Development and Evaluation of Tolerance Values for Lahontan Region Invertebrates
Preliminary Analysis Summary – February 28, 2007

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Data Source: Full Lahontan data set used for the Lahontan IBI

This data set contains 500 bugs per sample based on a 100-bug re-sampling from each of the original 5 replicate samples. There are 134 samples in this data set, consisting of 80 sites sampled over 6 years (1998 to 2003). Most sites are represented in the data set as a single site-date combination (44 of 80 sites), while 25 sites are represented in the dataset as 2 site-date combinations/surveys, 4 sites are represented as 3 site-date combinations/surveys, and 7 sites are represented as 4 site-date combinations/surveys (i.e., 4 years when that site was surveyed and where each year is included as a separate "sample"). The environmental data are likewise the same as were used in the Lahontan IBI development.

The data set was subdivided by eliminating less common taxa from the analysis. Different cut-offs were evaluated for selecting taxa that were present at enough sites-dates combinations for robust statistical analyses, and a cut-off of 18 site-date combos was used (i.e., if a taxon was present in 17 or less "samples" or site-date combos in the data set, it was not considered further in the tolerance value derivation). This represents a fairly low cut-off, requiring that a taxon be present in only 13% of the samples for inclusion. However, since the final assignment of tolerance involves comparing the weighted average scores among taxa, this level was chosen in order to obtain a relatively large pool of taxa that would define a broad range of sensitive-to-tolerant responses and serve as the basis for assigning tolerance values. Using this cut-off of 18 site-date combindations, a total of 99 taxa were retained for further analysis.

Analyses were based on relative abundance and not absolute density on the streambed. Fixed-count samples were created as 100 bugs drawn (statistically re-sampled) from each of 5 different samples with different levels of processing (subsampling), so it was not possible to equate these re-sampled data to an actual density. These analyses are therefore limited to using increases or decreases in the abundance of taxa relative to one another rather than actual increases in total abundance in the stream (although the two are likely correlated). The full "invertebrate + environmental variable" data set used for these analyses is included as the first sheet in the results Excel workbook (Tolerance.values.results_1.March.07).

Analyses [Following the guidance of Yuan (2004)].

We considered various forms of "abundance" or "commonness" for the taxa (i.e., number of samples, median abundance, mean abundance), but ultimately decided that what was necessary were those taxa at the most sites and thus for which we would have the greatest possibility of detecting important shifts in frequency along environmental gradients (i.e., patterns where a taxon was present at just 5 sites and clustered in some region of the environmental gradient was not viewed as evidence of the affinity or preference of that taxon for those specific habitat conditions).

The foundation of the analysis was to calculate weighted averages for each of the 99 "common" taxa for each of four environmental gradients. These four environmental gradients were:

1. Percent Fines-Sand-Gravel (FSG)
2. Temperature
3. Riparian Cover
4. Percent Bank Erosion

The calculation of weighted averages is relatively simple, and is akin to the calculation of a biotic index such as that of Hilsenhoff. The following is a summary of how these calculations were made for a hypothetical taxon, with respect to distribution along a sedimentation gradient:

Sample	Abundance	% FSG	Abund*FSG
1	200	50%	10,000
2	0	80%	0
3	25	25%	625
4	5	25%	125
5	18	5%	90
Sum =	248	-	10,840

Weighted Average = sum(Abund*FSG) / sum(Abundance)
= 10,840 / 248 = 43.7%

So, the apparent "optimum preference" of this taxon is for %FSG of around 44%.
[note the minimum number of samples required is actually 18, or 13% of 134 sites]

This procedure was repeated for each of the 99 taxa for each of the four environmental gradients. The creation of new tolerance values (TV) then involves converting these raw weighted averages to a 0-to-10 scale (just as done with the individual metrics in an IBI development to get them on the same scale). The minimum "weighted average" score for %FSG, Temperature, and % Bank Erosion was given a 0 score, the maximum given a 10 score, and the intermediate values are interpolated linearly between these two scores. For Riparian Cover, the 0 was given to the maximum score and the 10 given to the minimum riparian cover score. To create a more categorical TV for each taxon (as with Hilsenhoff tolerance values), these continuous scores between 0 and 10 were then rounded to the nearest integer.

