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Vital Signs Monitoring in Our Parks: What to Measure?

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ABSTRACT

The National Park Service (NPS) Inventory and Monitoring program seeks to define vital signs for the purpose of monitoring and managing park conditions throughout the United States. Aquatic macroinvertebrate biotic integrity ranks high as one potential vital sign of interest to park staff and partnering agencies. The objective of this effort was to identify discriminating measures of invertebrate community structure which might be used to monitor aquatic biotic integrity. Invertebrate sweepnet samples were collected from 58 large river, stream, spring and bison watering hole habitats during the summers of 2004 and 2005. Invertebrate counts were used to calculate 68 metrics of abundance, diversity, guild structure and pollution tolerance. A metric selection process was implemented to maximize between-site discriminatory power, reduce informational redundancy and maximize detection of anthropogenic disturbance. Two sets of 10 metrics each were selected using this process for future monitoring of wadeable and non-wadeable stream sites within the NGPN. Optimal sets consisted of metrics describing community structure, diversity, guild structure and pollution tolerance and all metrics displayed good discriminatory power between sampled sites. A total of 47 significant correlations were observed among wadeable stream metrics and measures of water quality, channel habitat and riparian condition. Only 19 significant correlations were observed for non-wadeable stream metrics. Wadeable stream metrics correlated poorly with stream size but 6 of 10 non-wadeable stream metrics were significantly correlated with drainage area. Several of the metrics selected from this process are currently in use by U.S. EPA, USGS and the states of Nebraska and Wyoming. Thus, the value of NPS monitoring data to partner agencies is high. Selected metrics will be incorporated into habitat specific indices of biotic integrity to facilitate vital signs monitoring by the National Park Service.

Keywords

Vital sign, biomonitoring, macroinvertebrates, metrics

INTRODUCTION

Monitoring is an important component of sustainable natural resource management and many state and federal agencies have devoted large investments toward the collection, management and use of monitoring data (Oakley et al. 2003). Monitoring programs are now carefully planned and designed to (1) provide cost-effective information for monitoring changes in natural resource conditions and (2) provide scientifically defensible data for monitoring changes over space and time.

The National Park Service (NPS) has initiated its Inventory and Monitoring (I&M) Program to (1) inventory natural resources within park boundaries and (2) initiate the collection of data to monitor change in park conditions (National Park Service 2006a). Monitoring efforts designed as part of this program focus on "vital signs", measurable signals that indicate changes that may impair the long-term health of natural resources or ecosystems (National Park Service 2006b). Vital signs are indicators. They tend to be both sensitive to a broad array of environmental changes and integrative of ecological structure and function across levels of biological organization. Aquatic macroinvertebrate community structure has been identified as one potential vital sign for monitoring NPS aquatic resources (National Park Service 2006c). However, there are many ways to characterize the macroinvertebrate community. Total and relative abundance, community composition, number of species, diversity, guild structure and disturbance tolerance measures all provide different perspectives on biotic integrity. A combination of several measures is recommended for development of an index of biotic integrity (Karr and Chu 1999). However, the question of what metrics to include is important as discriminatory abilities and relationships of different measures to environmental change are known to vary with stream size and geographically (Bramblett et al. 2003; Karr and Chu 1999; King and Richardson 2002; Klemm et al. 2002; Larson and Troelstrup 2001). The objectives of this effort were to (1) define the discriminatory power of different measures of macroinvertebrate community structure among aquatic systems within parks of the Northern Great Plains Network (NGPN) and (2) define relationships between community measures and aquatic habitat features within the NGPN. Optimal community structure measures (or metrics) are recommended for future monitoring of stream and large river systems within the NGPN.

STUDY AREA

All sampling sites were located within streams and rivers of the NGPN (Figure 1, Table 1). In many cases, three reaches (40x channel width) were sampled from the mainstem of each system. In some cases, only one or two reaches could be sampled within the park boundary.

Parks comprising the NGPN fall within six different ecoregions of Nebraska, North Dakota, South Dakota and Wyoming (Table 1). Consequently, natural differences in physical, chemical, channel habitat and riparian conditions exist among park locations.

Figure 1. Location of individual park units within the Northern Great Plains Network of the National Park Service.

METHODS

Methods for this effort were adapted from EPA's Environmental Monitoring and Assessment Program (EMAP) (Lazorchak et al. 2000; Peck et al. 2006). Water quality, habitat and invertebrate assessments were completed twice during 2004 and once during 2005 over the period May 15 – August 1 from 10 cross-channel transects within each sampled reach (40x channel width).

A D-frame net (350 um mesh) was used to sample invertebrates from five randomly chosen transects within each reach. These five sweepnet samples were pooled to generate one composite sample for each reach on each of three sampling dates. Composite samples were preserved with 70% ethanol and transported to the laboratory for processing. Invertebrate samples were subsampled

Table 1. National park stream and river reaches sampled during 2004 and 2005.

