Ecological state of the River Tornionjoki

– phytobenthos 2006

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ABSTRACT

Water chemistry together with phytoplankton, macroinvertebrate and fish communities were studied in the waters of the River Torne watershed in the first TRIWA project, “TRIWA – The River Torne International Watershed” (2003–2006). In 2006–2007, benthic algae in the rivers of the watershed was studied as part of the project “TRIWA II – Best practices for the management of an international river basin district”, to complement the ecological knowledge of the waters.

According to the European standards, diatoms were used as an indicator group of the phytobenthos communities. Diatoms are good indicators of the water quality, because they form a very diverse group of algae, both ecologically and taxonomically, and their ecological requirements are well known.

Altogether 49 river sites were studied for their diatom composition. The sampling covers all the seven river types the first TRIWA project proposed to be used in the watershed. The dataset represents mostly conditions of low or non-existing anthropogenic impacts, with a few exceptions of heavily impacted sites failing to reach good ecological status.

The revised system of river typology, proposed by the TRIWA project, is suitable for use in the ecological classifications, based on the diatom data. The un-impacted diatom communities can best distinguish alpine rivers from the rivers below tree-line, and humic rivers (high amount of organic material) from clearwatered rivers.

Use of diatom index IPS was found a suitable method for assessing the ecological status of the rivers. Mountain rivers and large rivers reach IPS values over 17 out of maximum of 20 in reference, unimpacted conditions. Some of the small, especially humic rivers gained IPS values below 17, without signicant human impacts. Based on this data, slightly deviating ecological status class boundaries could be used in the different types of rivers.

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INTRODUCTION

Description of the watershed

This short introduction to the conditions in The River Torne (*Tornionjoki* in Finnish, *Torne älv* in Swedish) watershed is based on a larger introduction in Puro-Tahvanainen *et al.* (2001). The catchment area of the River Torne is 40 157 km^2, of which 25 393 km^2 is situated in Sweden, 14 480 km^2 in Finland, and 284 km^2 in Norway. River Torne runs from the Lake Torneträsk to the Baltic Sea. Part of the water is diverted to River Kalix in Junosuando, via River Tärendö. Length of the River Torne is 470 km from the Lake Torneträsk to the Bothnian Bay, and 520 km from the Lake Kilpisjärvi via rivers Muonio and Torne to the Bothnian Bay.

The watershed of the river includes mountain areas with several mountains over 1000 m high. However, these mountain areas form only a minor part of the watershed; for most of the area the altitude is 200–500 m a.s.l. The lower part of the river (down from Övertorneå) the altitude is below 100 m a.s.l. Overall, the main channel of the River Torne is fairly gently sloping – the ecoregion of the Lake Torneträsk is only 342 m a.s.l.

The watershed is situated in middle- and north boreal vegetation zones. Middle boreal zone reaches upto Lainio and Vittangi areas in the north along the River Torne. In the middle boreal zone, pine and mixed forests dominate the landscape over spruce in more moisture soils. In the north boreal zone, the forests are more sparse. Areas above tree limit belong to the alpine vegetation zone.

For most part, the watershed of the river is situated on the Fennoskandian shield, with 1.6–2.7 billion years old bedrock. In the mountain area, the bedrocks are intrusive sediment- and volcanic-based rocks, which are easily weathering, and often calcareous. These calcareous rocks are also abundant in areas north and west from Pajala, and in the Kolari, Övertorneå and Tornio areas. The dominating soil type is moraine, which originates from the material detached from the bedrock by ice. Another common soil type is organic peat, especially in the middle- and lower parts of the watershed.

Utilization and quality of the waters

In the watershed of the River Torne, only the Rivers Tengeliönjoki and Puostijoki are dammed for the energy production. Other artificial constructions of the river banks, concentrated on the Finnish side, are connected to recreational use and protection from floods and erosion (Puro-Tahvanainen *et al*. 2001).

Diverse types of utilization affect the water quality in the river. In southern Finnish Lapland, about 30–50 % of the peat area is ditched for use in agriculture and forestry (Penttilä 1989), increasing the load of humic matter, nutrient and solid substances into the rivers. Point source pollution in the watershed derives mostly from waste water treatment plants with varying contaminant removal efficiency. In addition, there are some peat production fields both in Finland and Sweden, and fish farming in Finland.

As a whole, the level of anthropogenic loading is relatively low in the area: the total phosphorus load to the surface waters is estimated to be about 250 000 kg/yr, of which background load forms 77 %. Total nitrogen load estimation is 5 100 kg/yr, of which 74 % is background loading (Puro-Tahvanainen *et al*. 2001). However, high levels of loading are found in small scale in some tributaries of the River Torne. The highest levels of anthropogenic loading are found in the lower parts of the river (Puro-Tahvanainen *et al.* 2001).

The water quality of the rivers Torne and Muonio has been followed since the early 1960s. One site in the River Muonio (Palojoensuu) and three sites in the River Torne (in Pello, Kukkola and Mattila) have been monitored continuously since the 1960s or 1970s. Several tributaries of the River Torne have been monitored in shorter periods for water quality and macroinvertebrates (Puro-Tahvanainen *et al*. 2001).

According the monitoring results of the rivers, upper part of the River Torne in Sweden is clearwatered, and the water colour (ie. humic matter) is increasing downstream. Water is also clear in the upper part of the River Muonio, but its tributaries bring humic matter from the peat bogs and forests, and the colour of the water rapidly increases in the area of Kaaresuvanto–Palojoensuu. Median concentration of total organic carbon is about 1.7 mg l^{-1} in upper parts of the River Torne, 3.5 mg l^{-1} in the River Muonio, and 4.7–5.1 mg l^{-1} in the middle- and lower reaches of the River Torne (Puro-Tahvanainen *et al.* 2001).

Total phosphorus (TP) and total nitrogen (TN) concentrations reflect oligotrophy in the rivers Muonio and Torne. Only the lowest part of the River Torne can be considered mesotrophic, ie. TP concentrations are 15–25 µg l^{-1} (Puro-Tahvanainen *et al*. 2001).

In some of the smaller tributaries, the concentrations of nutrients and humic matter may be much higher than in the main channel. Puro-Tahvanainen *et al.* (2001) report that in Naamijoki and Martimojoki extensive ditching of the soils has deteriorated the water quality. In Martimojoki, also peat mining is responsible for the high amounts of solids, nutrients and humic matter. Humic matter lowers the pH levels in the rivers, but at the same time increases buffering capacity, so that strongly acid conditions (pH<5) are not usually found in the rivers.

River typologies

According to EU Water Framework Directive (WFD; European Parliament 2000), all rivers have to be allotted to ecologically meaningful river types, and biological reference conditions must be described for these types. The ecological quality status of the rivers is then determined by deviation from the reference conditions.

In TRIWA project, four different systems of typology of rivers have been tested for use in the assessment of reference conditions and ecological classification of the rivers: Finnish typology (FIN; Ministry of the Environment 2006), Swedish proposed typology (SWE, Fölster *et al*. 2004), original project TRIWA typology (TRIWA1; Elfvendahl *et al*. 2006), and revised TRIWA typology (TRIWA2; Elfvendahl *et al*. 2006).

In all of these typologies, ecoregion, catchment size and geology of the catchment area are used for determining the types directly or indirectly. Ecoregion is connected to the altitude – one category limit is either conifer tree limit (TRIWA1, TRIWA2) or highest historical coastline (FIN), that are both included in ecoregion definitions in SWE. Geology factor has two possible limits: > 20 % of peatland (TRIWA1, TRIWA2) or > 25 % of peatland in the catchment area (FIN) denoting organic geology in the catchment area. Swedish national typology replaces the geological factor by hydrological factors: colour (≤50 mg Pt l^{-1} or > 50 mg Pt l^{-1}) and alkalinity (≤1.0 mekv or > 1.0 mekv).

In Finnish typology a separate abbreviation is used for rivers that run above the tree line in North Lapland, i.e. first the rivers are defined according the basic typology and an additional PoLa (Pohjois-Lappi, North Lapland) separates these rivers from those below the tree line.

The Finnish and TRIWA typologies also use catchment size as an typology factor, with limiting areas 100 (only FIN), 1000, and 10 000 km^2. The revised typology of rivers in the Torne catchment area suggested by TRIWA project (TRIWA2) is presented in Figure 1.

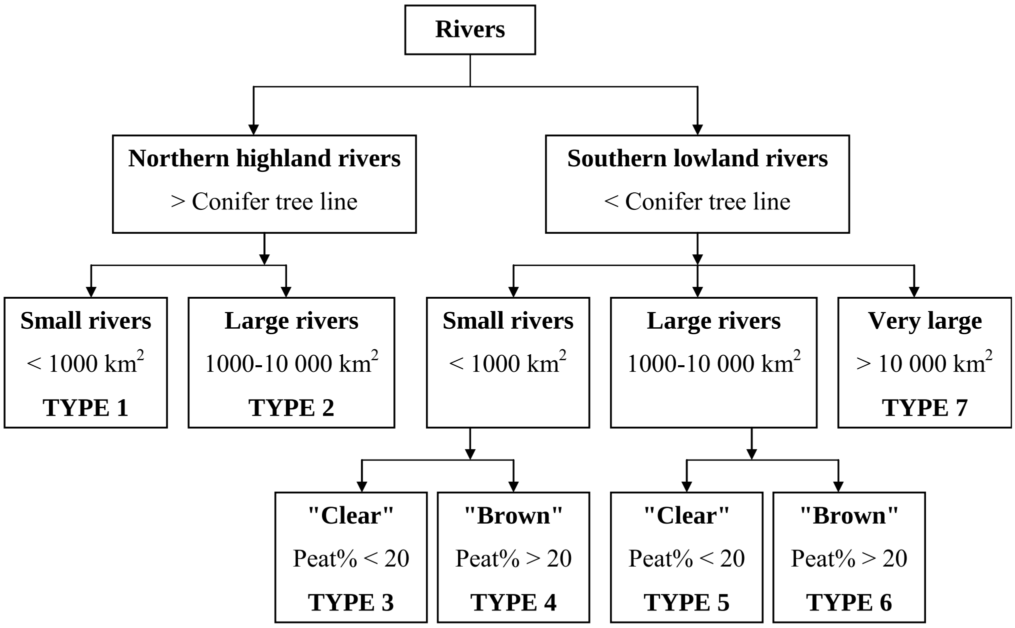

Fig. 1. Revised harmonized typology for rivers in River Torne watershed (Figure from Elfvendahl *et al*. 2006).

Aims of the study

In this study, diatom based methods are tested for assessing ecological conditions in the River Torne area. Also the suitability of the proposed river typologies are tested for the biological element phytobenthos, according to the WFD. At the same time, the ecological conditions of running waters in the watershed are surveyed using phytobenthos.

The survey of the diatom communities adds information on the impacts of land use and nutrient loading on the water quality. Diatom communities on the hard surfaces integrate information on the water quality during a period of months before the sampling (Jarlman *et al.* 1996).

Although several groups of algae form the phytobenthos, diatoms are routinely used as an indicator group for the phytobenthos. Diatoms are good indicators of water quality, because they are very diverse both taxonomically and ecologically, and the ecological requirements of the species are relatively well known (Eloranta 2000).

MATERIAL AND METHODS

Sites and sampling

During August 6^{th}-16^{th} 2006, 49 sites were sampled in the River Torne catchment area (Fig. 1). In Table 1, the river type for each site is defined according to the TRIWA2 typology. Only one sample for each site is analysed, because results gained from parallel diatom samples have been found almost identical in earlier studies (Miettinen 2003, 2006). Water samples were taken at the studied sites simultaneously for physical-chemical analyses (Appendix 1).

One of the five sampling sites in mountain type rivers studied in the earlier TRIWA-project, Lafoljåkka, was replaced by a sample in the River Lainio just below the mouth of the River Lafoljåkka by mistake. The site is named Lafoljåkka/Lainio below.

