Aquatic Stream Indicator Development in the Western United States; Preliminary Results for Arizona, Nevada, and Utah[1]

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1. ABSTRACT

Beginning in 1999, the U.S. Environmental Protection Agency initiated a 5-year study to monitor the condition of streams and rivers in 12 western states as a component of the Environmental Monitoring and Assessment Program (EMAP). States included in the survey are Arizona, California, Colorado, Idaho, Montana, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. The objective of EMAP is to develop and demonstrate tools to monitor and assess the condition of ecological resources at a regional and state level of scale. This is accomplished by randomly selecting sites and by obtaining a representative sample of biotic assemblages along with physical and chemical measures. EMAP is just completing its second year of data acquisition and the biological and physicochemical data are beginning to be examined relative to the development of core indicators, such as multimetric indices like the Index of Biological Integrity, that can be utilized in a region-wide assessment. This poster presents preliminary results of associations between simple candidate metrics based on native and nonnative fish abundance and selected measures of water chemistry and physical habitat, using data collected in 2000 from stream sites sampled in Arizona, Nevada, and Utah. These analyses represent an example of certain aspects of an overall indicator development and evaluation approach that will be used by EMAP.

2. INTRODUCTION

Fish communities possess a number of attributes which make them important potential indicators for both biological integrity and aquatic ecosystem health (Simon and Lyons, 1995). Included among them is the fact that fish 1) continually inhabit the aquatic medium and integrate the chemical, physical, and biological histories of the waters; 2) represent a broad spectrum of community tolerances and respond to degradation in predictable fashion; 3) represent a highly visible and valuable component of the public value system; and 4) are protected under public laws related to water quality standards (i.e. Clean Water Act) and sometimes in regard to rarity (i.e. Endangered Species Act) or harvest (e.g. various state statues related to take). The actual biotic and abiotic processes involved in environmental degradation and their combined effects are complex and often difficult to measure. Recent applications in developing integrative ecological indices that directly relate fish communities to biotic and abiotic components of the ecosystem have allowed natural resource managers, land planners, and decision-makers to assess environmental condition. Probably the most popular among integrative assessment tools are multimetric indicators such as the Index of Biological Integrity (IBI) which was first developed for use in Midwestern U.S. warmwater streams (Karr, 1981, Karr and Chu 2000), and has been modified repeatedly by other investigators for use in other regions and watersheds outside of the Midwest. Multimetric indicators are based upon the sum ratings for several different measures (termed metrics) of fish assemblage structure or function, such as fish species richness and composition; number and abundance of indicator species; trophic organization and function; reproductive behavior; fish abundance; and condition of individual fish.

Recently, increased attention has been given to rigorously evaluating candidate metrics and resulting multimetric indexes to ensure responsive, reproducible, and scientifically defensible indicators of ecological condition (Hughes et al. 1998, Angermeier et al. 2000). EMAP has developed an approach that will serve as the basis for evaluating candidate metrics of biological indicators for use throughout the U.S. (McCormick et al., 2001).

3. OBJECTIVE

The purpose of this poster is to demonstrate how we might evaluate candidate metrics for their responsiveness, using a few simple metrics that could eventually be used either individually or as a component of a multimetric indicator for assessing the condition of small wadeable streams in the Western U.S.

4. METHODS

Sample sites were selected using a randomized systematic survey design which provides for unbiased regional estimates of stream condition with known confidence (Herlihy et al. 2000). During May - August 2000 fish assemblage data were collected from 28 wadeable streams in Arizona, Nevada, and Utah (Figure 1).

FIGURE 1. Stream sampling locations in Arizona, Nevada, and Utah (Summer, 2000).

4a. Data Analysis

Six example metrics were calculated from the fish assemblage data, based on native and nonnative individuals and a further division based on coldwater and warmwater species (Tables 1 and 2, respectively). Nonnative species may represent a stressor in and of themselves; they can also represent surrogates for other potential metrics (e.g., tolerant species, carnivores). The coldwater/warmwater metrics are examples of how natural variability might be addressed. For each metric, two derivations were calculated: the actual number of individuals, and the proportion of individuals.