PARK	SYSTEM	TYPE	REACHES
Agate Fossil Beds National Monument	Niobrara River	Wadeable	1
Badlands National Park	Sage Creek	Wadeable	3
Devils Tower National Monument	Belle Fourche River	Non-Wadeable	1
Fort Laramie National Historic Site	North Platte River	Non-Wadeable	1
	Laramie River	Non-Wadeable	2
	Deer Creek	Wadeable	3
Fort Union Trading Post National Historic Site	Missouri River	Non-Wadeable	1
Knife River Indian Villages National Historic Site	Missouri River	Non-Wadeable	1
	Knife River	Non-Wadeable	1
Missouri National Recreation River	Missouri	Non-Wadeable	3
Mount Rushmore National Memorial	Beaver Dam Creek	Wadeable	3
	Lafferty Gulch	Wadeable	3
	Grizzly Creek	Wadeable	3
Niobrara National Scenic River	Niobrara River	Non-Wadeable	3
	Berry Falls	Wadeable	1
	Fort Falls	Wadeable	1
	Smith Falls	Wadeable	1
Scott's Bluff National Memorial	North Platte River	Non-Wadeable	1
Theodore Roosevelt National Park	Little Missouri River	Non-Wadeable	3
Wind Cave National Park	Beaver Creek	Wadeable	3
	Cold Spring Creek	Wadeable	3
	Highland Creek	Wadeable	3

and sorted in the laboratory (Barbour et al. 1999). Invertebrates were sorted into separate vials to be identified to the lowest possible taxonomic level (genus, species) (Merritt and Cummins 1996, Thorp and Covich 1991, Wiggins 1997, Weiderholm 1983). Invertebrate identifications were randomly checked by capable staff and voucher specimens of each taxon were retained.

Ten "optimal" community structure metrics were selected for future monitoring of stream and river sites based on the results of an iterative screening procedure. Optimal invertebrate metrics were those with (1) high between-site discriminatory power, (2) low redundancy with other metrics, (3) low number of undefined values (<25%), (4) high data range among sites, (5) high correlation with water quality and habitat indicators of disturbance and (6) high value to partnering resource agencies. Kruskal-Wallis F-statistics were calculated to evaluate among versus within site variability (discriminatory power) of individual community metric attributes. Metric redundancy and relationship to water quality and habitat features were evaluated using Spearman rank correlations (Conover 1980).

RESULTS

A total of 68 metrics were evaluated for monitoring wadeable and non-wadeable streams of the NGPN. Of the total pool, ten were selected for future wadeable (Table 2) and ten for non-wadeable (Table 3) stream monitoring. Selected metrics represent a mixture describing components of taxonomic composition, diversity, functional organization and tolerance to organic pollution. Taxa richness and diversity index measures were among those frequently displaying optimal characteristics. All of the metrics selected displayed high discriminatory power among sampled sites (KW $p<0.05$, Tables 2, 3).

Table 2. Optimal invertebrate metrics for monitoring wadeable stream conditions within the NGPN. Values presented include minimums, medians, maximums, Kruskal-Wallace F statistics and probability values to evaluate discriminatory power for each metric.

METRIC	MIN	MED	MAX	KW F (p)
Percent Non-Insecta	0.0	10.3	100	3.94 (<0.01)
EPT:Chironomidae Ratio	0.00	0.81	1.00	5.31 (<0.01)
EPT Richness	0	3	11	2.89 (<0.01)
Chironomidae Richness	0	3	14	3.06 (<0.01)
Shannon H’	0.00	1.85	2.80	3.15 (<0.01)
Predator Richness	0	4	14	4.60 (<0.01)
Feeding Guild H’	0.00	0.93	1.29	2.09 (0.02)
Percent Sprawlers	0.0	12.5	66.1	3.15 (<0.01)
Habit Guild H’	0.00	1.14	1.54	2.42 (<0.01)
Modified HBI	3.07	5.05	9.60	5.28 (<0.01)

Table 3. Optimal invertebrate metrics for monitoring non-wadeable stream conditions within the NGPN. Values presented include minimums, medians, maximums, Kruskal-Wallace F statistics and probability values to evaluate discriminatory power for each metric.