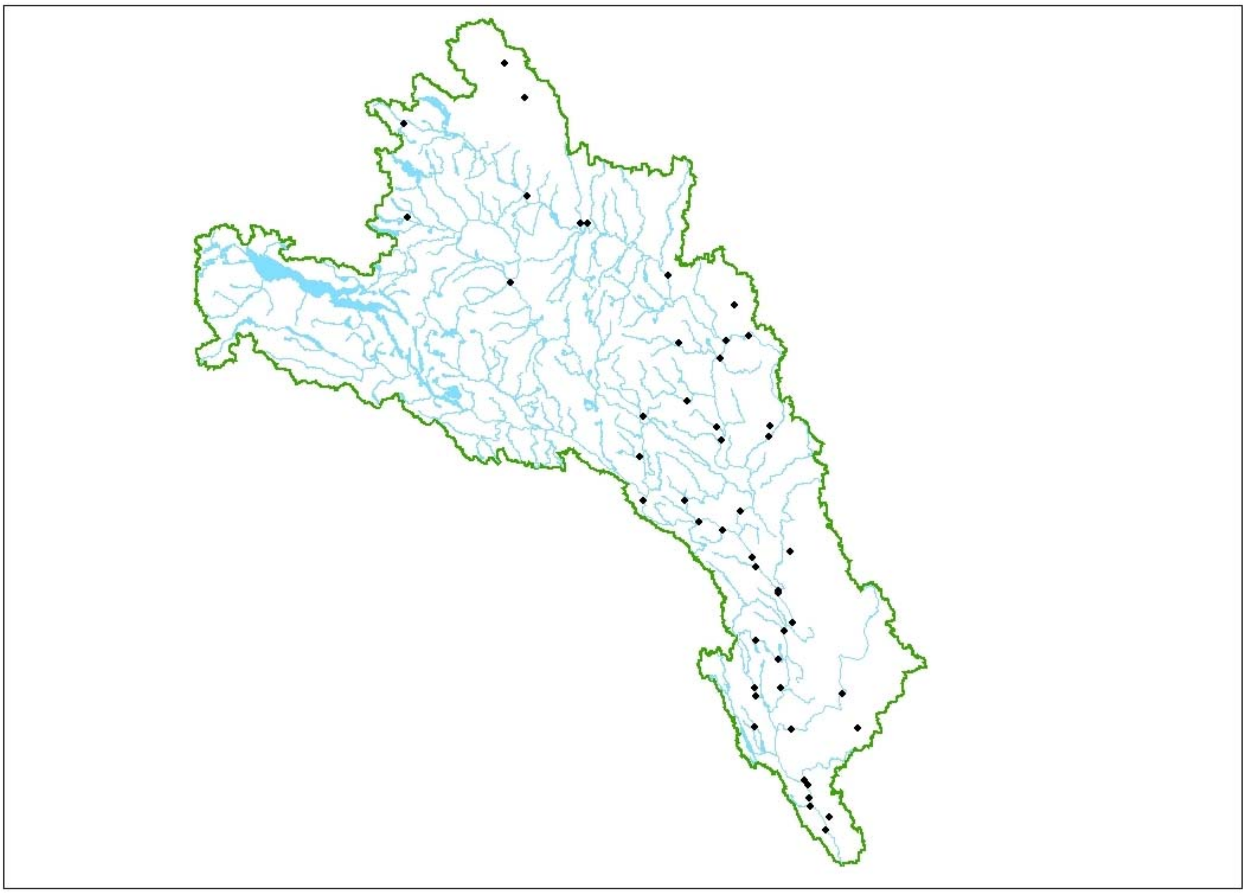

Fig. 2. Catchment area of the River Torne and the studied 49 sites.

Table 1. Sampled sites 6th –16th August 2006. River type according to the revised TRIWA2 typology. Sites marked TRIWA were included in the TRIWA I project. Coordinates are listed here according to the Finnish "Peruskoordinaatti" system; Swedish coordinates are listed in Appendix 1.

Ref.site	river type	Site	coord. PK (Y)	coord. PK (X)	country	area km^2	peat land%	fields%	peat mining %
R	1	Kåbmejåkka TRIWA	7658939	3237258	SE	102.2	2.02	0	0
R	1	Lafoljåkka/Lainio älv TRIWA	7580497	1508711	SE	?	?	0	0
R	1	Poroeno TRIWA	7668128	1514591	SE	158	1	0	0
R	1	Rommaeno TRIWA	7658187	1519127	SE	381	1	0	0
R	1	Skittsekallojåkka TRIWA	7584552	1468625	SE	59.71	5.57	0	0
R	2	Könkämäneno	7587518	1517787	FI	1496	3.48	0.02	0
R	2	Lainio älv, Jårkastaka	7564734	1511276	SE	2478	9.23	0.01	0
R	2	Lätäseno	7607629	3306606	FI	2151	4	0	0
R	3	Ylinen Kihlankijoki	7475872	2469359	SE	86.82	13.3	0.72	0
R	3	Olosjoki	7518246	3318386	SE	241.7	17	0.9	0
R	3	Äkäsjoki	7471354	2482719	FI	495	11	0.03	0
	3	Jerisjoki Muonio	7544932	3360905	FI	318	18	0.1	0
	3	Juojoki	7387829	3357398	SE	78.23	9.08	6.18	0
	3	Kannusjoki	7386117	3345739	SE	68.28	14.1	1.31	0
	3	Kuittasjoki	7400665	3358259	SE	274.8	12.9	1.39	0
	3	Ylinenjoki	7360646	2469428	SE	177.8	19.6	0.41	0
R	4	Jerisjoki Toras-Sieppi TRIWA	7544796	3371506	FI	263	21	0.13	0
R	4	Keräsjoki TRIWA	7559429	3367541	SE	112	27	0.1	0
R	4	Kuerjoki TRIWA	7474010	2500738	FI	162	20	0	0
R	4	Käymäjoki TRIWA	7457622	2457939	SE	194.1	46.8	0.72	0
R	4	Jylhäjoki TRIWA	7410711	3350250	SE	145	15.8	0.7	0
R	4	Kuijasjoki TRIWA	7364149	3387757	SE	359	53	1.58	0.16
R	4	Naalastojoki TRIWA	7440122	2501489	FI	82	33	0.01	0
R	4	Orjasjoki TRIWA	7372578	3342827	SE	62.62	13.4	0.64	0
R	4	Parkajoki TRIWA	7521252	3339050	SE	632.1	17	0	0
R	4	Tupojoki TRIWA	7443102	3355580	SE	172.5	29.7	1.64	0
R	4	Kangosjoki	7493882	2472581	FI	291	24.3	0.1	0
R	4	Rukojoki	7499644	2462192	SE	55.4	24.6	0	0
R	4	Nuuksujoki	7500575	3313840	SE	95.16	24.7	0.42	0
	4	Kaartijoki	7337223	3361145	SE	91.36	26.9	9.36	0
	3	Liakanjoki	7327222	3368250	FI	272	21.5	2.3	0
	4	Liviöjoki	7451337	2460911	SE	179	38.6	0.89	0
	4	Mertajoki	7448245	2467107	SE	66.74	40.1	1.56	0
	4	Martimojoki	7345493	3360262	FI	365	59	1.4	0.61
	4	Matojoki	7333608	3361101	SE	274.8	27.7	9.12	0
	4	Puruoja	7412474	3363239	SE	51.38	28.7	1.8	0
R	5	Muonio Markkina	7607061	3309535	FI	5732	8.06	0.08	0
R	5	Muonio Palojoensuu	7562529	2462390	FI	8025	16.2	0.23	0
	6	Naamijoki 290	7430917	3364142	FI	?	27	1.38	0
	6	Naamijoki K2	7429800	3364000	FI	1267	27	1.38	0
	6	Tengeliönjoki Pessakoski	7380445	3383764	FI	1338	32	0.61	0
	6	Tengeliönjoki Portimo	7349503	2477842	FI	3119	36	0.63	0

	7	Muonio Törmäsniva	7468780	3353572	FI	14561	23	0.56	0
R	7	Muonio Vanha-Kihlanki	7501519	3351041	FI	11784	19.9	0.47	0
R	7	Torne Huhtinen	7459733	1559707	SE	16103	14.8	0.18	0
R	7	Torne Kassa	7439872	2473922	SE	31683	19.5	0.34	<0.01
	7	Tornionjoki Pello	7376508	2481906	FI	33847	20.7	0.38	<0.01
R	7	Tornionjoki Matkakoski	7343931	3361542	FI	39017	21.9	0.62	<0.01
	7	Tornionjoki Kukkola	7275900	2501397	FI	40027	21.5	2.3	<0.01

Sampling was done according to the European standard (CEN 2002). Type of river bottom and abundance of macrovegetation were evaluated, and water temperature measured at every site. From every sampling site, five cobbles (stones with diameter 6-26 cm) were collected. The diatom film was rubbed from the stones using toothbrush. Macroalgae and mosses were brushed also into the samples, but long filaments of macroalgae were cut off, and cobbles most covered with macrovegetation were avoided. Each sample (five cobbles) was brushed in water, the water was mixed, and 100 ml of the mixture was poured in a plastic bottle. At the sampling sites, 1 ml of buffered formalin solution was added into the samples.

Reference vs. impacted sites

Of the 49 sites studied in this project, 15 have been studied earlier in TRIWA I project (Elfvendahl *et al.* 2006) for water quality and zoobenthos communities. These sites were chosen to represent reference, not anthropogenically altered, conditions in the TRIWA project. Of the remaining 34 sites in this study, reference sites were selected based on the following criteria:

1) cultivated area less than 1 % of the catchment area above, and
2) no hydrological alteration (regulation of the water level or artificial river banks at the studied site), and
3) no major point source pollution (e.g. waste water treatment plant in the vicinity of the site).

Of the 34 "new" sites, 15 fulfilled these criteria, and were chosen as reference sites, and the remaining 19 sites were chosen to represent impacted conditions in this study. During the writing of this report, additional data was received for the sites Liviöjoki and Ylinenjoki, indicating they fulfil the criteria for reference sites, but they are represented as impacted in the analyses.

Identification and enumeration of diatoms

The preparation of the samples, as well as identification and counting of the diatoms was done according to European standards (CEN 2002, 2004). Part of each sample was used for diatom slides, and the rest is stored in 4–8°C temperature. For diatom analysis, 30% hydrogen peroxide was used to remove all organic material from the samples. Permanent slides were prepared by drying about 0.2 ml of diluted sample on a cover glass, and gluing it to a heated slide with Naphrax®.

Diatoms were identified according to Krammer & Lange-Bertalot (1986–1991). For some taxa, new names in the list of Naturvårdsverket (2005) were used. A minimum of 400 diatom frustules was counted from each of the samples, and identified to the species level when possible. One diatom cell forms two frustules, that are counted as separate units. Magnification of 1000× and phase contrast optics were used for the counting. The abundance of each of the taxa was divided by the sample size, and the relative abundances are used for the multivariate analyses.

Testing diatom indices

Three indices, used earlier in Finland (e.g. Eloranta & Soininen 2002), are tested for use in the Torne catchment area: IPS (Index of Pollution Sensitivity; Coste & Ayphassorho 1991), GDI (Generic Diatom Index; Rumeau & Coste 1988), TDI (Trophic Diatom Index; Kelly & Whitton 1995, Kelly 1998). IPS is used also in Sweden (Kahlert *et al.* 2006).

IPS and GDI aim to assess both organic load (saproby) and trophic level of rivers, TDI only trophic level. In GDI, only genera are used, in TDI both species and genera, and in IPS always the lowest taxonomic level possible (reaching up to 2500 taxa). IPS and GDI are based on weighted averaging of the species indicator values.

The indices were calculated using software Omnidia (Lecointe & Coste 1993), version 4.2 (2006). Additional sensitivity and indicator values for some taxa by Amelie Jarlman are included in the calculations (Naturvådsverket 2005).

The indices were tested for the detection of pressures (land use, pollution, hydrological alteration) by T-tests of the equality of means in sites classified as reference and impacted. The pressure-metric relationships were assessed by correlation coefficients between the indices and pressure metric (field percentage in the catchment) and water quality (total P concentration).

Testing the different river typologies

The value of the different typology factors (ecoregion, catchment size, geology) for explaining the composition of diatom communities in reference sites was assessed with 1) testing if the within-type variation in the diatom data is smaller than the variation between types by Multi-Response Permutation Proceduces (MRPP); 2) grouping of the sites in multivariate ordination.

MRPP (Mielke & Iyer, 1982) tests were run with program PC-ORD v. 4.25 (McCune & Mefford, 1999). In MRPP, the within-group agreement $A = 0$ when heterogeneity within groups equals expectation by chance, and $A = 1$ when all samples are identical within groups. If $A < 0$, there is more heterogeneity within groups than expected by chance.

The MRPP tests were run separately for each limiting factors, e.g. mountain rivers vs. inland rivers in forested areas. This way the number of samples is larger in each test than when testing the system of typology in one test. Also separate tests have the advantage that the value of each of the typology factors (ecoregion, catchment size, geology) can be evaluated individually.

After evaluating the factors separately, the different typologies were tested for the combined factors, ie. the grouping of the samples according to the types. This was done by an indirect form of multivariate ordination, Detrended Correspondence Analysis (DCA; Hill & Gauch 1980). Ordinations using only the species data are called indirect ordination methods. The direction of the ordination axes are set to capture the maximum amount of variation in the data, which are typically explained by combinations of environmental factors. The closer two samples are to each other in the ordination space, the more similar their diatom taxa composition is (ter Braak 1987).

In DCA, unimodal responses to environmental variables are assumed for the species. When the length of the first ordination axis exceeds two of these variation units, most of the species are considered to respond unimodally to the differences in the samples (ter Braak & Prentice 1988). If the first ordinations axis is shorter than this, linearly based methods are more appropriate. Program CANOCO 4 (ter Braak & Šmilauer 1998) was used for the ordinations.