A subset of the available habitat metrics and water chemistry variables were selected to represent a variety of potential natural and human disturbance gradients associated with various components of physical and chemical habitat (Table 3).

Spearman correlation analyses combined with visual examination of scatterplots were performed to identify associations and discernible patterns between fish metrics and each of the habitat metrics and chemical variables. We also used principal components analysis (PCA) to help identify patterns of covariation among habitat and chemistry variables, and to develop multivariate-based variables that may represent natural or disturbance-related gradients. All statistical analyses were conducted in PC-SAS for Windows, Release 6.11.

Fish collected in Arizona, Nevada, and Utah streams are listed in TABLE 1 (Native) and TABLE 2 (Nonnative). Number of sites where collected are in parentheses.

TABLE 1

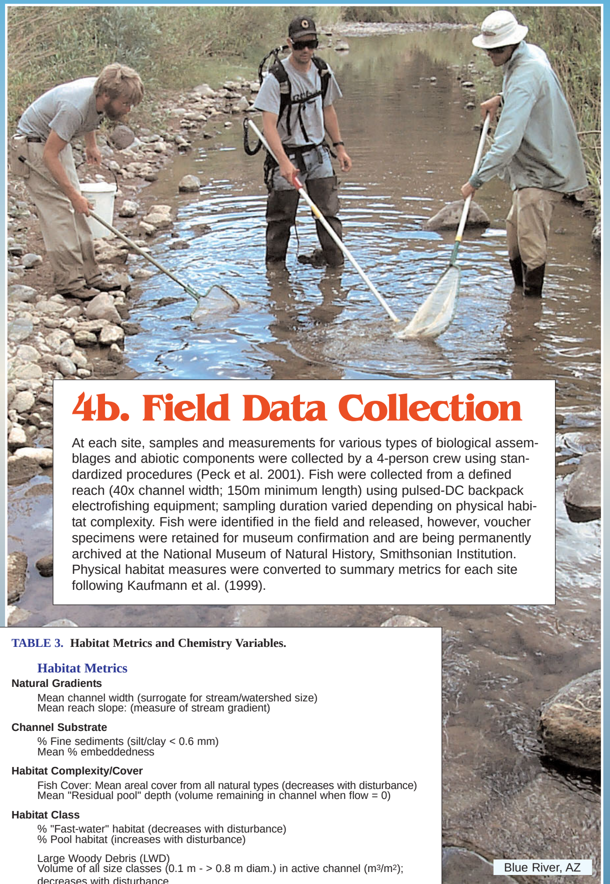
Common name	Scientific name	States
Cutthroat trout (6)	*Oncorhynchus clarki*	NV, UT
Mountain whitefish (2)	*Prosopium williamsoni*	UT
Longfin dace (4)	*Agosia chrysogaster*	AZ
Roundtail chub (2)	*Gila robusta*	AZ
Redside shiner (3)	*Richardsonius balteatus*	NV, UT
Lahontan redside (1)	*Richardsonius egregius*	NV
Longnose dace (1)	*Rhinichthys cataractae*	UT
Speckled dace (11)	*Rhinichthys osculus*	AZ, NV, UT
Loach minnow (1)	*Tiaroga cobitis*	AZ
Bluehead sucker (1)	*Catostomus discobolus*	UT
Utah sucker(1)	*Catostomus ardens*	UT
Desert sucker (3)	*Catostomus clarki*	AZ
Sonora sucker (3)	*Catostomus insignis*	AZ
Mountain sucker (8)	*Catostomus platyrhynchus*	NV, UT
Tahoe sucker (2)	*Catostomus tahoensis*	NV
Mottled sculpin (5)	*Cottus bairdi*	UT
Paiute sculpin (1)	*Cottus beldengi*	UT

Coldwater Warmwater

TABLE 2

Common name	Scientific name	States
Rainbow trout (7)	*Oncorhynchus mykiss*	AZ, NV, UT
Brown trout (4)	*Salmo trutta*	AZ, UT
Brook trout(6)	*Salvelinus fontinalis*	NV, UT
Common carp (2)	*Cyprinus carpio*	AZ, NV
Red shiner(4)	*Cyprinella lutrensis*	AZ
Fathead minnow (2)	*Pimephales promelas*	AZ
Black bullhead (1)	*Ameiurus melas*	AZ
Yellow bullhead (1)	*Ameiurus natalis*	AZ
Channel catfish (1)	*Ictalurus punctatus*	AZ
Green sunfish (3)	*Lepomis cyanellus*	AZ
Smallmouth bass (1)	*Micropterus dolomieu*	AZ
Largemouth bass (1)	*Micropterus salmoides*	NV
Mosquitofish (5)	*Gambusia affinis*	AZ, NV