Results [see Table of raw Tolerance Values, Cross-Tabulations, and Graphs for Selected Taxa]

The main result table is the spreadsheet ("New TVs") with both the original tolerance values used for each of these 99 taxa in our Lahontan IBI analysis (based on those given in CAMLnet/SAFIT STE documentation) and the new tolerance values for each of the four environmental gradients. This table also includes the number of site-date combinations for each taxon (out of 134 total). We also ran cross-tabulations to see whether there was consistency between the original tolerance values and the new tolerance values for each environmental gradient (refer to spreadsheets for each variable). This was done separately for each environmental gradient, and only the total number of taxa in each grid cell is reported (but not the identify of each; this can be determined from the first table).

To exhibit the most representative results from this analysis, taxa were selected that spanned the original tolerance value scale and for which we had a relatively high proportion of site-date combinations. From this, 8 taxa were selected across different taxonomic groups for simple graphical summaries that demonstrate the weighted average calculation. These graphs show relative abundance (# of the selected taxon / 500 total per sample) over the measured range of the environmental variable, and display all samples including those where the taxon was absent so that tolerance limits might be detected.

Discussion

The original Hilsenhoff tolerance values were based on correlations of invertebrate distribution with organic pollution loading (urban and agricultural) in lowland streams of Wisconsin (Hilsenhoff 1982, 1987). The primary sources of disturbance in the Sierra Nevada mountain streams examined here were related to channel degradation, erosion and sedimentation. Each of the environmental variables represents a component of this disturbance, with loss of stabilizing riparian cover, erosion of banks, deposition of smaller particle sizes (fines, sand and gravel), and higher temperatures (as shade cover is lost and livestock-exposed channels become wide and shallow). The tolerance values derived from these stressors were more closely correlated with one another than they were with the Hilsenhoff-derived tolerance values that have been the standard listing for California (CAMLnet and SAFIT lists). Sediment cover may be most similar in effect to organic loading (increased BOD), and was most highly correlated with the original values, followed by temperature (reduced oxygen availability at higher temperature). Riparian cover and bank erosion showed no correlation with the original tolerance values. Although the Hilsenhoff biotic index and associated tolerance values have been shown in many studies to be a robust indicator of generalized stress, the variables examined here measure another dimension of habitat disturbance. As such these TVs may be informative as separate or composite indicesof habitat conditions that are stressed by physical degradation. [note than an option for using these data would be to combine and average the four separate TVs and then re-scale these averages, and placement in integer ranks from 0-10 could also be done as even bin groupss rather than as interpolated values (because this results in fewer TVs falling into the very sensitive or very tolerant values of the scale). Use of these tolerance values together should reflect a more integrated tolerance of physical habitat disturbance rather than any one alone, though it also risks dampening the signal. Percent FSG may be the most direct and clear TV response as it represents an in-stream integrative measure of benthic habitat deterioration. Differential sensitivity to varied stressors and how tolerance values are derived has been reviewed and integrated in several recent comprehensive EPA reports (Blocksom and Winters 2006, Yuan 2006).

It is difficult to compare the tolerance values derived here to Hilsenhoff-derived TVs not only because the nature of the stressor source differs, but because Hilsenhoff scaled these values by the subjective approach of using judgment based on natural history experience and an extensive data set that was used to make adjustments. As such, the approach taken here (where the weighted average relative abundance was scaled to the minimum-maximum extremes of the taxa response distribution) would not produce comparable data sets, so lack of correspondence is not surprising.

In a study of fine sediment effects on invertebrates in Idaho streams (Relyea et al. 2000), common taxa were placed into 4 broad categories of tolerance according frequency of presence/absence associations in streams with varied levels of percent fines and sand present.