For the sites studied earlier in TRIWA project, the types used in Elfvendahl et al. (2006) are used also in this study. For other sites, the types are based on catchment data in the Finnish and Swedish national data archives (Hertta-database in Finland and Länsstyrelsen in Sweden). The water colour values, which define the geological type in the Swedish typology, are taken from the Elfvendahl *et al*. (2006) for the TRIWA sites, and for the other sites from the single samples taken together with the periphyton samples in August 2006. All the sites classified as reference sites, have water alkalinity values less than 1.0 mekv for the year 2006.

Modelling colour

Diatom communities react to the dystrophy (amount of humic material in the water, seen as the water colour) in rivers. However, the IPS and other indices available, are not developed for use in dystrophic rivers. This is why a diatom-based model of water colour was developed, and used in the evaluation of the index-based methods of ecological classification using diatoms.

Method of Weighted Averaging Partial Least Squares (WA-PLS; ter Braak & Juggins 1993) was used for modelling the water colour. The model includes the 49 sites of the present study, and in addition 23 sites from the catchment area of River Simojoki (Miettinen 2003) and five sites in the River Tenojoki catchment area (Miettinen 2006) in Finnish Lapland.

Describing reference conditions

Reference conditions were described as IPS values attributable to the sites within the river types. Median of the index values within a river type can be used as the expected value in reference conditions. 25^{th} percentile of the values in the reference sites is generally used as the limit for high ecological status.

Determining ecological status

Two methods for classifying the ecological status were compared: using the national Finnish or Swedish status boundaries for the IPS values. The proportions of diatom taxa indicating different ecological properties were used for an additional measure of the ecological status: the ecological classifications of Van Dam *et al*. (1994) were used to calculate the proportion of diatom frustules indicating different trophy levels and saprobity classes at the sampled sites.

RESULTS

Total of 171 diatom taxa were identified. Mean number of taxa in one site was 31, minimum 18 (Jylhäjoki), and maximum 43 (Kaartijoki, Torne Pello). The amount of taxa in one sample generally increases with increasing trophy level. The most abundant taxa in the data are *Fragilaria capucina* var. *gracilis*, *Achnanthes minutissima*, and *Tabellaria flocculosa*, all very common diatoms in oligotrophic northern rivers (e.g. Soininen 2002, Niemelä *et al*. 2002, Miettinen 2006, 2007).

Human impacts in the studied sites

DCA for the 49 samples in the Torne catchment area resulted in eigenvalues of 0.402 and 0.225 for the ordination axis 1 and 2, respectively. The length of the first ordination axis is 2.52 standard units, which implicates that the variation in the data set is large enough for the use of DCA in ordinating the sites. In Fig. 3, the socalled impacted and reference sites are presented on the DCA ordination axis 1 and 2 (no transformation of species data, downweighting of rare species). In the ordination, the sites with significant known pressures (agriculture, forestry and/or peat ditching) in their catchments are mostly separated from the reference sites in the ordination.

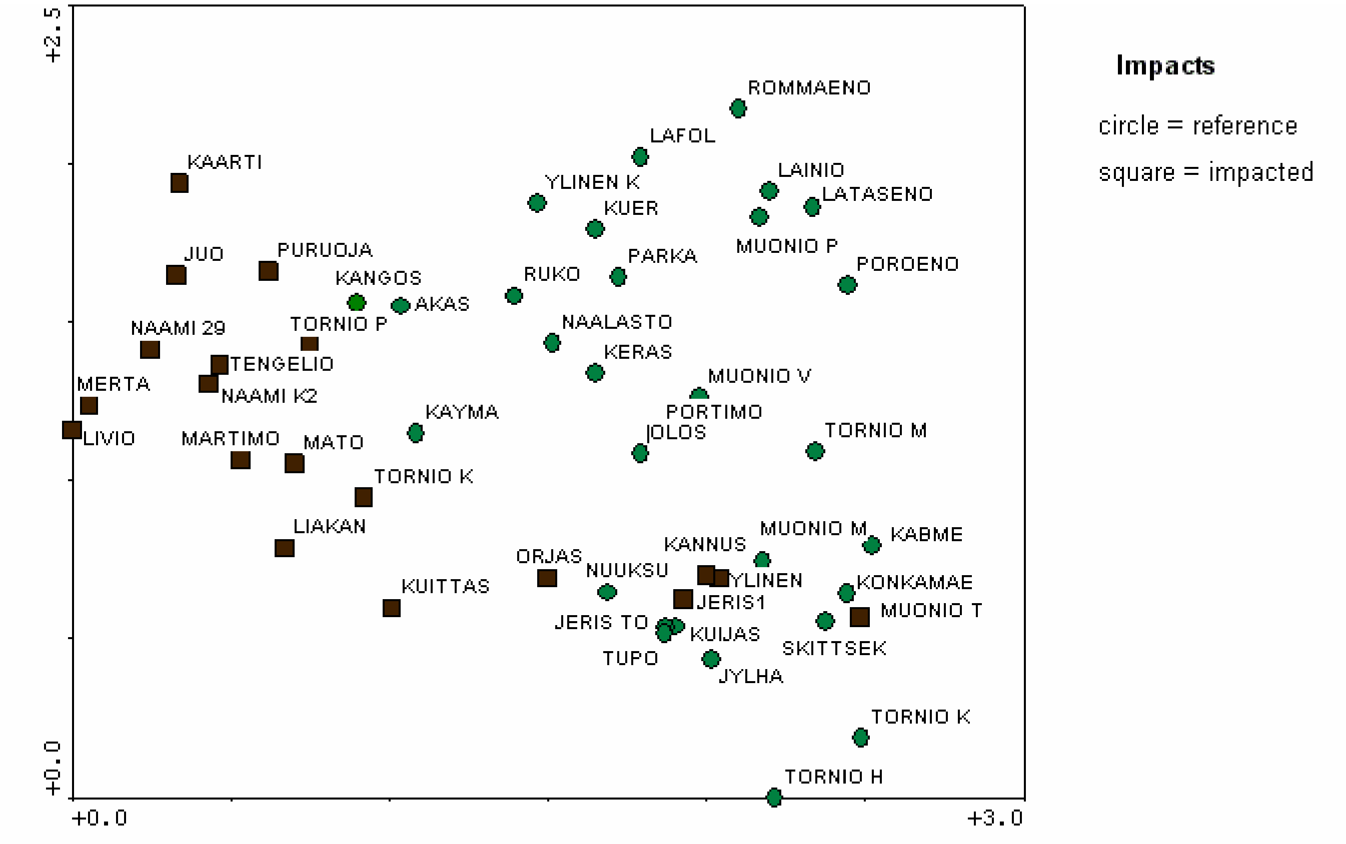

Fig. 3. DCA ordination for the 49 sites studied in the River Torne watershed. The reference samples are marked by green circles, and sites with significant human pressures by black squares.

The pressures in the catchment areas can be easily seen as impacts on the diatom communities, with some exceptions: Kannusjoki, Nuuksujoki and Tengeliönjoki Portimo. River Muonio Törmäsniva site (Muonio T) is situated below a small waste water treatment plant, and so is allotted to the impacted category, but no impacts are found in the diatom composition. On the other hand, reference sites Kangosjoki and Äkäsjoki are grouped together with the impacted sites, which may be explained by settlements and field cultivation near the sampling site Kangosjoki, and construction works upstream the Äkäsjoki site (Äkäslompolo).

The ordination of the diatom species (Fig. 4) indicates that the first ordination axis (horizontal) is reflecting the trophy level of the sites, with species indicating oligotrophy ordinated to the high end (right side) of the axis. The abundant species indicating oligotrophy include *Achnanthes abundans, Fragilaria arcus, Achnanthes petersenii* (Ach_pete) and *Cymbella cesatii* (Cym_cesa). The species or forms indicating eutrophy or pollution include *Fragilaria nanana, F. ulna* var. *ulna, Gomphonema parvulum* var. *parvulum* and *N. atomus* (Nav_atom).

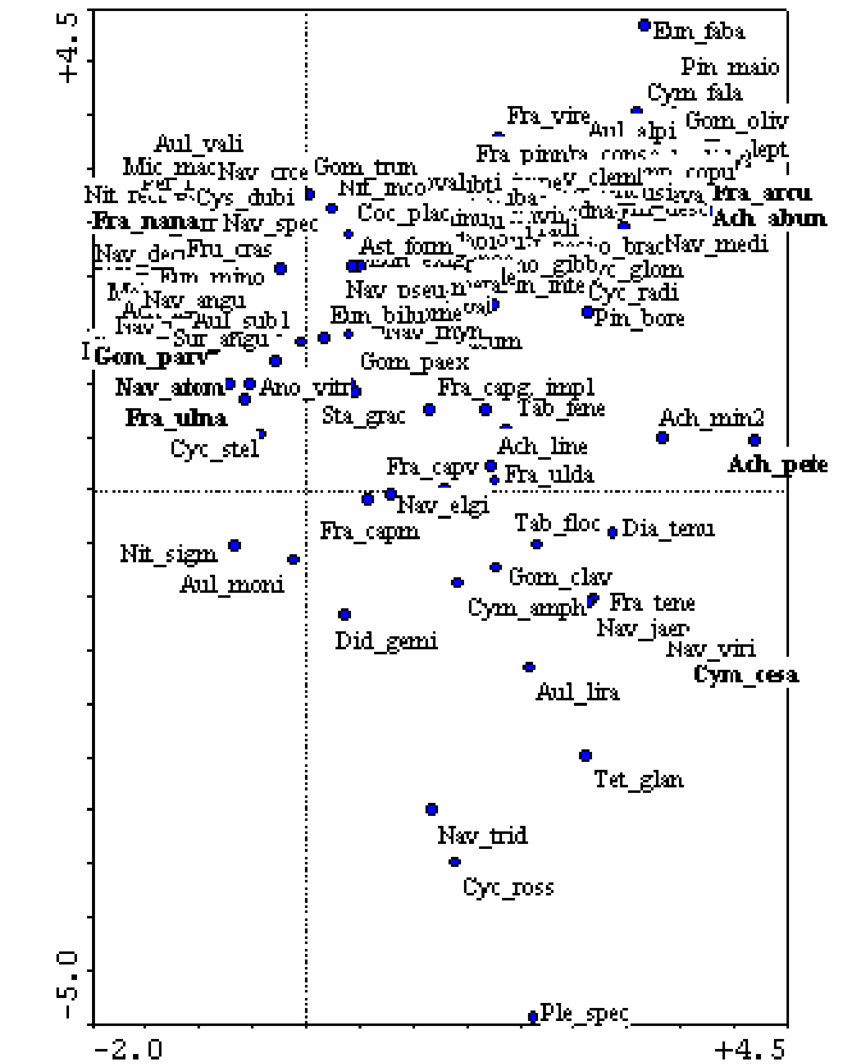

Fig. 4. DCA ordination for the diatom taxa in the 49 sites studied in the River Torne watershed. Taxa mentioned in the text are printed with bold font. Genus names are presented by first three letters, and species names by four letters, except when subspecies are identified they are presented by the last letter of the abbreviation

Testing the diatom indices

Independent samples T-tests were used to indicate if the indices can detect the land use and other impacts on the river sites (Table 2) and these differences were visualised with box-plots (Fig. 5). IPS and TDI receive statistically significant differences ($p < 0.05$) in the mean values of reference vs. impacted sites.

Table 2. T-tests for the equality of means in the reference and impacted sites using IPS, GDI and TDI. Equal variances are not assumed.

	t-test for Equality of Means						
			Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
	t	d.f.	**p**			Lower	Upper
IPS	2.442	21.970	**0.023**	1.3444	.5506	.2024	2.4864
GDI	.793	38.318	**0.433**	.3074	.3875	-.4768	1.0916
TDI	2.155	38.447	**0.037**	.9933	.4609	.0607	1.9260

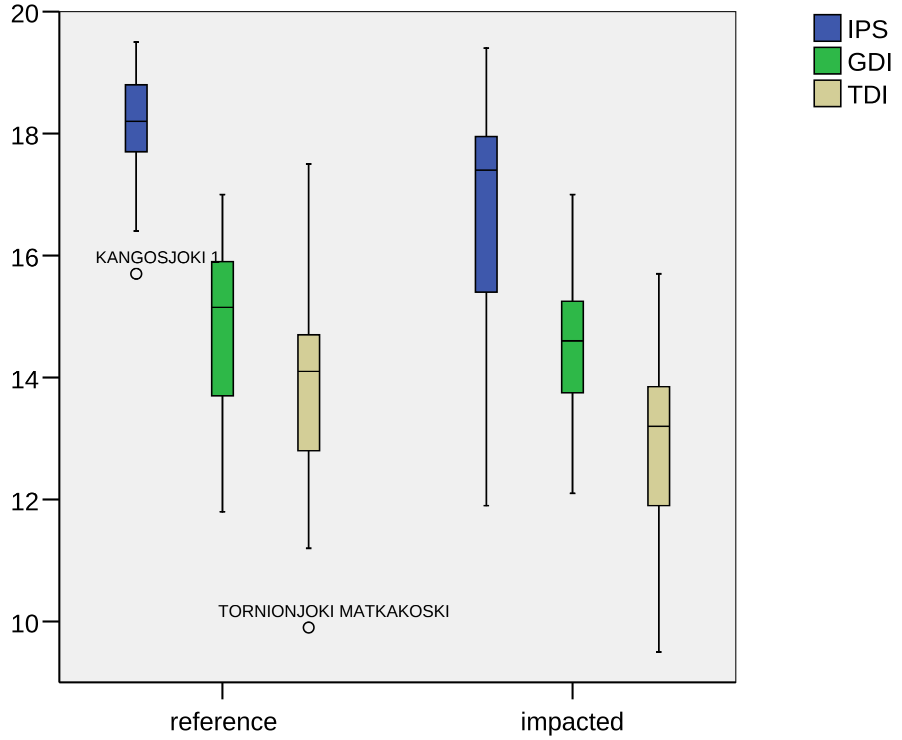

Fig. 5. Distribution of IPS, GDI and TDI values in reference (N=30) vs. impacted sites (N=19).

