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TOLERANCE VALUES AND EFFECTS OF SELECTED ENVIRONMENTAL DETERMINANTS ON DIATOM DISTRIBUTION IN NORTHWEST AND NORTH CENTRAL WASHINGTON, USA

Dean W. Blinn[1]

ABSTRACT.—Diatoms were collected at 165 stream, river, wall seep, and pond/lake sites in 9 counties in northwest and north central Washington, including the Olympic Pennsisula, over a 5-year period. Four hundred and fifteen species in 77 genera were identified. Species assemblages were compared to altitude, physicochemical factors, aquatic habitats, and land use on west and east sides of the North Cascade Range. Species richness averaged 30.5 per site on the west side and 43 on the east side. Diatom species richness showed significant positive correlations to total nitrogen, total phosphorus, pH, specific conductance, channel embeddedness, and water temperature, and a significant negative correlation to percent canopy cover. A multilevel hierarchical clustering model separated streams, rivers, wall seeps, and ponds/lakes into geographic and land-use regions based on diatom assemblages. A multimetric index (diatom tolerance index [DTI]) was developed to determine environmental tolerance levels for diatom species over a large number and variety of sites. The index performed well in distinguishing between the role of embeddedness, total nitrogen, total phosphorus, and specific conductance on the distribution of diatom species and showed close agreement between land use and diatom distribution. These DTI values provide baseline information for monitoring changes in ecosystem health in drainages throughout Washington landscapes. *Didymosphenia geminata* occurred in 46% of the streams and rivers sampled and ranged from <1% to 27% in relative abundance, but it was not collected in ponds/lakes or wall seeps. *Didymosphenia geminata* density showed a significant positive correlation to suspended sediment and significant negative correlations to altitude and total nitrogen. This invasive alga attained a higher average relative abundance in rivers compared to streams and occurred in 28% of the sites examined west of the Cascade Range compared to 63% of the sites east of the Cascades.

RESUMEN.—Se colectaron diatomeas en 165 arroyos, ríos, paredes filtradas y estanques/lagos de 9 condados del noroeste y centro-norte de Washington, incluyendo la Península Olímpica, durante un período de 5 años. Se identificaron cuatrocientas quince especies de 77 géneros. Se compararon los grupos de especies con respecto a la altitud, los factores fisicoquímicos, los hábitats acuáticos y el uso de suelo en los el este y oeste de la Cordillera de las Cascadas del Norte (North Cascade Range). La riqueza de especies tuvo un promedio de 30.5 en cada ubicación de la zona oeste y 43 en el lado este. Se obtuvieron correlaciones positivas significativas entre la riqueza de especies y el nitrógeno total, fósforo total, el pH, la conductividad específica, la incrustación en la acequia y la temperatura del agua, y una correlación negativa significativa con el % de cobertura vegetal. Un modelo de agrupación jerárquica multinivel separó los arroyos, los ríos, las paredes filtradas y los estanque/lagos en regiones geográficas y el uso de suelo, basándose en las asociaciones de diatomeas. Se desarrolló un índice multimétrico [Tolerancia Diatomea Index (DTI, por sus siglas en inglés)] para determinar los niveles de tolerancia ambiental en especies de diatomeas a lo largo de un gran número y variedad de ubicaciones. El índice funcionó bien a la hora de distinguir entre el papel jugado por la incrustación, el nitrógeno total, el fósforo total y la conducción específica sobre la distribución de especies de diatomeas, y mostró una estrecha concordancia entre el uso de suelo. Estos valores DTI proporcionan información de referencia para el seguimiento de los cambios en la salud de los ecosistemas en pozos a lo largo de Washington. Se encontró *Didymosphenia geminata* en el 46% de los arroyos y ríos medidos, la abundancia relativa osciló entre <1% al 27%, pero no se colectó en estanques/lagos o paredes filtradas. Se encontró una correlación positiva significativa entre la densidad de *D. geminata* con los sedimentos en suspensión y con la altitud y el nitrógeno total se encontraron correlaciones negativas significativas. Esta alga invasora alcanza una mayor abundancia relativa promedio en ríos en comparación con arroyos, y se encontró en el 28% de las zonas inspeccionadas al oeste de la Cordillera de las Cascadas, en comparación con el 63% de las zonas al este de las Cascadas.

Few studies have been published on the distribution and ecology of diatoms in the state of Washington, even though the state contains habitats ranging from low agricultural lands to shrubsteppe ecosystems, rainforests on the Olympic Pennisula, and true alpine habitats. The high diversity of ecoregions in Washington should yield equally high diversity in diatom assemblages.

One of the earliest publications on diatoms in the state was by Sovereign (1963) who described 27 species of diatoms from springs

[1]Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ 86011. E-mail: deandiacad@gmail.com

and lakes throughout the state. Blinn (1993) described the role of salinity on diatom communities in 3 salt lakes in the interior of Washington. Also, Bahls (2004–2006) provided a photographic catalogue with optima physicochemical values, as well as a checklist from northwestern USA (Bahls 2009) of 118 genera and 380 diatom species for the state of Washington.

Other Washington-based research has examined diatoms in sediment cores to depict environmental and climatic changes over time (Bennett 1962, Stockner and Benson 1967, Tynni 1986, Wallace et al. 2006). Also, Hollingshead (2012) examined climate and hydrologic changes in Castor Lake, and Enache et al. (2013) reported 3 new *Psammothidium* species in sediment cores from oligotrophic lakes in Washington Cascade Mountain Lakes. Recently, Sheibley et al. (2014) noted an increase in *Asterionella formosa* and *Fragilaria tenera* in sediment cores from Hoh Lake in Olympic National Park beginning in 1969–1975 which suggested nitrogen enrichment during this period.

Hawkins and Norris (2000) suggested that indices based on the most robust and finest taxonomic resolution are preferable over family or generic resolution for the bioassessment of habitats and landscapes. In addition, Barbour et al. (1995) recommended a multimetric approach for measuring biological conditions. Stevenson et al. (2008) hypothesized that indicators based on species traits determined in streams with similar natural landscape features would be most effective in developing tolerance indices. More recently, Stevenson (2014) further suggested that future research on the regional-scale resilience of algal assemblages will improve water quality management. Kociolek (2006) discussed the limited checklists of diatom taxa for various regions in the USA and the need to develop species lists for various regions, especially regions such as the state of Washington with a wide variety of geomorphic conditions, land use, and aquatic habitats.

The distribution and ecology of diatoms were examined in the state of Washington, with tolerance values for common diatom species based on channel embeddedness, nutrients (total nitrogen [TN], total phosphorus [TP]), and specific conductance. These tolerance values provide a functional baseline for monitoring changes in ecosystem health for aquatic ecosystems in the varied landscapes of the state (Blinn and Ruiter 2013).

Northwestern Washington is experiencing a rapid expansion in agricultural activities and urban centers (Washington State Agriculture: 2025; www.agr.wa.gov). This study provides physicochemical and biotic baselines to monitor future changes in aquatic ecosystems in northwestern Washington. The following objectives were addressed in this paper: (1) determine the diatom flora in the northwest and central portions of the state of Washington, including the Olympic Pennisula; (2) determine the role land use plays in determining the diatom flora on the west and east sides of the Cascade Range; (3) develop a multimetric index to determine environmental tolerance levels to embeddedness, TN, TP, and specific conductance for dominant diatom species in the region; (4) determine the distribution and relative abundance of the invasive *Didymosphenia geminata* on the west and east sides of the Cascade Range.

STUDY AREA

The study area encompasses about 50,000 km^2 in 9 counties in northwest and central Washington, including Clallam and Jefferson counties on the Olympic Pennisula. The region includes the North Pacific Coastal and Columbia Glaciated freshwater ecoregions with a variety of temperate coastal streams, rivers, wall seeps, and ponds/lakes (Abell et al. 2000). The North Pacific Coastal region includes mesic landscapes on the west side of the North Cascade Range and a drier Columbia Glaciated region east of the Cascade Range. The study area also encompassed 5 physiographic regions including the Olympic Mountains, Puget Lowland, Northern Cascades, Okanogan West, and Columbia Basin (Rosenfeld 1985).

These landscapes contain a number of urban communities with a combined total of over 300,000 residents (United States Census Bureau 2013). Bellingham is the largest urban center with over 80,000 residents; most other urban centers have <10,000 residents (Blinn and Ruiter 2013). Dairy, corn, and berry farming make up a large portion of the agriculture in the lowland landscapes on the west side of the Cascade Range, while dryland crops and rangelands are common on the east side of the Cascade Range (personal observation). The urban and agricultural landscapes west of the Cascades are typically <300 m in elevation, and most forest landscapes range from 300 to 2000 m. In contrast, agricultural landscapes east of the Cascade range are typically >300 m. Average elevation for the study area on the western side of the Cascade Range was 226 m (SE 27), while study areas east of the range averaged 638 m (SE 30).

Riparian vegetation in urban landscapes includes *Acer macrophyllum*, *Alnus rubra*, and *Pseudotsuga menziesii*, while agricultural landscapes include grasses, sedges, and *A. rubra*. Riparian vegetation along lowland forest sites contain *A. macrophyllum*, *A. rubra*, *Salix scouleriana*, *Salix sitchensis*, *P. menziesii*, and *Populus balsamifera* ssp. *trichocarpa*, which is largely replaced by *Tsuga heterophylla* and *Thuja plicata* in lowland riparian systems (Blinn and Ruiter 2013). *Picea sitchensis* is also present along the streams in the lowlands on the Olympic Pennisula. Riparian vegetation in drier eastern Washington includes *P. menziesii*, *Pinus ponderosa*, and dry grassland vegetation (personal observation).

METHODS

Diatoms were collected from 99 streams, 41 rivers, 9 wall seeps (water running down rock faces), and 16 ponds/lakes based on access during mid-June through September from 2008 through 2012 in northwest and north central Washington, including the Olympic Pennisula (Appendix 1). Diatoms were collected by scraping algal material from an approximate 3 × 3-cm area from rock and sediment substrates and by collecting submerged leaves and moss at all sites. The diatom floras by Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b, 2000) were routinely used for the identification of species.

Land use (urban, agriculture, forest) was noted and physicochemical information was collected at each site. Agricultural regions included cornfields and livestock pastures with cattle and horses; urban areas had ≥1000 residents; and forested land contained >50% tree cover. Maximum water temperatures were measured with a handheld thermometer on-site. Specific conductance (at 25 °C) of water was determined with a conductance meter (Radiometer, Copenhagen, Denmark; Model CDM2e) in the laboratory, and pH was measured with an Oakton pH 6 meter onsite. Channel embeddedness was determined to the nearest 5% interval at each site following Platts et al. (1983). Suspended sediments were determined according to MacDonald et al. (1991), and canopy cover was determined with a spherical densiometer (Forest Densiometer Model A) to the nearest 5% interval.

Water collections for TN and TP were immediately placed on dry ice and analyzed within 14 days by the persulfate digestion and flow injection method on an FS3000 Flow Injection Analyzer made by OI Corporation (APHA 2005). The digestion method was an alkaline oxidation (APHA 4500-P J) using sodium hydroxide and potassium persulfate. Following the digestion, TP was measured using the ascorbic acid method (APHA 4500-PH) and TN was measured using the cadmium reduction method on the FS3000 (APHA 4500 NO3-I).

Kendall's tau (τ) rank correlation coefficients were calculated between species richness and TN, TP, specific conductance, altitude, maximum water temperature, pH, and percent canopy. Principal components analysis was used based on singular value decomposition of the centered, scaled data matrix to extract the important relationships among water quality and diatom variables (Jongman et al. 1995, Ben-Hur and Guyon 2003, R Development Core Team 2011). Principal components were used as new variables to identify stable clusters using hierarchical clustering with Euclidean distance and Ward's minimum variance cluster method, following the methods outlined by Ben-Hur and Guyon (2003). Rare species were included in the analyses. The PCA variables were centered on the mean and scaled to unit variance. Shannon's diversity index was also calculated for diatom assemblages at each site.

A tolerance index was used for channel embeddedness, TN, TP, and specific conductance to compare the distribution of diatom species along each of these environmental gradients. The following equation was developed by Blinn (1993) for specific conductance (SCI) to examine the distribution of diatoms in salt lakes in western USA and expanded by Blinn and Ruiter (2006, 2013) for caddisflies:

$$SCI_x = \frac{\sum^{N_x} [\log_{10} (RA_i \cdot 100)] \text{ (Specific Conductance, } \mu\text{S/cm)}}{N_x},$$

where *RA* = relative abundance (percent) of species *x* at a given stream site, and *N* = number of streams in which species *x* occurred. The diatom tolerance index (DTI) is a summation of the adjusted combined numeric values of total nitrogen index (TNI), total phosphorus index (TPI), specific conductance index (SCI), and embedded index (EMBI). Elevated nutrients, salinization of water, and siltation of cobbles are 3 of the most influential stressors for stream biota (Laws 2000, Enger and Smith 2009). We adjusted the DTI numeric scores to a 0–10 scale for comparison.

RESULTS

Diatom Distribution and Physicochemical Features

Four hundred and fifteen diatom species were identified from streams, rivers, wall seeps and pond/lake sites in northwest and north central Washington (Appendix 2). Three hundred and fifty-two species were collected from streams/rivers, 87 species from wall seeps, and 213 species from ponds/lakes.