Surveys of caddisflies from streams of the southwest United States (Blinn and Ruiter 2006) found close agreement between USEPA tolerance values and new TVs based on conductivity and embeddedness-related disturbance when compared for species-level listings, but poor correspondence for those listed only at the genus level (only 7 of 42 genera were within 2 units of the USEPA TVs). These TVs were based on weighted average relative abundance analysis. This suggests that species-specific tolerances are important to separate from the genus-level when possible, but that TVs based on different stressor responses may not correspond. The traits permitting adaptation to organic pollution may have little or no function in resisting the influence of sedimentation, conductivity, or metals for example. Specialization in coping with particular stressors may produce taxa with narrow capacities for surviving in disturbance gradients, while others may possess generalized traits that enable broader though non-specific tolerances.

Contrast of adjusted tolerance values for taxa shared between southwestern caddisflies and Lahontan Basin based on substrate sedimentation measures

Caddisfly species	Adjusted tolerance values based on embeddedness (Blinn & Ruiter 2006)	Adjusted tolerance values based on % FSG (this study)
Brachycentrus americanus	1	3
*Hydropsyche occidentalis**	6	7
*Ceratopsyche oslari**	5	5
Hydroptila arctia and *H. ajax**	6 and 7	8

*compared to genus-level identifications of larvae in Lahontan data set

<u>Problems with the data set and analysis: sample size, coverage, and validation</u>

- The range of very sensitive (0) to very tolerant (10) taxa were not adequately represented here, as they were not common enough in the data set, in part because site conditions tended toward the moderate (central tendency of the distribution) and the extremes were not sampled with enough frequency. That is, sample size was too small and not evenly represented across the disturbance gradients.
- Disturbance gradients were mixed (but highly correlated for channel degradation), so this may be an advantage as well.
- Need to test this data set through validation with an independent set of sites distributed over a broad gradient physical habitat disturbance

References

Blinn, D.W. and D.E. Ruiter. 2006. Tolerance values of stream caddisflies (Trichoptera) in the lower Colorado River basin, USA. The Southwestern Naturalist 51:326-337.

Blocksom, K.A. and L.Winters. 2006. The evaluation of methods for creating defensible, repeatable, objective and accurate tolerance values for aquatic taxa. EPA 600/R-06/045. USEPA, National Exposure Research Laboratory, Cincinnati, Ohio.

Hilsenhoff, W.L. 1982. Using a biotic index to evaluate water quality in streams. Department of Natural Resources Technical Bulletin No. 132. Madison, Wisconsin. 22 pp.

Hilsenhoff, W.L. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomologist 20:31-39.

Relyea, C.D., G.W. Minshall, and R.J. Danehy. 2000. Stream insects as bioindicators of fine sediment. Water Environment Federation.

Yuan, L.L. 2004. Assigning macroinvertebrate tolerance classifications using generalized additive models. Freshwater Biology 49:662-677.

Yuan, L.L. 2006. Estimation and application of macroinvertebrate tolerance values. EPA/600/P-04/116F. USEPA, National Center for Environmental Assessment. Washington, D.C. 20460.

<u>Tolerance Value Listings for California:</u>

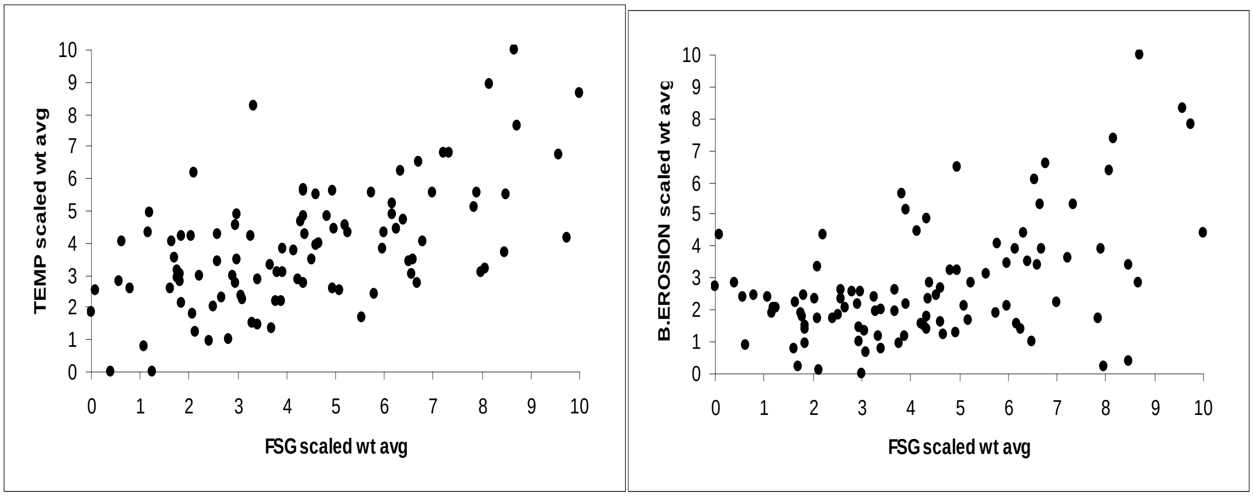
CAMLnet (California Aquatic Monitoring Laboratory network). List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort (STE). 2003 revision.