Reference samples receive shorter range of IPS values than GDI or TDI values, indicating that IPS is better detecting reference conditions than GDI or TDI. GDI is very insensitive to the pressures identified, since the lower quartile GDI value for reference sites is almost identical to the impacted sites.

The effect of the pressure variables on the diatom metrics was studied by correlations between the indices and pressure metrics (cultivated land % and total P concentration), presented in Table 3. IPS and GDI have significant correlations (p<0.05) with the pressure variables of both the land use (cultivation %) and the water quality (total P).

Table 3. Correlation coefficients between the diatom indices, percentage of cultivated land in the catchment and total P concentration in the water for the 49 sites studied.

		cultivated%	total P
IPS	Pearson correlation	-0.632	-0.702
	Sig. (2-tailed)	<0.001	<0.001
GDI	Pearson correlation	-0.296	-0.344
	Sig. (2-tailed)	0.039	0.017
TDI	Pearson correlation	-0.213	-0.198
	Sig. (2-tailed)	0.141	0.178

IPS is the only metric out of these three, that statistically both correlates strongly with the pressures variables, and is sensitive to the pressures (difference in reference vs. impacted sites). Based on the results, only IPS is suitable for use in the ecological classification of the sites.

Testing the different river typologies

MRPP for the diatom data (Table 4) proved significant effects of alpine vs. inland areas ($p < 0.001$), small vs. large catchment area ($p = 0.028$) and organic vs. inorganic geology ($p = 0.019$). Highest historical coastline and catchment size limit 10,000 km^2 did not prove to be significant in explaining the diatom composition at the sites.

Table 4. MRPP results testing the amount of variance in the diatom data between the typology categories vs. in the whole data.

	alpine vs. inland	inland vs. coastal	small vs. large	large vs. very large	clearwater vs. brown
A	0.031	0.005	0.015	0.004	0.014
p	<0.001	0.204	0.028	0.376	0.019

After evaluating the factors separately, the different typologies were tested for the combined factors, ie. the grouping of the reference sites in the DCA ordination. Eigenvalue for the first ordination axis is 0.345, and for the second axis 0.216. The length of the ordination axis 1 is 2.317, indicating mostly unimodal responses of the diatom taxa, and so the suitability of the DCA for ordinating the data.

Ordination of the diatom taxa in the reference sites is presented in Fig. 6. The ordination of the species using only reference samples is similar to the ordination with 49 samples (Fig. 49), indicating that the first ordination axis represents decreasing trophy and humic substances in the water from left to right.

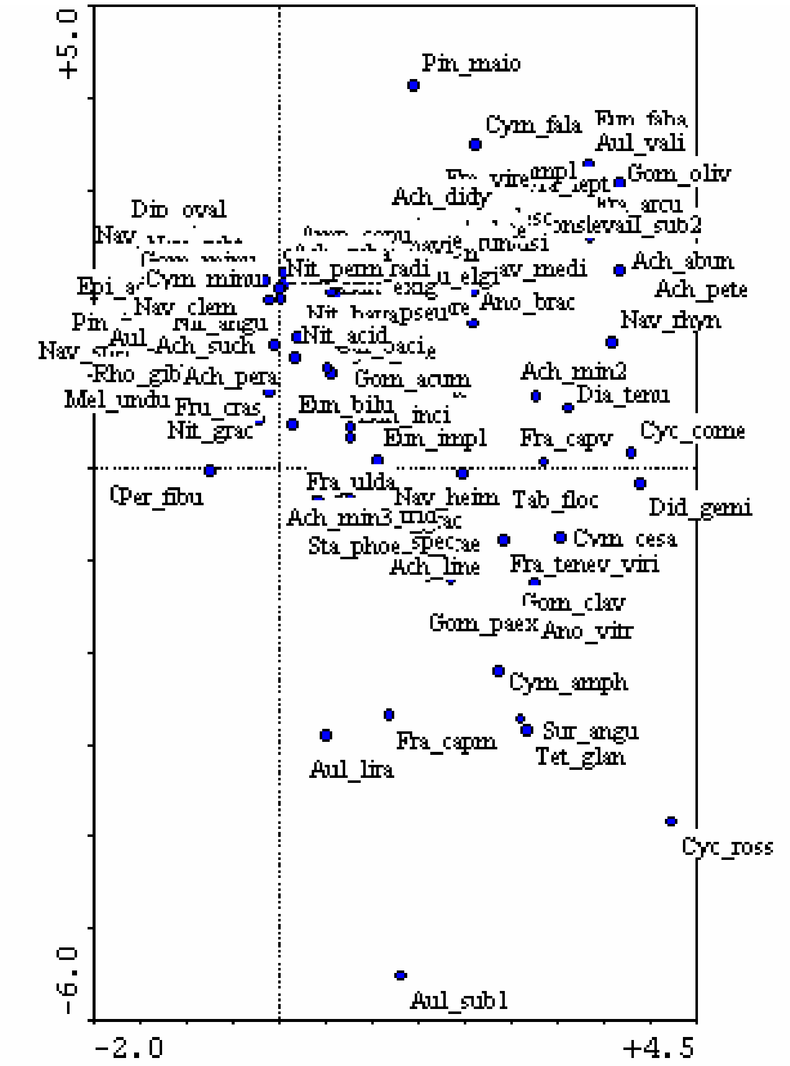

Fig. 6. DCA ordination of the diatom taxa in the 30 reference sites. Genus names are presented by first three letters, and species names by four letters, except when subspecies are identified they are presented by the last letter of the abbreviation.

Ordination plot, with sites marked according to the Swedish typology is presented in Fig. 7, Finnish typology in Fig. 8, original TRIWA1 typology in Fig. 9, and revised TRIWA2 typology in Fig. 10.

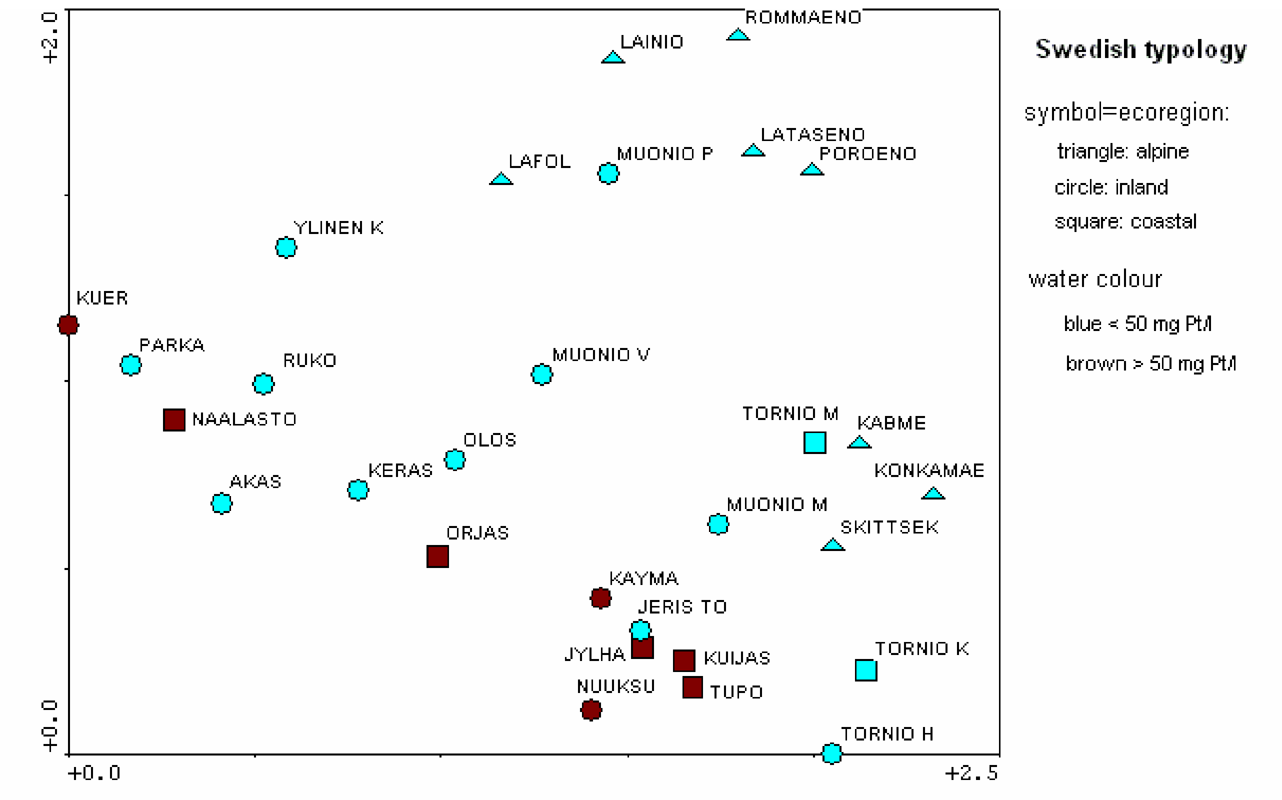

Fig. 7. DCA ordination for the 30 studied sites (except Kangosjoki site not plotted here), symbolized using the proposed Swedish national river typology.

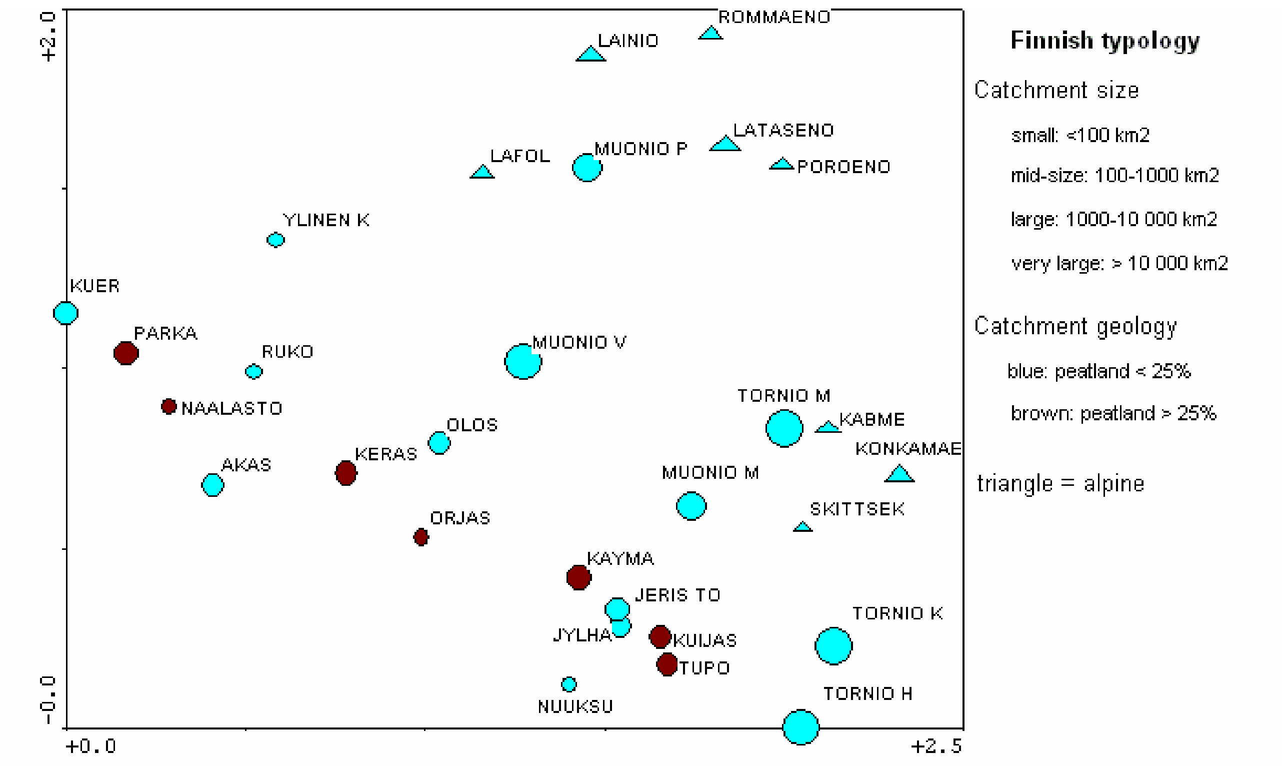

Fig. 8. DCA ordination for the 30 studied sites, symbolized using the Finnish national river typology.

