Macroinvertebrate Bioassessment of Black Hills Streams, South Dakota

Final Report

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SD GFP Report 2006-09

Submitted
June 16, 2006

Abstract

Macroinvertebrate data from 64 stream sites sampled in 2003 and 2004 throughout the Black Hills of South Dakota was evaluated to develop an alternative approach to reference site selection. Seventy-nine macroinvertebrate community variables (metrics) were screened for variability, precision, response to physical habitat condition, and redundancy. Six macroinvertebrate metrics were selected that had a high signal:noise ratio ($\geq$2.0), were variable across a range of conditions, had a strong correlation (p <.01, Spearman's rho) to habitat quality, and were not highly correlated to other metrics (*r* < 0.75, Spearman's rho). Selected macroinvertebrate metrics represented species composition, function feeding guilds, life history, and tolerance to pollution. This approach provides an alternative in identifying reference condition in an "ecologically uniform" region where traditional approaches may not be suitable.

Introduction

Human disturbance of landscapes can have a profound impact on aquatic systems ranging from water quality and habitat degradation to altered hydrologic and energy regimes (McCormick et al. 2001). Traditional chemical evaluations, though useful in assessing point source pollutants, have been largely inadequate in monitoring nonpoint source impacts to stream biota due in part to confounding interactions with physical habitat disturbance (Barbour et al. 1996). Biological monitoring integrates changes in stream biota (e.g. fish, macroinvertebrates, periphyton) from the individual to assemblage level, and thus provides a more comprehensive analysis when assessing human disturbance to stream integrity (Karr et al. 1986, Karr and Chu 1999).

Although the use of biological indices has been prevalent in the past twenty years, bioassessment in South Dakota has received little attention. Most biomonitoring studies in South Dakota have focused on fish communities in the Big Sioux, Vermillion, and James River basins (Milewski et al. 2001, Shearer and Berry 2002); however, fish biomonitoring is limited in areas of South Dakota where the native fish community is naturally depauperate, such as the Black Hills. The macroinvertebrate community would be more appropriate target for stream bioassessment of the Black Hills ecoregion. Despite the unique nature of the Black Hills (Hall et al. 2002), baseline data, needed to develop an ecoregion-based macroinvertebrate index, are lacking.

Integral in any bioassessment study is the identification of reference conditions to establish biological standards. Aquatic reference sites are often selected as benchmarks in biological assessments (e.g. multi-metric or multivariate indices) by evaluating a suite of human disturbance parameters at the watershed and local level (Hughes 1995). This evaluation process relies on the premise that a range of variation in human disturbance exists within the area of interest to clearly distinguish reference from impact site conditions (Yuan and Norton 2003). However, this approach may be limited in a region where large tracts of land are in public ownership and administered by a single entity, partially restricting anthropogenic impacts at the watershed level. In regions, such as the Black Hills of South Dakota, where large-scale management policies provide a certain level of protection from human influence, local-level variables may play a greater role in determining reference site selection. Furthermore, biological communities, as a reflection of local physical, chemical, and anthropogenic parameters, may offer an alternative approach to defining reference benchmarks (Gerritsen et al. 2000). The objectives of this study were to 1) screen a variety of macroinvertebrate metrics based on four performance criteria, and 2) use a subset of metrics to identify stream reaches within the Black Hills that exhibit reference and disturbed site characteristics. This study was initiated in an effort to develop a macroinvertebrate-based biological assessment tool for identifying stream reaches of high biological significance (i.e. reference sites) and stream reaches were appropriate management techniques would improve the stream conditions.

Methods

This project involved two primary components: 1) macroinvertebrate sampling at selected stream sites, and 2) taxonomic processing of samples. Jeff Shearer, South Dakota Game Fish & Parks (SDGF&P), conducted field sampling, data analysis, and index development. Taxonomy was contracted to a consulting laboratory.

<u>Site Selection</u>:
Sites were sampled between late June 2003 and early September 2004 throughout the Black Hills ecoregion in South Dakota. Most sites were sample during summer months; however, a few locations were sampled seasonally to assess temporal variability in the macroinvertebrate community. Sites were selected on 2nd to 4th order streams. Final site location depended on land access, site conditions (e.g. lack of water), and how well sites represent the stream as a whole. First order streams were avoided due to the tendency to become intermittent; however, several 1st order streams (e.g. Raddick Gulch, East Fork Cleopatra Creek) were sampled due to strong groundwater inputs that resulted in perennial flows. Site locations varied from entirely encompassed within a natural area (Pine Creek) to immediately downstream from an urban area (Whitewood Creek). However, most site locations were predominantly in narrow grassy meadows or deciduous (quaking aspen *Populus tremuloides* and willows *Salix* spp.) riparian areas surrounded by Ponderosa pine *Pinus ponderosa* forests. Whenever possible, site locations were matched with nearby stream electrofishing sites established by SDGF&P's Fisheries Program.

<u>Invertebrate Collection</u>:
Sampling procedures followed the macroinvertebrate protocol established for the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program Western Pilot (EMAP-WP) wadeable stream project (Peck et al. *unpublished draft*). Following the EMAP-WP protocol allowed for two distinct advantages: 1) procedures have been developed and tested for wadeable streams throughout the western U.S., and 2) data comparability with EMAP-WP sites in the Black Hills. The only modifications to the EMAP-WP procedure were to collect samples along eight transects and a targeted-

riffle sample was not taken. Following sample collection, macroinvertebrates were sorted from sample debris (e.g. substrate, organic matter, etc.), placed in a sample container with an identification number and sample date, and sent to a laboratory for taxonomic processing.