Aquatic systems sampled west of the Cascade Range averaged 278 m (SE 30.5) in altitude, while those east of the Cascade Range averaged 855 m (SE 68.3). H′ ranged from 1.57 to 5.06 west of the Cascades, and from 1.85 to 4.98 east of the Cascade Range. Nearly 77% of the taxa were either mono- or biraphid diatoms. Species richness averaged 30.5 (SE 1.3) per site on the west side of the Cascades and 43 (SE 2.8) on the east side. *Achnanthidium minutissimum, Cocconeis placentula* f. *lineata, Diatoma mesodon, Encyonema silesiacum, Eunotia bilunaris, Fragilaria capucina, Fragilaria vaucheria, Frustulia vulgaris, Gomphonema parvulum, Meridion circulare, Nitzschia dissipata, Planothidium lanceolatum,* and *Ulnaria ulna* occurred in over 50% of the sites examined throughout the study area.

Ponds and lakes had the highest average number of species at 42.2 (SE 3.2) per site (Fig. 1). H′ diversity for these habitats at lower elevations (<700 m) ranged from 2.83 to 4.77 with an average of 34 (SE 2) species, while those at higher elevations (>1150 m) ranged from 3.53 to 5.19 with an average of 56 (SE 7) species. *Achnanthidium minutissimum, C. placentula* v. *lineata, E. bilunaris, F. capucina, F. vaucheria, U. ulna, Gomphonema truncatum,* and *Staurosira construens* f. *venter* were common in low-elevation ponds and lakes, while *A. minutissimum, Aulacoseira alpigena, D. mesodon, Eunotia* spp., *Frustulia* spp., *Pinnularia* spp., and *Tabellaria floculossa* were common taxa in high-elevation lakes.

Urban streams and rivers averaged 38 (SE 2.6) species compared to 33 (SE 2.1) species in agricultural landscapes, and 26 species (SE 1.9) in forest landscapes (Fig. 1). *Cocconeis placentula* v. *lineata, F. capucina, P. lanceolatum, U. ulna,* and *Rhoicosphenia abbreviatum* were common species in urban streams, while *Melosira varians, N. dissipata, Nitzschia linearis, Nitzschia palea,* and *U. ulna* were common taxa in lowland agricultural streams and rivers. H′ diversity ranged from 2.98 to 4.92 for urban streams and from 3.33 to 5.04 for lowland agricultural streams. *Aulacoseira alpigena, Diatoma hyemalis, D. mesodon, Eunotia* spp., *Hannaea arcus, M. circulare, Pinnularia divergens,* and *T. flocculosa* were common in streams and rivers at higher elevations (>700 m) on both sides of the Cascades. H′ diversity in high-elevation streams ranged from 2.45 to 4.27 on the west side of the Cascades and from 2.90 to 4.98 on the east side. Wall seeps had the lowest average number of species (18, SE 2.1) with H′ ranging from 1.57 to 2.99. *Diatoma mesodon, D. hyemalis, Diatomella balfourinia, F. capucina, F. vaucheria, Eunotia* spp., *T. flocculosa, Tetracyclus glans,* and *Tetracyclus rupestris* were common assemblages in wall seeps.

pH ranged from 6.6 to 8.3, with a mode of 7.1 throughout the study area. Average TN was nearly 6-fold higher on the west side of the Cascades compared to the east side (Table 1). TN and TP values for streams west of the Cascades were 725 $\mu g \cdot L^{-1}$ (SE 122) and 18.5 $\mu g \cdot L^{-1}$ (SE 3.8) compared to 88.7 $\mu g \cdot L^{-1}$ (SE 21.7) and 21.7 $\mu g \cdot L^{-1}$ (SE 5.3) east of the Cascades. Lowland sites in the agricultural region west of the Cascades had the highest average TN (1673 $\mu g \cdot L^{-1}$, SE 349) and TP levels (63.5 $\mu g \cdot L^{-1}$, SE 21) and the highest average specific conductance (2.75 $mS \cdot cm^{-1}$, SE 2.3). Channel embeddedness averaged 85% (SE 7.1). Average TN and TP values for rivers west of the Cascades were 101.5 $\mu g \cdot L^{-1}$ (SE 12.6) and 18.9 $\mu g \cdot L^{-1}$ (SE 3.5), respectively, compared to 115.7 $\mu g \cdot L^{-1}$

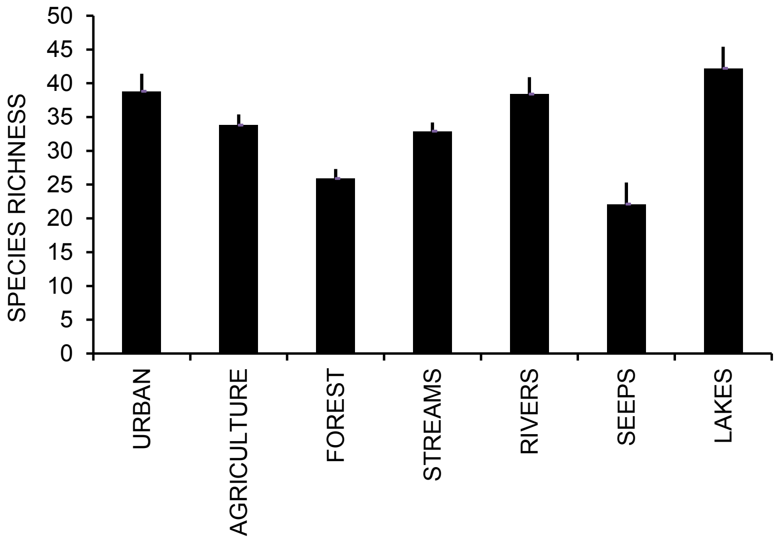

Fig. 1. Mean diatom species richness for land use and habitats in northwest and north central Washington.

TABLE 1. Average values (standard errors in parentheses) for physicochemical features of aquatic systems on the west and east sides of the North Cascade Mountain Range.

Physicochemical feature	West	East
Altitude (m)	278 (30.5)	855 (68.3)
Total phosphorus ($\mu g \cdot L^{-1}$)	20.5 (3)	16.2 (2.5)
Total nitrogen ($\mu g \cdot L^{-1}$)	452 (79)	80.2 (11.2)
Specific conductance ($mS \cdot cm^{-1}$)	0.379 (0.254)	0.122 (0.02)
Canopy cover (%)	47 (3.6)	38 (6)
Embeddedness (%)	35 (3.1)	16.8 (3.5)

TABLE 2. Kendall's τ rank-based correlations between diatom species richness and environmental determinants.

	Kendall's τ
Altitude	–0.050
Specific conductance**	0.146
Maximum water temperature**	0.171
Total phosphorus**	0.210
Total nitrogen*	0.106
pH**	0.156
% Canopy cover*	–0.136
Channel embeddedness**	0.213

*$P \leq 0.05$
**$P \leq 0.01$

(SE 21.7) and 18.3 $\mu g \cdot L^{-1}$ (SE 3) east of the Cascades.

Diatom species richness showed significant positive correlations to channel embeddedness, TN, TP, specific conductivity, maximum water temperature, and pH, and a significant negative correlation to percent canopy cover (Table 2). More detailed information on physicochemical features between landscapes (urban, agriculture, forest) and habitats (stream, river, seep, pond/lake) in the study area can be found in Blinn and Ruiter (2013).

Hierarchical clustering produced 6 stable cluster groups using the first 3 principal components as clustering variables (Fig 2, Table 3). These cluster groups appeared to match natural groups formed by geographic location and land-use type. A simple chi-square contingency table showed a significant association between the 6 "blind" hierarchical cluster groups and the following location/land-use groups (Crawley 2007).

Cluster A included 7 stream, 10 river, and 11 pond/lake sites primarily west of the Cascade Range at an average altitude of 88 m (SE 19), a canopy cover of 8.3% (SE 2), and a channel embeddedness of 92% (SE 1.0) (Table 3). These sites were primarily located in the lowland agricultural region (berry, dairy, and corn) west of the Cascades in Whatcom County. The only sites east of the Cascade Range included

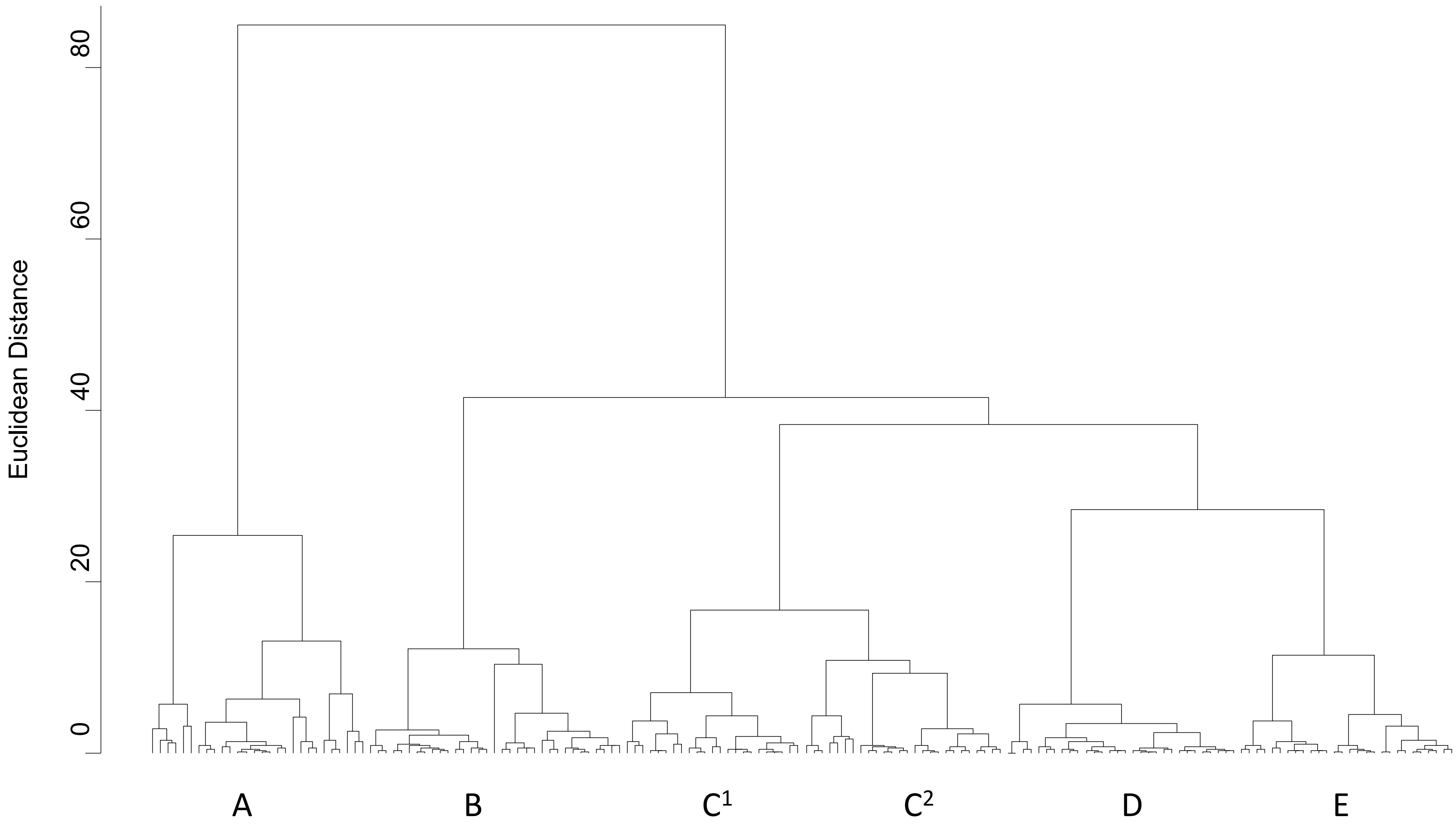

Fig. 2. Multilevel hierarchical clustering using 3 environmental factors for seeps, streams, and rivers in northwest and north central Washington. Cluster letters are provided in Appendix 1. A = sites at low altitudes in a dairy and berry agricultural region primarily on the west side of the Cascades (28 sites); B = sites located in muncipal areas and regions of moderate agriculture primarily west of the Cascades; 6 of these sites are located on the Olympic Peninsula (33 sites); C1 = mainly stream sites primarily west of the Cascades at moderate altitudes, many of which are located in municipal areas and regions of moderate agriculture (21 sites); C2 = sites mainly on the east side of the Cascades with moderate agriculture (25 sites); D = stream and river sites all west of the Cascades with moderate agriculture (30 sites); E = high-altitude sites, including streams, rivers, and wall seeps on both sides of the Cascades (28 sites).

TABLE 3. Average values (standard errors in parentheses) for physicochemical features of the 6 hierarchial cluster groups for aquatic habitats in western Washington.

	Cluster group					
Physicochemical feature	A	B	C1	C2	D	E
Altitude (m)	88	337	169	487	208	850
	(19)	(69)	(51)	(42)	(27)	(64)
Total phosphorus ($\mu g \cdot L^{-1}$)	48	129	20	8.8	13.9	7.1
	(10)	(25)	(3.6)	(1.2)	(2.3)	(1.2)
Total nitrogen ($\mu g \cdot L^{-1}$)	898	138	526	90	285	60
	(196)	(21)	(69)	(16)	(51)	(8.2)
Specific conductance ($mS \cdot cm^{-1}$)	1.17	0.08	0.174	0.09	0.109	0.07
	(0.9)	(0.01)	(0.01)	(0.01)	(0.03)	(0.01)
% Canopy cover	8.3	18.6	76	54	85	39
	(2)	(3.1)	(6)	(7)	(2.9)	(7.2)
% Embeddedness	92	55	18.5	12.2	12.3	7.3
	(1)	(6.2)	(2.6)	(1.7)	(1.5)	(0.8)
Temperature (°C)	21	16.3	18.2	16.6	16	14.1
	(0.6)	(0.3)	(0.5)	(0.4)	(0.2)	(0.2)

the Columbia and Okanogan rivers. TN and TP averaged 898 $\mu g \cdot L^{-1}$ (SE 196) and 48 $\mu g \cdot L^{-1}$ (SE 10), respectively, for sites in this cluster. These sites had the lowest average altitude and the highest average channel embeddedness, TN, specific conductance, and water temperature of all sites examined.