Coldwater Warmwater



4b. Field Data Collection

At each site, samples and measurements for various types of biological assemblages and abiotic components were collected by a 4-person crew using standardized procedures (Peck et al. 2001). Fish were collected from a defined reach (40x channel width; 150m minimum length) using pulsed-DC backpack electrofishing equipment; sampling duration varied depending on physical habitat complexity. Fish were identified in the field and released, however, voucher specimens were retained for museum confirmation and are being permanently archived at the National Museum of Natural History, Smithsonian Institution. Physical habitat measures were converted to summary metrics for each site following Kaufmann et al. (1999).

TABLE 3. Habitat Metrics and Chemistry Variables.

Habitat Metrics

Natural Gradients
- Mean channel width (surrogate for stream/watershed size)
- Mean reach slope: (measure of stream gradient)

Channel Substrate
- % Fine sediments (silt/clay < 0.6 mm)
- Mean % embeddedness

Habitat Complexity/Cover
- Fish Cover: Mean areal fish cover from all natural types (decreases with disturbance)
- Mean "Residual pool" depth (volume remaining in channel when flow = 0)

Habitat Class
- % "Fast-water" habitat (decreases with disturbance)
- % Pool habitat (increases with disturbance)
- Large Woody Debris (LWD) Volume of all size classes (0.1 m - > 0.8 m diam.) in active channel (m^3/m^2); decreases with disturbance

Riparian Vegetation
- Canopy density (bank and mid-channel; decreases with disturbance)
- Mean areal "cover" of barren ground (increases with disturbance)

Channel-Riparian Interaction
- Mean incision height (increases with disturbance)
- Reach sinuosity (decreases with disturbance)

Anthropogenic Alterations:
- Intensity of disturbance on or near stream margin (increases with disturbance)

Chemical Variables:

- **Conductivity** (probably natural, but can increase with disturbance)
- **pH** (probably natural, but can increase or decrease with disturbance)
- **Chloride** (shown to be "tracer" for general human disturbance in other areas of U.S.)
- **Nutrients**: Total nitrogen and phosphorus (increase with disturbance)
- **Total suspended solids** (TSS; increase with disturbance)

5. RESULTS

A total of 30 species of fish were collected. Species richness was low (median native species = 2; median total richness = 3; range 1 - 9). At least one nonnative species was collected at 22 of the 28 sites; and introduced species were solely collected at 7 of the 28 sites. Coldwater introduced fish species (salmonids) were collected at 15 sites and warmwater introduced fish species (primarily centrarchids, cyprinids, and ictalurids) were collected at 7 sites.

Spearman correlation analyses for the proportional derivations of each fish metric are shown in Tables 4 and 5. Derivations based on the number of individuals behaved similarly. Metrics for total native or nonnative individuals were not correlated with any individual habitat or chemistry variable. Metrics based on coldwater individuals were significantly associated with habitat variables related to substrate, cover/complexity (fish cover and woody debris), and riparian vegetation (canopy cover). The nonnative coldwater individuals metric responded to more variables than the native coldwater individuals metric. The native warmwater individuals metric was significantly associated with only two variables (fish cover and sinuosity).

The nonnative warmwater individuals metric was significantly associated with almost all of the same habitat variables as the nonnative coldwater individuals metric, but in the opposite direction. The nonnative warmwater individuals metric was significantly associated with chloride and total phosphorus. Habitat and chemistry variables that were not significantly associated with any fish metric included mean channel width, residual pool volume, per cent fast water habitat, mean areal cover of barren ground, riparian disturbance, incision height/mean width, and total nitrogen.