In addition to the collection of macroinvertebrates, a physical habitat evaluation was conducted at each sampling site. The evaluation was a modification of the rapid bioassessment protocol for high gradient streams presented in Barbour et al. (1999). Epifaunal substrate / available cover, substrate embeddedness, velocity / depth regime, sediment deposition, channel alteration, vegetative cover, riparian width, and local disturbance were habitat variables evaluated at the reach scale and given a score of 5 (optimal) through 0 (poor) for a maximum score of 50.

Taxonomic Processing:
The Macroinvertebrate Lab at Valley City State University in Valley City, North Dakota processed and identified all samples. A fixed-count of 300 individuals was used to sort and process all samples. All macroinvertebrates were identified to the genus/species level, except for Chironomidae which were identified to the sub-family level. A voucher sample of each species identified was fixed for quality assurance / quality control purposes. All processed samples are currently archived at Valley City State University. Voucher specimens are housed with SDGF&P.

Metric Selection and Screening:
I calculated and evaluated 79 metrics representing pollution tolerance, species richness, trophic guilds, life history, and habitat preference of the macroinvertebrate community. Regional pollution tolerance values listed in Barbour et al. (1999) were used for calculation of tolerance metrics. In an effort to reduce temporal variability, only data from sites sampled during summer months were used for metric testing. Metrics were screened in a stepwise process based on variability, precision, sensitivity, redundancy, and adjustment for watershed size similar to those methods used by Klemm et al. (2003) and Bramblett et al. (2005). The concepts behind the metric screening process are to identify optimal metrics for evaluating a variety of site conditions but not influenced by measurement error or natural variability. That is, to identify those metrics that measure a predicted response only to anthropogenic disturbances. Metric variability was evaluated using a range test. Those metrics with a range less than four or > 90% zeros were eliminated from further consideration. A low range indicates a metric that would be unresponsive across a gradient of conditions, and thus would not be useful in distinguishing site quality.

Metric precision was tested by a signal : noise ratio. Signal represents the variability of metrics among sites whereas noise represents within-year repeat variance of the same site. Metrics were rejected if their signal : noise ratio was < 2. A low signal : noise ratio indicates a metric is subject to measurement error.

Metric sensitivity was assessed by comparing metrics with reach-wide habitat quality assessment. A Spearman's rank correlation coefficient (*r*) was used to correlate metrics to habitat quality ratings. Only those correlations with alpha values < 0.01 were considered sensitive to human disturbance.

Metric redundancy was evaluated by correlating remaining metrics with a Spearman's rank correlation coefficient. If two metrics had a correlation coefficient (r) $\geq$ 0.75, the metric with the poorest relationship (based on scatter plots) to habitat quality was rejected. This test was preformed to identify those metrics that were highly correlated with one another, and thus contributed little additional information to distinguishing site quality.

Certain macroinvertebrate metrics are expected to increase with stream size in accordance to the River Continuum Concept (Vannote et al. 1980). As such, some metrics may vary based on natural variables regardless of human disturbance. Metrics were calibrated to watershed size (km^2) based on Spearman's rank correlation coefficients ($p < 0.01$) and scatter plots.

<u>Site Ranking Criteria</u>:
Reference and disturbed sites were designated according to their ranking based on metric percentiles. Reference sites were those sites scoring in the 80th percentile (20th for negatively responding metrics) for at least 67% of selected metrics. Disturbed sites were those with sites scoring in the 20th percentile (80th for negatively responding metrics) for at least 67% of selected metrics. The percentile cut-offs were intentionally kept conservative so that selected sites represented the best or worst case scenarios with regards to site condition. In an ecologically uniform region, conservative selection criteria should not lead to the exclusion of true reference or disturbed sites as might be expected in a region with more diverse geologic and hydrologic features.

Results

Eighty-eight samples were collected at 64 locations throughout the Black Hills. Sample site locations ranged in size from 1 km^2 (East Fork Cleopatra Creek) to 878 km^2 (Rapid Creek) (Table 1). One hundred thirty-eight different taxa were collected at the sample locations representing 27 orders and 74 families of macroinvertebrates (Appendix A). Insects from the order Diptera were the most diverse group represented in samples with 32 taxa identified while round worms (Phyla: Nemata and Nematomorpha) were the least diverse.

Habitat quality scores at sampling sites range from excellent (48) to poor (15) with a mean ($\pm$ 1 SD) score of 39 ($\pm$ 6.36) for all sites. Means for individual habitat variables were assessed to identify habitat variables most- and least-effected by disturbance across all sites. Overall, sediment deposition had the lowest mean score (3.2 $\pm$ 1.20) indicating that sedimentation was the most-prevalent perturbation assessed at sample sites. Sediment deposition scores also had the highest coefficient of variation (0.38), suggesting a wider range of variability in this habitat measure across sites than other variables. Channel alteration had the highest mean (4.4 $\pm$ 0.87) due to low degree of direct channel modifications (e.g. channelization, armored banks) across sample sites.