Cluster B included 7 stream, 20 river, and 6 pond/lake sites at an average altitude of 337 m (SE 69) and a canopy cover of 18.6% (SE 3.1). This cluster included 30 sites west and 3 sites east of the Cascades. Six river and stream sites were located on the Olympic Peninsula. TN and TP averaged 138 $\mu g \cdot L^{-1}$ (SE 21) and 19.8 $\mu g \cdot L^{-1}$ (SE 3), respectively. Average water temperature and specific conductance for sites in this cluster were 16.3 °C (SE 0.3) and 0.08 $mS \cdot cm^{-1}$ (SE 0.01), respectively. This cluster had one of the lowest average specific conductance values.

Cluster C1 included 21 stream and 2 river sites located at an average altitude of 169 m (SE 51) and a canopy cover of 76% (SE 6). Nineteen sites were located on the east side of the Cascades. TP averaged 526 $\mu g \cdot L^{-1}$ (SE 69) for sites on the west side and 20 $\mu g \cdot L^{-1}$ (SE 3.6) east of the Cascades. Average water temperature and specific conductance were 18.2 °C (SE 0.5) and 0.174 $mS \cdot cm^{-1}$ (SE 0.01). Many of these sites were located in small municipal regions or areas with moderate agriculture. Cluster C2 included 17 stream and 9 river sites at moderate altitudes (487 m, SE 42) and canopy cover (54%, SE 7). Seventeen sites were located on the east side of the Cascades. Average water temperatures and embeddedness were similar to C1 sites west of the Cascades, while average specific conductance, TN, and TP were considerably lower (Table 3).

Cluster D included a total of 30 stream and river sites, all west of the Cascades with 3 sites on the Olympic Peninsula. The average altitude of these sites was 208 m (SE 27) with a canopy cover of 85% (SE 2.9). TN and TP averaged 285 $\mu g \cdot L^{-1}$ (SE 51) and 13.9 $\mu g \cdot L^{-1}$ (SE 2.3), and specific conductance averaged 0.109 $mS \cdot cm^{-1}$ (SE 0.03).

Cluster E included 28 high-altitude (850 m; SE 64), cool water (14.1 °C; SE 0.2) streams, rivers, and wall seeps. This included 20 sites west and 8 sites east of the Cascade Range. TN and TP averaged 60 $\mu g \cdot L^{-1}$ (SE 1.2) and 7.1 $\mu g \cdot L^{-1}$ (SE 1.2), while specific conductance averaged 0.07 $mS \cdot cm^{-1}$ (SE 0.01). Sites in this cluster had the highest average altitude and lowest average water temperature, specific conductance, TN, TP, and channel embeddedness of any cluster (Table 3).

The invasive alga *Didymosphenia geminata* was collected in 46% of the stream and river sites sampled and ranged from <1% to 27% in relative abundance, but was not collected in ponds/lakes or wall seeps. *Didymosphenia geminata* showed significant ($P = 0.05$) negative correlations to altitude ($r = -0.138$) and TN ($r = -0.127$) and a significant positive correlation (0.319) to suspended sediment. The average relative abundance of *D. geminata* was 2.2% (SE 0.6) in streams compared to 4.7% (SE 2.1) in rivers. *Didymosphenia geminata* was collected

TABLE 4. Average physicochemical features (standard errors in parentheses) for sites with *Didymosphenia geminata* (all sites, sites west and east of the Cascade Mountain Range, and sites on the Olympic Penisula [Oly Pen]). ALTI = altitude, MTEMP = maximum water temperature, TP = total phosphorus, TN = total nitrogen, SPCO = specific conductance, CAN = % canopy, EMBE = % embeddedness, SUSE = suspended sediments, % relative abundance = percent relative abundance of *Didymosphenia geminata*, n = number of sites.

	ALTI (m)	MTEMP (°C)	TP ($\mu g \cdot L^{-1}$)	TN ($\mu g \cdot L^{-1}$)	SPCO ($mS \cdot cm^{-1}$)	CAN (%)	EMBE (%)	SUSE ($mg \cdot L^{-1}$)	% Relative abundance
All sites (n = 64)	300	15.6	16.1	177.2	0.558	34.4	27.8	16.6	2.8
	(28.6)	(0.5)	(1.8)	(41.5)	(0.428)	(4.2)	(3.7)	(6.2)	(0.8)
West (n = 37)	159	16.0	16.0	240	0.837	41.6	33.9	23.4	3.7
	(23)	(0.6)	(2.5)	(66)	(0.71)	(5.8)	(5.1)	(10.1)	(1)
East (n = 21)	519	15.1	16.5	83	0.125	25.8	18.3	6.1	2.8
	(29)	(0.8)	(2.8)	(13)	(0.03)	(5.5)	(4.7)	(1.4)	(1.2)
Oly Pen (n = 6)	97	14.4	8	126	0.092	29.2	20.0	20.0	4.3
	(38)	(0.7)	(2.4)	(38)	(0.01)	(9.8)	(4)	(4)	(1.2)

in 87% of the river sites examined on the mainland and all river sites on the Olympic Peninsula except the Elwa River. This invasive alga was present throughout the main channel of the Nooksack River, including the north, middle, and south forks (Appendix 1). In contrast, *D. geminata* was only collected in 33% of the stream sites examined.

Average physicochemical features of habitats throughout the study area with *D. geminata,* including the Olympic Penisula, are presented in Table 4. The average TN was 134 $\mu g \cdot L^{-1}$ (SE 35) in streams compared to 93 $\mu g \cdot L^{-1}$ (SE 7.9) in rivers. Also, specific conductance in streams with *D. geminata* averaged 0.08 $mS \cdot cm^{-1}$ (SE 0.02) compared to 3 $mS \cdot cm^{-1}$ (SE 1.9) in rivers. Average water temperature for *D. geminata* on the Olympic Peninsula was 14.4 °C (SE 0.7; n = 5) compared to 17 °C (SE 0.3; n = 59) on the mainland. Average water temperature for aquatic systems with this alga throughout the study area was 15.6 °C (SE 0.5; n = 64).

The average TN for rivers with *D. geminata* was 98.4 $\mu g \cdot L^{-1}$ (SE 10.7) compared to 491 $\mu g \cdot L^{-1}$ (SE 131) for those without this alga. Stream sites with *D. geminata* had a TN value of 131.4 $\mu g \cdot L^{-1}$ (SE 23.6) compared to 838.3 $\mu g \cdot L^{-1}$ (SE 182) for those without *D. geminata.* All sites with this alga had an average TN value of 127 $\mu g \cdot L^{-1}$ (SE 19.4), while sites without this alga had an average TN value of 788 $mg \cdot L^{-1}$ (SE 163). The average relative frequency of *D. geminata* was 2.2% (SE 0.6) in streams compared to 4.7% (SE 2.1) in rivers.

The average relative abundance of *D. geminata* in habitats west of the Cascades was 3.7% (SE 1; n = 37) compared to 2.8% (SE 1.2; n = 22) on the east side. The relative abundance of *D. geminata* on the Olympic Pennisula was 4.3% (SE 1.2). Average TP and TN concentrations for all sites with *D. geminata* throughout the study area were 16.1 $\mu g \cdot L^{-1}$ (SE 1.8) and 177.2 $\mu g \cdot L^{-1}$ (SE 41.5), respectively. Highest TN value for streams with *D. geminata* was 408 $\mu g \cdot L^{-1}$ in Thompson Creek compared to 278 $\mu g \cdot L^{-1}$ in the Calawah River for river systems. Fifty-five percent of the sites with *D. geminata* had TP values $\leq$10 $\mu g \cdot L^{-1}$, while 53% had TN values $\leq$100 $\mu g \cdot L^{-1}$. Mean TP and TN for streams with *D. geminata* west of the Cascades was 10.1 (SE 1.9) and 154.8 $\mu g \cdot L^{-1}$ (SE 21.8), respectively, compared to 9.7

(SE 2.8) and 52.4 (SE 16.4) μg · L^{-1} east of the Cascades. *D. geminata* made up 5.4% (SE 1.2) of the diatom assemblage in streams and rivers with ≥5 mg · L^{-1} suspended sediment, compared to 2.2% (SE 0.4) for those with <5 mg · L^{-1} suspended sediment. Other physicochemical features for habitats with *D. geminata* are provided in Table 4.

Diatom Tolerance Values

A diatom tolerance index (DTI) for channel embeddedness (EMBI), nutrients (TNI, TPI), and specific conductance (SCI) is provided in Table 5 for 114 of the most common diatom taxa in the region. The percent relative frequency for each species throughout the study area is also provided. The adjusted DTI values (ADJUS) ranged from 0 to 10. Tolerance values ≤4.0 are considered more sensitive to the measured environmental parameters, while tolerance values ≥6.0 are considered more tolerant.

The majority of taxa with DTI values ≤4.0 were either araphid or monoraphid (e.g., *Aulacoserira alpigena, Diatomella balfourniana, Eunotia paludosa, Gomphonema affine, Orthoseira dendroteres,* and *Tetracyclus glans,* etc.), and occurred on hard substrata with limited motility. These taxa were common in the higher-altitude sites. In contrast, 55% of the species with DTI values ≥6.0 were keeled or canal-raphed taxa (e.g., *Cymatopleura solea, Nitzschia amphibia, N. dissipata, N. linearis, N. palea,* and *Surirella ovalis,* etc.) and occurred in habitats with elevated embeddedness and nutrients in stream channels throughout the study area.

Genera, which included species with active movement (*Navicula, Nitzschia,* and *Surirella*), made up <10% of the taxa with ADJUS values ≤4.0, while species in these genera made up over 70% of taxa with ADJUS values ≥6.0. *Achnanthidium minutissimum, C. placentula* f. *lineata, D. mesodon, E. silesiacum, F. capucina, F. vaucheria, F. vulgaris, G. parvulum, P. lanceolatum, N. dissipata,* and *U. ulna* occurred in over 50% of the sites with WADJUS values ranging from 4.6 to 6.4. Araphid, monoraphid, and centric diatoms typically had lower EMBI values, which implied species associated with vegetation and hard surface substrates. Biraphid diatoms were more common along increasing EMBI values which suggested habitats with fine sediments.

Discussion

Diatom species richness declined as stream channel conditions deteriorated throughout the Washington landscape. Cooke and Prepas (1998) reported that crop fertilizers and animal manure constituted a large portion of nonpoint-source pollution of phosphorus and nitrogen in streams. Also, Lee and Ziegler (2010) found that urbanization, construction activity, and impoundments influence rates of embeddedness and salinity in streams, while Kauffman and Krueger (1984) reported livestock impacts on riparian ecosystems. These conditions also influenced both composition and species richness in diatom communities throughout the Washington landscape. Fore and Grafe (2002) developed a river diatom index (RDI) for Idaho rivers and found it to be significantly correlated with human disturbance at the site (i.e., conductivity, percentage of fine sediments, and number of human activities) and at the catchment level (i.e., percentage of urbanization and agriculture in the upstream catchment).

The hierarchial clustering model indicated that diatoms were useful environmental indicators of both land use and altitudinal gradients in Washington aquatic ecosystems. The model separated diatom assemblages into distinct clusters that ranged from lowland aquatic habitats with heavy crop and dairy farming to those with low to moderate agriculture activity at moderate to high altitudes west of the Cascades. The model also separated diatom communities located west and east of the Cascades. Use of dominant diatom taxa associated with low and highly disturbed habitats provides a useful monitoring program for the region.

DTI values for embeddedness, nutrients, and salinity for each species enhanced the ability to determine which environmental parameter(s) are responsible for conditions in the stream systems in the Washington landscape. Diatom species showed distinct associations with physicochemical conditions in aquatic habitats throughout the study area. The majority of taxa with DTI values ≤4.0 were either araphid, monoraphid, or biraphid, and their presence suggested hard substrata and limited motility. These taxa were common in the higher-altitude sites.

In contrast, 55% of the species with DTI values ≥6.0 were keeled or canal-raphed taxa,

TABLE 5. Diatom tolerance index (DTI) for 114 species collected in Washington. Ranking of diatom taxa is based on combined tolerance values for channel embeddedness (EMBI), total phosphorus (TPI), total nitrogen (TNI), and specific conductance (SCI). Combined tolerance values (ADJUS) were adjusted to a scale of 0 to 10. Species were arranged from most sensitive to most tolerant based on combined tolerance values. % Relative frequency = percentage of sites in which species occurred throughout the study area.