[and SAFIT – Southestern Association of Freshwater Invertebrate Taxonomists, similar more recent listing documents available online: http://www.waterboards.ca.gov/swamp/safit/html]

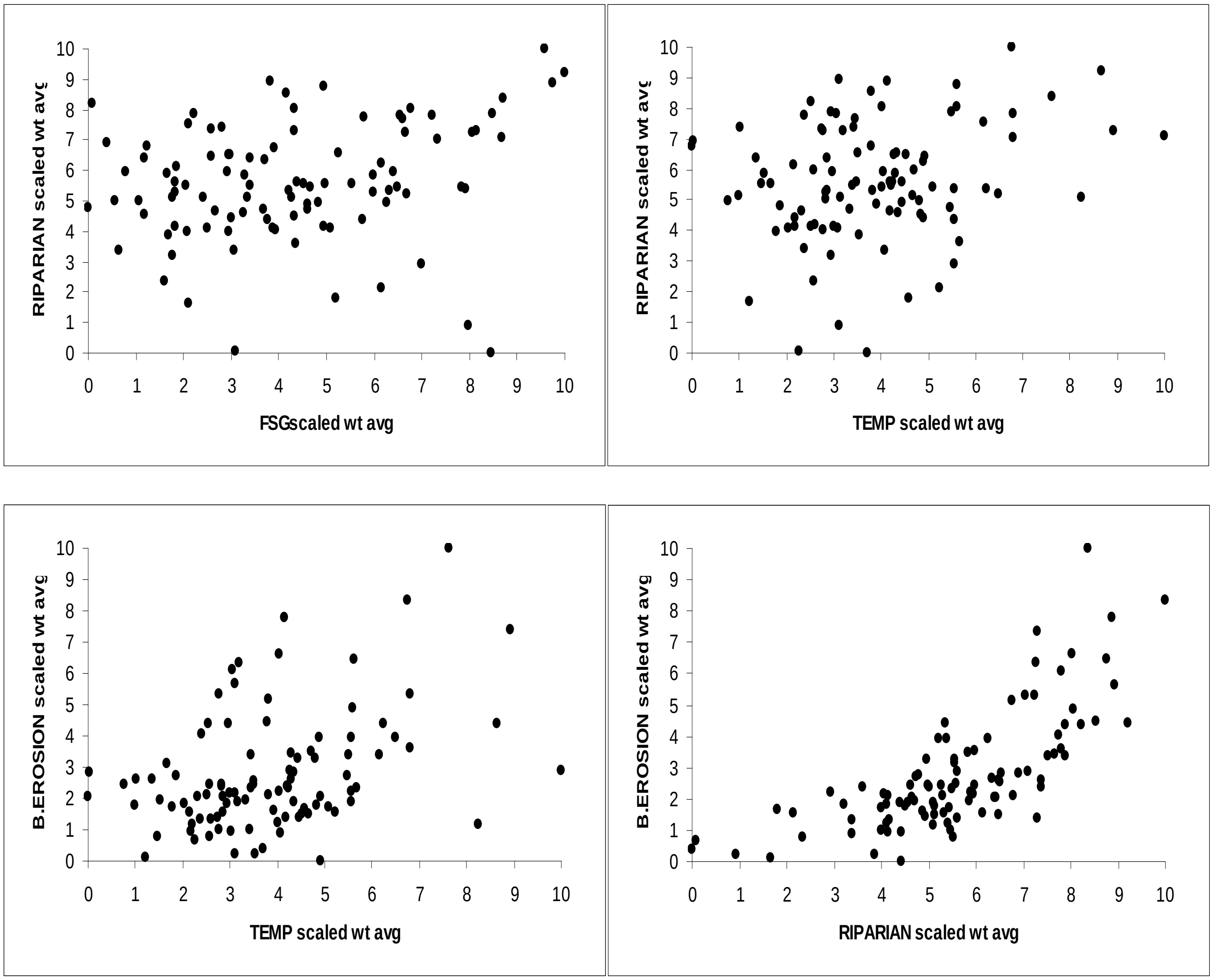
Correlations among tolerance value stressor variables and original (CAMLnet STE) listings of tolerance values drawn mainly from Hilsenhoff designations.

