Reconstruction of Total Phosphorus from Kamloops Lake based on Sediment Diatom Assemblages.

Roland I. Hall, Department of Biology, Queen's University, Kingston, Ontario, K7L 3N6, Canada.

Introduction

Diatoms have long been known to be sensitive ecological indicators of certain lake chemistry variables (e.g. pH, phosphorus, nitrogen, chlorophyll a). Powerful numerical and statistical techniques have recently been developed for the quantitative reconstruction of lakewater chemistry based on the distributions of diatom species. Such reconstructions generally involve two mathematical stages (Birks et al., 1990). First, the responses of modern diatoms to contemporary lake chemistry are modelled by REGRESSION. This involves linking the distributions of diatom species in surficial sediment samples (from a variety of lakes) with associated lake chemistry and limnological variables. Second, these modelled responses are used to infer past chemistry from the composition of fossil diatom asssemblages by CALIBRATION.

Numerical procedures involved canonical ordination (computer program CANOCO 3.10) to identify the most important chemical and limnological variables controlling the distribution of diatom taxa, and weighted averaging regression and calibration (using the computer program WACALIB 2.1).

Canonical Ordination

The modern data consist of diatom counts from the surficial sediments of 46 lakes in British Columbia with accompanying water chemistry supplied by the Ministry of the Environment, B.C. (Colin McKean). The lakes were chosen to include a wide range of total phosphorus (5-85 ug/L) and a narrow range of pH (7.5-8.5). The following limnological variables were included in the analyses; altitude, watershed area, surface area, maximum depth, mean depth, Secchi, pH, specific conductivity, total phosphorus, calcium, iron, magnesium, manganese, and aluminum. The diatom data include all taxa identifiable to the species level or lower, that were present in at least 2 samples with a relative abundance of 1% or greater in at least one sample. A total of 134 diatom taxa meet these requirements.

Canonical correspondence analysis (CCA) was the ordination technique used to identify the limnological variables that explained statistically significant directions of variation in the diatom distributions. CCA simultaneously represents diatom taxa, samples, and environmental variables in low-dimensional space (i.e. the majority of variation is usually accounted for by the first 2 axes), asssuming that species respond to environmental variables in a unimodal manner. The limnological variables that were identified as significant determinants of diatom species distributions (Monte Carlo permutation test, $p \leq 0.05$) were: maximum depth, conductivity, total phosphorus, and calcium.

Weighted Averaging Regression and Calibration

Weighted averaging regression estimates the optima and tolerances of diatom species for the limnololgical variable of interest (i.e. total phosphorus). Models differ with respect to the use of species tolerance downweighting and deshrinking options. The model that performed best for total phosphorus was weighted averaging regression (without tolerance downweighting) with classical deshrinking (r^2=0.733, RMSE=0.2264), on the basis that it had the highest correlation between observed and predicted values, the lowest root mean squared error of prediction, and produced an even spread of residuals. The WA regression and calibration model includes 37 lakes from British Columbia that include a range of total phosphorus values from 5-28ug/L.

Kamloops Lake

The inferred historical values of total phosphorus are presented in Table 1.

Table 1. Diatom inferred total phosphorus values for Kamloops Lake based on weighted averaging regression and calibration.

Sediment Depth	WA totalP (ug/L)	Upper STD (ug/L)	Lower STD (ug/L)	Number of Species
0-1 cm	8.7	11.1	6.7	44
5-6 cm	9.3	12.0	7.2	48
10-11 cm	9.1	11.7	7.1	51
15-16 cm	8.4	10.8	6.5	41
20-22 cm	7.1	9.1	5.5	40
24-26 cm	6.4	8.2	4.9	47
30-32 cm	7.2	9.3	5.5	52
34-36 cm	8.1	10.4	6.2	46
40-42 cm	8.7	11.1	6.7	45
42-44 cm	7.3	9.4	5.6	46
44-46 cm	8.7	11.2	6.7	47
46-48 cm	8.2	10.5	6.3	54