Diatom species	EMBI	TPI	TNI	SCI	DTI	ADJUS	% Relative frequency
Diatomella balfourniana	21	2	38	101	162	0.8	11.0
Orthoseira dendroteres	11	20	52	84	167	0.8	1.2
Tetracyclus rupestris	15	23	81	88	207	1.0	4.5
Rossithidium nodosum	17	23	87	139	266	1.3	4.5
Orthoseira roeseana	42	12	91	123	268	1.3	2.5
Epithemia argus	14	11	125	120	270	1.4	4.0
Pinnularia borealis	48	12	204	142	406	2.0	5.0
Tetracyclus glans	43	17	203	149	412	2.1	3.2
Aulacoseira alpigena	44	18	243	152	457	2.3	7.6
Surirella linearis	25	40	228	165	458	2.3	5.7
Eunotia soleirolii	54	24	272	113	463	2.3	8.9
Pinnularia subcapitata	59	14	317	86	476	2.4	5.4
Epithemia adnata	31	49	199	236	515	2.6	4.5
Caloneis tenuis	62	15	263	182	522	2.6	4.5
Nitzschia angustata	73	26	209	253	561	2.3	3.8
Rossithidium petersennii	35	27	349	177	588	2.9	6.4
Diatoma anceps	54	21	341	175	591	3.0	5.7
Eunotia paludosa	66	37	330	164	597	3.0	13.3
Tabellaria flocculosa	72	25	348	153	598	3.0	34.4
Diatoma hyemalis	58	29	333	184	604	3.0	17.8
Fragilaria virescens	77	18	431	89	615	3.1	5.1
Gomphonema affine	32	16	411	184	643	3.2	6.4
Aulacoseira distans	65	9	470	113	657	3.3	3.9
Eunotia monodon	62	25	450	150	687	3.4	3.2
Psammothidium subatomoides	45	22	475	150	692	3.5	28.6
Didymosphenia geminata	73	28	406	200	707	3.5	2.6
Hannaea arcus	63	35	404	211	713	3.6	49.2
Caloneis alpestris	68	22	376	258	724	3.6	5.5
Rhopalodia gibba	67	39	407	226	739	3.7	15.9
Achnanthidium exile	67	31	464	178	740	3.7	10.8
Gomphonema olivaceum	51	26	486	180	743	3.7	16.5
Eucocconeis laevis	45	24	467	211	747	3.7	7.0
Diploneis oblongella	24	23	494	219	760	3.8	3.8
Tabellaria fenestrata	67	51	395	249	762	3.8	5.1
Diatoma vulgaris	43	34	486	227	790	4.0	24.2
Cymbella affinis	56	29	501	206	792	4.0	49.7
Caloneis schumanniana	29	20	549	223	821	4.1	5.5
Amphipleura pellucida	43	37	537	237	854	4.3	7.6
Navicula margalithii	54	43	493	267	857	4.3	6.3
Gomphonema truncatum	61	36	517	248	862	4.3	19.1
Caloneis silicula	56	24	620	163	863	4.3	11.5
Eunotia pectinalis v. *undulata*	61	33	586	199	879	4.4	23.0
Brachysira brebissonii	65	33	627	165	890	4.5	5.7
Navicula recens	55	24	620	204	903	4.5	11.5
Diatoma mesodon	56	33	584	239	912	4.6	62.0
Sellaphora pupula	76	58	528	256	918	4.6	11.4
Gomphonema acuminatum	57	29	587	246	919	4.6	21.6
Hantzschia amphioxys	49	51	589	232	921	3.6	11.5
Caloneis sublinearis	61	30	693	151	935	4.7	2.5
Aulacoseira italica	84	48	549	261	942	4.7	9.5
Encyonema minutum	69	35	628	214	946	4.7	24.0
Reimeria sinuata	49	31	656	215	951	4.8	47.0
Fragilaria vaucheriae	67	35	606	243	951	4.8	65.7
Encyonopsis microcephala	69	35	638	212	954	4.8	26.8
Navicula radiosa	65	46	627	224	962	4.8	12.0
Psammothidium bioretii	69	28	651	226	974	4.9	9.5
Achnanthidium minutissimum	65	44	599	266	974	4.9	68.0
Pinnularia divergens	54	40	701	181	976	4.9	33.7

TABLE 5. Continued.

Diatom species	EMBI	TPI	TNI	SCI	DTI	ADJUS	% Relative frequency
Navicula recens	58	25	684	212	979	4.9	11.5
Encyonema silesiacum	72	41	633	244	990	5.0	64.7
Fragilaria tenera	51	34	688	221	994	5.0	14.6
Eunotia bilunaris	70	28	648	250	996	5.0	38.0
Amphora pediculus	42	40	675	253	1010	5.1	21.0
Epithemia sorex	61	33	688	236	1018	5.1	9.5
Diatoma tenuis	63	30	693	233	1019	5.1	16.5
Nitzschia sigma	76	24	723	197	1020	5.1	9.6
Nitzschia fonticola	76	46	670	232	1024	5.1	15.9
Staurosira construens f. *venter*	72	43	645	270	1030	5.2	13.3
Fragilaria capucina v. *vaucheria*	69	40	664	258	1031	5.2	63.4
Frustulia vulgaris	64	34	713	227	1038	5.2	54.0
Navicula cincta	59	38	655	289	1041	5.2	4.5
Gyrosigma acuminatum	55	58	668	267	1048	5.2	5.1
Nitzschia frustulum	59	44	717	233	1053	5.3	36.9
Gomphonema parvulum	60	35	714	246	1055	5.3	63.0
Staurosirella pinnata	65	39	708	256	1068	5.3	8.3
Staurosira construens	65	47	706	252	1070	5.4	29.9
Entomoneis paludosa	105	31	723	221	1080	5.4	2.5
Eunotia pectinalis v. *undulata*	60	30	754	236	1080	5.4	28.0
Cymbella aspera	61	44	755	225	1085	5.5	16.6
Cymbella tumida	62	21	829	180	1092	5.5	7.6
Ctenophora pulchella	27	44	744	277	1092	5.5	3.2
Gomphonema minutum	76	37	730	259	1102	5.5	35.3
Stauroneis anceps	103	29	730	248	1110	5.6	5.1
Planothidium lanceolatum	62	43	763	264	1132	5.7	74.5
Surirella brebissonii	54	41	898	190	1183	5.9	8.0
Meridion circulare	66	43	838	239	1186	5.9	50.3
Cocconeis placentula f. *lineata*	72	46	801	270	1189	6.0	70.3
Nitzschia vermicularis	83	90	643	380	1196	6.0	5.2
Nitzschia dissipata	76	46	817	263	1202	6.0	53.0
Luticola goeppertiana	84	34	923	173	1214	6.1	5.1
Navicula rhynchocephala	79	30	843	265	1217	6.1	29.3
Cymbopleura naviculiformis	73	34	954	158	1219	6.1	7.6
Nitzschia linearis	53	47	870	258	1228	6.2	46.9
Rhoicosphenia abbreviata	61	44	862	286	1253	6.3	38.2
Ulnaria ulna	80	49	852	286	1267	6.4	77.8
Nitzschia amphibia	73	49	912	238	1272	6.4	6.4
Amphora ovalis	46	61	913	273	1293	6.5	5.6
Cocconeis pediculus	67	67	857	304	1295	6.5	8.9
Stauroneis phoenicenteron	106	45	865	289	1305	6.5	8.2
Nitzschia palea	70	42	937	258	1307	6.5	30.6
Navicula gregaria	69	52	929	267	1317	6.6	36.0
Surirella brebissonii v. *kuetzingii*	51	68	1032	259	1410	7.1	5.7
Cymatopleura solea	55	58	989	316	1418	7.1	8.3
Nitzschia acicularis	81	38	1052	289	1460	7.3	3.8
Nitzschia filiformis	76	50	1084	272	1482	7.4	31.8
Surirella angustata	61	53	1137	267	1518	7.6	16.7
Aulacoseira ambigua	86	57	1110	268	1521	7.6	22.3
Hippodonta capitata	86	57	1110	294	1547	7.7	9.5
Entomoneis alata	74	34	1160	366	1634	8.2	2.5
Bacillaria paradoxa	81	37	1202	332	1652	8.3	4.5
Surirella minuta	53	51	1352	269	1725	8.6	5.6
Surirella ovalis	72	61	1390	251	1774	8.9	3.2
Melosira varians	93	71	1277	358	1799	9.0	42.0
Nitzschia sigmoidea	102	127	1316	455	2000	10.0	5.7

and their presence suggested elevated embeddedness and nutrients in stream channels throughout much of the study area. These species were common in the lowland agricultural region west of the Cascade Range. Van Dam et. al. (1994) and Potapova and Charles

(2007) also found these species to be associated with eutrophic conditions. In addition, 26% of the taxa were considered motile in soft sediments (Kociolek and Spaulding 2003). In contrast, species with the highest relative abundance typically had the greatest tolerance to variation in the measured parameters, whereas more sensitive species had the lowest tolerance.

The diatom tolerance index (DTI) indicated that keeled and canalled-raphed diatoms were more common in habitats with high EMBI values or highly silted substrates. It is notable that over 50% of the species with high WADJUS had keeled or canalled raphe structures. In addition, these taxa were associated with high TN values. In contrast, araphid and monoraphid species with WADJUS values ≤4.0 comprised 40% of taxa associated with substrates such as plants, sand, and rocks (Kingston 2004).

Blinn and Ruiter (2013) developed a caddisfly tolerance index (CTI) for caddisfly species collected throughout Washington in the same habitats at the same time as the diatoms. Tolerance values were comparable for the dominant components at both primary (diatom) and secondary (caddisfly) levels of the food chain. Diatom species with high DTI values occupied the same habitats as caddisfly species with high CTI values. For example, *C. placentula* v. *lineata, M. varians, Navicula rhynchocephala,* and *P. lanceolatum,* all with a DTI ≥1132, made up 33% of the diatom assemblage in Johnson Creek, and *Hydrotila xera* (CTI = 1097) made up 89% of the caddisfly assemblage. In contrast, *A. alpigena, D. balfourniana,* and *T. glans* in Upper Galena Cr. had low DTI values ranging from 162 to 457 (Table 5) and were associated with caddisflies (*Ecclisocosmoecus scylla, Hesperophylax alaskensis, Ecclisomyia conspersa, Ecclisomyia maculosa*) with CTI values ≤133.

Table 6 provides a monitoring program utilizing diatom assemblages from 165 aquatic systems in the state of Washington. Diatom assemblages are provided for the 3 condition levels of stream environments (good, fair, and poor condition). Potapova and Charles (2007) found that diatom indices developed in certain parts of the USA are not as effective when used in other regions of the same continent. Therefore, DTI values for individual species derived from streams, rivers, and lakes in Washington provide a more accurate index for monitoring the status of various watersheds in the state.

Didymosphenia geminata was first reported in North America on Vancouver Island, British Columbia, in the late 1800s (Spaulding and Elwell 2007). More recently, Bahls (2004–2006) reported low numbers of *D. geminata* in 11 stream and river periphyton samples collected in Washington. The most suitable habitats for *D. geminata* were predicted to occur in the western United States, in relatively cool sites, and at high elevations with a high baseflow index (Kumar et al. 2009).

Sutherland et al. (2007) reported that substrates colonized by *D. geminata* in the laboratory died or disappeared when positioned in spring-fed creeks in New Zealand, while those placed in rivers showed growth. In addition, they found water in spring-fed creeks had higher nitrate concentrations and specific conductivity than river waters.

Although nitrates were not measured, similar patterns were found for TN and specific conductivity in Washington streams and rivers. The average TN in streams was 134 $\mu g \cdot L^{-1}$ (SE 35) compared to 93 $\mu g \cdot L^{-1}$ (SE 7.9) in rivers. Furthermore, the average relative frequency of *D. geminata* was 2.2% (SE 0.6) in streams compared to 4.7% (SE 2.1) in rivers. This further suggests that elevated nitrogen has a negative influence on the growth of this invasive alga. Also, higher TN values in streams and rivers on the west side of the Cascades compared to those on the east side may explain the higher percentage of sites with *D. geminata* on the east side of the Cascades.

Eighty-seven percent of the river sites sampled contained *D. geminata* compared to 33% of the stream sites sampled. This likely resulted from higher TN concentrations in streams compared to rivers. Many of the small streams examined were spring-fed with high TN concentrations, while larger rivers had a lower average TN concentration. River sites without *D. geminata* had an average TN concentration of 531 $\mu g \cdot L^{-1}$ (SE 157). Twenty-nine river systems contained *D. geminata,* including all forks of the Nooksack River system. The transport of *D. geminata* by fishermen in the Nooksak River drainage may have been responsible for the high occurrence of this invasive species.

TABLE 6. Monitoring progam for streams and rivers based on the diatom tolerance index (DTI) developed for the state of Washington. This program includes diatom assemblages associated with good, fair, and poor channel conditions based on collections from 165 stream, river, wall seep, and pond/lake sites throughout the state. DTI is also presented for each species, as well as the mean relative freqency of occurrence for each assemblage. These assemblages are in general agreement with Bahls (2004–2006), Lowe (1974), Potapova and Charles (2007), and Van Dam et al. (1994).

Good channel conditions		Fair channel conditions		Poor channel conditions	
Species	DTI	Species	DTI	Species	DTI
Aulacoseira alpinena	457	*Caloneis schumanniana*	821	*Aulacoseira ambigua*	1521
Aulacoseira distans	657	*Cymbella affinis*	792	*Bacillaria paradoxa*	1652
Diatoma hyemalis	604	*Cymbella tumida*	1092	*Cocconeis pediculus*	1295
Diatomella balfourniana	162	*Diatoma mesodon*	912	*Entomoneis alata*	1652
Eucocconeis laevis	747	*Diatoma vulgaris*	790	*Luticola goeppertinana*	1214
Eunotia paludosa	597	*Encyonema minutum*	946	*Melosira varians*	1799
Eunotia soleirolii	463	*Epithemia sorex*	1018	*Meridion circulare*	1186
Fragilaria virescens	615	*Gomphonema accuminatum*	919	*Navicula rhynchocephala*	1217
Hannaea arcus	713	*Gyrosigma acuminatum*	1048	*Nitzschia amphibia*	1272
Pinnularia borealis	406	*Gomphonema parvulum*	1055	*Nitzschia palea*	1307
Pinnularia subcapitata	476	*Gomphonema truncatum*	862	*Nitzschia sigmoidea*	2000
Psammnothidium subatomoides	692	*Navicula recens*	979	*Nitzschia vermicularis*	1196
Rossithidium petersennii	588	*Nitzschia frustulum*	1053	*Planothidium lanceolatum*	1132
Surirella linearis	458	*Reimeria sinuata*	951	*Rhoicosphenia abbreviata*	1253
Tetracyclus glans	412	*Stauroneis anceps*	1110	*Surirella minuta*	1725
Tetracyclus rupestris	207	*Staurosira construens*	1070	*Ulnaria ulna*	1267
Mean relative frequency	11.4% (SE 3%)		22.9% (SE 4.5%)		25.5% (SE 6.3%)

The absence of *D. geminata* in the Elwa River is likely due to the abrasive high suspended solids in this river. Similar patterns were observed in Glacier and Barr creeks, both with high suspended solid loads (Appendix 1). Although the Elwa River on the Olympic Peninsula had relatively low TN concentration, the abrasive nature of a high suspended sediment load may have restricted the occurrence of this invasive alga in this system (Appendix 1). However, Reid and Torres (2014) recently reported increases in soluble reactive phosphorus uptake within *D. geminata* biomass associated with fine sediments because of altered redox conditions within the algal biomass. *Didymosphenia geminata* ranked in the top 25% of the diatom tolerance index with a value of 707 (Table 5). The negative correlation to altitude may have resulted from limited dispersal vectors to isolated, high-altitude sites.