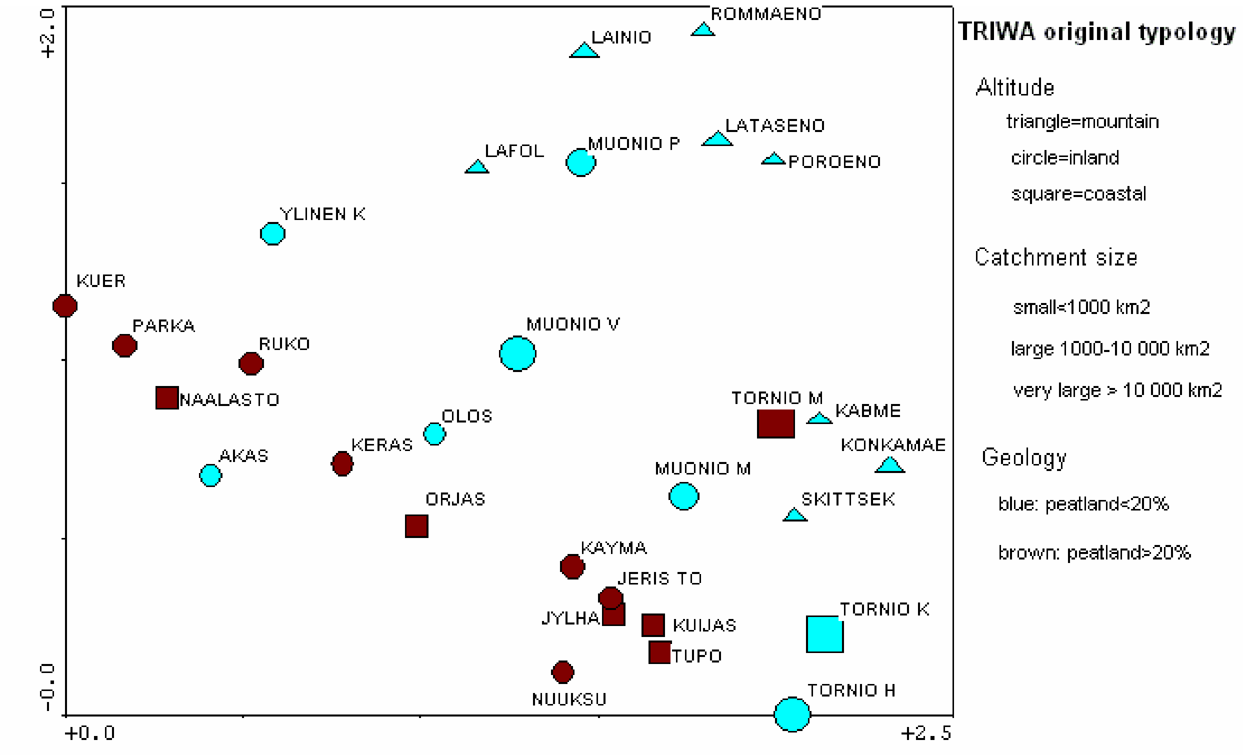

Fig. 9. DCA ordination for the 30 studied sites, symbolized using the TRIWA1 river typology.

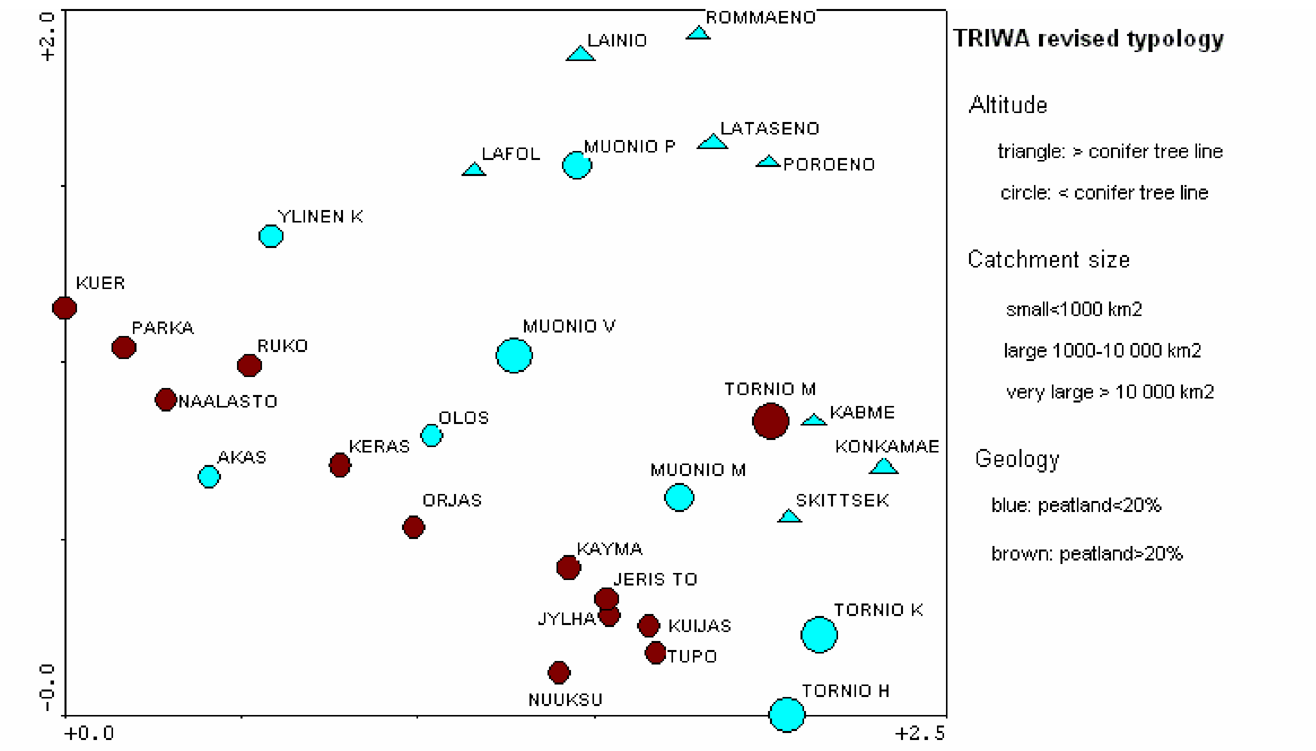

Fig. 10. DCA ordination for the 30 studied sites, symbolized using the revised TRIWA2 river typology.

The four tested river typologies are similar, with only minor differences in the defining factors. The degree of dystrophy (amount of humic material) is well reflected in the diatom composition. The proposed national typology for Sweden has the disadvantage that the use of 50 mg Pt l^{-1} water colour as the boundary is dependent on the annual and seasonal variation in the water colour. In 2006, the water colour was generally lower than usual in the area. The limit of 25 % peatland in the catchment area, as used by the Finnish system, appears too high; the 20% limit, used by the TRIWA typologies, is better in grouping the sites in this dataset.

The catchment size factor has relatively small effect on the diatom communities. The Finnish national typology has four catchment size categories, which appears unnecessary according to the diatom data. The use of only two ecoregions (above and below the conifer treeline) appears sufficient for the periphyton, since the historical coastline did not form distinct grouping of the sites.

Based on the results, the revised TRIWA2 typology is best suited for interpreting the diatom composition. However, the result is somewhat dependent on the dataset available; catchment size usually is a factor influencing diatom communities (because nutrient levels tend to increase downstream), but the other factors can mask the influence of the catchment size.

Reference conditions

The low number of reference sites within the types (0–5 sites in each), except in type 4 (13 sites), limits the interpretation of the type-spesific reference conditions. The reference conditions must be defined using the same metric that will be used for the ecological classification of the impacted sites, to enable the calculation of the Ecological Quality Ratios. As the metric for the ecological classification will probably be IPS, the reference conditions are here defined in the means of IPS values.

The 25^{th} percentile value of the reference IPS values for type 3 is the lowest of all types, 16.4 (N=3). The low 25^{th} percentile value is caused by the Äkäsjoki site, possibly affected by concstruction works in Äkäslompolo. For the brown water (organic geology) type 4, the 25^{th} percentile value is 16.5 and median value is 17.9 (N=13).

Reference value independent of the river type, ie. the median value for IPS in all the reference sites (N=30) is 18.2. Since some minor anthropogenic impacts are found in the reference data (see Table 1), the 25th percentile value for IPS in the reference data, 17.7, can be set as the lower limit of IPS indicating high ecological status. The 25th percentile value for the reference data (N=30) is close to the Swedish national high/good status boundary (17.5). With this dataset, type-spesific reference conditions can be set only for the type 4 (median IPS value = 17.9; N=13).

Table 5. Statistics of the IPS values in reference sites of the different river types.

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
25th PERC.	17.65	18.10	16.40	16.50	18.00	-	17.98
MEDIAN	18.80	18.70	17.70	17.90	18.20	-	18.80
MIN	17.10	18.10	16.40	15.70	18.00	-	17.70
MAX	19.10	18.70	17.90	19.10	18.40	-	19.50
N samples	5	3	3	13	2	0	4

Modelling colour

The WA-PLS two-component model estimated the water colour of the 77 sites quite accurately (Fig. 28). The squared correlation coefficient (R^2) between the estimated and measured water colour values is 0.71, and the root mean squared error of prediction ($RMSEp_{jack}$) is 26 mg Pt l^{-1}.

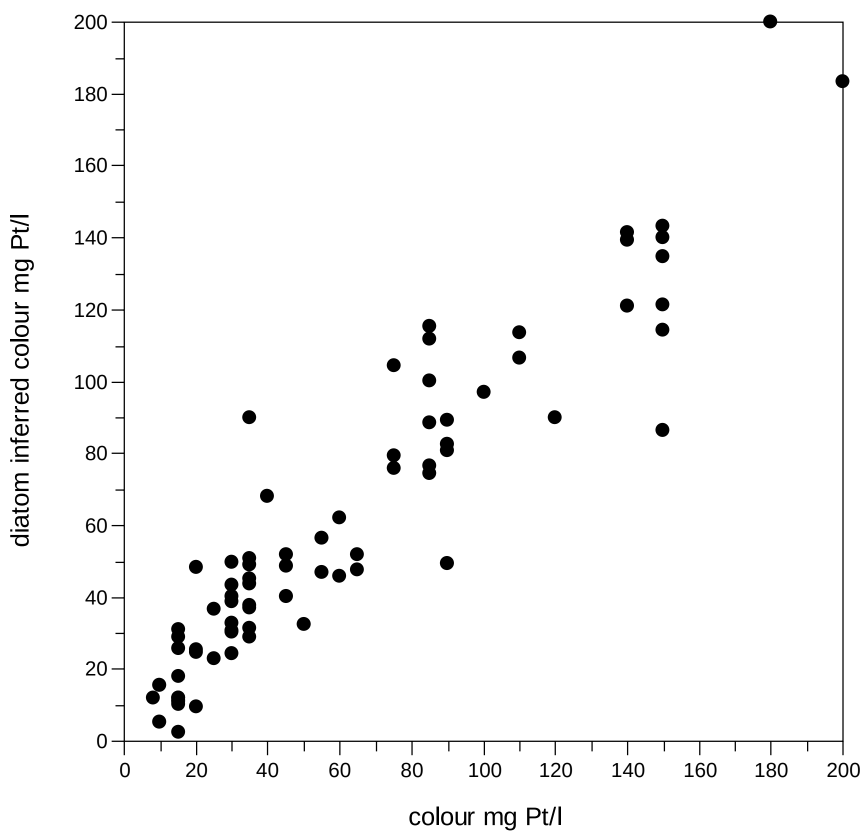

Fig. 16. Estimated water colour against measured water colour in a 77-site calibration model.

In Table 6, colour optimum and tolerance values, together with the number of occurrences in the data, are presented for the 17 taxa obtaining high colour optima in the model (>90 mg Pt l^{-1}). Among these species favouring humic conditions are *Brachysira neoexilis (Anomoeoneis vitrea), Eunotia pectinalis, Frustulia crassinervia,* and *Eunotia praerupta*. Taxa that are included in this list, but are probably indicating more land use impacts than natural humidity, are *Gomphonema parvulum* var. *parvulum, Achnanthes minutissima* group 3 (wide form varieties), and *Navicula veneta.*

Table 6. Ranked colour optimum values (>90 mg Pt l^{-1}), in descending order.

