Regional Ecological Monitoring and Assessment Program

A Comparison of Macroinvertebrate and Habitat Methods of Data Collection in the Little Colorado River Watershed, Arizona 2007

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Cover Photo: Clear Creek downstream of Willow Creek confluence on Mogollon Rim in the Little Colorado River basin (site ID AZ06631-088).

Executive Summary

The Arizona Department of Environmental Quality (ADEQ) and the U.S. Environmental Protection Agency (USEPA) Ecological Monitoring and Assessment Program (EMAP), use different field methods for collecting macroinvertebrate samples and habitat data for bioassessment purposes. Arizona's Biocriteria index was developed using a riffle habitat sampling methodology, whereas the EMAP method employs a multi-habitat sampling protocol. There was a need to demonstrate comparability of these different bioassessment methodologies to allow use of the EMAP multi-habitat protocol for both statewide probabilistic assessments for integration of the EMAP data into the national (305b) assessment and for targeted in-state bioassessments for 303d determinations of standards violations and impaired aquatic life conditions. The purpose of this study was to evaluate whether the two methods yield similar bioassessment results, such that the data could be used interchangeably in water quality assessments. In this Regional EMAP grant funded project, a probabilistic survey of 30 sites in the Little Colorado River basin was conducted in the spring of 2007. Macroinvertebrate and habitat data were collected using both ADEQ and EMAP sampling methods, from adjacent reaches within these stream channels.

All analyses indicated that the two macroinvertebrate sampling methods were significantly correlated. ADEQ and EMAP samples were classified into the same scoring categories (meeting, inconclusive, violating the biocriteria standard) 82% of the time. When the ADEQ-IBI was applied to both the ADEQ and EMAP taxa lists, the resulting IBI scores were significantly correlated ($r=0.91$), even though only 4 of the 7 metrics in the IBI were significantly correlated. The IBI scores from both methods were significantly correlated to the percent of riffle habitat, even though the average percent riffle habitat was only 30% of the stream reach. Multivariate analyses found that the percent riffle was an important attribute for both datasets in classifying IBI scores into assessment categories.

Habitat measurements generated from EMAP and ADEQ methods were also significantly correlated; 13 of 16 habitat measures were significantly correlated ($p<0.01$). The visual-based percentage estimates of percent riffle and pool habitats, vegetative cover and percent canopy cover, and substrate measurements of percent fine substrate and embeddedness were all remarkably similar, given the different field methods used. A multivariate analysis identified substrate and flow conditions, as well as canopy cover as important combinations of habitat attributes affecting both IBI scores. These results indicate that similar habitat measures can be obtained using two different field sampling protocols. In addition, similar combinations of these habitat parameters were important to macroinvertebrate community condition in multivariate analyses of both ADEQ and EMAP datasets.

These results indicate the two sampling methods for macroinvertebrates and habitat data were very similar in terms of bioassessment results and stressors. While the bioassessment category was not identical for all sites, overall the assessments were significantly correlated, providing similar bioassessment results for the cold water streams used in this study. The findings of this study indicate that ADEQ can utilize either a riffle-based sampling methodology or a multi-habitat sampling approach in cold water streams as both yield similar results relative to the macroinvertebrate assemblage. These results will allow for use of either macroinvertebrate dataset to determine water quality standards compliance with the ADEQ Indexes of Biological Integrity, for which threshold values were just recently placed into the Arizona Surface Water Quality Standards. While this survey did not include warm water desert streams of Arizona, we would predict that EMAP and ADEQ sampling methodologies would provide similar bioassessment results and would not be significantly different, as we have found that the percent riffle habitat in cold and warm water perennial, wadeable streams is not significantly different. However, a comparison study of sampling methodologies in warm water streams should be conducted to confirm the predicted similarity of bioassessment results. ADEQ will continue to implement a monitoring strategy that includes probabilistic monitoring for a statewide ecological assessment of stream conditions. Conclusions from this study will guide decisions regarding the most appropriate sampling methods for future probabilistic monitoring sample plans.