Studies of streams in New Zealand and North America have demonstrated that *D. geminata* populations decrease with high numbers of Ephemeroptera, Plecoptera, and Trichoptera insect trophic groups, and increase with dipterans, crustaceans, and oligochaetes (Gillis and Chalifour 2010, James et al. 2010, Larned and Kilroy 2014). This has a major effect on the aquatic food web in streams and rivers.

Future studies are needed in the Columbia Unglaciated freshwater ecoregion that runs along the southern border of Washington and into Oregon and Idaho in the Blue Mountains of the Umatilla National Forest (Abell et al. 2000). This region escaped glaciation during the Pleistocene and may yield endemic diatoms not included in this study or in Bahls's (2009) checklist of species in northwestern USA. This may be especially true for seeps and springs in the region.

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APPENDIX 1. Site, location, altitude (ALTI), maximum water temperature (MTEM), total phosphorus (TP), total nitrogen diatom richness (RICH), and H′ for 165 aquatic habitats in northwestern Washington, USA, including North Cascades listed in order of increasing altitude. Letters for 6 clusters in Fig. 1 are provided. Counties: CH = Chelan, CLA = Whatcom. NA = not available; NCNP = North Cascades National Park. Lakes and ponds are in boldface type. Woolley, WA. An asterisk (*) indicates that *Didymosphenia geminata* was collected. (Data taken in part from Blinn and

Cluster letter	SITE	LOCATION	ALTI (m)	MTEM (°C)
*A	Nooksack River on Slater Rd. (WH)	N48.818168 W122.5803	3	20
A	California Cr.; Knickerville Rd. (WH)	N48.947139 W122.7044	4	27
C1	Squalicum Cr.; Bellingham (WH)	N48.765213 W122.5022	5	19
A	California Cr.; Valley View Rd. (WH)	N48.920695 W122.6601	7	19
A	Sammamish River (KIN)	N47.66036 W122.12372	7	17
A	Terrell Cr. on Jackson Rd. (WH)	N48.89690 W122.74884	10	19
A	Johnson Cr. in Sumas, WA (WH)	N48.99828 W122.26665	13	20
C1	Oyster Cr.; Chuckanut Drive (SK)	N48.61770 W122.43954	13	17
D	Hoko River on Hoko Ozette Rd. (CLA)	N48.25867 W124/35221	15	15
C1	Chuckanut Cr.; Fairhaven (WH)	N48.71569 W122.49484	15	19
A	Tenmile Cr. on Tenmile Rd. (WH)	N48.86994 W122.46700	22	19
A	Fourmile Cr. on Tenmile Rd. (WH)	N48.86980 W122.48189	22	21
*C1	Green Cr. on Hwy. 112 (CLA)	N48.17839 W124.20638	23	16
C1	Fever Cr.; Bellingham (WH)	N48.77181 W122.44167	24	18
*B	Dungeness River on Ward Rd. (CLA)	N48.11823 W123.14843	24	14
A	**Scudder Pond, Bellingham (WH)**	**N48.76162 W122.42091**	**25**	**25**
A	Elwa River on Elwa Rd. (CLA)	N48.11376 W123.55392	25	16
C1	Breckenridge Cr. Goodwin Rd. (WH)	N48.88900 W122.28790	25	19
*C1	White Cr. (Mi. 60.6) Hwy. 530 (SK)	N48.39765 W121.55106	99	19
C1	Whatcom Cr.; Bellingham (WH)	N48.75329 W122.43503	25	22
*A	Nooksack River at Everson (WH)	N48.91771 W122.34920	26	18
B	Snoqualamie River in Fall City (KIN)	N47.56819 W121.88284	26	15
C1	Unknown stream to Dakota Cr. (WH)	N48.96522 W122.66006	27	19
A	Fish Trap Cr. (Hwy. 546) (WH)	N48.96427 W122.43164	33	20
A	Sumas River on Lindsay Rd. (WH)	N48.94922 W122.30856	33	20
*A	Nooksack River at Cedarville (WH)	N48.84179 W122.29380	33	22
*B	Stilliquamish River on Strotz Rd. (SN)	N48.19859 W122.20468	34	16
C1	Bear Cr.; Cain Lk. Rd. (SK)	N48.62792 W122.36263	40	18
*B	Bogachiel River on Hwy. 101 (CLA)	N47.89416 W124.35709	44	17
B	Olney Cr. 9 Mi. 26.5 on Hwy. 2 (SN)	N47.87764 W121.71800	44	18
*A	Baker River in Concrete (SK)	N48.53707 W121.74216	48	19
D	Anderson Cr. on Oil City Rd. (JEF)	N47.77206 W124.32293	48	14
B	Swift Cr. bridge on Goodwin Rd. (WH)	N48.90595 W122.28746	50	21
D	Lost Cr. on Hwy. 101 (JEF)	N47.78170 W124.27018	52	15
*C2	Grandy Cr. (Mi. 82.7) Hwy. 20 (SK)	N48.53285 W121.88413	53	25
*D	Smith Cr. (Mi. 11.4) Hwy. 542 (WH)	N48.84145 W122.26037	54	16
*C1	Jackman Cr. (Mi. 91) Hwy. 20 (SK)	N48.53079 W121.71985	55	21
A	**Wiser Lake near Lynden (WH)**	**N48.90516 W122.48491**	**57**	**27**
*B	Calawah River on Hwy. 101 (CLA)	N47.95981 W124.39283	60	17
A	**Lake Terrell (WH)**	**N48.86054 W122.68965**	**65**	**28**
*B	Nooksack River (Hwy. 9 bridge) (WH)	N48.86054 W122.89650	69	16
*D	Bacon Cr. (Mi. 110.8) Hwy. 20 (SK)	N48.58796 W121.39524	70	16
A	**Lake Padden, Bellingham (WH)**	**N48.70138 W122.44709**	**74**	**20**
C1	Padden Cr.; Padden Cr. Park (WH)	N48.70277 W122.24465	75	18
A	**Sammish Lake, Bellingham WA (WH)**	**N48.67045 W122.38134**	**75**	**21**
*B	Skagit River at Rockport (SK)	N48.48464 W121.59299	76	16
D	Stream/waterfall at Mi. 245 on I-5 (WH)	N48.67373 W122.38669	80	13
C1	Samish River (old Hwy. 99) (SK)	N48.52577 W122.34008	82	16
*B	N. F. Stillaquamish Hwy. 530) (SN)	N48.27748 W121.80850	83	16
C1	Friday Cr.; Friday Cr. Rd. (SK)	N48.57403 W122.33828	90	19
A	**Lake Whatcom; Agate Bay (WH)**	**N48.75664 W122.35585**	**93**	**19**
*B	Sauk River (Mi. 61.6) Hwy. 530 (SK)	N48.40871 W121.55528	93	19
D	Unknown stream by Whatcom Lk. (WH)	N48.70716 W122.29792	96	15
*B	Skagit River at Marblemount WA (SK)	N48.52704 W121.42845	96	14
D	Carpenter Cr.; Bellingham (WH)	N48.75664 W122.35486	96	15
D	Wall Seep at Mi. 71.3 Hwy. 9 (WH)	N48.69127 W122.19295	98	16
*B	N. Fork Nooksack on Mosquito Rd. (WH)	N48.78476 W122.11269	98	15
C1	Anderson Cr. bridge on Hwy. 542 (WH)	N48.79027 W122.42083	103	18

(TN), specific conductance (SPCO), canopy cover (CAN), embeddedness (EMBE), suspended sediment (SUSE), National Park, Olympic Peninsula, and Mt. Baker–Snoqualmie, Okanogan, and Wenatchee National Forests. Sites are Clallam, JEF = Jefferson, KIN = King, KIT = Kittitas, OK = Okanogan, SK = Skagit, SN = Snohomish, WH = Information and collections by National Park Service and North Cascades National Park Service Complex; Sedro Ruiter 2013).

TP ($\mu g \cdot L^{-1}$)	TN ($\mu g \cdot L^{-1}$)	SPCO ($mS \cdot cm^{-1}$)	CAN (%)	EMBE (%)	SUSE ($mg \cdot L^{-1}$)	RICH	H′
58	190	0.110	5	95	16	53	4.68
30	2359	26.20	5	95	4	46	5.04
25	578	0.247	30	55	5	53	3.74
181	3238	0.381	95	95	2	38	4.54
17	437	0.105	10	90	2	69	4.76
209	1209	0.490	95	95	1	45	4.92
84	5615	0.264	85	85	5	53	4.25
4	1420	1.187	85	10	2	40	4.02
15	225	0.085	85	10	1	28	2.95
11	951	0.243	90	15	2	29	3.49
52	817	0.340	5	95	3	40	4.58
85	3157	0.386	5	95	5	37	4.37
15	329	0.087	75	35	1	35	3.94
19	527	0.262	60	40	1	36	3.48
6	94	0.102	25	20	1	45	4.45
99	**787**	**0.182**	**0**	**95**	**1**	**41**	**4.20**
112	121	0.084	20	75	279	14	2.21
19	401	0.244	90	15	3	42	3.85
5	66	0.060	80	15	1	57	3.56
8	440	0.226	20	20	4	57	3.56
64	138	0.123	5	90	14	25	4.06
23	432	0.052	5	85	3	24	3.47
30	1021	0.180	85	20	2	29	2.74
24	3429	0.303	45	85	5	39	3.32
54	974	0.360	5	95	12	31	3.40
20	105	0.080	5	80	156	38	3.33
6	188	0.045	5	25	10	24	3.48
4	609	0.102	80	25	2	33	3.19
4	108	0.091	20	25	2	34	3.44
26	221	0.038	10	45	35	42	4.27
25	110	0.045	5	85	15	55	3.42
14	235	0.068	90	15	1	28	3.51
10	390	0.240	5	95	4	14	1.78
17	88	0.093	95	20	1	14	0.93
11	217	0.200	70	45	5	27	3.40
7	275	0.099	85	35	1	17	1.72
5	158	0.090	60	40	5	23	2.91
86	**1633**	**0.341**	**0**	**95**	**1**	**33**	**3.38**
8	278	0.093	20	30	2	33	2.71
36	**1149**	**0.098**	**0**	**99**	**2**	**44**	**4.40**
20	105	0.080	5	95	15	30	2.96
4	68	0.040	50	20	1	29	3.45
11	**471**	**0.055**	**5**	**99**	**1**	**34**	**4.12**
10	638	0.183	95	10	1	42	4.63
19	**370**	**0.068**	**10**	**40**	**2**	**24**	**3.53**
16	35	0.088	50	10	10	10	3.77
7	436	0.061	90	30	1	25	2.65
9	757	0.128	60	40	4	37	3.77
4	123	0.068	5	15	5	24	3.48
8	572	0.135	80	15	2	64	5.06
4	**455**	**0.063**	**5**	**80**	**5**	**28**	**3.33**
28	31	0.050	5	20	150	34	3.17
4	830	0.099	85	80	1	18	2.48
7	71	0.040	10	90	5	46	4.05
22	660	0.119	95	25	1	27	2.72
31	363	0.085	75	20	1	25	2.95
7	64	0.095	10	65	14	29	3.77
18	400	0.126	85	20	1	38	3.89

APPENDIX 1. Continued.