Taxon	**Optimum**	**Tolerance**	**N**
Anomoeoneis styriaca	149.2	45.54	5
Gomphonema parvulum var. *parvulum*	126.8	55.77	3
Brachysira neoexilis	123.9	57.86	33
Peronia fibula	121.6	53.36	4
Eunotia pectinalis	117.8	44.16	22
Caloneis silicula	114.9	48.31	5
Eunotia meisteri	111.4	30.71	5
Caloneis tenuis	109.8	55.85	3
Gomphonema gracile	106.2	60.87	18
Eunotia minor	105.4	42.70	25
Surirella angusta	99.7	87.69	3
Frustulia crassinervia	99.6	59.15	29
Tetracyclus glans	99.3	29.34	4
Achnanthes minutissima grupp3	94.8	52.13	25
Navicula veneta	91.4	18.31	3
Navicula mediocris	90.6	69.38	16
Eunotia praerupta	90.4	58.36	16

Ecological status

Results for the IPS indicate high status for most of the sites (Table 7). In Table 7, the ecological status classification is derived from the IPS according the status limits proposed in Finland (Eloranta & Soininen, 2002) and in Sweden (Kahlert *et al.* 2006). The status limits are in Finland/Sweden: high 17/17.5, good 15/14.5 , moderate 12/11, poor 9/8, bad < 9/<8.

The results for the GDI and TDI indices are not treated further, because these indices proved to be not applicable for the data (see chapter *Testing the diatom indices*).

Table 7. Diatom index values IPS, GDI and TDI for the studied sites. Ecological status according to the status limits for IPS proposed in Finland and in Sweden by March 2007.

site	IPS	GDI	TDI	Ref. site	class FIN	class SWE
Jerisjoki 1	17.9	14.3	11.5		high	high
Jerisjoki Toras-Sieppi	18.2	13.7	12.9	R	high	high
Juojoki	11.9	12.1	9.5		poor	moderate
Jylhäjoki	19.1	15.9	14.8	R	high	high
Kaartijoki	12.2	12.7	13.3		moderate	moderate
Kangosjoki	15.7	13.4	11.2	R	good	good
Kannusjoki	19.4	16.4	15.7		high	high
Keräsjoki	17.9	16.9	17.5	R	high	high
Kuerjoki	16.4	14.7	15.9	R	good	good
Kuijasjoki	18.8	15.2	12.8	R	high	high
Kuittasjoki	17.9	17.0	14.5		high	high
Kåbmejåkka	18.9	15.4	14.8	R	high	high
Käymäjoki	18.5	16.1	14.2	R	high	high
Könkämäeno Pättikä	18.1	15.1	12.9	R	high	high
Lafoljåkka/Lainio	17.1	13.3	12.5	R	high	good
Lainio Jårkastaka	18.7	16.2	14.8	R	high	high
Liakanjoki	17.4	14.8	12.7		high	good
Liviöjoki	17.5	16.0	14.6		high	high
Lätäseno	18.7	15.4	13.3	R	high	high
Martimojoki	15.4	13.2	12.3		good	good
Matojoki	15.4	14.6	14.0		good	good
Mertajoki	18.0	16.2	11.6		high	high
Muonio Markkina	18.4	16.0	14.3	R	high	high
Muonio Palojoensuu	18.0	15.9	14.3	R	high	high
Muonio Törmäsniva	18.9	15.5	13.7		high	high
Muonio Vanha-Kihlanki	17.7	13.7	14.0	R	high	high
Naalastojoki	17.7	14.7	14.9	R	high	high
Naamijoki 290	13.0	14.1	10.9		moderate	moderate
Naamijoki K2	15.1	14.5	13.5		good	good
Nuuksujoki	18.4	13.2	11.4	R	high	high
Olosjoki	17.9	13.1	13.8	R	high	high
Orjasjoki	17.8	14.2	14.2	R	high	high
Parkajoki	16.4	15.7	16.8	R	good	good
Poroeno	19.1	15.3	14.5	R	high	high
Puruoja	16.8	12.8	10.2		good	good
Rommaeno	18.2	15.3	13.6	R	high	high
Rukojoki	16.6	11.8	13.2	R	good	good
Skittsekallojåkka	18.8	17.0	14.7	R	high	high
Tengeliönjoki 240	17.3	15.0	12.2		high	good
Tengeliönjoki Portimo	18.9	15.0	12.5		high	high
Torne Huhtanen	18.8	16.7	14.6	R	high	high
Torne Kassa	19.5	16.1	14.3	R	high	high
Torne Kukkola	17.5	13.7	13.2		high	high
Torne Matkakoski	18.8	14.3	9.9	R	high	high
Torne Pello	17.1	14.8	13.3		high	good
Tupojoki	18.4	14.7	12.6	R	high	high
Ylinen Kihlankijoki	17.7	13.9	12.7	R	high	high
Ylinenjoki	19.3	13.8	14.0		high	high
Äkäsjoki	16.4	12.9	12.4	R	good	good

Of the reference data set of 30 sites, 5 sites received only good status. These sites are Kangosjoki, Kuerjoki, Parkajoki, Rukojoki, and Äkäsjoki. Of all sites, Juojoki received the lowest IPS value, indicating poor status. The other sites below good status are Kaartijoki and Naamijoki 290 (below fish farm).

The IPS values for the sites in the River Muonio and the River Torne all indicate high status, except good for Torne Pello according to the Swedish limits. However, the value declines downstream, from the Muonio Törmäsniva site (18.9) to Pello (17.1). The upper reach of the River Torne at Huhtanen and Kassa sites receives values comparable to the Muonio Markkina and Törmäsniva sites, 18.8 and 19.5, respectively.

The tributaries received more variable IPS values than the River Muonio and the River Torne, as expected from the more variable land use pressures.

Based on the data, different ecological status class boundaries for IPS could be set for three groups of river types: alpine (> conifer tree line), clearwater inland (peatland < 20%), dystrophic inland (peatland > 20%). The TRIWA2 types 1 and 2 form the alpine rivers, types 3, 5 and 7 the clearwater inland rivers, and types 4 and 6 the dystrophic rivers.

The small inland sites have all more than 10 % of peatland in their catchment area, separating them from the alpine sites with inorganic geology. If only these three types are used, the reference conditions (high ecological status) could be defined as IPS > 18 for alpine type, IPS > 17.5 for clearwater type, and IPS > 17 for brown water type (Fig. 34).

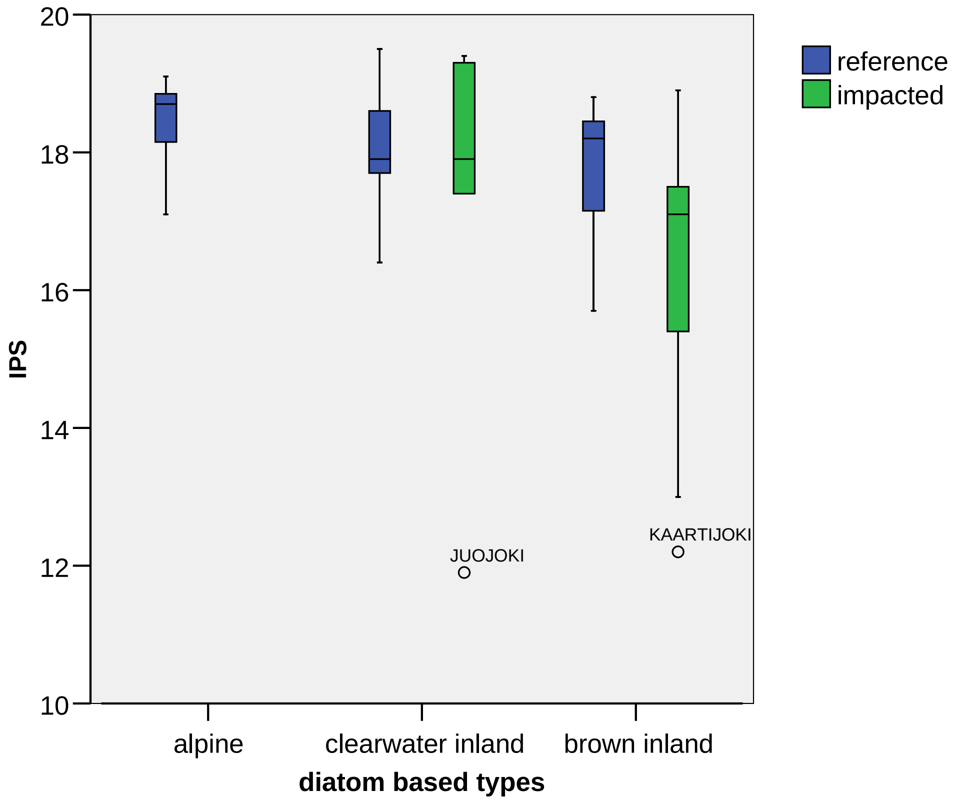

Fig. 11. Distribution of IPS values in reference and impacted rivers in the alpine, clearwater inland, and dystrophic river types.

The Ecological Quality Ratios (EQRs) for the sites (Fig. 27) are calculated as the observed/predicted IPS value. The predicted value is the median of the reference data in each type. The minimum EQR value in the dataset is received by Juojoki (IPS=11.9, EQR=0.650).

The number of sites in different status categories, based on the class limits proposed in Finland (Kelly *et al.* 2007), is presented in Table 8, and results based on the class limits proposed in Sweden (Kelly *et al.* 2007) in Table 9.

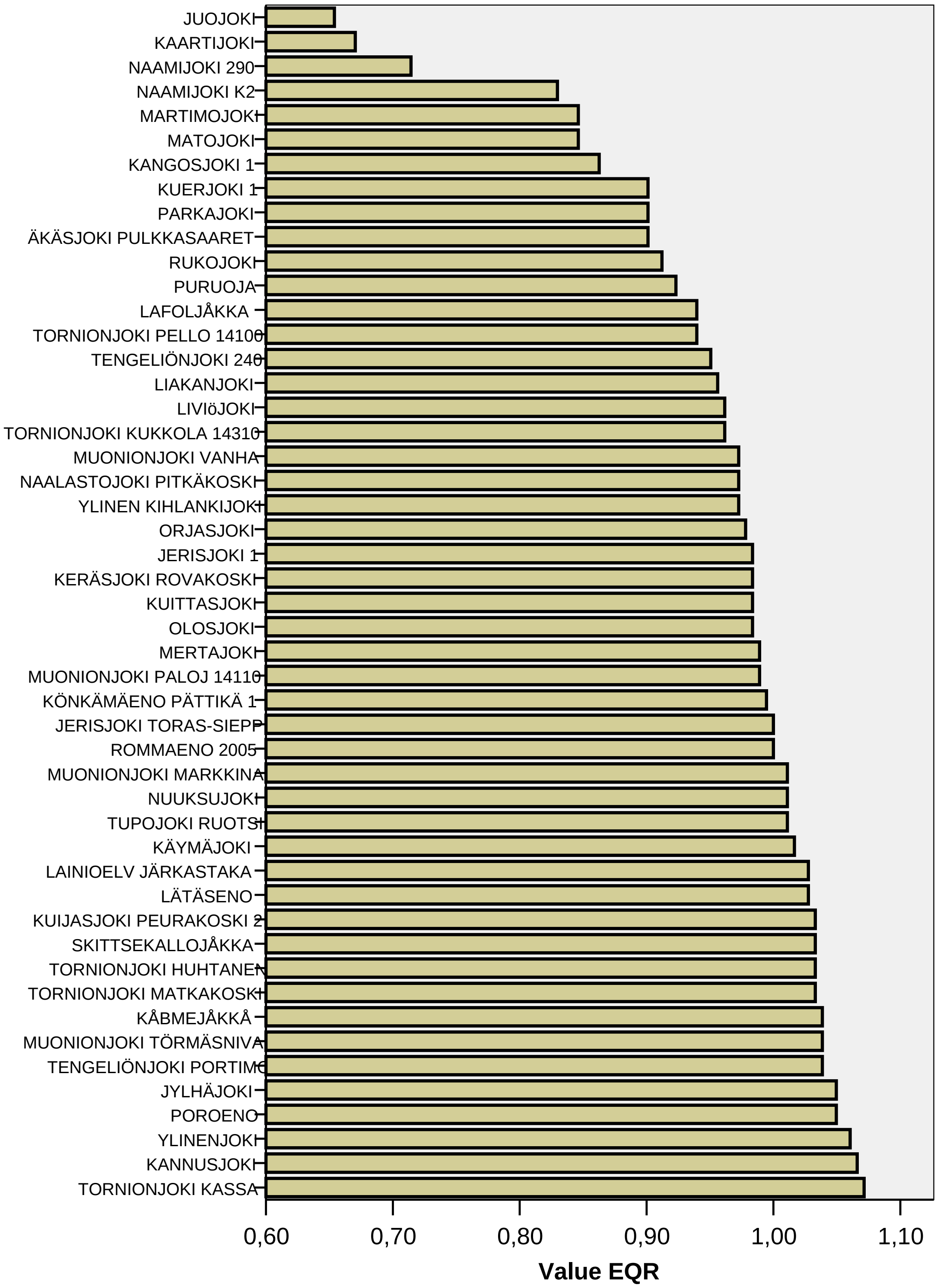

Fig. 12. Ecological Quality Ratios (EQRs) for the studied 49 sites, based on the IPS values.