METRIC	MIN	MED	MAX	KW F (p)
Percent EPT	0.0	24.5	93.5	3.98 (<0.01)
Percent Chironomidae	0.0	9.6	100	2.95 (<0.01)
Total Richness	2	9	26	3.60 (<0.01)
Non-Insecta Richness	0	2	6	2.29 (0.02)
EPT Richness	0	2	10	5.09 (<0.01)
Collector-Filterer Richness	0	1	6	5.30 (<0.01)
Collector-Gatherer Richness	1	4	13	2.81 (<0.01)
Clinger Richness	0	2	10	4.70 (<0.01)
Swimmer Richness	0	2	7	2.83 (<0.01)
Modified HBI	2.92	5.23	9.00	2.73 (<0.01)

Optimal wadeable stream metrics (Table 2) displayed 47 significant ($p < 0.1$) rank correlations with water quality, channel habitat and riparian condition data. The Hilsenhoff Biotic Index (Figure 2a), EPT:Chironomidae ratio, percent sprawlers (Figure 2b), EPT richness, predator richness and feeding guild diversity metrics displayed the greatest number of significant rank correlations. Those water quality and habitat attributes most frequently correlated with invertebrate metrics included stream substrate embeddedness, percent silt-clay channel substrate, nitrate-nitrogen and total Kjeldahl nitrogen. None of our optimal stream invertebrate metrics were correlated with bank vegetation density, ammonia-nitrogen or total suspended solids habitat and water quality data.

Optimal non-wadeable stream metrics (Table 3) displayed only 19 significant ($p < 0.1$) rank correlations with water quality, channel habitat and riparian condition data. Of 18 water quality and habitat features, only fecal coliform counts, total dissolved solids, total Kjeldahl nitrogen, total suspended solids, specific conductance, channel snag counts and water temperature were significantly ($p < 0.1$) correlated with invertebrate metrics. Clinger richness and Hilsenhoff Biotic Index values were most frequently correlated at a significant level while richness of collector-gatherers was not significantly correlated with any of the water quality or habitat measures. Those water quality and habitat attributes most highly correlated with invertebrate metrics were channel snag counts and water temperature. Some metrics displayed what appeared to be a threshold relationship with selected water quality and habitat features (Figure 2c).

None of the optimal wadeable stream metrics were significantly correlated with stream size as indicated by stream discharge and all metrics except preda-

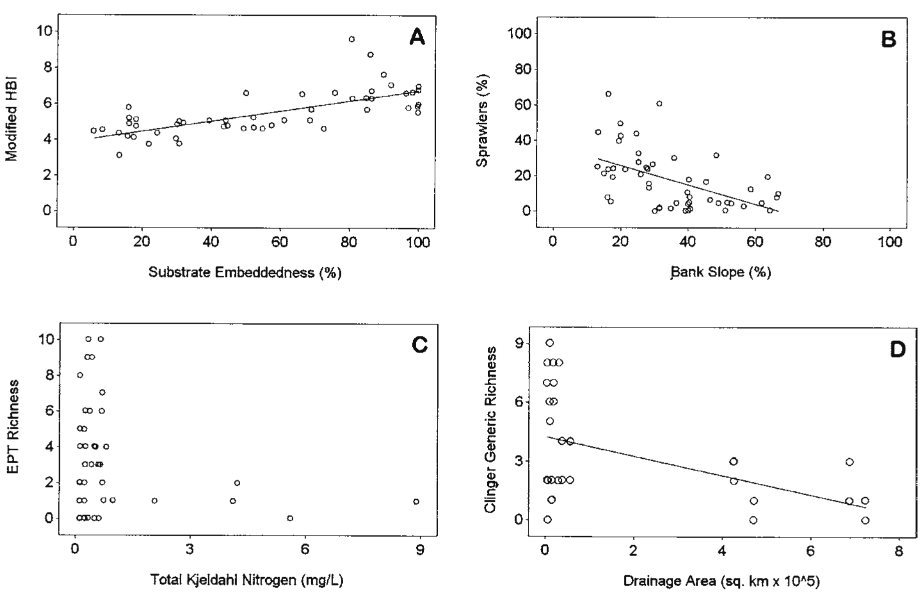

Figure 2. Relationships of selected invertebrate metrics to water quality and habitat features of wadeable (2a, 2b) and non-wadeable (2c, 2d) streams of the Northern Great Plains Network.

tor richness, percent sprawlers and habit guild diversity were positively related to discharge. However, six of ten optimal non-wadeable stream metrics were significantly correlated with stream size as indicated by drainage area (Figure 2d). In addition, all optimal non-wadeable stream metrics were negatively correlated with drainage area except percent Chironomidae and Hilsenhoff Biotic Index values which increased as drainage area increased above the sampled reach. Percent Chironomidae, non-insect richness, swimmer richness and Hilsenhoff Biotic Index values displayed no significant relationship with stream size for non-wadeable streams.