Cluster letter	SITE	LOCATION	ALTI (m)	MTEM (°C)
*C²	Canyon Cr. on Mosquito Lk. Rd. (WH)	N48.83365 W122.13649	105	17
C²	Bell Cr. (Mi. 17.4) Hwy. 542 (WH)	N48.84871 W122.16121	107	17
*D	S. Fork Nooksack on Saxon Rd. (WH)	N48.67807 W122.16582	108	16
C¹	Olsen Cr.; N. Shore Dr. Bellingham (WH)	N48.89768 W122.14376	114	20
D	Kendell Cr. Nooksack Hatchery (WH)	N48.89768 W122.14376	124	16
*B	Hoh River at Hoh Ox Box camp (JEF)	N47.81239 W124.25117	125	16
*C²	Rocky Cr. (Mi. 102.6) Hwy. 20 (SK)	N48.52644 W121.45381	133	18
*B	Squire Cr. at Squire Cr. campground (SN)	N48.27023 W121.67094	134	16
*D	Proctor Cr. (Mi. 31.2) Hwy. 2 (SN)	N47.83384 W121.64453	134	17
C¹	Beaver Cr. on Hwy. 113 (CLA)	N48.11969 W124.21705	135	17
A	**Mirror Lake (WH)**	**N48.66279 W122.21809**	**135**	**22**
D	Fir Cr.; Sudden Valley (WH)	N48.67346 W122.26760	138	16
D	Brannian Cr.; Sudden Valley (WH)	N48.66903 W122.28041	139	16
D	Austin Cr.; Sudden Valley (WH)	N48.71297 W122.33139	147	17
*D	Porter Cr. on Mosquito Lk. Rd. (WH)	N48.79416 W122.11621	149	17
*B	Middle F Nooksack; Mosquito Rd. (WH)	N48.78483 W122.11246	152	16
*D	Damnation Cr. (Mi. 115) Hwy. 20 (SK)	N48.62717 W121.33821	157	16
A	**Silver Lake (WH)**	**N48.97137 W122.06909**	**157**	**25**
B	**Bog pond (Mi. 6.1); Mosquito Rd. (WH)**	**N48.78022 W122.11444**	**161**	**17**
C¹	Maple Cr. (Mi. 26.1) Hwy. 542 (WH)	N48.92134 W122.07188	165	16
*B	N. Fork Nooksack (Mi. 27) (WH)	N48.92027 W122.06338	168	15
D	Hutchinson Cr.; Mosquito Rd. (WH)	N48.74097 W122.12128	174	15
C¹	Saar Cr. on South Pass Rd. (WH)	N48.96306 W122.18544	183	18
*C²	Boulder Cr. (Mi. 26.6) Hwy. 542 (WH)	N48.92772 W122.03107	194	15
D	Stream on Mosquito Lk. Rd. (WH)	N48.74098 W122.12155	201	16
A	**Mosquito Lake Mosquito Lk. Rd. (WH)**	**N48.76881 W122.11814**	**203**	**17**
A	**Toad Lake, Bellingham WA (WH)**	**N48.79067 W122.39366**	**217**	**22**
*B	Sol Duc River near Fish Hatchery (CLA)	N48.06066 W124.12282	233	15
*A	Columbia River (CH)	N48.53549 W120.29815	248	21
*A	Okanogan River (OK)	N48.35345 W119.59373	260	23
*E	Cornell Cr. (Mi. 32.5) Hwy. 542 (WH)	N48.89208 W121.96208	263	15
D	Sulpher Cr. (Mi. 13.3) Baker Lk. Rd. (WH)	N48.65962 W121.71178	269	15
B	Glacier Cr. on Hwy. 542 (WH)	N48.88889 W121.94097	272	14
*D	Gallop Cr. on Hwy. 542 (WH)	N48.88921 W121.94331	274	16
D	Bear Cr. (Mi. 9.5) Baker Lk. Rd. (SK)	N48.62027 W121.74832	287	17
*B	N. Fork Nooksack Hwy. 542 (WH)	N48.90183 W121.91176	292	14
*B	Bechler River on FS 65 River RD (CH)	N47.72789 W121.33824	304	16
*D	Thompson Cr. on FS 39 (WH)	N48.87905 W121.91206	324	16
E	Wall seep (Mi. 125.1) Hwy. 20 (WH)	N48.69190 W121.22426	337	15
*C²	Stream (Mi. 123.5) Hwy. 20 (SK)	48°69085N,121°22611W	341	16
E	Stream/falls (Mi. 124) Hwy. 20 (WH)	48°69102N,121°22563W	353	16
*D	Falls Cr. on FS38 (WH)	N48.75477 W121.97300	369	15
D	Clearwater Cr. on FS 38 (WH)	N48.74640 W121.94625	373	15
*B	Cascade River 0.9 mi. on FS 1550 (SK)	N48.50134 W121.25027	377	16
D	Wall seep on FS Rd. 1550 (SK)	N48.50134 W121.25027	377	16
A	**Pond on Baker Lake Rd. (WH)**	**N48.72526 W121.73040**	**381**	**24**
*B	Skykomish River (Mi. 54.8) Hwy. 2 (KIN)	N47.71184 W121.31284	385	16
*C²	Mill Cr. Hwy. 97 (CH)	N47.51102 W120.63229	421	19
*C²	Wenatchee River (Mi. 96.5) Hwy. 2 (CH)	N47.59482 W120.71292	422	16
*C²	Monogram Cr. on Cascade Hwy. (SK)	N48.53565 W121.27194	429	9
D	N. Fork Nooksack River at Falls (WH)	N48.90561 W121.80847	458	15
*D	Trib near Nooksack Falls (WH)	N48.90657 W121.80682	469	16
*C²	Stream (Mi. 40.1) Hwy. 542 (WH)	N48.90785 W121.81145	474	15
*C²	Twisp River near Twisp (OK)	N48.36965 W120.14859	500	18
*C²	Wenatchee River (Mi. 90.5) Hwy. 2 (CH)	N47.76895 W120.80300	506	16
D	Talapus Cr.; NSF RD 9030 (KIN)	N47.39747 W121.53539	522	16
E	Stream (Mi. 40.9) Hwy. 542 (WH)	48°90793N;121°80636W	522	15
*C²	Chewuch River in Winthrop WA (OK)	N48.48010 W120.18144	537	16
C¹	Beaver Cr. (Mi. 205.9) Hwy. 20 (OK)	N48.34903 W120.04261	541	18
E	Stream/falls (Mi. 41.6) Hwy. 542 (WH)	N48.90879 W121.80725	558	14
*C²	Confluence of Ruby & Granite Cr. (WH)	N48.70691 W120.91772	573	15
E	Stream (Mi. 42.8) Hwy. 542 (WH)	N48.91127 W121.79332	574	16

TP (µg · L⁻¹)	TN (µg · L⁻¹)	SPCO (mS · cm⁻¹)	CAN (%)	EMBE (%)	SUSE (mg · L⁻¹)	RICH	H′
4	73	0.100	70	15	1	23	2.84
5	255	0.065	80	10	2	16	2.37
5	120	0.073	20	20	5	36	4.16
16	460	0.137	75	20	2	34	3.87
7	586	0.203	25	80	2	38	4.75
17	77	0.070	5	40	2	31	3.52
4	79	0.100	75	35	1	24	3.10
4	92	0.032	85	15	1	29	2.36
15	145	0.016	90	5	8	25	2.96
14	239	0.087	35	25	1	58	4.14
12	**343**	**0.055**	**10**	**95**	**1**	**37**	**4.45**
18	956	0.069	85	55	1	37	4.45
14	1016	0.050	90	55	1	40	1.97
12	444	0.149	90	10	1	30	3.23
4	188	0.050	15	10	1	28	3.93
7	89	0.100	10	10	50	20	3.36
4	94	0.040	20	20	5	36	2.86
9	**225**	**0.144**	**5**	**80**	**1**	**42**	**4.40**
48	**551**	**0.127**	**15**	**95**	**5**	**37**	3.49
4	855	0.192	10	10	7	62	4.31
11	48	0.060	5	20	18	25	3.24
11	268	0.092	95	10	1	21	2.79
6	605	0.152	85	20	1	33	3.67
7	160	0.110	5	5	15	34	2.28
12	437	0.085	85	25	1	32	3.44
48	**551**	**0.128**	**5**	**95**	**1**	**29**	**2.70**
9	**934**	**0.114**	**10**	**80**	**2**	**47**	**4.37**
5	74	0.105	30	25	1	38	4.13
16	149	0.137	0	90	10	83	4.76
23	217	0.230	0	85	25	75	4.03
4	113	0.050	60	5	2	26	3.30
29	190	0.090	90	15	1	41	4.17
38	61	0.065	5	15	325	31	2.70
11	301	0.060	45	15	1	22	2.38
5	137	0.070	75	25	2	30	3.69
22	89	0.070	40	20	16	34	4.12
18	30	0.027	30	5	7	34	3.91
29	408	0.080	95	10	1	26	3.83
4	64	0.066	50	5	1	17	2.44
4	46	0.050	50	20	1	31	3.24
4	75	0.062	20	10	1	18	2.62
9	231	0.070	95	5	1	16	2.25
7	68	0.064	5	5	5	16	2.67
41	63	0.027	20	10	5	20	3.10
25	14	0.169	90	25	1	14	1.85
22	**646**	**0.058**	**20**	**90**	**1**	**25**	**3.63**
16	35	0.025	5	10	5	22	3.56
9	19	0.147	15	10	1	42	4.12
19	94	0.026	5	10	16	43	4.17
5	273	0.033	95	10	1	37	3.75
22	64	0.036	20	65	5	32	3.72
20	40	0.080	85	20	1	36	2.93
7	67	0.130	80	20	1	36	3.24
8	173	0.144	40	40	5	67	4.98
18	90	0.027	5	10	20	38	3.17
8	99	0.040	95	5	1	32	3.43
5	51	0.074	90	15	19	23	3.24
7	98	0.120	25	15	1	66	4.93
53	240	0.133	35	30	8	32	4.30
4	22	0.060	15	10	1	20	2.83
4	29	0.026	65	5	1	32	3.38
4	8	0.131	10	5	1	24	3.15

APPENDIX 1. Continued.

Cluster letter	SITE	LOCATION	ALTI (m)	MTEM (°C)
*B	Chiwaukum Cr. (Mi. 89.9) (Hwy. 2) (CH)	N47.72320 W120.73655	574	16
B	Skinny Cr. (Mi. 88.5) Hwy. 2 (CH)	N47.73061 W120.73897	574	17
*B	N. Fork Nooksack Hwy. 542 (WH)	N48.91236 W121.78424	592	14
*C^2	Cle Elum River I-90 (KIT)	N47.18411 W121.00428	599	17
E	N. Fork Nooksack; Hannegan Pass (WH)	N48.90588 W121.69389	608	14
E	Swamp Cr.; Hannegan Pass Rd. (WH)	N48.90561 W121.68723	609	14
E	Stream (Mi. 46.2) Hwy. 542 (WH)	N48.91100 W121.76732	610	14
*C^1	Teanaway River (Hwy. 970) (KIT)	N47.19562 W120.78508	614	23
*C^2	Big Cr. on Nelson Siding Rd. (KIT)	N47.20397 W121.11251	618	16
*C^2	Yakima River (Mi. 79.1) I-90 (KIT)	N47.18580 W121.04352	620	17
C^2	Stream 1.2 mi. on Hannegan Pass (WH)	N48.90304 W121.67	634	14
*C^2	Nason Cr. (Mi. 81.4) Hwy. 2 (CH)	N47.76910 W120.80270	644	15
C^2	Lower Goat Cr.; Goat Cr. Rd. (OK)	N48.58104 W120.37939	660	16
*C^2	Methow River at Mazama WA (OK)	N48.59052 W120.40689	664	16
C^1	Loup Loup Cr. (Mi. 222.2) Hwy. 20 (OK)	N48.36698 W119.72832	664	15
*C^2	Early Winter Cr. Hwy. 20 (OK)	N48.59790 W120.44338	669	15
*E	Varden Cr. (Mi. 173.1) Hwy. 20 (OK)	N48.58836 W120.49825	675	14
*C^2	Upper Goat Cr. (FS 52) (OK)	N48.59038 W120.37012	686	15
*C^2	Boulder Cr. on FS37 near Winthrop (OK)	N48.58300 W120.14850	694	16
C^{2-}	Stream (Mi. 48.1) Hwy. 542 (WH)	N48.88998 W121.67530	712	15
B	Barr Cr. (Mi. 4.4) FS33 (WH)	N48.86704; W121.76761	715	13
E	Wells Cr. (Mi. 4.4) FS33 (WH)	N48.86718; W121.76630	718	13
E	Wall seep; Wells Cr. (Mi. 4.4) F33 (WH)	N48.86736; W121.76635	729	13
E	Wall seep (Mi. 47.6) Hwy. 542 (WH)	N48.88854; W121.67356	734	15
E	Wall seep (Mi. 48.6) Hwy. 542 (WH)	N48.88758 W121.67236	741	15
E	Stream/falls (Mi. 144.3) Hwy. 20 (SK)	N48.68110 W120.88167	763	14
E	Bagley Cr. (Mi. 49.1) Hwy. 542 (WH)	N48.87708 W121.67064	822	14
C^1	Frazer Cr. (Mi. 210.3) Hwy. 20 (OK)	N48.36466 W120.01267	848	15
E	Lower Galena Cr. Hwy. 542 (WH)	N48.87028 W121.6651	921	14
E	Commonwealth Cr. (KIT)	N47.42945 W121.42017	922	16
E	Ruth Cr. at Ruth Cr. campground (WH)	N48.90943 W121.59166	934	13
C^2	Swauk Cr. (Mi. 159.7) Hwy. 97 (KIT)	N47.24250 W120.69739	944	15
E	Wall seep (Mi. 52.1) Hwy. 542 (WH)	N48.85164 W121.68526	1051	14
E	Jack Cr. (Mi. 213.9) Hwy. 20 (OK)	N48.36783 W120.00336	1117	14
B	**Pond (Mi. 53.1) Hwy. 542 (WH)**	**48°51953N, 121°39965W**	**1167**	**14**
E	Wall seep (Mi. 54) Hwy. 542 (WH)	N48.86222 W121.67215	1229	14
B	Highwood Lake; Mt. Baker (WH)	N48.86513 W121.67473	1238	21
E	Cutthroat Cr. Mi. 167 Hwy. 20 bridge (OK)	N48.54965 W120.66954	1242	12
B	**Picture Lake; Mt. Baker (WH)**	**N48.86565 W121.67627**	**1317**	**19**
E	Stream on Fire & Ice trail (WH)	N48.85586 W121.68795	1329	13
E	Stream near Heather Info Center (WH)	N48.85507 W121.68295	1343	16
B	**Terminal Lake; Mt. Baker (WH)**	**N48.85315, 121°68473W**	**1344**	**18**
E	Wall seep at Artist Point Hwy. (WH)	N48.85177 W121.68473	1381	13
E	Early Winter Cr. Headwaters (WH)	N48.52873 W120.64003	1410	13
E	Bridge Cr. (Mi. 158.7) Hwy. 20 (CH)	N48°30.29 W120°43.16	1414	13