Table 8. Number of sites in different status categories, based on status limits for IPS proposed in Finland by Eloranta & Soininen (2002).

Status	IPS limits	Frequency
high	17-20	37
good	15-17	9
moderate	12-15	2
poor	9-12	1
bad	<9	0
Total		49

Table 9. Number of sites in different status categories, based on status limits for IPS proposed in Sweden.

Status	IPS limits	Frequency
high	17.5-20	33
good	14.5-17.5	13
moderate	11-14.5	3
poor	8-11	0
bad	<8	0
Total		49

The Finnish and Swedish class limits for the IPS result in the same sites receiving lower than good status: Juojoki, Kaartijoki and Naamijoki 290. The reference data of 30 sites would suggest the use of the higher Swedish IPS limit for high ecological status in the River Torne area: the 25th percentile of the reference sites, 17.7, is close to the Swedish high status boundary. The project was mainly aiming at reference areas, thus the data is weighted towards them, and a reliable assessment of the lower status boundaries is not possible with this dataset.

Ecological groups of diatoms

The proportion of the diatoms in different trophy, saproby and nitrogen uptake classes according to Van Dam *et al*. (1994) supports the IPS results. However, the trophic classification of Van Dam *et al.* (1994) is not fully relevant in the northern conditions, where the scale of trophy levels is much lower than in the Netherlands, where the classifications are made. For example, an abundant species, *Tabellaria flocculosa*, is classified as mesotrophic by Van Dam *et al*., although in nordic rivers it thrives in oligotrophic conditions.

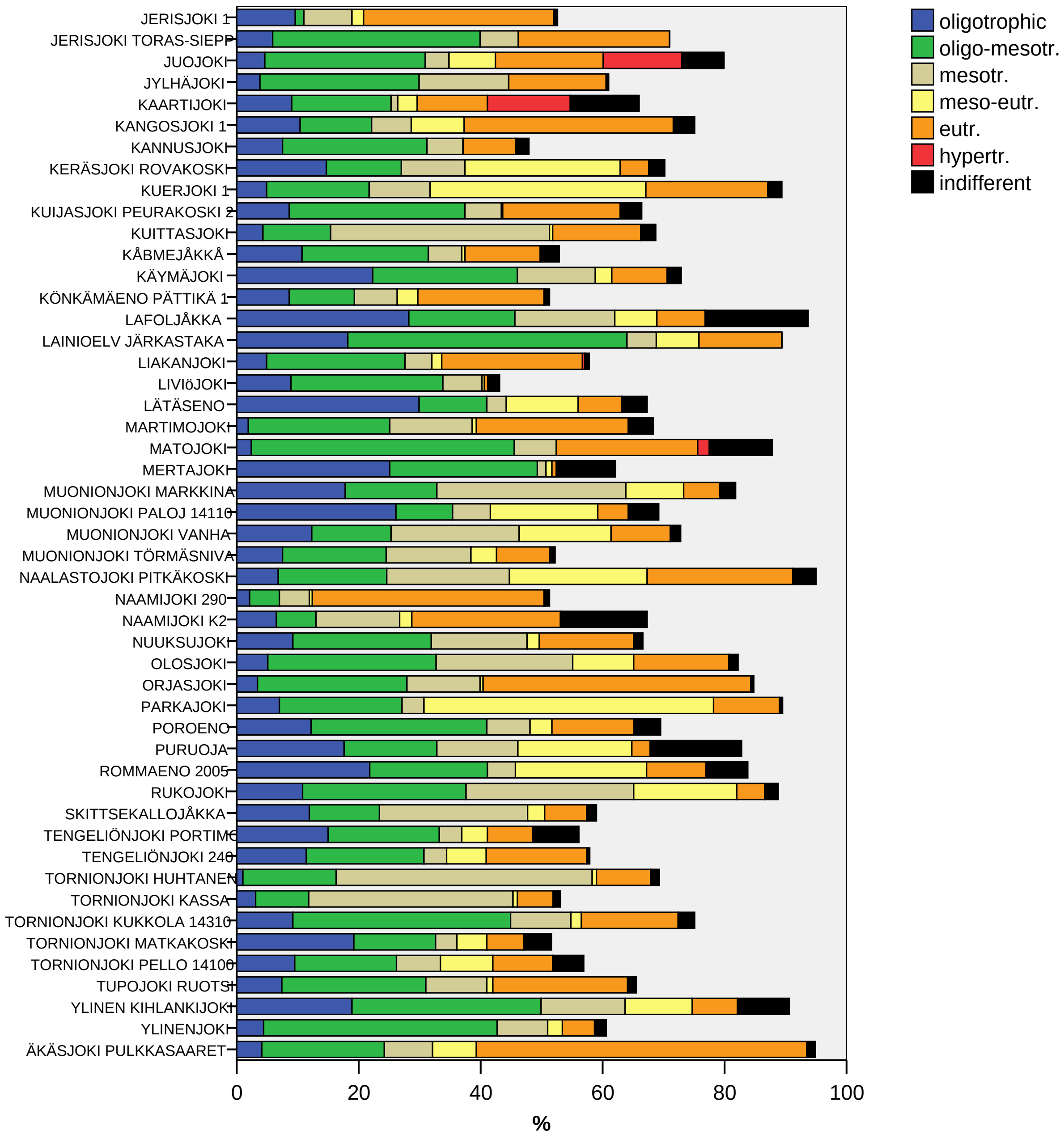

Fig. 13. Trophic classification of the diatoms in the studied samples according to Van Dam et al. (1994).

Samples from Juojoki and Kaartijoki include significant proportion of diatoms indicating hypertrophic conditions (Fig. 13). The highest proportion of diatoms indicating eutrophy is found in Naamijoki 290.

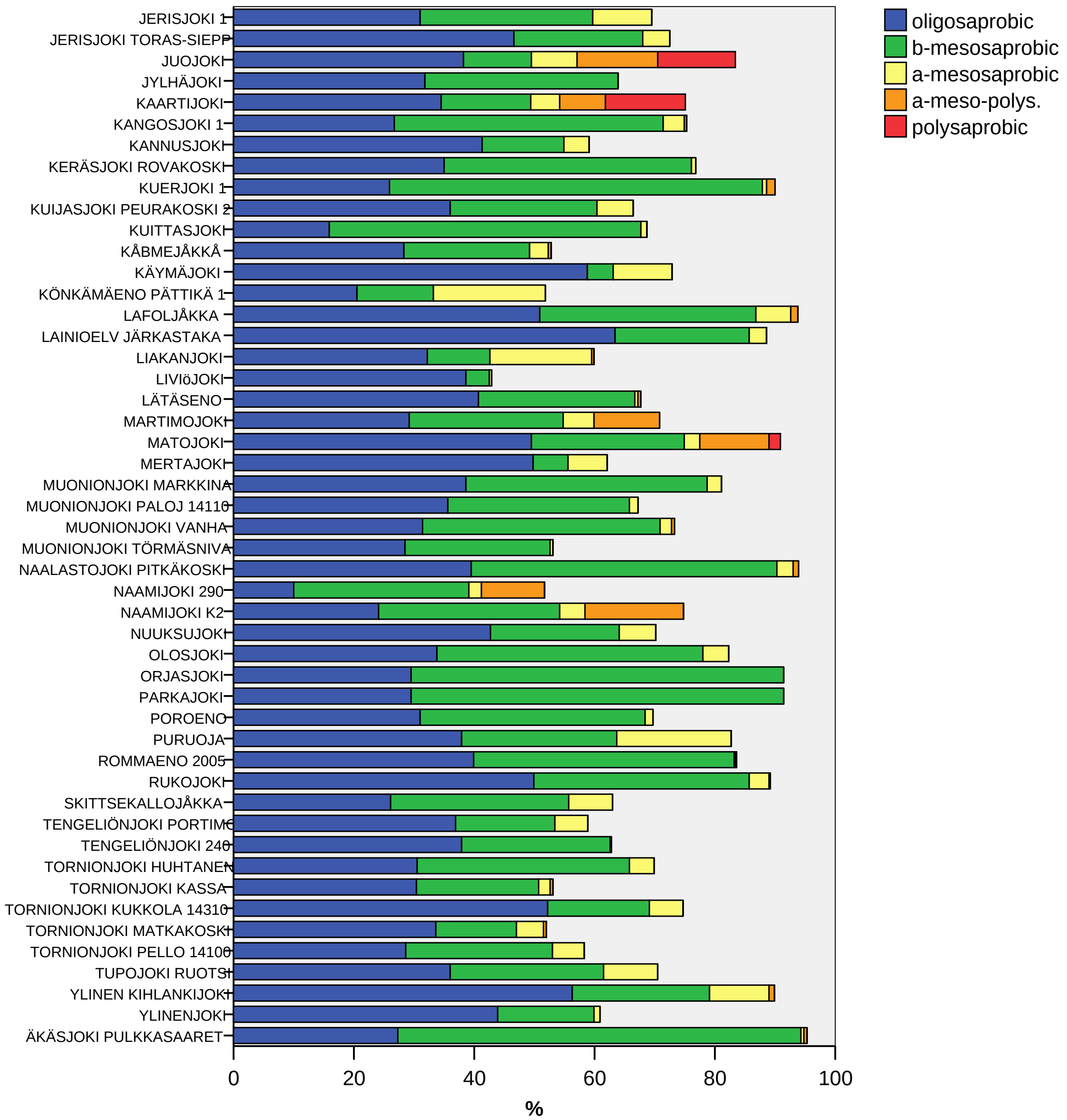

Fig. 14. Saprobic classification of the diatoms in the studied samples according to Van Dam *et al*. (1994). *Tabellaria flocculosa* forms most of the class beta-mesosaprobic in these samples, although it apparently thrives in oligosaprobic conditions in Lapland.

Saprobic classifications clearly indicate the dominance of primarily autotrophic diatoms, expected in conditions of low levels of organic loading in the rivers (Fig. 14). However, both saprobic and trophic classifications indicate pollution in Juojoki, Kaartijoki, Matojoki and Naamijoki. Saprobic classification also points to some organic loading in Martimojoki.

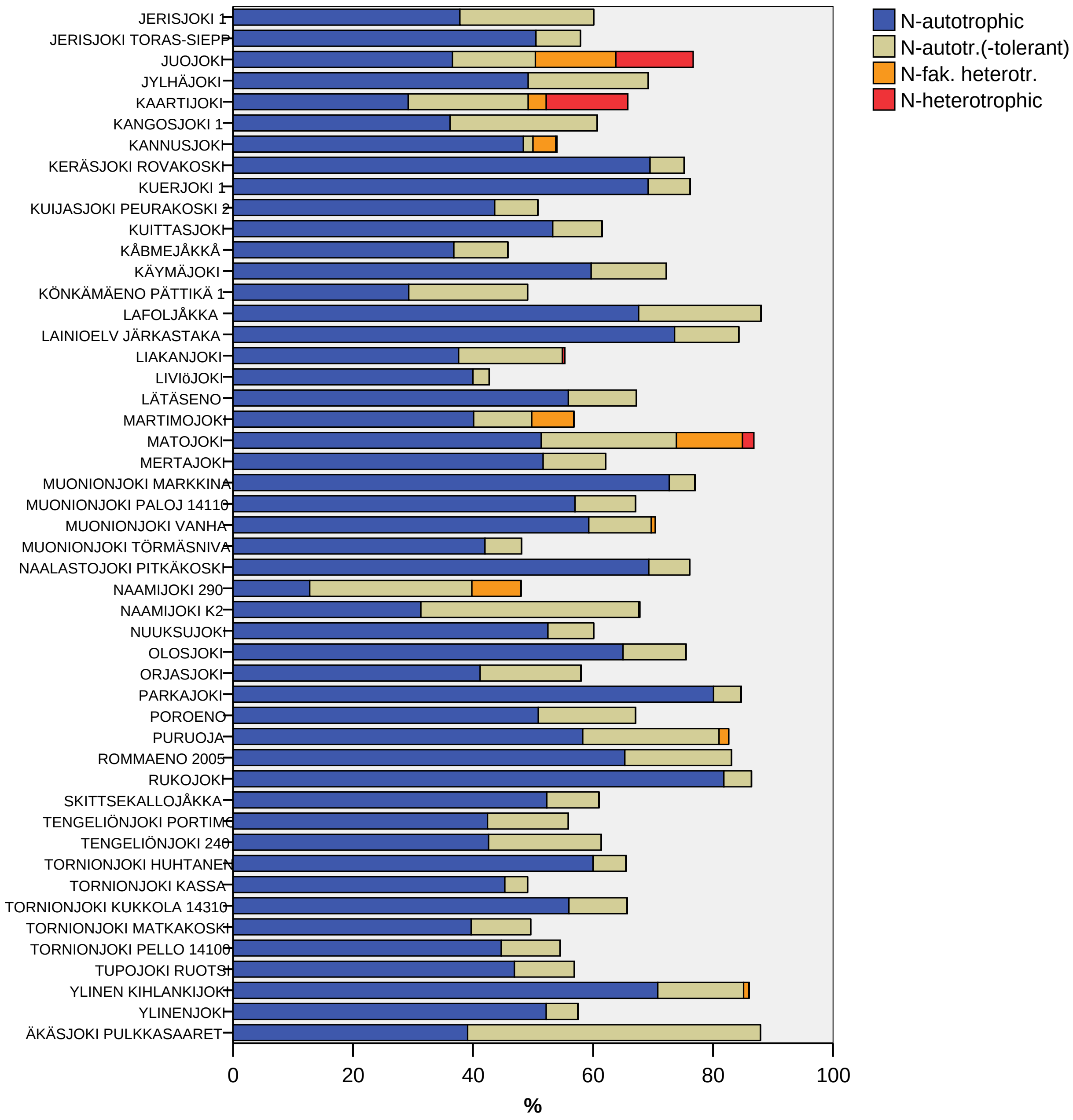

Fig. 15. Classification of the nitrogen uptake metabolism of the diatoms in the studied samples according to Van Dam *et al*. (1994).