DISCUSSION

All of the optimal wadeable and non-wadeable stream metrics selected in this study were capable of discriminating well among streams within their respective classes. Metrics contributing to development of an index of biotic integrity (IBI) should be able to discriminate degraded sites from non-degraded sites (Barbour et al. 1999; Karr and Chu 1999). Because our sites were all located within the boundaries of National Parks and may be expected to be relatively undegraded, we used between-site discriminatory power as a measure of metric ability to detect site differences. Future comparison of these NPS metric values against those from truly degraded sites would further validate their effectiveness in detecting stream impairment (Bramblett et al. 2003; Larson and Troelstrup 2001; Klemm et al. 2002).

Both of our optimal metric sets included measures of community composition, diversity, guild structure and pollution tolerance. Representation among these metric categories is necessary to provide an integrated evaluation of biological integrity within sampled streams (Barbour et al. 1999; Karr and Chu 1999).

Most metrics within our optimal sets displayed significant correlations with paired measurements of water quality, channel habitat and/or riparian condition. Channel substrate conditions and nutrient enrichment appeared to be strong correlates with macroinvertebrate metrics from wadeable streams while woody snag densities and water temperature appeared to be stronger correlates from non-wadeable sites. These relationships are important to establish the sensitivity of each metric to different possible sources of degradation (Barbour et al. 1999; King and Richardson 2003; Klemm et al. 2002). However, many more significant relationships were observed for wadeable than non-wadeable stream metrics. Better relationships between invertebrate community metrics and habitat features may reflect the tighter linkage normally found between water quality, channel habitat and riparian conditions for smaller streams (Vannote et al. 1980; Troelstrup and Perry 1990; Dovciak and Perry 2002).

Optimal wadeable stream metrics in this study were not significantly correlated with stream size. However, several of our non-wadeable stream metrics were significantly correlated with drainage area above the sampled site. Indices of Biotic Integrity are known to vary as a function of stream size even in the absence of degradation (Barbour et al. 1999; Karr and Chu 1999). Our observation of significant relationships for the non-wadeable stream group is probably a reflection of the greater range of stream sizes within this class. Some of our "non-wadeable" streams were reduced to smaller, shallower channels later in the growing season. Future IBI development by the NPS should account for natural variation in metric values with stream size.

Many of the metrics selected from this analysis are currently in use by state and federal monitoring agencies (Table 4). North and South Dakota have not presently defined optimal metrics for monitoring wadeable and non-wadeable streams. However, three of the four optimal metrics selected for use by Nebraska also ranked high from our analysis (Bazata 2005), 5 of 12 metrics selected for Montana streams are members of our optimal sets (Bahls et al. 1992) and Wyoming currently reports 16 of the 18 metrics we selected as part of their state monitoring effort (Jeremy ZumBerge, Wyoming Department of Environmental Quality, personal communication). The United States Geological Survey and U.S. Environmental Protection Agency also utilize several of the metrics resulting from our optimization effort (Bramblett et al. 2003). Individual parks within the NPS network are unlikely to have resources sufficient to shoulder their entire monitoring burden. Costs associated with monitoring may be offset through collaborative partnering efforts as many of these groups would benefit from sharing data and associated site information.

Table 4. Optimal metrics selected for NGPN streams and rivers and use by associated water quality agencies.

METRIC	ND	NE	SD	WY	USEPA	USGS
Percent EPT	-	-	-	X	X	-
Percent Chironomidae	-	-	-	X	-	-
Total Richness	-	X	-	X	-	X
Non-Insecta Richness	-	-	-	X	-	-
EPT Richness	-	X	-	X	X	-
Collector-Filterer Richness	-	-	-	X	X	-
Collector-Gatherer Richness	-	-	-	X	-	-
Clinger Richness	-	-	-	X	-	-
Swimmer Richness	-	-	-	X	X	-
Modified HBI	-	X	-	X	-	-
Percent Non-Insecta	-	-	-	X	X	-
EPT:Chironomidae Ratio	-	-	-	X	-	X
Chironomidae Richness	-	-	-	X	-	-
Shannon H'	-	-	-	X	-	X
Predator Richness	-	-	-	X	-	-
Feeding Guild H'	-	-	-	-	-	-
Percent Sprawlers	-	-	-	X	-	-
Habit Guild H'	-	-	-	-	-	-

Biological monitoring is widely recognized as a necessary component of water resources management (Karr and Chu 1999). Of course, use of biological monitoring requires some knowledge of the flora and fauna. Many of the parks and systems sampled in this effort had no baseline description of their invertebrate communities. While some community metrics appear to be robust across a number of ecoregions and system types, metric selection procedures are needed to identify those measures which are regionally sensitive, integrate ecosystem properties and correlate well with likely disturbance sources (Klemm et al. 2003; Larson and Troelstrup 2001). These "optimal" metric sets are those most likely to detect changes induced by the predominant disturbance types found within an ecoregion.

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