Correlation Matrix for Decimals (unrounded TVs):					
	Old TVs	*FSG*	*TEMP*	*RIPAR*	*EROS*
Old TVs	1				
FSG	0.403281	1			
TEMP	0.342382	0.578249	1		
RIPAR	0.050788	0.228655	0.240978	1	
EROS	0.110109	0.49281	0.386773	0.730451	1

Percent FSG weighted averages re-scaled to 0-10 range in comparison to old tolerance value (CAMLnet STE) listings for 99 taxa (this stressor had the highest correlation).



Inter-correlated tolerance values that measure different components of physical habitat degradation. These plots show that the stressors often co-vary to a substantial extent and that tolerance is a response to these related environmental changes.



Inter-correlated variables that measure different components of physical habitat degradation. These plots show that while the inter-correlations are mostly high, tolerance to both high temperature and low riparian cover or temperature and high bank erosion are somewhat less related than other variables. Where banks are highly eroded, riparian cover is low, so these tolerances are strongly inter-correlated.

Taxon **and table of tolerance values for habitat stressors and standard list of TVs for California**	Number of site/dates (out of 134)	Original Tolerance Values (CAMLnet)	% FSG -weighted ave	% FSG 1-to-10 scale	Temperature - weighted ave	Temperature 1-to-10 scale	% Riparian - weighted ave	% Riparian - 1-to-10 scale	% Bank Erosion - weighted ave	% Bank Erosion - 1-to-10 scale
Baetis	127	5	0.51	4	13.9	3	0.36	5	0.13	2
Diphetor.hageni	34	5	0.54	4	16.2	6	0.42	4	0.15	2
Ameletus	60	0	0.52	4	14.4	4	0.24	7	0.30	5
Paraleptophlebia	110	4	0.62	6	14.9	4	0.29	6	0.21	3
Serratella	96	2	0.61	6	13.0	2	0.19	8	0.24	4
Attenella.delantala	45	2	0.46	3	11.6	1	0.21	7	0.17	3
Caudatella.hystrix	34	1	0.48	3	12.9	2	0.43	3	0.10	1
Drunella.doddsi	58	0	0.38	1	11.3	1	0.34	5	0.16	2
Drunella.flavilinea	47	0	0.43	2	14.8	4	0.31	5	0.15	2
Drunella.grandis	47	0	0.57	5	16.2	6	0.13	9	0.37	6
Drunella.spinifera	34	0	0.43	2	12.4	2	0.40	4	0.12	2
Cinygmula	86	4	0.51	4	11.9	1	0.27	6	0.17	3
Epeorus	54	0	0.37	1	13.1	3	0.29	6	0.16	2
Rhithrogena	66	0	0.44	2	11.6	1	0.33	5	0.12	2
Malenka	46	2	0.58	5	15.1	5	0.52	2	0.12	2
Zapada	69	2	0.63	6	15.8	5	0.50	2	0.11	2
Capniidae	41	1	0.65	7	13.6	3	0.19	8	0.35	6
Plumiperla.Haploperla	47	1	0.74	8	16.0	6	0.18	8	0.21	3
Suwallia	36	1	0.44	2	13.5	3	0.18	8	0.26	4
Sweltsa	80	1	0.60	6	12.2	2	0.31	6	0.19	3
Yoraperla	29	1	0.48	3	12.8	2	0.61	0	0.07	1
Cultus	29	2	0.47	3	13.6	3	0.29	6	0.15	2
Frisonia.picticeps	30	2	0.41	2	13.7	3	0.34	5	0.13	2
Isoperla	55	2	0.61	6	16.1	6	0.37	4	0.13	2
Skwala	57	2	0.54	4	16.1	6	0.17	8	0.28	5
Calineuria.californica	20	2	0.42	2	14.7	4	0.31	6	0.10	1
Doroneuria.baumanni	48	1	0.45	3	12.6	2	0.39	4	0.13	2
Rhyacophila.acropedes	49	1	0.52	4	12.8	2	0.39	4	0.09	1
Rhyacophila.angelita	22	0	0.38	1	14.9	4	0.36	5	0.13	2
Rhyacophila.arnaudi	32	0	0.49	3	12.1	2	0.29	6	0.13	2
Rhyacophila.betteni	46	1	0.41	2	13.1	3	0.49	2	0.07	1
Rhyacophila.sibirica	41	0	0.43	2	11.8	1	0.52	2	0.04	0
Hydroptila	41	6	0.72	8	13.8	3	0.22	7	0.36	6
Brachycentrus.americanus	37	1	0.45	3	14.0	3	0.21	7	0.15	2
Micrasema	34	1	0.47	3	15.5	5	0.37	4	0.03	0
Agapetus	20	0	0.36	1	14.6	4	0.43	3	0.08	1
Glossosoma	62	1	0.49	3	13.4	3	0.26	6	0.14	2
Arctopsyche.grandis	32	1	0.39	1	10.6	0	0.24	7	0.14	2
Ceratopsyche	77	4	0.55	5	14.6	4	0.32	5	0.10	1
Hydropsyche	18	4	0.68	7	17.3	7	0.23	7	0.31	5
Lepidostoma	52	1	0.65	7	13.3	3	0.22	7	0.31	5
Wormaldia	21	3	0.49	3	18.8	8	0.34	5	0.09	1