A stratigraphy of the inferred total phosphorus values for the Kamloops Lake sediment core is presented in figure 1 (the dotted lines indicate one standard deviation unit about the inferred total phosphorus values). Total phosphorus values have changed very little (approximately 2 ug/L) over the period of time represented in the core. The highest phosphorus values occur at the intervals 5-6 cm and 10-11 cm. I also present a list of all the diatom taxa (along with their relative abundances and optima for total phosphorus) from Kamloops lake sediment samples that are included in the weighted averaging regression and calibration model (Table 2). The taxa included in the WA model account for between 74 and 84% of the total diatom abundances from Kamloops Lake.

The techniques employed in these phosphorus reconstructions are thought to be very applicable to the Kamloops Lake sediment samples for several reasons, and should perform well. First, the WA model includes a high percent of the diatom abundance from the Kamloops Lakes samples. Second, the Kamloops Lake samples did not form outliers based on diatom species composition in a Detrended Correspondence Analysis of the full B.C lake training set. Third, the present day total phosphorus values for Kamloops Lake are within the range of values covered by the training set of lakes. Finally, the diatom inferred value for the surface sediment sample (8.7ug/L) closely agrees with the average present day water chemistry value determined by the B.C. Ministry of the Environment (8.8ug/L, Colin McKean, personal communication).

References

Birks, H.J.B., Juggins, S., and J.M. Line. 1990. Lake surface-water chemistry reconstructions from palaeolimnological data. In Mason, B.J. (ed) The surface waters acidification programme. Cambridge University Press, Cambridge, 301-313.

ter Braak, C.J.G. 1988. CANOCO - a FORTRAN program for canonical community ordination by (partial) (detrended) (canonical) correspondence analysis, principal components analysis and redundancy analysis (version 2.1). TNO Institute of Applied Computer Science, Wageningen. pp.95.

ter Braak, C.J.F. 1990 Update Notes: CANOCO version 3.10. Agricultural Mathematics Group Wageningen, 35 pp.