TP ($\mu g \cdot L^{-1}$)	TN ($\mu g \cdot L^{-1}$)	SPCO ($mS \cdot cm^{-1}$)	CAN (%)	EMBE (%)	SUSE ($mg \cdot L^{-1}$)	RICH	H′
29	157	0.029	45	5	1	37	2.90
5	101	0.208	0	35	16	28	4.26
29	67	0.033	10	15	15	37	4.27
10	61	0.051	5	10	5	39	4.44
20	53	0.029	5	5	1	26	4.00
4	55	0.076	10	35	5	19	3.38
6	10	0.141	5	5	1	20	3.11
51	207	0.162	5	20	5	41	1.98
16	35	0.090	90	20	1	33	4.11
16	108	0.065	35	10	10	57	4.20
4	46	0.062	5	5	1	23	2.79
15	35	0.038	25	10	5	51	4.28
5	25	0.099	10	5	5	40	4.58
4	28	0.090	25	5	5	44	4.15
61	166	0.188	30	15	1	49	3.47
4	29	0.070	10	5	5	57	4.09
4	17	0.042	5	5	1	27	3.12
5	20	0.061	5	5	1	28	4.31
6	78	0.080	10	5	1	47	3.92
4	19	0.066	75	5	1	38	3.80
12	83	0.147	0	15	785	15	2.56
9	44	0.060	5	10	1	26	2.46
4	83	0.205	75	20	1	30	2.99
4	83	0.104	5	5	1	19	2.53
4	38	0.168	20	10	1	13	1.57
4	51	0.034	20	5	1	27	3.13
8	106	0.033	95	5	1	30	3.11
51	180	0.161	95	15	3	63	4.74
4	56	0.023	80	20	1	23	3.20
21	123	0.283	75	20	1	33	3.29
4	91	0.022	75	5	1	20	3.19
38	28	0.246	95	25	5	43	3.99
8	73	0.034	50	75	1	11	2.13
30	194	0.108	95	5	1	29	3.22
20	**248**	**0.152**	**10**	**90**	**1**	**36**	**4.53**
5	117	0.016	25	5	1	21	2.47
15	163	0.037	0	95	1	31	3.90
4	25	0.010	90	5	1	24	3.11
8	**164**	**0.062**	**0**	**90**	**1**	**36**	**3.95**
11	30	0.025	0	5	1	37	4.00
4	0.8	0.006	0	5	1	21	3.00
13	**130**	**0.013**	**0**	**75**	**NA**	**31**	**3.83**
10	21	0.004	0	5	0	12	1.99
8	19	0.009	0	5	0	15	3.15
4	42	0.030	10	5	1	26	3.43

APPENDIX 2. Diatom species collected in northwestern Washington, including the Olympic Pennisula. Total = 415 species; 352 river/stream; 213 pond and lake.

Species	Stream/river	Lake and pond
Achnanthes grischuna Wuthrich	x	
Achnanthes nitidiformis Lange-Bertalot		x
Achnanthes rupestoides Hohn		x
Achnanthes rupestris Krasske	x	
Achnanthes stolida Krasske		x
Achnanthes subsalsa Petersen	x	
Achnanthidium affine (Grun.) Czar.	x	
Achnanthidium biasolettianum (Grun.) Round & Bukht.	x	x
Achnanthidium exiguum (Grun.) Czar.	x	
Achnanthidium exile (Kütz.) Heiberg	x	
Achnanthidium gracillimum (Meister) Lange-Bertalot		x
Achnanthidium jackii Rabh.	x	
Achnanthidium minutissimum (Kütz.) Czar.		x
Adlafia bryophila (Petersen) Moser, Lange-Bertalot & Metzeltin		x
Adlafia miniscula (Grun.) Lange-Bertalot	x	
Adlafia miniscula v. *muralis* (Grun.) Lange-Bertalot	x	
Amphipleura lindheimeri Grun.	x	
Amphipleura pellucida (Kütz.) Kütz.	x	
Amphora ovalis (Kütz.) Kütz.		x
Amphora pediculus (Kütz.) Grun. ex A. Schmidt		x
Anomoeoneis brachysira (Bréb) Grun.		x
Anomoeoneis sphaerophora E. Pfitzer	x	
Anomoeoneis styriaca (Grun.) Hust.	x	
Anomoeoneis vitrea (Grun.) Ross		x
Asterionella formosa Hass.	x	
Aulacoseira alpigina (Grun.) Krammer	x	x
Aulacoseira ambigua (Grun.) Simonsen		x
Aulacoseira distans (Ehr.) Simonsen	x	x
Aulacoseira granulata (Ehr.) Simonsen	x	x
Aulacoseira islandica (Müller) Simonsen	x	x
Aulacoseira italica (Ehr.) Simonsen	x	
Aulacoseira italica v. *tenuissima* (Grun.) Simonsen	x	
Aulacoseira valida (Grun.) Krammer		x
Bacillaria paradoxa Gmelin		x
Biddulphia laevis Ehr.	x	
Brachysira brebissonii Ross	x	
Caloneis alpestris (Grun.) Cl.	x	
Caloneis bacillum (Grun.) Cl.	x	x
Caloneis latiuscula (Kütz.) Cl.		x
Caloneis molaris (Grun.) Krammer	x	
Caloneis permagna (Bailey) Cl.	x	
Caloneis pulchra Messikommer	x	
Caloneis schumanniana (Grun.) Cl.	x	
Caloneis silicula (Ehr.) Cl.	x	x
Caloneis sublinearis (Grun.) Krammer	x	
Caloneis tenuis (Greg.) Krammer	x	
Caloneis undulata (Greg.) Krammer	x	
Caloneis westii (W. Sm.) Hendy	x	
Campylodiscus clypeus (Ehr.) Ehr. ex Kütz.	x	
Cocconeis neodiminuta Krammer	x	
Cocconeis pediculus Ehr.	x	
Cocconeis placentula Ehr.	x	x
Cocconeis placentula v. *euglypta* (Ehr.) Grun.	x	
Cocconeis placentula f. *lineata* (Ehr.) Van Heurck	x	
Cocconeis scutellum Ehr.	x	
Craticula cuspidata (Kütz.) Mann		x
Craticula halophila (Grun.) Mann		x
Ctenophora pulchella (Ralfs. ex Kütz.) Williams & Round		x
Cyclotella atomus Hust.		x
Cyclotella distinguenda Hust.	x	
Cyclotella hakanssoniae Wendker	x	
Cyclotella menghiniana Kütz.	x	x

APPENDIX 2. Continued.

Species	Stream/river	Lake and pond
Cyclotella michiganana Skvortzow		x
Cyclotella planctonica Brunnthaler	x	
Cymatopleura solea (Bréb.) W. Sm.	x	
Cymbella aequalis W. Sm.		x
Cymbella affinis Kütz.	x	x
Cymbella aspera (Ehr.) Cl.	x	x
Cymbella austriaca Grun.	x	x
Cymbella caespitosa (Kütz.) Brun		x
Cymbella cesatii (Rabh.) Grun.	x	
Cymbella cistula (Hemprich & Ehr.) Kirchner	x	x
Cymbella cuspidata Kütz.	x	
Cymbella cymbiformis C. Ag.	x	x
Cymbella cymbiformis v. *nonpunctata* Fontell	x	
Cymbella delicatula (Kütz.) Krammer	x	
Cymbella ehrenbergii Kütz.	x	
Cymbella hauckii Van Heurck	x	
Cymbella helvetica Kütz.	x	x
Cymbella hungarica (Grun.) Pantocsek	x	
Cymbella hybrida Grun. ex Cl.		x
Cymbella incerta (Grun.) Krammer		x
Cymbella incerta v. *crassipunctata* Krammer		x
Cymbella janischii (A. Schmidt) De Toni.	x	
Cymbella laevis Nägeli	x	x
Cymbella lata Grun. ex Cl.	x	
Cymbella mesiana Cholnoky	x	
Cymbella mexicana (Ehr.) Cl.	x	
Cymbella naviculiformis (Auerswald) Cl.	x	x
Cymbella norvegica Grun.	x	
Cymbella proxima Reimer		x
Cymbella rainierensis Sov.	x	
Cymbella reinhardtii Grun.	x	x
Cymbella schimanskii Krammer	x	
Cymbella tumida (Bréb) Van Heurck	x	
Cymbopleura amphicephala (Nageli) Krammer		x
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer	x	
Decussata placenta (Ehr.) Lange-Bertalot	x	
Denticula elegans Kütz	x	x
Denticula kuetzingii Grun.	x	
Denticula subtilis Grun.	x	
Diatoma anceps (Ehr.) Kirchner	x	x
Diatoma hyemalis (Roth) Heiberg	x	
Diatoma mesodon (Ehr.) Kütz.	x	x
Diatoma tenuis C. Ag.	x	
Diatoma vulgaris Bory	x	x
Diatomella balfouriana Grev.	x	
Didymosphaenia geminata (Lyngbye) M. Schmidt	x	x
Diploneis elliptica (Kütz.) Cl.	x	x
Diploneis modica Hust.		x
Diploneis oblongella (Nägeli ex Kütz.) CL-EU	x	
Diploneis ovalis (Hilse) Cl.	x	x
Diploneis pseudovalis Hust.	x	
Diploneis puella (Schumann) Cl.	x	
Discotella stelligera (Cl. & Grun.) Houk & Klee	x	x
Encyonema gracile Rabh.	x	x
Encyonema minutum (Hilse) Mann	x	x
Encyonema muelleri Hust.	x	
Encyonema prostratum (Berkeley) Kütz.	x	
Encyonema silesiacum (Bleisch) Mann	x	x
Encyonopsis cesatii (Rabh.) Krammer	x	x
Encyonopsis descripta (Hust.) Krammer		x
Encyonopsis falaisensis (Grun.) Krammer	x	
Encyonopsis microcephala (Grun.) Krammer	x	x
Entomoneis alata (Ehr.) Reimer	x	

APPENDIX 2. Continued.

Species	Stream/river	Lake and pond
Entomoneis paludosa (W. Sm.) Reimer	x	
Epithemia adnata (Kütz.) Bréb.	x	x
Epithemia alpestris (W. Sm.)	x	
Epithemia argus (Ehr.) Kütz.	x	x
Epithemia sorex Kütz.	x	x
Epithemia turgida (Ehr.) Kütz.	x	x
Epithemia turgida v. *granulata* (Ehr.) Brun	x	x
Epithemia turgida v. *westermannii* (Ehr.) Grun.	x	x
Eucocconeis flexella (Kütz.) Cl.	x	
Eucocconeis laevis (Østrup) Lange-Bertalot	x	
Eunotia arcus Ehr.	x	x
Eunotia bilunaris (Ehr.) Schaarschmidt	x	x
Eunotia bilunaris v. *mucophila* (Lange-Bertalot & Norpel-Schempp) Lange-Bertalot	x	
Eunotia diodon Ehr.	x	x
Eunotia exigua (Bréb.) Rabh.	x	
Eunotia formica (Ehr.)	x	
Eunotia implicata Nörpel, Lange-Bertalot & Alles	x	x
Eunotia incisa Smith ex Greg.	x	x
Eunotia monodon Ehr.	x	
Eunotia muscicola Krasske	x	
Eunotia muscicola v. *tridentula* Nörpel & Lange-Bertalot	x	
Eunotia pectinalis (Kütz) Rabh.	x	x
Eunotia pectinalis v. *undulata* (Ralfs.) Rabh.	x	x
Eunotia praerupta Ehr.	x	
Eunotia serra v. *diadema* (Ehr.) Patrick		x
Eunotia serra v. *tetraodon* (Ehr.) CL-EU	x	
Eunotia soleirolii (Kütz) Rabh.	x	
Fallacia pygmaea (Kütz) Stickle & Mann	x	
Fragilaria capucina Desm.	x	x
Fragilaria constricta Ehr.	x	
Fragilaria crotonensis Kitton	x	x
Fragilaria delicatissima (W.Sm.) Lange-Bertalot	x	
Fragilaria familica (Kütz.) Lange-Bertalot		x
Fragilaria mazamaensis (Sov.) Lange-Bertalot	x	
Fragilaria nanana Lange-Bertalot		x
Fragilaria pseudoconstruens Marciniak	x	
Fragilaria tenera (W. Sm.) Lange-Bertalot	x	x
Fragilaria vaucheriae (Kütz.) Perersen	x	x
Fragilaria virescens (Ralfs) Williams & Round	x	
Frustulia crassinervia (Bréb) Lange-Bertalot & Krammer	x	x
Frustulia krammeri Lange-Bertalot & Metzeltin	x	x
Frustulia saxonica Rabh.		x
Frustulia spicula Amossé		x
Frustulia vulgaris (Thwaites) De Toni	x	x
Geisslera decussis (Østrup) Lange-Bertaot & Metzeltin	x	
Geisslera ignota (Krasske) Lange-Bertalot & Metzeltin	x	
Geisslera schoenfeldii (Hust.) Lange-Bertalot & Metzeltin	x	x
Gomphoneis eriense v. *varabilis* Kociolek & Stoermer	x	
Gomphoneis herculeana (Ehr.) Cl.	x	
Gomphoneis minuta (Stone) Kociolek and Stoermer	x	
Gomphonema accuminatum Ehr.	x	x
Gomphonema affine Kütz.	x	x
Gomphonema angustatum (Kütz.) Rabh.	x	x
Gomphonema angustum C. Ag.	x	
Gomphonema auger v. *sphaerophorum* (Ehr.) Grun.	x	
Gomphonema clavatum Ehr.	x	x
Gomphonema clevei Fricke	x	x
Gomphonema gracile Ehr.	x	
Gomphonema hebridense W. Greg.	x	
Gomphonema kobayasii Kociolek & Kingston	x	
Gomphonema minutum (C. Ag.) C. Ag.	x	x
Gomphonema olivaceum (Hornemann) Ehr.	x	

APPENDIX 2. Continued.