Associations between fish metrics and PCA axes are shown in Table 6. The nonnative coldwater individuals metric was significantly associated with Axes 1 and 3. The nonnative warmwater individuals metric was also associated with Axis 1, but in the opposite direction from the coldwater metric. The native coldwater individuals metric was the only metric that was significantly associated with Axis 2.

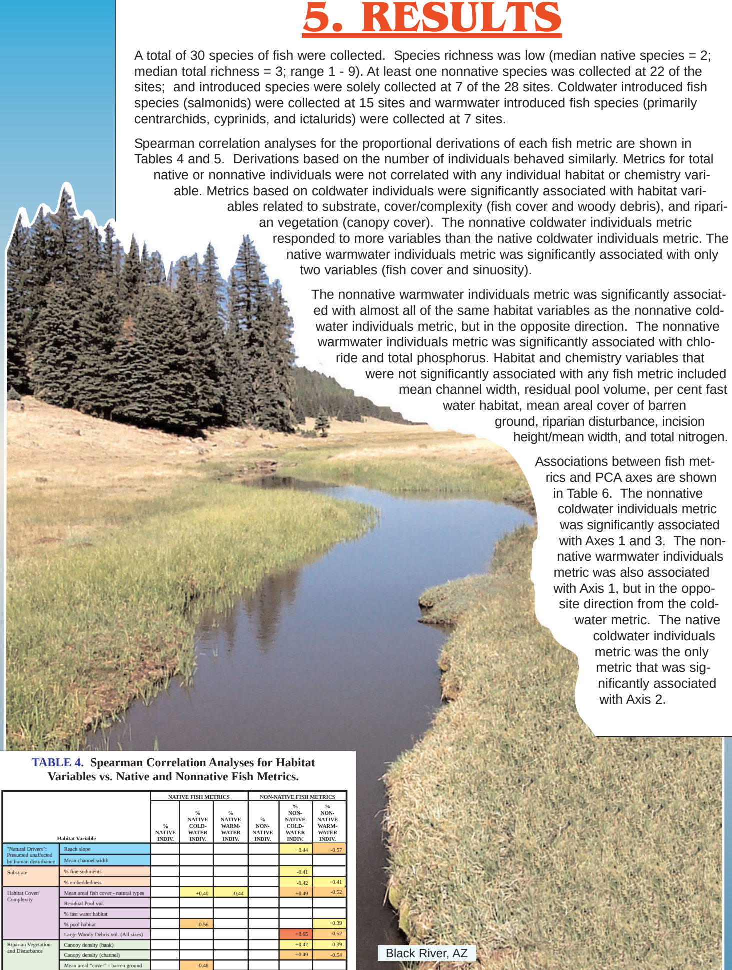


TABLE 4. Spearman Correlation Analyses for Habitat Variables vs. Native and Nonnative Fish Metrics.

Habitat Variable		NATIVE FISH METRICS: % NATIVE INDIV.	% NATIVE COLD-WATER INDIV.	% NATIVE WARM-WATER INDIV.	NON-NATIVE FISH METRICS: % NON-NATIVE INDIV.	% NON-NATIVE COLD-WATER INDIV.	% NON-NATIVE WARM-WATER INDIV.
"Natural Drivers": Presumed unaffected by human disturbance	Reach slope					+0.44	-0.57
	Mean channel width						
Substrate	% fine sediments					-0.41	
	% embeddedness					-0.42	+0.41
Habitat Cover/ Complexity	Mean areal fish cover - natural types		+0.40	-0.44		+0.49	-0.52
	Residual Pool vol.						
	% fast water habitat						
	% pool habitat		-0.56				+0.39
	Large Woody Debris vol. (All sizes)					+0.65	-0.52
Riparian Vegetation and Disturbance	Canopy density (bank)					+0.42	-0.39
	Canopy density (channel)					+0.49	-0.54
	Mean areal "cover" - barren ground		-0.48				
	Riparian disturbance						
Channel-Riparian Interaction	Reach sinuosity		+0.45	-0.45			-0.50
	Incision height/mean width						

$0.01 < p \leq 0.05$ $0.01 \leq p \leq 0.001$ $p < 0.001$

TABLE 5. Spearman Correlation Analyses for Chemistry Variables vs. Native and Nonnative Fish Metrics.