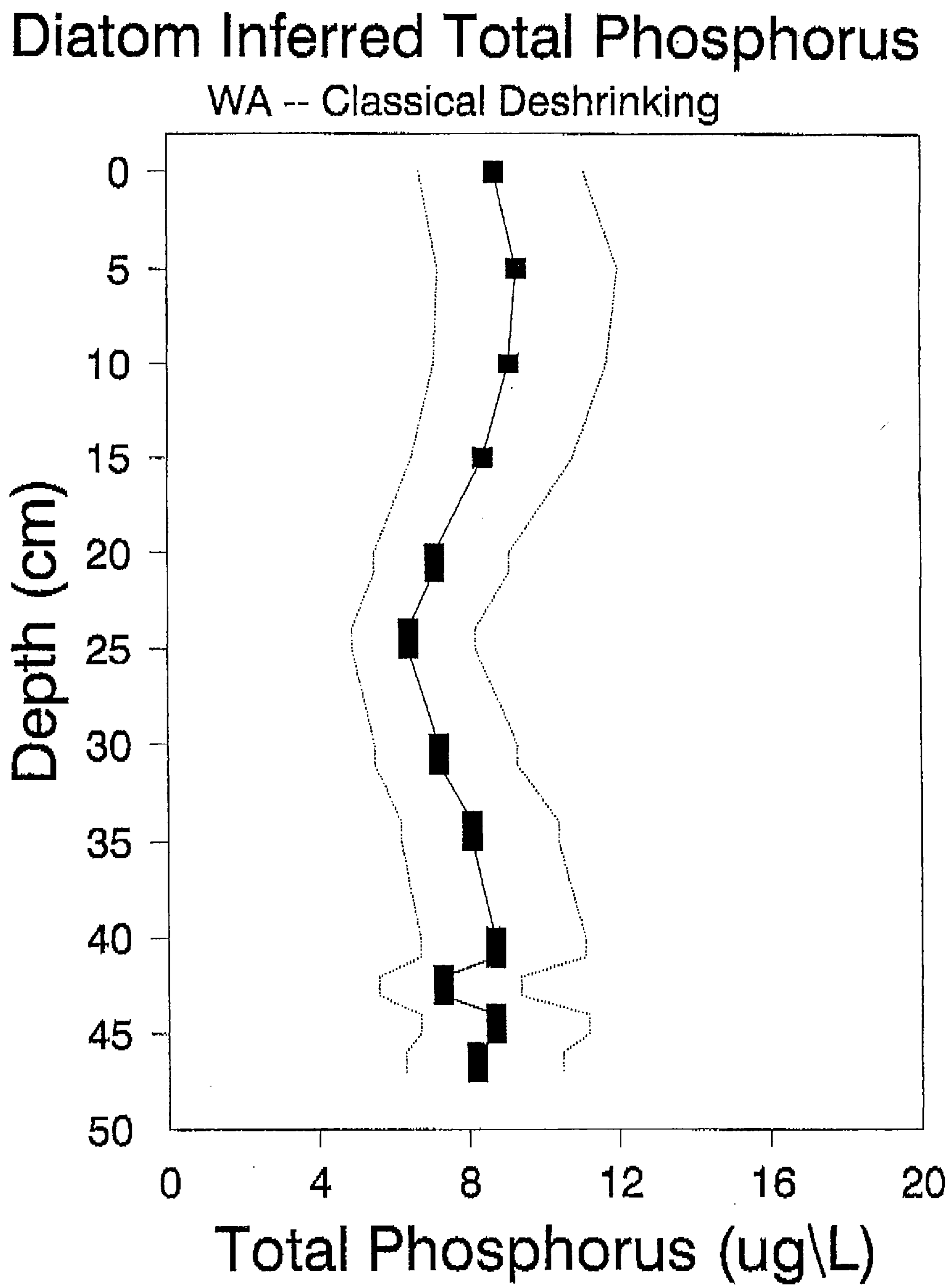
Diatom Inferred Total Phosphorus
WA -- Classical Deshrinking
Depth (cm)
0
5
10
15
20
25
30
35
40
45
50
0
4
8
12
16
20
Total Phosphorus (ug\L)

TABLE 2.

Kamloops lake, B.C. -- Diatom percentage data and WA optima for totalP
File c:@moe@KamWATP.wq1 18/03/91