Metric Screening:
Ten of 79 metrics were eliminated from further consideration after the range test (Table 2). The precision test rejected 29 additional metrics due to a low signal : noise ratio. Of the 40 metrics remaining, only 8 were significantly correlated (Spearman's rho (*r*), $p<0.01$) with habitat quality. Two metrics, Number of EPT Taxa and Number of EPT Taxa minus Baetidae, were highly correlated ($r \geq 0.75$) with several other metrics, and thus were rejected. Number of Intolerant Taxa was highly correlated with Number of Uni-Voltine Taxa ($r = 0.747$) but was retained as these metrics provide two distinct measures (macroinvertebrate community pollution tolerance versus life history). The remaining 6 metrics, Number of Plecoptera, Number of Shredders, Proportion of Oligochaetes and Hirudinea, Number of Uni-Voltine Taxa, Proportion of Semi-Voltine Individuals, and Number of Intolerant Taxa, displayed a range of variability across site conditions, had a low sampling error, were sensitive to habitat conditions and did not show any significant correlations (Spearman's rho, $p < 0.01$) to watershed size (Table 3).

Site Rankings:
Eight sites met the criteria of reference sites while ten sites met designation criteria for disturbed sites (Table 4). Reference sites were primarily characterized by an undisturbed riparian area with silt-free, gravel and cobble substrates. Disturbed sites, on the other hand, had heavily silted substrates with obvious nearby human influences (e.g. multiple stream crossings, degraded riparian conditions, etc). The two exceptions for disturbed sites were the Rhoades Fork Rapid Creek and Pine Creek. Although the sample location on Rhoades Fork Rapid Creek classified as a disturbed site, the upstream watershed was primarily forest land with very few human disturbances. Stream substrate for this particular site was cemented due to a unique geologic feature which provided poor habitat for most aquatic insects. Pine Creek met criteria for a disturbed site, but intermittent flows likely contributed to the poor metric values for this location. The riparian zone for Pine Creek was undisturbed and the entire upstream watershed is located within a natural area.

Discussion

The term "reference site" and its implications in biological assessments has been debated greatly in recent years (Hughes 1995, Reynoldson et al. 1997, Gerritsen et al. 2000, Hawkins et al. 2000, Chessman and Royal 2004, Herbst and Silldorff 2006). Terms, such as least disturbed, pristine, best available condition and least impacted, have all been used to describe reference conditions. To some reference implies those natural conditions that existed prior to European settlement of North America. To others reference simply means the best of what is left. That is, given current conditions the areas that most closely reflect natural conditions prior to human influence should reflect reference conditions. For the purposes of this study, reference represents the least-disturbed conditions given the present status of streams within the Black Hills ecoregion. Stream locations selected as reference sites should not be considered "pristine" or without human impacts. However, the process of distinguishing between site conditions based on macroinvertebrate community characteristics should provide a strong indication of those stream locations that currently reflect a standard for biological assessment or mitigation purposes on Black Hills streams.

Metric screening criteria were kept conservative to only target those macroinvertebrate community characteristics that displayed a large degree of separation between reference and disturbed site conditions. The result was only 6 of 79 potential metrics passing the screening process. However, the information provided by these 6 metrics proved useful in identifying reference and disturbed sites. The Number of Plecoptera metric provides a direct measure to an especially sensitive group of taxa. Huntsman et al. (1999) documented 27 stonefly (Order: Plecoptera) species in the Black Hills. Stoneflies are a taxonomic group often characteristic of cool, clear running water and are often impacted by changes in stream temperature or siltation (Stewart and Harper 1996). The Proportion of Oligochaetes and Hirudinea (e.g. leeches) metric provides another measurement of taxa richness. Leeches are predominant in sluggish, warm waters with excessive nutrient enrichment, siltation, and are capable of withstanding anoxic conditions (Davies 1991). An abundance of leeches at a site would be a strong indication of severe anthropogenic disturbance. Number of Shredder Taxa is a measure of the trophic stability of a stream. Under tenants of the River Continuum Concept (Vannote et al. 1980), shredders process coarse particulate organic matter and are usually most abundant in headwater streams. Impacts to a stream's riparian area that directly alter allochthonous inputs (e.g. leaves, twigs, grasses) would have a direct impact on the trophic structure of the associated macroinvertebrate community. Number of Uni-Voltine Taxa represents an assessment of macroinvertebrate community life history structure. Uni-voltine taxa are those insects that complete one life history cycle (egg to adult) in one year. Multi-voltine taxa are often the first insects to colonize a stream after a large-scale disturbance and are most-resilient to continuous disturbance. Proportion of Semi-Voltine Individuals, similar to Number of Uni-Voltine Taxa, is another assessment of macroinvertebrate life history. Semi-voltine taxa complete their life cycle over two or more years. This metric is similar to "long lived species" metrics used in fish indices of biotic integrity by Bramblett et al. (2005) and Hughes et al. (1998). The presence of longer lived macroinvertebrates indicates a permanence of suitable habitat and connection to a source population. Number of Intolerant Taxa is a measure of tolerance to various forms of pollution. Tolerance metrics have been widely used for both macroinvertebrate (Maxted et al. 2000, Klemm et al. 2003) and fish (Karr 1981, Shearer and Berry 2002, Bramblett et al. 2005) indices of biotic integrity.

