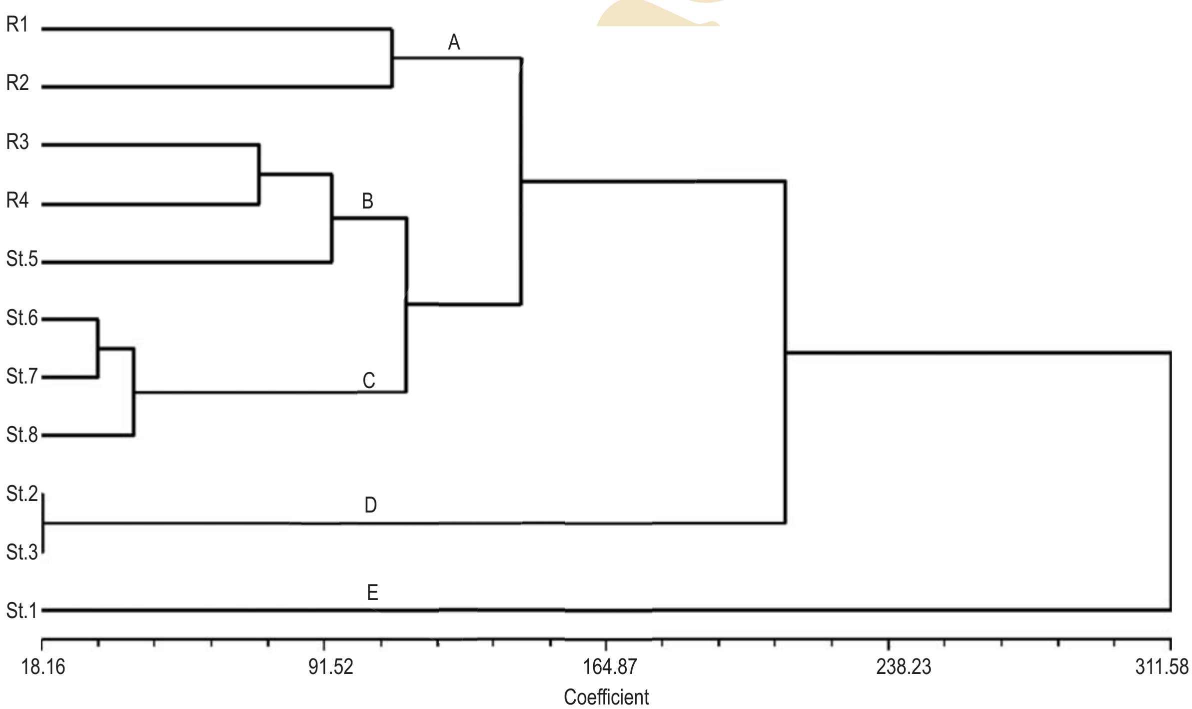

Fig. 4 : Dendrogram showing the overall similarity of the different epilithic diatom assemblages at the 11 sampling site

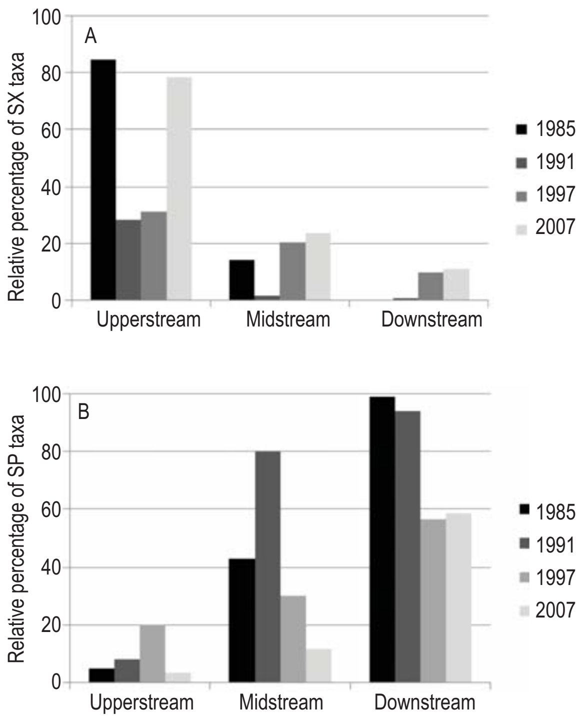

Fig. 5 : Long-term comparision of saproxenous (A) and saprophilous(B) species based on the tolerance to organic pollution