TAXA		WA - Optimum totalP (ug/L)	CODE	SEDIMENT DEPTH (cm) 0	5	10	15	20	24	30	34	40	42	44	46
Achnanthes	biasolettiana Grun.	10.5	ABIASOL	0.0	0.0	0.2	0.0	0.0	0.0	0.7	0.2	0.0	0.4	2.3	0.7
	bioreti Germ.	7.3	ABIORET	0.5	0.4	0.0	0.0	0.0	0.2	1.2	0.0	0.0	0.4	0.0	0.2
	clevei Grun.	11.7	ACLEVEI	0.0	0.4	0.2	0.3	0.2	0.2	0.0	0.2	0.8	0.0	0.2	0.4
	conspicua A. Mayer	9.3	ACONSPI	0.0	0.0	0.2	0.0	0.0	0.4	0.0	0.2	0.0	0.0	0.0	0.0
	detha Hohn and Hellerman	12.2	ACDETHA	0.0	0.2	0.0	0.0	0.4	0.0	0.0	1.1	0.0	0.2	0.0	0.5
	exigua Grun.	12.7	AEXIGUA	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	lanceolata (Breb. ex Kutz.) Grun	12.3	ALANCEO	0.2	0.4	0.0	0.0	0.8	0.4	0.2	0.0	0.4	0.0	0.4	1.2
	lanceolata var. dubia Grun.	12.6	ALANDUB	0.0	0.0	0.2	0.5	1.0	0.4	0.8	0.9	0.0	0.8	0.0	0.2
	lanceolata var. elliptica Cleve	14.3	ALANELL	0.2	0.0	0.4	0.2	0.0	0.0	0.2	0.0	0.0	0.4	0.0	0.0
	levanderi Hust.	6.9	ACHLEVE	0.0	0.0	0.2	0.7	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
	linearis (W. Smith) Grun.	9.3	ALINEAR	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.4	0.4	0.0	0.0	0.0
	microcephala (Kutz.) Cleve	8.8	AMICROC	0.0	1.9	1.1	2.7	1.1	1.0	1.7	1.1	0.2	1.7	0.8	1.2
	minutissima Kutz.	9.0	AMINUT1	11.0	9.2	4.8	11.6	15.8	13.1	12.5	13.3	10.0	11.6	13.3	9.5
	suchlandtii Hust.	11.2	ASUCHLA	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.4	0.0	0.2
Amphora	libyca Ehrenb. ex Kutz.	11.2	AMPLIBY	0.3	0.2	0.2	0.0	0.4	0.0	0.0	0.0	0.0	0.2	0.0	0.0
	pediculus (Kutz.) Grun. ex A.Schmidt	10.4	AMPPEDI	0.0	1.0	1.3	1.2	0.4	0.0	0.8	0.9	0.4	0.6	0.8	0.7
Anomoeneis	vitrea (Grun.) R.Ross	7.3	ANNVITR	0.0	0.6	0.2	0.2	0.2	0.4	1.2	0.5	0.8	0.0	0.4	0.2
Asterionella	formosa Hasall	11.8	ASTFORM	6.9	3.1	6.1	1.7	6.5	5.0	2.5	3.2	2.9	5.6	2.5	2.3
Cocconeis	diminuta Pant.	11.6	COCDIMU	0.0	0.2	0.2	0.2	0.0	0.0	0.0	0.4	0.4	0.0	0.2	0.5
	placentula Ehrenb.	12.9	COCPLAC	0.3	0.4	0.2	0.3	0.4	0.0	0.3	0.4	0.8	1.2	0.4	0.4
Cyclotella	bodanica Grun.	11.7	CYCBODA	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
	bodanica var. affinis Grun.	10.2	CBODAFF	1.5	0.6	0.4	0.2	0.6	0.2	0.7	0.2	0.2	0.4	0.2	0.2
	comensis Grun.	7.4	CYCCOMN	8.5	4.6	3.1	5.4	3.6	3.3	1.2	0.5	0.8	0.4	0.2	1.2
	kuetzingiana Thwaites	13.6	CYCKUET	0.0	0.2	0.2	0.0	0.6	0.0	0.8	0.2	0.6	0.2	0.8	0.2
	kuetzingiana var. radiosa Fricke	8.3	CKUETRA	0.3	0.2	0.0	0.0	0.0	0.2	0.3	0.4	0.0	0.0	0.2	0.0
	meneghiniana Kutz.	9.0	CYCMENE	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	michiganiana Skvortzow	10.1	CYCMICH	0.5	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	ocellata Pant.	14.5	CYCOCEL	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.9	0.8	0.0	0.4	1.1
	stelligera (Cleve&Grun.) Van Heurck	9.7	CYCSTEL	6.6	16.8	18.4	10.9	17.3	17.7	16.7	18.4	13.7	20.9	14.3	17.9
Cymbella	cesatii (Rabenh.) Grun.	9.0	CYMCESA	0.0	0.0	0.2	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0
	delicatula Kutz.	8.3	CYMDELI	0.2	0.4	0.2	0.2	0.0	0.2	0.5	0.0	0.0	0.8	0.2	0.2
	diluviana (Krasske) M.B. Florin	9.3	CYMDILU	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0