Several metrics, including Number of EPT Taxa and Number of Chironomidae Taxa, that are common in macroinvertebrate-based assessment indices were not selected following screening procedures for this study. Number of EPT Taxa, in reference to the number of mayfly (Order: Ephemeroptera), stonefly, and caddisfly (Order: Trichoptera) taxa, is widely used in stream assessment studies (see Karr and Kerans 1992, Barbour et al. 1996 and Klemm et al. 2002 as examples). Taxa from these orders comprise a diverse component of the Black Hills macroinvertebrate community (J. Shearer *personal observation*). However, due to multiple high correlations with other optimally performing metrics (e.g. Number of Plecoptera and Number of Intolerant Taxa), and thus high biological similarities, the Number of EPT Taxa metric was not selected. The Number of Chironomidae Taxa metric has also been used for large geographic-based macroinvertebrate assessments (also see Barbour et al. 1996 and Klemm et al. 2002) and even within South Dakota (Larson and Troelstrup 2001). Chironomids represented a large portion of the total individuals within the Black Hills streams (J. Shearer, *unpublished data*). However, due to taxonomic procedures taxa from this family were only identified to the sub-family level, which restricted variability in the metric range. A higher level of taxonomic resolution would increase the utility of the Number of Chironomidae Taxa metric (Waite et al. 2004).

This study provides a key step in the development of a macroinvertebrate-based assessment tool; however, further analyses of water quality, quantitative physical habitat, and landscape data would refine metric utility. Due to project and funding logistics, water quality information (e.g. nutrients, metals) was not collected at sample sites during this study. Water quality parameters as they relate to various levels of human influence are a common component of reference site selection for large geographic areas (Klemm et al. 2003, Yuan and Norton 2003, Bramblett et al. 2005). However, several water quality parameters, such as chlorides and nutrients, that are indicative of a high population density or large-scale land use alterations (e.g. conversion of prairie to row-crop agriculture) may not be applicable to the Black Hills ecoregion given the relatively low population density within most watersheds and the restrictions on land use (i.e. Black Hills National Forest).

An evaluation of quantitative physical habitat data versus a qualitative habitat assessment may provide more detailed information on local-scale habitat variables and their relation to macroinvertebrate community characteristics. Qualitative habitat assessments, such as the Rapid Bioassessment Protocol (Barbour 1999), were developed to provide a generalized characterization of localized physical habitat conditions without a labor-intensive field protocol. However, the variability of such qualitative assessments due to biases in recorder observations can limit utility in detailed data analysis (Hannaford and Resh 1995). All physical habitat evaluations during this project were performed by the same observer (J. Shearer), thus reducing sampling errors associated with multiple field crews. Furthermore, the intent of the physical habitat evaluation was to provide a generalized assessment of conditions to aid in distinguishing between site classes (reference versus disturbed). Significant correlations with road density (m of road / km^2; $r = -0.279$, $p = 0.018$), road crossings (# of stream crossings / km^2; $r = -0.353$, $p = 0.002$), mine densities (# of mines / km^2, $r = -0.287$, $p = 0.014$), and chemical spill densities (# of spills / km^2, $r = -0.452$, $p < 0.001$) suggest that the habitat assessment conducted during this study was able to reflect the effect of watershed-level disturbances on local-level physical habitat parameters. A quantitative analysis of physical habitat in conjunction with a more comprehensive Geographic Information System assessment of landscape variables (e.g. land use) may have provided more links between watershed- and local-level variables.

In the Black Hills of South Dakota land use is predominantly selective timber harvest and livestock grazing in association with public land recreational activities so watershed level disturbances are less subtle than one would expect in areas of intensive irrigation agriculture, clear cut logging, or urbanization. Based on personal observations during this study and subsequent research, local-level conditions (e.g. riparian and substrate) appear to largely dictate macroinvertebrate community characteristics. Hawkins et al. (2000) also note that local habitat features account for substantially more biotic variation than larger-scale environmental features. Geology and hydrology, two watershed-level mechanisms that dictate site specific conditions, vary across the Black Hills ecoregion (Driscoll et al. 2002). However, further research aimed at refining the results of this study should focus on identifying those local-level habitat features that influence macroinvertebrate communities, and thus stream condition.

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Table 1. Streams sampled in the Black Hills, South Dakota during 2003 and 2004.