Chemical Variable		NATIVE FISH METRICS: % NATIVE INDIV.	% NATIVE COLD-WATER INDIV.	% NATIVE WARM-WATER INDIV.	NON-NATIVE FISH METRICS: % NON-NATIVE INDIV.	% NON-NATIVE COLD-WATER INDIV.	% NON-NATIVE WARM-WATER INDIV.
Water Chemistry	Conductivity			+0.38			
	pH			+0.38			
	Chloride						+0.38
	Total Phosphorus						+0.44
	Total Nitrogen						
	Total Suspended Solids					-0.39	+0.39

$0.01 < p \leq 0.05$ $0.01 \leq p \leq 0.001$ $p < 0.001$

TABLE 6. Principal Components Analyses for Multivariate-based Variables vs. Native and Nonnative Fish Metrics.

Principal Component Axis	NATIVE FISH METRICS: % NATIVE INDIV.	% NATIVE COLD-WATER INDIV.	% NATIVE WARM-WATER INDIV.	NON-NATIVE FISH METRICS: % NON-NATIVE INDIV.	% NON-NATIVE COLD-WATER INDIV.	% NON-NATIVE WARM-WATER INDIV.
Axis 1 (Explains 34% of variance): Larger positive values: Greater % fine substrate, riparian disturbance, chloride, total phosphorus, total nitrogen, total suspended solids, and conductivity. Larger negative values: Greater reach slope, canopy density, and lg. woody debris vol.					-0.47	+0.54
Axis 2 (Explains 16% of variance): Larger positive values: Greater incision/mean width value, lg. woody debris vol., canopy cover (channel), total phosphorus; reach slope, and % pool habitat. Larger negative values: Greater mean width, % fast water habitat		-0.41				
Axis 3 (Explains 10% of variance): Larger positive values: Greater riparian disturbance, residual pool volume, % pool habitat, and total nitrogen. Larger negative values: Greater incision/mean width value, sinuosity, total suspended solids, and pH					+0.38	

$0.01 < p \leq 0.05$ $0.01 \leq p \leq 0.001$ $p < 0.001$

6. DISCUSSION

Preliminary evaluation of these example fish metrics suggest there is potential to develop metrics for at least some assemblage characteristics. Based on the number of sites where nonnative species were collected, this is a potentially significant stressor to streams in this region. Metrics based on warmwater and coldwater species appear to have more promise than those based on the total assemblage; this suggests that temperature regime may be one way to reduce natural variability in candidate metrics. Metrics based on native individuals alone do not look promising at present. The responses seen in the nonnative metrics suggest that metrics based on habitat guild, trophic guild, or tolerance to disturbance developed from the entire assemblage may prove useful.

Major environmental gradients identified in this preliminary effort are not clearly related to human disturbance; accounting for the effect and influence of anthropogenic versus natural causes requires additional information to describe habitat and chemical conditions in the absence of human disturbance. The strongest associations of fish metrics were with variables related to habitat complexity, substrate, and riparian vegetation. Large woody debris appears to be a key variable related to fish occurrence, even in these Southwestern streams not ordinarily characterized in terms of the amount/availability of wood. These associations may simply represent a major difference in natural stream conditions (e.g., upland vs. lowland streams), but they do identify important variables that will help focus future evaluation efforts.

It is clear from this early analysis that enormous work needs to be accomplished over the next several years related to metric screening, indicator development and indexing, establishment of reference conditions with threshold values, and landscape analyses, including both historical and current land use and their relation to the hydrological regime. With the addition of the scheduled subsequent 3 years of data collection and analyses we hope to combine rigorously evaluated metrics into integrative multimetric indices, e.g. IBI, or other appropriate indicators, and issue a national assessment report on the condition of our western streams.

At present, the Environmental Monitoring and Assessment Program provides the most unique project undertaken at a multi-state scale from which to develop the tools necessary to monitor and assess that status and trends of our national ecological resources. It is anticipated that information gathered and managed as a public asset will assist environmental managers and decision-makers in understanding stream ecological function in relation to human influence.

7. REFERENCES

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http://www.epa.gov/emap/wpilot/
http://www.epa.gov/nerlesd1land-sci/streams.htm