Taxon	Number of site/dates (out of 134)	Original Tolerance Values	% FSG -weighted ave	% FSG 1-to-10 scale	Temperature - weighted ave	Temperature 1-to-10 scale	% Riparian - weighted ave	% Riparian - 1-to-10 scale	% Bank Erosion - weighted ave	% Bank Erosion - 1-to-10 scale
Continued….										
Apatania	23	1	0.47	3	13.3	3	0.40	4	0.08	1
Pedomoecus.sierra	19	0	0.36	1	13.4	3	0.34	5	0.16	2
Neophylax	46	3	0.41	2	14.1	4	0.40	4	0.04	0
Heterlimnius.corpulentus	25	4	0.71	8	13.7	3	0.57	1	0.04	0
Optioservus.divergens	50	4	0.71	8	15.6	5	0.32	5	0.12	2
Optioservus.quadrimaculatus	98	4	0.71	8	16.1	6	0.32	5	0.24	4
Antocha.monticola	52	3	0.47	3	15.1	5	0.26	6	0.11	1
Dicranota	51	3	0.63	6	15.0	4	0.34	5	0.11	1
Hexatoma	50	2	0.51	4	13.7	3	0.12	9	0.32	6
Atherix.pachypus	20	2	0.35	0	10.6	0	0.23	7	0.18	3
Bezzia.Palpomyia	66	6	0.63	6	15.4	5	0.27	6	0.24	4
Chelifera	33	6	0.41	2	14.6	4	0.29	6	0.15	2
Pericoma	48	4	0.49	3	12.0	1	0.31	6	0.07	1
Simulium	109	6	0.65	7	17.0	6	0.33	5	0.24	4
Diamesa	20	6	0.62	6	14.4	4	0.32	5	0.14	2
Pagastia	71	1	0.53	4	15.2	5	0.33	5	0.11	2
Potthastia.gaedii	30	2	0.54	4	13.3	3	0.21	7	0.10	1
Pentaneura	34	6	0.72	8	19.4	9	0.21	7	0.41	7
Thienemannimyia	77	6	0.66	7	14.6	4	0.17	8	0.37	7
Apedilum	18	6	0.81	10	19.2	9	0.11	9	0.26	4
Phaenopsectra	22	7	0.79	10	17.3	7	0.06	10	0.46	8
Polypedilum.aviceps	42	6	0.39	1	15.5	5	0.26	6	0.14	2
Pseudochironomus	20	5	0.75	9	20.5	10	0.22	7	0.18	3
Cladotanytarsus.vanderwulpi	38	7	0.80	10	14.7	4	0.13	9	0.44	8
Micropsectra	96	7	0.46	3	12.9	2	0.36	5	0.14	2
Rheotanytarsus	53	6	0.65	7	14.0	3	0.19	8	0.21	3
Stempellinella	37	4	0.33	0	12.5	2	0.35	5	0.17	3
Tanytarsus	46	6	0.53	4	14.3	4	0.14	9	0.26	4