Date	Site ID	Stream Name	Lat	Long	Revisit Dates	Order	Watershed Area (km^2)
07/08/2003	03BBTC0101	Bear Butte Creek	44.324070	-103.651250		2	30.8
07/07/2003	03BVRC0101	Beaver Creek	44.381730	-104.004350	08/25/2004	2	12.8
07/09/2003	03BJMC0101	Bogus Jim Creek	44.123900	-103.424210		2	24.7
07/09/2003	03BXEC0101	Boxelder Creek	44.157920	-103.468840		3	197.1
08/01/2003	03CASC0201	Castle Creek	44.069860	-103.753650		3	274.0
07/31/2003	03CASC0101	Castle Creek	44.082820	-103.726030		3	321.7
08/08/2003	03CONC0101	Coon Creek	43.904320	-103.680720		1	5.1
06/20/2003	03ESFC0101	East Spearfish Creek	44.265770	-103.847620	7/8/2003, 11/13/2003	3	31.3
07/09/2003	03ELKC0101	Elk Creek	44.269780	-103.739050		2	11.8
07/09/2003	03ESTC0101	Estes Creek	44.169560	-103.497470		2	14.7
08/08/2003	03FLNC0101	Flynn Creek	43.679700	-103.533850	07/12/2004	2	4.5
07/31/2003	03GIMC0101	Gimlet Creek	44.113850	-103.647160		2	14.0
08/07/2003	03GRCC0101	Grace Coolidge Creek	43.781000	-103.402000	08/29/2003	2	30.7
08/06/2003	03GZBC0101	Grizzly Bear Creek	43.873870	-103.441640	07/13/2004	2	20.8
06/19/2003	03IRNC0101	Iron Creek	44.373810	-103.919460	7/7/2003, 11/13/2003	2	25.5
08/07/2003	03IRON0201	Iron Creek	43.833120	-103.456070		2	16.9
08/07/2003	03IRON0101	Iron Creek	43.845910	-103.402740		2	26.6
07/09/2003	03JIMC0101	Jim Creek	44.147080	-103.502320		2	29.7
06/20/2003	03KLYG0101	Kelly Gulch	44.095500	-103.596070	07/31/2003	2	5.6
06/20/2003	03LSFC0101	Little Spearfish Creek	44.327850	-103.989830	07/07/2003	2	28.9
07/31/2003	03NCAC0101	North Fork Castle Creek	44.099700	-103.832990		2	12.3
07/31/2003	03NRAC0101	North Fork Rapid Creek	44.131770	-103.736270		3	91.1
08/07/2003	03PALC0101	Palmer Creek	43.894900	-103.539500		2	7.3
08/07/2003	03PINC0101	Pine Creek	43.891060	-103.484080		2	4.8
07/24/2003	03PRAC0101	Prairie Creek	44.050410	-103.453920		2	14.1
06/20/2003	03RAPC0101	Rapid Creek	44.087770	-103.572690	07/31/2003	4	757.9
06/20/2003	03RAPC0201	Rapid Creek	44.055110	-103.403500	07/24/2003, 08/03/2004	4	878.1
07/31/2003	03RRAC0101	Rhoades Fork Rapid Cr.	44.142070	-103.849390		2	26.1
07/09/2003	03BXEC0201	Boxelder Creek	44.191700	-103.517400		3	152.5
08/01/2003	03SLTC0101	Slate Creek	44.033920	-103.632180		3	72.8
08/01/2003	03SCAC0101	South Fork Castle Creek	43.980280	-103.861400		2	31.3
06/19/2003	03SPFC0301	Spearfish Creek	44.384980	-103.913030		4	322.5

Date	Site ID	Stream Name	Lat	Long	Revisit Dates	Order	Watershed Area (km^2)
06/19/2003	03SPFC0201	Spearfish Creek	44.406120	-103.898830	7/8/2003, 11/13/2003	4	354.9
06/19/2003	03SPFC0101	Spearfish Creek	44.417320	-103.880940	7/7/2003, 11/13/2003	4	363.5
08/08/2003	03SPRC0301	Spring Creek	43.863170	-103.629680		3	64.5
08/01/2003	03SPRC0101	Spring Creek	43.961570	-103.488250		4	327.6
08/01/2003	03SPRC0201	Spring Creek	43.981700	-103.440900		4	378.1
06/19/2003	03SQUC0101	Cleopatra Creek	44.401210	-103.894180	7/7/2003, 8/28/2003, 08/25/2004	2	18.9
07/08/2003	03STRG0101	Strawberry Gulch	44.324180	-103.651660		2	4.7
08/08/2003	03VNDC0101	Vanderlehr Creek	43.866661	-103.673935	07/13/2004	2	22.8
07/08/2003	03WARD0101	Ward Draw	44.256870	-103.842120	08/28/2003	2	19.7
07/08/2003	03WWDC0201	Whitewood Creek	44.351370	-103.744160		3	60.6
07/08/2003	03WWDC0101	Whitewood Creek	44.391290	-103.704970	08/24/2004	3	117.6
08/25/2004	04ANNC0101	Annie Creek	44.33099	-103.87662		2	7.5
07/13/2004	04BTLC0101	Battle Creek	43.89738	-103.40035		3	49.2
08/24/2004	04BBTC0201	Bear Butte Creek	44.30872	-103.65976		2	26.1
08/02/2004	04CASC0301	Castle Creek	44.04827	-103.77237		3	253.6
08/03/2004	04CASC0401	Castle Creek	44.03267	-103.84587		2	71.8
08/26/2004	04DDWC0101	Deadwood Creek	44.37095	-103.74633		2	20.1
08/03/2004	04DITC0101	Ditch Creek	43.97467	-103.84570		2	34.9
08/25/2004	04GRIG0101	East Fork	44.46367	-103.94820		1	4.7
07/14/2004	04ESQC0101	East Cleopatra Creek	44.37096	-103.84487		1	1.0
07/12/2004	04FRNC0101	French Creek	43.71817	-103.48912		4	240.6
08/25/2004	04IBXG0101	Icebox Gulch	44.29805	-103.86209		1	5.1
08/24/2004	04LEKC0101	Little Elk Creek	44.23815	-103.49010		2	20.4
08/24/2004	04MDWC0101	Meadow Creek	44.29340	-103.56032		1	10.0
08/24/2004	04NBXC0101	North Fk. Boxelder Cr.	44.21291	-103.55462		3	103.8
07/13/2004	04RADG0101	Raddick Gulch	44.25546	-103.92787		1	3.2
07/13/2004	04RAPC0301	Rapid Creek	44.07612	-103.48011		4	831.6
08/03/2004	04SILC0101	Silver Creek	44.02952	-103.85350		1	9.9
08/24/2004	04SBXC0101	South Fk. Boxelder Cr.	44.19798	-103.54298		2	40.3
08/03/2004	04SFRC0101	South Fk. Rapid Creek	44.15722	-103.87312		1	15.1
08/25/2004	04SPFC0401	Spearfish Creek	44.26535	-103.91554		3	89.6
08/26/2004	04WHTC0101	Whitetail Creek	44.33322	-103.78817		1	8.8