Species	Stream/river	Lake and pond
Gomphonema olivaceum f. *fonticola* Hust.	x	
Gomphonema parvulum (Kütz.) Kütz.	x	x
Gomphonema subtile Ehr.	x	x
Gomphonema tenellum Kütz.	x	
Gomphonema truncatum Ehr.	x	x
Gomphonema truncatum v. *turgidum* (Ehr.) Patr.	x	
Gyrosigma acuminatum (Kütz.) Rabh.		x
Gyrosigma attenuatum (Kütz.) Rabh	x	
Gyrosigma spencerii (W. Sm) Griffith & Henfrey	x	
Halamphora coffeaeformis (Ag.) Levkov.	x	
Halamphora veneta (Kütz.) Levkov		x
Hannaea arcus (Ehr.) Patr.	x	x
Hantzschia amphioxys (Ehr.) Grun.	x	
Hippodonta capitata (Ehr.) Lange-Bertalot, Metzeltin & Witkowski	x	
Karayevia oblongella (Østrup) M. Aboal		x
Karayevia suchlandtii (Hust.) Bukhtiyarova	x	x
Lemnicola hungarica (Grun.) Round & Basson	x	
Luticola cohnii (Hilse) Mann	x	
Luticola goeppertiana (Bleisch) Mann	x	x
Luticola mutica (Kütz.) Mann	x	
Mastogloia braunii Grun.	x	
Mastogloia pumila (Cl. & Möller, Grun.) Cl.	x	
Melosira varians C. Ag.	x	
Meridion circulare (Grev.) C. Ag.	x	x
Meridion circulare v. *constrictum* (Ralfs) Van Heurck	x	
Navicula aboensis (Cl.) Cl.	x	
Navicula abiskoensis Hust.	x	
Navicula angusta Grun.	x	x
Navicula cari Ehr.	x	
Navicula cincta (Ehr.) Ralfs.	x	x
Navicula cocconeiformis Greg. ex Greville		x
Navicula concentrica Carter & Bailey-Watts		x
Navicula crucicula (W. Sm.) Donkin	x	
Navicula crucicula v. *cruciculoides* (Brockman) Lange-Bertalot	x	
Navicula cryptocephala Kütz.	x	x
Navicula cryptonella Lange-Bertalot	x	
Navicula dentata Hust.	x	x
Navicula expecta VanLandingham	x	
Navicula gottlandica Grun.	x	x
Navicula gregaria Donkin	x	x
Navicula hambergii Hust.	x	
Navicula hasta Pantocsek	x	
Navicula heimansii Van Dam & Kooyman	x	x
Navicula insociabilis Krasske	x	
Navicula jaernefeltii Hust.		x
Navicula lacustris W. Greg.	x	
Navicula lanceolata Ehr.	x	
Navicula leptostriata Jørgensen		x
Navicula libonensis Schoeman	x	
Navicula margalithii Lange-Bertalot	x	
Navicula menisculus Schumann	x	x
Navicula molestiformis Hust.	x	
Navicula ordinaria Hust.		x
Navicula peregrina (Ehr.) Kütz.	x	
Navicula phyllepta Kütz.	x	
Navicula placentula (Ehr.) Grun.	x	
Navicula pseudoscutiformis Hust.	x	x
Navicula pseudoventralis Hust.		x
Navicula pusilla v. *incognita* (Krasske) Lange-Bertalot	x	
Navicula pusio Cl.		x
Navicula radiosa Kütz.	x	x
Navicula recens (Lange-Bertalot) Lange-Bertalot	x	x
Navicula reinhardtii (Grun.) Grun.	x	

APPENDIX 2. Continued.

Species	Stream/river	Lake and pond
Navicula rhynchocephala Kütz.	x	x
Navicula rostellata Kütz.		x
Navicula saxophila W. Bock ex Hust.	x	
Navicula schroeteri Meister	x	
Navicula scutiformis Grun. ex A. Schmidt		x
Navicula semen Ehr.	x	
Navicula similis Krasske		x
Navicula striolata (Grun.) Lange-Bertalot	x	
Navicula stroemii Hust.	x	x
Navicula subminuscula Manguin		x
Navicula submuralis Hust.	x	
Navicula subrhynchocephala Hust.	x	
Navicula tenelloides Hust.	x	
Navicula tridentula Krasske		x
Navicula tripunctata (Müller) Bory	x	
Navicula variostriata Krasske	x	
Navicula veneta Kütz.	x	x
Navicula viridula (Kütz.) Kütz.	x	
Navicula vulpina Kütz.	x	x
Neidium affine (Ehr.) Pfitzer	x	
Neidium affine v. *longiceps* (Greg.) Cl.	x	x
Neidium alpinum Hust.		x
Neidium ampliatum (Ehr.) Krammer		x
Neidium bisulcatum (Lagerstedt) Cl.	x	x
Neidium dubium (Ehr.) Cl.	x	
Neidium iridis (Ehr.) Cl.	x	x
Neidium productum (Sm.) Cl.	x	
Nitzschia acicularis (Kütz.) W. Sm.	x	x
Nitzschia acuminata (W. Sm.) Grun.	x	
Nitzschia alpina Hust.	x	x
Nitzschia amphibia Grun.	x	x
Nitzschia angustata (W. Sm.) Grun.	x	x
Nitzschia clausii Hantz.	x	
Nitzschia communis Rabh.	x	x
Nitzschia commutata Grun.	x	
Nitzschia desortorum Hust.		x
Nitzschia dissipata (Kütz.) Grun.	x	x
Nitzschia dissipata v. *media* (Hantz.) Grun.	x	
Nitzschia dubia W. Sm.	x	
Nitzschia filiformis (W. Sm.) Hust.	x	x
Nitzschia flexa Schumann	x	
Nitzschia flexioides Geitler	x	
Nitzschia fonticola (Grtun.) Grun.	x	
Nitzschia frustulum (Kütz.) Grun.	x	x
Nitzschia hantzschiana Rabh.	x	
Nitzschia heufleriana Grun.	x	
Nitzschia hybrida Grun.	x	
Nitzschia inconspicua Grun.	x	
Nitzschia intermedia Hantz. ex Cl. & Grun.		x
Nitzschia linearis West	x	x
Nitzschia linearis v. *tenuis* (W. Sm.) Grun.	x	
Nitzschia microcephala Grun.	x	
Nitzschia palea (Kütz.) W. Sm.	x	x
Nitzschia paleacea Grun.	x	x
Nitzschia pellucida Grun.	x	
Nitzschia perminuta (Grun.) M. Peragallo	x	x
Nitzschia plana W. Sm.	x	
Nitzschia pusilla Grun.	x	
Nitzschia sigma (Kütz.) W. Sm.	x	
Nitzschia sigmoidea (Nitzsch) W. Sm.	x	
Nitzschia sublinearis Hust.	x	
Nitzschia umbonata (Ehr.) Lange-Bertalot	x	
Nitzschia vermicularis (Kütz.) Hantz.	x	x

APPENDIX 2. Continued.

Species	Stream/river	Lake and pond
Orthoseira dendroteres (Ehr.) Round, Crawford, Mann	x	
Orthoseira roeseana (Rabh.) O'Meara	x	x
Pinnularia appendiculata (C. Ag.) Cl.		x
Pinnularia borealis Ehr.	x	x
Pinnularia brevicostata Cl.	x	
Pinnularia dactylus Ehr.	x	
Pinnularia divergens W. Sm.	x	x
Pinnularia gibba Ehr.	x	x
Pinnularia gibba v. *linearis* Hust.	x	
Pinnularia hemiptera (Kütz.) Cl.		x
Pinnularia intermedia (Lagerstedt) Cl.		x
Pinnularia interrupta W. Sm.	x	x
Pinnularia karelica Cl.	x	
Pinnularia lata (Bréb) W. Sm.	x	x
Pinnularia maior (Kütz.) Cl.	x	
Pinnularia microstauron (Ehr.) Cl.	x	x
Pinnularia nobilis (Ehr.) Ehr.	x	
Pinnularia obscura Krasske	x	x
Pinnularia stomatophora (Grun.) Cl.	x	
Pinnularia streptoraphe Cl.	x	x
Pinnularia subcapitata W. Greg.	x	x
Pinnularia subrostrata Lohman & Andrews	x	
Pinnularia sudetica (Hilse) Peragallo	x	
Pinnularia viridis (Nitzsch.) Ehr.	x	x
Placoneis clematis (Grun.) Cox	x	
Placoneis elginensis (Greg.) Cox	x	
Placoneis explanata (Hust.) Lange-Bertalot	x	
Planothidium delicatulum (Kütz.) Round & Bukht.	x	x
Planothidium dubium (Grun.) Round & Bukht.	x	
Planothidium lanceolatum (Bréb. ex Kütz.) Round & Bukht.	x	x
Planothidium oestrupii (Cl.-Euler) Round & Bukht.	x	
Planothidium rostratum (Øestrup) Lange-Bertalot	x	
Pleurosigma delicatulum W. Sm.	x	
Pleurosira laevis (Ehr.) Comprère	x	
Psammothidium bioretii (Germain) Bukht. & Round	x	x
Psammothidium didymum (Hust.) Bukht. & Round		x
Psammothidium grischunum f. *daonensis* (Lange-Bertalot) Bukht. & Round	x	
Psammothidium helveticum (Hust.) Bukht. &Round	x	x
Psammothidium levanderi (Hust.) Bukht. & Round	x	x
Psammothidium marginulata (Grun.) Bukht. & Round		x
Psammothidium rossi (Hust.) Bukht. & Round		x
Psammothidium subatomoides (Hust.) Bukht. & Round		x
Pseudostaurosira brevistriata (Grun.) Williams & Round	x	x
Pseudostaurosira parasitica (W. Sm.) Morales	x	x
Pseudostaurosira robusta (Fusey) Williams & Round		x
Puncticulata bodanica (Eulenstein ex Grun.) Håkansson	x	
Reimeria sinutata (Greg.) Kociolek & Stoermer	x	x
Rhoicosphenia abbreviata (C. Ag.) Lange-Bertalot B	x	
Rhopalodia gibba (Ehr.) O. Müll.	x	x
Rhopalodia gibba v. *minuta* Krammer	x	
Rhopalodia gibberula (Ehr.) O. Müll.	x	x
Rossithidium linearis (W. Sm.) Round & Bukht.	x	
Rossithidium nodosum (Cl.) M. Aboal	x	x
Rossithidium petersenii (Hust.) Round & Bukht.	x	x
Rossithidium pusillum (Grun.) Round & Bukht.	x	
Sellaphora americana (Ehr.) Mann	x	
Sellaphora laevissima (Kütz.) Mann		x
Sellaphora pupula (Kütz.) Mereschkowsky	x	x
Sellaphora seminulum (Grun.) Mann	x	
Stauroneis anceps Ehr.	x	x
Stauroneis lundii Hust.	x	
Stauroneis phoenicenteron (Nitz.) Ehr	x	x
Stauroneis producta Grun.	x	

APPENDIX 2. Continued.

Species	Stream/river	Lake and pond
Stauroneis undata Hilse	x	
Staurosira construens Ehr.	x	x
Staurosira construens v. *binodus* (Ehr) Hamilton		x
Staurosira construens f. *venter* (Ehr.) Hamilton	x	x
Staurosirella lapponica (Grun.) Williams & Round	x	
Staurosirella leptostauron (Ehr.) Williams & Round	x	x
Staurosirella pinnata (Ehr.) Williams & Round	x	x
Stenopterobia curvula (W. Sm.) Krammer		x
Stenopterobia densestriata (Hust.) Krammer		x
Stephanodiscus niagarae Ehr.	x	x
Stephanodiscus parvus Stoermer & Håkansson		x
Surirella amphioxys W. Sm.	x	
Surirella angustata Kütz.	x	
Surirella biseriata Bréb.		x
Surirella brebissonii Krammer & Lange-Bertalot	x	
Surirella brebissonii v. *kuetzingii* Krammer & Lange-Bertalot	x	
Surirella brightwellii W. Sm.	x	
Surirella elegans Ehr.	x	
Surirella linearis W. Sm.	x	x
Surirella minuta Bréb.	x	
Surirella ovalis Bréb.	x	
Surirella robusta Ehr.		x
Surirella splendida (Ehr.) Kütz.	x	x
Surirella subsalsa W. Sm.	x	
Surirella tenera W. Greg.	x	
Tabellaria binalis (Ehr.) Grun.	x	
Tabellaria fenestra (Lyngbya) Kütz.	x	x
Tabellaria flocculosa (Roth) Kütz.	x	x
Tetracyclus glans (Ehr.) Mills	x	
Tetracyclus rupestris (Braun) Grun.	x	
Tryblionella apiculata Greg.	x	
Tryblionella calida (Grun.) Mann	x	
Tryblionella compressa (Bailey) M. Poulin	x	
Tryblionella corctata (Grun.) Mann	x	
Tryblionella hungarica (Grun.) Frenguelli	x	
Tryblionella levidensis W. Sm	x	
Tryblionella littoralis (Grun.) Mann	x	
Ulnaria ulna (Nitz.) P. Compère	x	x
Ulnaria ulna v. *acus* (Kütz) Lange-Bertalot	x	