Brillia	25	5	0.41	2	13.5	3	0.44	3	0.13	2
Corynoneura	88	7	0.55	5	16.0	5	0.35	5	0.17	3
Cricotopus.Nostococladius	46	7	0.49	3	14.8	4	0.36	5	0.16	2
Cricotopus.Orthocladius	130	7	0.58	5	14.9	4	0.25	7	0.18	3
Eukiefferiella.brehmi	92	8	0.53	4	13.4	3	0.32	5	0.11	2
Eukiefferiella.claripennis	54	8	0.56	5	15.4	5	0.34	5	0.20	3
Eukiefferiella.devonica	30	8	0.42	2	12.7	2	0.28	6	0.11	2
Eukiefferiella.gracei	52	8	0.64	7	14.0	3	0.31	5	0.08	1
Heleniella	28	6	0.57	5	13.2	3	0.39	4	0.10	1
Krenosmittia	21	1	0.33	0	13.1	3	0.16	8	0.26	4
Parametriocnemus	74	5	0.57	5	15.0	4	0.31	6	0.20	3
Rheocricotopus	52	6	0.42	2	13.4	3	0.33	5	0.16	2
Synorthocladius	27	2	0.75	9	18.2	8	0.15	8	0.55	10

Taxon	Number of site/dates (out of 134)	Original Tolerance Values	% FSG -weighted ave	% FSG 1-to-10 scale	Temperature - weighted ave	Temperature 1-to-10 scale	% Riparian - weighted ave	% Riparian - 1-to-10 scale	% Bank Erosion - weighted ave	% Bank Erosion - 1-to-10 scale
Continued….										
Thienemanniella.xena	61	6	0.47	3	14.1	4	0.26	7	0.16	3
Tvetenia.bavarica	107	5	0.55	5	14.1	3	0.31	6	0.16	2
Oligochaeta	112	5	0.64	6	15.3	5	0.29	6	0.21	4
Dugesia	66	4	0.57	5	13.1	3	0.39	4	0.14	2
Ostracoda	62	8	0.67	7	16.1	6	0.45	3	0.15	2
Pisidium	31	8	0.74	8	14.3	4	0.62	0	0.05	0
Atractides	81	8	0.63	6	16.8	6	0.32	5	0.26	4
Aturus	89	5	0.52	4	13.7	3	0.39	4	0.14	2
Feltria	50	5	0.42	2	13.6	3	0.39	4	0.08	1
Hydrozetes	38	5	0.43	2	16.7	6	0.20	8	0.21	3
Hygrobates	19	8	0.68	7	17.3	7	0.18	8	0.22	4
Lebertia	97	8	0.54	4	14.8	4	0.31	6	0.18	3
Protzia	44	8	0.55	5	14.5	4	0.35	5	0.12	2
Sperchon	92	8	0.54	4	15.4	5	0.37	5	0.12	2
Testudacarus	49	5	0.51	4	12.8	2	0.37	4	0.08	1
Torrenticola	52	5	0.45	3	14.8	4	0.26	6	0.17	3