Table 2. Seventy-nine metrics representing pollution tolerance, species richness, trophic guilds, life history, and habitat preference of the macroinvertebrate community. Response indicates the metric's expected response (positive: +, or negative: -) due to increase anthropogenic disturbance. Limiting factor indicates the test (variability, precision, sensitivity, or redundancy) that removed the metric from further consideration.

Metric	Response	Limiting Factor
Number of Taxa	-	sensitivity
Proportion of Ephemeroptera	-	sensitivity
Number of Ephemeroptera Taxa	-	sensitivity
Proportion of Trichoptera	-	precision
Number of Trichoptera Taxa	-	sensitivity
Proportion of Plecoptera	-	precision
Number of Plecoptera Taxa	-	passed all tests
Proportion of EPT	-	precision
Number of EPT Taxa	-	redundancy
Proportion of Chironomidae	+	precision
Number of Chironomidae Taxa	+	variability
Proportion of Coleoptera	-	sensitivity
Number of Coleoptera Taxa	-	sensitivity
Proportion of Diptera	+	precision
Number of Diptera Taxa	+	precision
Proportion of Dominant 3 Taxa	+	sensitivity
Proportion of Dominant 2 Taxa	+	sensitivity
Proportion of Dominant 1 Taxa	+	precision
Proportion of Tanypodinae	+	precision
Proportion of Chironominae	+	sensitivity
Proportion of Orthocladiinae	+	precision
Proportion of Hydroptila	+	precision
Proportion of Simuliidae	+	sensitivity
Proportion of Oligochaete and Hirudinea	+	passed all tests
Proportion of Odonata	+	variability
Proportion of Zygoptera	+	variability
Proportion of Anisoptera	+	variability
Proportion of Gastropoda	+	sensitivity
Proportion of Non-insects	+	sensitivity
Number of Non-insects	+	sensitivity
Simpson's Diversity Index	-	precision
Proportion of Collector-Filterers	+	sensitivity
Number of Collector-Filterer Taxa	+	sensitivity
Proportion of Shredders	-	precision
Number of Shredder Taxa	-	passed all tests
Proportion of Scrapers	-	sensitivity
Number of Scraper Taxa	-	sensitivity
Proportion of Predators	-	precision
Number of Predator Taxa	-	sensitivity
Proportion of Parasites	+	variability
Number of Parasite Taxa	+	variability
Proportion of Collector-Gatherers	-	precision
Number of Collector-Gatherer Taxa	-	sensitivity
Proportion of Multi-Voltine Individuals	+	sensitivity
Number of Multi-Voltine Taxa	+	variability
Proportion of Semi-Voltine Individuals	-	passed all tests

Table 2 Continued.

Metric	Response	Limiting Factor
Number of Semi-Voltine Taxa	-	sensitivity
Proportion of Uni-Voltine Individuals	-	precision
Number of Uni-Voltine Taxa	-	passed all tests
EPT : Chironomid Ratio (Proportion)	-	precision
EPT : Tanypodinae Ratio (Proportion)	-	precision
EPT : Orthocladiinae Ratio (Proportion)	-	precision
EPT : Oligochaete / Hirudinea (Proportion)	-	precision
Proportion of Intolerant Individuals	-	sensitivity
Number of Intolerant Taxa	-	passed all tests
Proportion of Super Intolerant Individuals	-	precision
Number of Super Intolerant Taxa	-	precision
Proportion of Tolerant Individuals	+	precision
Number of Tolerant Taxa	+	sensitivity
Proportion of Super Tolerant Individuals	+	sensitivity
Number of Super Tolerant Taxa	+	sensitivity
Proportion of Clingers	-	precision
Number of Clinger Taxa	-	sensitivity
Proportion of Burrowers	+	sensitivity
Number of Burrower Taxa	+	sensitivity
Proportion of Swimmers	+	sensitivity
Number of Swimmer Taxa	+	variability
Proportion of Sprawlers	-	precision
Number of Sprawler Taxa	-	sensitivity
Proportion of Climbers	-	variability
Proportion of Climber Taxa	-	variability
Family Biotic Index	-	precision
Pollution Tolerance Index	-	precision
Number of Ephemeroptera Taxa minus Baetidae	-	sensitivity
Proportion of Ephemeroptera minus Baetidae	-	sensitivity
Number of EPT Taxa minus Baetidae	-	redundancy
Proportion of EPT minus Baetidae	-	precision
EPT minus Baetidae : Chironomid Ratio	-	precision
EPT minus Baetidae : Oligochaete / Hirudinea Ratio	-	precision

Table 3. Metrics (and abbreviations) selected for site classification based on screening process. Correlations based on Spearman's rho (*r*).