Nitrogen uptake metabolism indicates primarily N-autotrophy in most of samples (Fig. 15). Organic N-compounds appear available in the same rivers where saprobic level is also high, supporting the results of the saprobic classification.

DISCUSSION

The summer 2006 was very dry and during the sampling period the water levels were low, especially in the southern part of the watershed. This appears to have some effect on the water quality of the rivers. The nutrients and total organic carbon levels were lower than normal in the rivers: mean total P concentration in the Finnish national monitoring sites in the area (N=10) has been 10 µg l^{-1} during the period of 2000–2005, whereas in 2006 it was 8 µg l^{-1}. Mean water colour value was 45 mg Pt l^{-1} for the same sites in 2000–2005, whereas in 2006 it was 30 mg Pt l^{-1} (unpublished data, database of the Ministry of the Environment).

Niemelä *et al*. (2002) studied nine sites in the rivers Muonio and Torne common with this study in 2001 for diatoms and water quality. Total P concentrations and water colour were systematically lower in 2001 than in 2006. However, lower IPS values were calculated in this study than Niemelä et al. (2002). Updates to the indicator values of some taxa in IPS index may account for at least some of the difference in the results.

Water quality monitoring data on eight of the small tributaries (unpublished data, compiled by Patrik Olofsson, County Administrative Board of Norrbotten) indicates for all the rivers that water colour and total organic carbon concentrations have been lower than earlier in summer 2006, and free cations (Mg, K, Ca) levels higher. Ylinen Kihlankijoki site is the most frequently monitored of these sites (Fig. 17, 18).

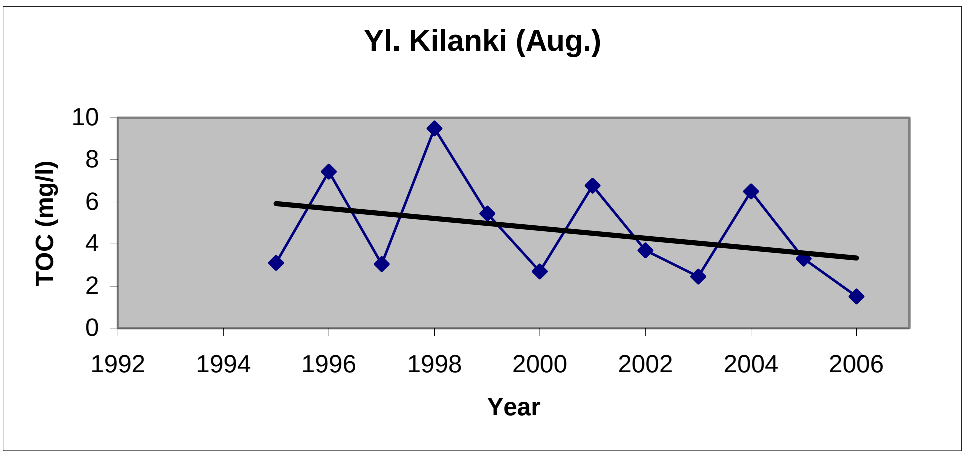

Fig. 17. Total organic carbon (TOC) concentrations (mg l^{-1}) in Ylinen Kihlankijoki site 1995–2006 (mean values in August). Figure by Patrik Olofsson.

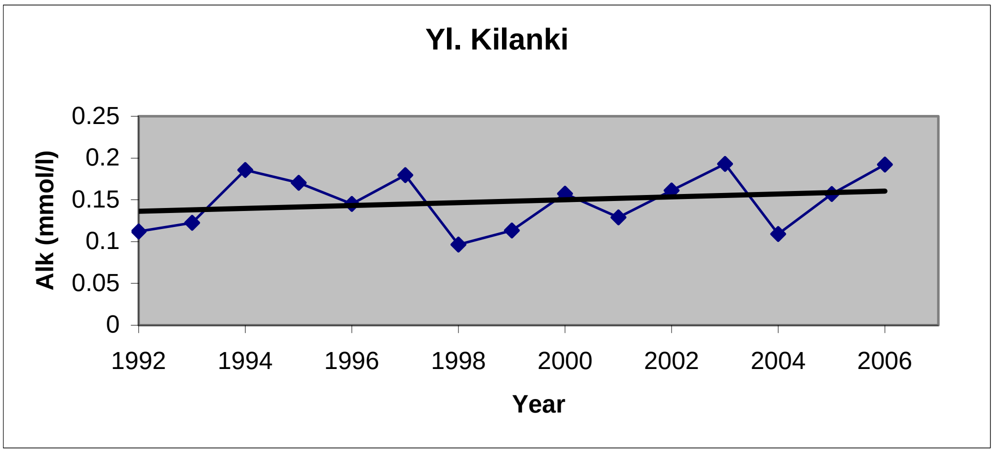

Fig. 18. Alkalinity (mmol l^{-1}) in Ylinen Kihlankijoki site from 1992–2006 (mean values in August). Figure by Patrik Olofsson.

The use of peatland percentage of the whole catchment area, for inference on a particular site may be problematic, many times not correctly representing the organic load at the site. The peatland percentage is not very strongly connected to the water colour in the dataset (Fig. 19). This may be the main reason for mixing of some of the clearwater and brown water sites in the ordinations. All the inland sites in small catchments (>1000 km^2) have organic geology in some parts of their catchments (> 10 % peatland).

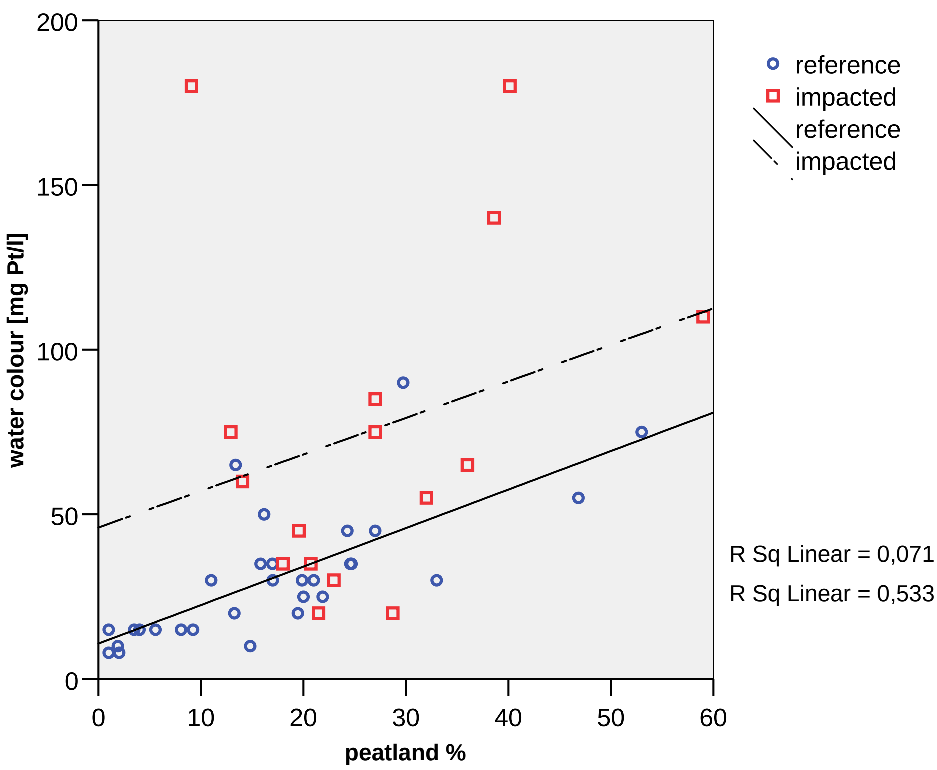

Fig. 19. Relation between the peatland percentage in the catchment area and water colour (mg Pt l^{-1}) at the studied river sites, separately for reference and impacted site data.

IPS was found sensitive for the pressures existing in the studied area, which is the most important criteria for a good metric for the ecological classification. IPS is not too dependent on the typology factors, so that the influence of the varying natural conditions is not mixed with the human impacts.

When the IPS values were compared with the ecological classification of Van Dam *et al.* (1994) for the sites with intense water colour, the IPS values were found consistent with the ecological classifications for most of the cases. Only sites Martimojoki and Matojoki received good status regardless of the elevated levels of saproby in the diatoms, significant human pressures and deteriorated water quality. The IPS value 15.4 for both of the sites is however close to the moderate status, and they could be classified as moderate when the growing amount of data is utilized for the setting of the ecological status limits in the region.

The good/moderate and lower status boundaries cannot be reliably assessed by the available data, because too few sites represent conditions below good status. Based on the data, the higher Finnish limits for good, moderate, and poor status are more suitable in the River Torne area, than the Swedish limits. More data is needed on the impacted conditions, for adjusting the limits according to the natural conditions in the area. The IPS limit for the good ecological status may be adjusted to 15.5 or 16 in the future, if more data will support this. After all, clearly impacted sites such as Martimojoki and Matojoki receive IPS value of 15.4.

CONCLUSIONS

Total of 171 diatom taxa were identified in the 49 sites. Number of taxa in one site varied from 18 to 43. The most common and abundant diatom taxa in the rivers in reference conditions are *Achnanthes minutissima* (thin varieties), *A. pusilla, Eunotia implicata, Fragilaria capucina* var. *gracilis, F. ulna* var. *danica*, and *Tabellaria flocculosa. Cymbella falaisensis* was found common species in the alpine, mountain rivers.

Diatom communities in the River Torne catchment area are different in alpine and inland conditions, when conifer tree line is the limit. Inland vs. coastal communities could not be differentiated, ie. highest historical coastline was not found to be an important factor. Headwater rivers in small watersheds (< 1000 km^2) have more variable water quality and diatom communities than larger rivers downstream. Catchment geology is an important factor, but setting of the category limit(s) is problematic; organic vs. inorganic geology is also reflected in the alpine vs. inland grouping of the diatom communities.

Based on the analyses of the 49 site dataset, the revised TRIWA2 typology with seven river types is recommended as a simple and working typology. Possibly three different status class limits for phytobenthos could be used in the future: for alpine, clearwater and brown water river types.

Of the tested diatom indices (IPS, GDI, TDI), only IPS fulfilled the criteria for a good metric for ecological classification – detection of impacts and consistent (linear) relationship with the pressures. IPS was used for assessing the ecological status of the studied 49 sites in the River Torne watershed. According to the reference site data, the IPS limit for high ecological status in Swedish system (17.5–20) is suitable for the River Torne watershed.

Multivariate analysis clearly shows that ecoregion (alpine vs. forested) and geology (amount of peatland) have strong effect on the diatom communities. However, the IPS index is much less affected by these typology factors than the human pressures, suggesting that the same metric can be used for all the river types in the area for ecological classification.

More sites should be analysed in the future for fine adjustment of the reference conditions and ecological status classes, and to make specific pressure-response analysis for the IPS and other possible metrics. More data is needed especially on the reference conditions for river types 3 and 6, and impacted conditions generally. Data from other studies done in Lapland could be used for filling the gaps in the data.

In the future, monitoring the rivers where large-scale soil ditching and peat mining occur, is important. Also the sites, that received values of diatom index IPS below 15 or close (ie. the rivers Juojoki, Kaartijoki, Matojoki, Martimojoki and Naamijoki) should be monitored for the development of their ecological status.

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Appendice:

1) Site coordinates in Swedish system, and physical and chemical measurements of the water samples 6^{th} –16^{th} August, 2006.
2) Diatom valve counts for the sites.