	microcephala Grun.	11.6	CYMICRO	0.3	0.4	0.2	0.2	0.4	0.2	0.7	0.4	0.4	0.2	0.0	0.0
	minuta Hilse ex Rabenh.	10.2	CYMINUT	0.2	0.2	0.6	0.0	0.0	0.8	0.7	0.5	1.4	1.7	2.3	1.4
Diatoma	tenue var. elongatum Lyngb.	11.0	DIATENE	0.5	0.6	0.6	0.7	1.3	1.5	0.7	0.9	0.4	1.4	1.2	1.6
	hiemale var. mesodon (Ehrenb.) Grun.	9.2	DHIEMES	0.7	0.2	0.4	0.7	0.0	0.6	0.3	0.5	1.0	0.2	0.2	0.2
Fragilaria	brevistriata Grun.	10.1	FRABREV	0.5	1.2	0.4	2.0	0.2	1.0	0.7	0.7	0.2	1.2	1.9	1.2
	brevistriata var. inflata (Pant.) Hust.	10.2	FRBRINF	0.2	1.7	0.2	0.0	1.0	1.9	0.5	1.6	1.2	1.5	1.5	1.9
	brevistriata var. elliptica Herib.	12.3	FRBRELL	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.0
	capucina var. mesolepta (Rabenh.) Rabenh.	12.2	FRCAPME	1.5	1.2	0.4	1.2	0.4	0.0	1.0	0.4	0.8	0.0	0.0	0.2
	construens var. binodis (Ehrenb.) Grun.	12.3	FRCOBIN	0.0	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
	construens var. brevistriata	11.2	FRCOBRE	0.2	1.7	0.2	0.9	0.6	1.3	0.2	1.3	2.4	0.2	1.9	1.1
	construens var. venter (Ehrenb.) Grun.	12.0	FRCOVEN	0.8	0.4	0.2	1.5	0.0	0.4	1.7	0.7	0.8	0.8	0.0	0.5
	crotonensis Kitton	13.9	FRACROT	15.8	2.7	10.5	14.3	7.4	1.5	3.8	8.5	9.4	2.7	8.7	5.6
	lapponica Grun.	11.8	FRALAPP	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	pinnata Ehrenb.	15.0	FRAPINN	0.5	1.0	2.2	0.0	1.7	1.3	1.8	2.3	1.0	0.6	1.7	1.2
	pinnata var. intercedens (Grun.) Hust.	11.4	FRPIINT	0.2	1.5	1.8	0.5	0.8	0.4	1.3	0.2	0.4	0.0	0.4	0.5
	pinnata var. lancettula (Schum.) Hust.	12.1	FRPILAN	0.7	0.8	0.2	0.0	0.0	0.4	0.2	0.0	0.0	0.4	0.4	1.1
	vaucheriae (Kutz.) J.B. Petersen	11.4	FRAVAUC	3.4	0.8	2.4	1.0	2.3	1.7	2.3	1.8	1.6	4.1	2.1	2.1
	sp. 4 PIRLA	9.9	FRASP4X	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
Gomphonema	angustatum (Kutz.)Rabenh.	11.1	GOMANGU	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.1
	angustum Agardh.	8.6	GOUSTUM	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
	subtile Ehrenb.	21.5	GOMSUBT	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.6	0.8	0.0
	parvulum (Kutz.) Kutz.	10.2	GOMPARV	0.0	0.0	1.5	0.5	1.5	0.6	0.7	0.0	0.0	0.0	0.4	0.2
Aulacoseira	ambigua (Grun.) Simonsen	16.9	MELAMBI	1.5	0.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	distans (Ehrenb.) Simonsen	7.8	MELDIST	1.1	3.5	0.2	0.0	1.1	0.0	0.5	0.0	0.4	0.0	0.0	0.0
	granulata var. angustissima (O.Mull.) Simonsen	23.3	MGRANGU	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	italica var. subarctica (O.Mull.) Simonsen	13.2	MITALSU	4.4	0.2	7.7	10.0	5.7	3.3	4.0	2.2	5.3	4.1	3.5	4.9
	perglabra var. floriniae Camburn	9.3	MPERFLU	0.0	0.0	0.0	0.0	0.4	0.8	0.0	0.0	0.0	0.2	0.6	0.5
Navicula	absoluta Hust.	15.2	NAVABSO	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	cari Ehrenb.	12.8	NAVCARI	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.4	0.0
	cryptocephala Kutz.	10.8	NCRYPCE	0.7	0.8	0.2	0.2	0.6	0.0	1.0	0.0	0.6	0.0	0.4	0.2
	explanata Hust.	10.5	NAVEXPL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0