Metric	Range	Signal : Noise	Correlation to Habitat Scores	Highest Correlation to other Metrics
Number of Plecoptera (N_PLECO)	0 – 4	3.8	*r* = 0.526, $p < 0.001$	N_INTOL, *r* = 0.697
Proportion of Oligochaetes and Hirudinea (P_OLIHIR)	0 – 0.134	2.1	*r* = -0.328, $p = 0.005$	N_PLECO, *r* = -0.285
Number of Shredder Taxa (N_SHRED)	0 – 5	2.7	*r* = 0.325, $p = 0.005$	N_SHRED, *r* = 0.590
Number of Uni-Voltine Taxa (N_UVOL)	0 – 8	4.9	*r* = 0.308, $p = 0.008$	N_INTOL, *r* = 0.747
Proportion of Semi-Voltine Individuals (P_SVOL)	0 – 0.613	4.0	*r* = 0.305, $p = 0.009$	N_INTOL, *r* = 0.410
Number of Intolerant Taxa (N_INTOL)	0 – 16	6.0	*r* = 0.351, $p = 0.003$	N_UVOL, *r* = 0.747

Table 4. Reference and disturbed sites with associated selection metric values. Definitions for metric abbreviations can be found in Table 3.

		Metrics					
Site	Stream	N_PLECO	P_OLIHIR	N_SHRED	N_UVOL	P_SVOL	N_INTOL
Reference							
03GRCC0102	Grace Coolidge Creek	3	0.000	1	8	0.085	12
03GZBC0101	Grizzly Bear Creek	3	0.004	3	6	0.069	14
03SPRC0301	Spring Creek	3	0.000	2	5	0.433	12
04NBXC0101	North Fk. Boxelder Creek	3	0.000	2	8	0.256	17
04VNDC0101	Vanderlehr Creek	3	0.000	4	7	0.267	13
03SQWC0102	Cleopatra Creek	4	0.003	3	5	0.032	13
04IBXG0101	Icebox Gulch	4	0.026	5	8	0.355	15
04SBXC0101	South Fk. Boxelder Creek	3	0.014	3	9	0.257	12
Disturbed							
03FLNC0101	Flynn Creek	0	0.095	1	3	0.401	2
03BXEC0201	Boxelder Creek	0	0.014	1	1	0.098	6
03SPRC0201	Spring Creek	0	0.029	1	2	0.049	6
03BJMC0101	Bogus Jim Creek	0	0.026	0	1	0.046	4
03RRAC0102	Rhoades Fk. Rapid Creek	0	0.003	1	2	0.032	3
04WWDC0101	Whitewood Creek	0	0.021	0	4	0.024	6
03PINC0101	Pine Creek[1]	0	0.007	0	1	0.007	6
04BLTC0101	Battle Creek	0	0.026	0	1	0.003	3
03SCAC0101	South Fk. Castle Creek	0	0.114	0	1	0.000	1
04FLNC0101	Flynn Creek[2]	0	0.110	1	1	0.467	4
03WWDC0101	Whitewood Creek[3]	0	0.050	1	1	0.004	1
03CONC0101	Coon Creek	2	0.004	1	2	0.014	4

[1] Pine Creek was intermittent at the time of sampling and flow conditions were not representative of the site. Upstream stream and riparian conditions were undisturbed.
[2] Same site as 03FLNC0101
[3] Same site as 04WWDC0101

Appendix A. Voucher list of all macroinvertebrate taxa collected from Black Hills stream from 2003-2004.

Phylum	Class	SubClass	Order	Family	SubFamily	Genus species	Stage
Annelida	Clitellata	Hirudinea	Arhynchobdellida	Erpobdellidae		*Erpobdella punctata*	
						Mooreobdella microstoma	
			Rhynchobdellida	Glossiphoniidae		*Glossiphonia complanata*	
						Helobdella stagnalis	
		Oligochaeta					
			Branchiobdellida	Branchiobdellidae			
			Haplotaxida	Lumbricidae		*Eiseniella tetraedra*	
Arthropoda	Arachnida		Araneae				
		Acarina	Hydracarina				
	Branchiopoda	Phyllopoda	Diplostraca	Daphniidae			
	Entognatha		Collembola				
	Insecta		Coleoptera	Chrysomelidae			P
				Curculionidae			A
				Dryopidae		*Helichus sp.*	A
				Dytiscidae		*Agabus sp.*	L
				Elateridae			A
				Elmidae		*Cleptelmis sp.*	L
							A
						Dubiraphia sp.	L
							A
						Heterlimnius sp.	L
							A
						Microcylloepus sp.	L
							A
						Narpus sp.	L
							A
						Optioservus sp.	L
							A
						Stenelmis sp.	L