8. These TDI values indicated mesotrophic conditions which is, in agreement with Table 1, and the DAIpo values indicated a more oligotrophic than mesotrophic water quality. DAIpo values at St. 1-3 (mean: 36.2-50.6), which were affected by effluent from the closed mine, indicated a β-mesotrophic environment whereas TDI values at these sites (mean: 1.7−42.3) indicated good water quality, especially at St.1 (0.24-6.0). St. 1 had the fewest number of species (Fig. 3) and a very high composition (85.7-98.8%) of acidobiontic *Eunotia exigua*, however the water quality by TDI indicated good water quality throughout the year.

DAIpo at St. 4 and St. 5 were higher because another tributary joined the creek in this region (Fig. 1), and the mean values of 56.6 and 68.6 indicated an α-mesotrophic to oligotrophic environment relative to St. 1-3 (Table 4). TDIs at St. 4-5 (mean: 53.1- 6.9) indicate a mesotrophic state, similar to DAIpo. Both indices changed dramatically at St. 6-8, due to influx of treated sewage with high level of nutrients. High eutrophic states of these sites were due to the higher levels of TN and TP (Table 1).

Chung *et al*. (1985) published the first report on the water quality of Sinchun Stream based on assessment of the diatom community. Three subsequent studies of this stream have also assessed the diatom community of this stream (Choi *et al*., 1993, 1998; Kim *et al*., 2008). However, since 1997, when treated sewage was first discharged in the lower part of the stream to maintain an adequate flow, there have been no water quality assessments based on the epilithic diatom communities.

Two or three decades previously, the water quality of Sinchun Stream was very polluted at mid- and downstream regions, but now the water quality of these regions have improved considerably since the development of a treated sewage facility in 1997. Fig. 2 shows that DAIpo was very low in the downstream regions in 1985 and 1991, but was dramatically higher in 1997 and 2007. Fig. 5 shows that after 1997, the percentage of saproxenous species increased and the number of saprophilous species decreased at the upper-, mid-, and downstream regions. Correlation analysis indicated that TN, TP, and EC were correlated with each other. DAIpo was negatively correlated with these parameters, where TDI was positively correlated with these parameters (Table 3).

Several indices of diatom assemblages have been proposed for the assessment of organic and inorganic pollution of natural waters (Prygiel and Coste, 1993; Kelly and Whitton, 1995; Kelly, 1998; Watanabe, 2005). Until recently, most studies of stream water quality based on diatom communities in Korea have used DAIpo, and most of these studies were performed on the Nakdong River system (Choi *et al*., 1993, 1998; Kim and Won, 2011). The more recently developed (TDI) may be more useful tool for monitoring of Korean rivers and streams (unpublished report, MOE/NIER, 2008). The present study is one of the few studies of Korean natural waters to assess the water quality by useing TDI.

The present study showed that the water quality of Sinchun Stream, as indicated by DAIpo and TDI values, was more polluted at downstream regions, but these regions have improved since 1997. Moreover, our results also indicated that DAIpo provides a better measure of water quality than TDI indices in the Sinchun Stream, which is characterized by pollution from heavy metals and treated sewage in downstream regions. Our results also indicate that DAIpo and TDI values did not fully reflect the poor water quality at our St. 1, which had high acidity, high EC, and high concentrations of heavy metals. Thus, it may be necessary to develop another assessment model based on epilithic diatom community in order to adequately monitor the water quality of streams polluted with heavy metals.

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