	laevissima Kutz.	10.2	NAVLAEV	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0
	minima Grun.	10.9	NAVMINI	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	pupula Kutz.	12.1	NAVPUPU	1.0	0.2	0.0	0.3	0.4	0.2	0.3	0.2	0.2	0.6	0.0	0.2
	radiosa Kutz.	10.3	NAVRADI	0.7	0.2	0.0	0.0	0.2	0.0	0.3	0.2	0.0	0.2	0.2	0.2
	seminuloides Hust.	12.6	NAVSEMI	0.0	0.0	0.4	0.2	0.4	0.6	0.7	0.2	0.4	0.2	0.0	0.0
	subminiscula Manguin	10.4	NVSUBMI	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	submuralis Hust.	12.5	NVSUBMU	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.2	0.2	0.4
	ventralis Krasske	18.7	NAVVENT	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
	vitabunda Hust.	11.8	NAVVITA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Neidium	ampliatum (Ehrenb.) Krammer	8.0	NEIAMPL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Nitzschia	denticula Grun.	11.7	NITDENT	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
	fonticola Grun.	11.5	NITFONT	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stauroneis	anceps Ehrenb.	21.0	STAANCE	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	phoenicenteron (Nitzsch) Ehrenb.	9.6	STAPHOE	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Stephanodiscus	alpinus Hust.	11.3	STALPIN	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	hantzschii Grun.	12.5	STHANTZ	0.2	0.4	3.9	1.5	0.0	0.0	0.5	2.7	1.4	1.0	0.6	0.9
	medius Hakansson	11.0	STMEDIU	0.8	1.0	2.9	3.7	1.0	4.8	2.7	7.6	9.2	3.7	2.9	4.4
	minutulus (Kutz.) Cleve& Muller	12.3	STMINUT	0.0	0.0	3.7	1.2	0.6	0.4	0.0	0.0	0.0	0.0	0.4	0.7
	niagare Ehrenb.	15.0	STNIAGR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.4
	parvus Stoermer&Hakansson	11.4	STPARVU	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.7	3.5	1.0	0.4	0.5
Synedra	cyclopum Brutschy	11.7	SYNCYCL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
	filiformis var. exilis Cl.-Eul.	11.6	SYNFILI	0.0	0.6	0.7	0.7	0.0	0.6	0.5	1.8	1.0	1.2	1.0	0.4
	parasitica (W.Smith) Hust.	10.1	SYNPARA	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.4	0.0	0.0	0.0	0.0
	ulna var. chaseena Thomas	10.8	SYNULCH	1.3	0.8	0.9	0.3	1.0	0.2	1.2	0.4	0.4	0.4	0.2	0.7
Tabellaria	fenestrata (Lyngb.) Kutz.	9.5	TABFENE	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.6	0.6	0.0	0.0
	flocculosa III sensu Koppen	15.1	TABFL03	0.5	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
	flocculosa IIIp sensu Koppen	17.6	TABFL3P	3.0	17.9	2.4	2.0	1.3	3.1	2.3	2.2	2.4	2.1	4.3	3.2
	% of total diatom abundance incuded in WA TP reconstructions			79	82	83	82	80	74	76	84	81	78	78	78