Phylum	Class	SubClass	Order	Family	SubFamily	Genus species	Stage
						Zaitzevia sp.	L
							A
				Hydraenidae		*Hydraena sp.*	A
				Hydrophilidae		*Helophorus sp.*	A
				Staphylinidae			A
			Diptera	Athericidae		*Atherix sp.*	L
				Ceratopogonidae			P
						Atrichopogon sp.	L
						Bezzia sp.	L
						Culicoides sp.	L
						Probezzia sp.	L
Arthropoda	Insecta		Diptera	Chironomidae			P
					Chironominae		L
					Orthocladiinae		L
					Tanypodinae		L
				Dixidae		*Dixa sp.*	L
						Meringodixa sp.	L
				Empididae			P
						Chelifera sp.	L
						Hemerodromia sp.	L
						Oreogeton sp.	L
						Trichoclinocera sp.	L
				Muscidae			L
				Psychodidae		*Maruina sp.*	L
						Pericoma sp.	L
				Ptychopteridae		*Ptychoptera sp.*	L
				Simuliidae			P
						Simulium sp.	L
				Stratiomyidae		*Caloparyphus sp.*	L
				Tabanidae		*Chrysops sp.*	L
						Hybomitra sp.	L

Phylum	Class	SubClass	Order	Family	SubFamily	Genus species	Stage
						Tabanus sp.	L
				Tipulidae			P
						Antocha sp.	L
						Dicranota sp.	L
						Hexatoma sp.	L
						Tipula sp.	L
			Ephemeroptera	Baetidae		*Acentrella sp.*	L
						Baetis sp.	L
						Procloeon sp.	L
				Caenidae		*Caenis sp.*	L
				Ephemerellidae		*Ephemerella sp.*	L
				Ephemeridae		*Ephemera sp.*	L
				Heptageniidae		*Epeorus sp.*	L
						Nixe sp.	L
				Leptohyphidae		*Tricorythodes sp.*	L
				Leptophlebiidae		*Choroterpes sp.*	L
						Leptophlebia sp.	L
						Paraleptophlebia sp.	L
				Siphlonuridae		*Siphlonurus sp.*	L
Arthropoda	Insecta		Heteroptera	Corixidae		*Sigara lineata*	
				Gerridae		*Gerris sp.*	
				Naucoridae		*Ambrysus sp.*	
				Veliidae		*Microvelia sp.*	
						Rhagovelia sp.	
			Hymenoptera				A
			Lepidoptera	Pyralidae		*Petrophila sp.*	L
			Megaloptera	Sialidae		*Sialis sp.*	L
			Odonata	Aeshnidae		*Aeshna sp.*	L
				Coenagrionidae		*Argia sp.*	L
						Enallagma sp	L
				Corduliidae		*Somatochlora sp.*	L

Phylum	Class	SubClass	Order	Family	SubFamily	Genus species	Stage
				Gomphidae		*Ophiogomphus sp.*	L
				Lestidae		*Archilestes sp.*	L
			Plecoptera	Chloroperlidae		*Sweltsa sp.*	L
				Nemouridae		*Malenka sp.*	L
				Perlidae		*Claassenia sp.*	L
						Hesperoperla sp.	L
				Perlodidae		*Isoperla sp.*	L
						Skwala sp.	L
			Thysanoptera				A
			Trichoptera	Apataniidae		*Apatania sp.*	L
				Brachycentridae		*Brachycentrus sp.*	L
						Micrasema sp.	L
				Glossosomatidae			P
						Glossosoma sp.	L
				Helicopsychidae		*Helicopsyche sp.*	L
				Hydropsychidae			P
						Ceratopsyche sp.	L
						Cheumatopsyche sp.	L
				Hydroptilidae		*Hydroptila sp.*	L
						Leucotrichia sp.	L
						Ochrotrichia sp.	L
				Lepidostomatidae			P
						Lepidostoma sp.	L
				Leptoceridae			P
						Mystacides sp.	L
						Nectopsyche sp.	L
						Oecetis sp.	L
Arthropoda	Insecta		Trichoptera	Limnephilidae			P
						Glyphopsyche sp.	L
						Hesperophylax sp.	L
						Psychoglypha sp.	L

Phylum	Class	SubClass	Order	Family	SubFamily	Genus species	Stage
						Pycnopsyche sp.	L
				Philopotamidae		*Chimarra sp.*	L
						Wormaldia sp.	L
				Polycentropodidae		*Paranyctiophylax sp.*	L
						Polycentropus sp.	L
				Psychomyiidae		*Psychomyia sp.*	L
				Rhyacophilidae		*Rhyacophila sp.*	L
				Uenoidae		*Neophylax sp.*	L
	Malacostraca		Amphipoda	Gammaridae		*Gammarus sp.*	
				Hyalellidae		*Hyallela azteca*	
			Decapoda	Cambaridae		*Orconectes sp.*	
	Maxillipoda		Cyclopoida	Cyclopidae			
	Ostracoda						
Mollusca	Bivalvia		Veneroida	Pisidiidae		*Pisidium sp.*	
						Sphaerium sp.	
Mollusca	Gastropoda		Basommatophora	Ancylidae		*Ferrissia sp.*	
				Lymnaeidae			
				Physidae		*Physa sp.*	
				Planorbidae			
						Helisoma anceps	
			Neotaenioglossa	Hydrobiidae			
Nemata							
Nematomorpha	Gordioida		Gordea	Gordiidae		*Gordius sp.*	
Platyhelminthes	Turbellaria		Tricladida				