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Introduction

There is a large variety of biological field and laboratory survey methods being used by state and federal monitoring programs. Comparisons of the data collected with different types of sampling equipment, sub-sampling counts, and levels of taxonomic resolution have provided a basis for evaluating some of the field and laboratory methods in use (Barbour and Gerritsen, 1996; Carter and Resh, 2001; Herbst and Silldorff, 2006). Comparisons of bioassessment data analyses have also been published, as contrasts of different analytical approaches based on the same sets of biological data (Fore and Karr, 1996; Reynoldson and others, 1997; Ode and others, 2008). With the advent of regional and national level bioassessment surveys such as the National Wadeable Stream Assessment a need has arisen to determine if the federal and state bioassessment methods are comparable (USEPA, 2006). Some studies have compared macroinvertebrate methods among state, regional, and federal monitoring programs (Herbst and Silldorff, 2006; Ode and others, 2008). However, no macroinvertebrate methods comparison studies between state and federal monitoring methods have been conducted in Arizona or hot desert streams of the southwestern U.S. This study fills that gap by comparing State of Arizona and federal USEPA-EMAP macroinvertebrate and habitat collection methods and bioassessment results.

The objective of this study was to compare USEPA's EMAP derived macroinvertebrate metrics, macroinvertebrate Indices of Biological Integrity (IBI), and habitat metrics with those derived using ADEQ's methods to determine if the datasets produce similar assessments of biological integrity and habitat conditions. If both methods produce similar results, then datasets can be combined, State of Arizona standards can be applied, and either method could then be used in future ambient monitoring strategies.

Study Area

This study was conducted in streams above 1524 meters (5,000 ft) elevation within the LCR watershed, located in northeastern Arizona. The watershed drains a total of 79,880 square kilometers, almost the entire northeast quarter of the state and a small portion of northwestern New Mexico. Approximately 50% of the watershed area is on Native American Indian Reservations. This study focuses on the non-tribal area within the Arizona state border as shown in Figure 1.

The LCR watershed includes several large mountain ranges with some of the highest peaks in Arizona. The highest peak in the watershed is Humphreys Peak at 3850 meters in the San Francisco Mountains just north of Flagstaff. Much of the watershed's southern edge is defined by the 480-kilometer long Mogollon Rim, a steep escarpment with an average elevation of 2100 meters. The Mogollon Rim transitions into the White Mountains near the New Mexico border, where Mount Baldy and Escudilla Mountain are two prominent peaks with elevations 3500 meters and 3000 meters, respectively. The lowest elevation in the basin is 820 m at the mouth of the LCR.

The LCR headwaters originate in the White Mountains and form the main stem of the LCR in Greer, Arizona. From Greer, the LCR flows generally northeast and perennially to Lyman Lake and continues mostly intermittently northwest to the Colorado River in the Grand Canyon. Flow alterations caused by impoundments and diversions are common throughout the watershed, causing a number of stream reaches to flow only intermittently or ephemerally. Perennial flows are found in the higher elevations due to winter snow, monsoon storms, and springs. The largest tributary, Silver Creek is fed by the largest spring in the basin, Silver Creek Spring southeast of Snowflake-Taylor. Sources of perennial flows at the 30 random sites sampled for this assessment were snowmelt at 37% and springs at 27%. Ten percent of the sites were located downstream of reservoirs and had regulated flows. The LCR and its tributaries flow through a variety of landforms such as mountain meadows, coarse colluvial deposits, bedrock canyons, and alluvial deposits. Rosgen (1996) devised a stream classification system that uses characterizations of

channel morphology, valley types, and landforms where stream systems are found to assign streams to one of six categories (A through G) in the first level of classification. The most dominant stream types among the 30 random sites evaluated in our study were B (riffle-dominated channel on moderate gradient in narrow valley; 50% of sites) and C (meandering riffle/pool channel with point bars and well-defined floodplains; 20% of sites).

Omernik (1987) divided the United States into 104 Level III ecoregions. Both the EMAP West assessment (Stoddard and others, 2005) and the Arizona EMAP assessment (Robinson, 2006) reported results within broader ecoregions aggregated from Omernik's ecoregions. Though the sample size in this study is not large enough to report results in different ecoregions, two of the Omernik Level III ecoregions occur in the study area: Arizona/New Mexico Mountains and Arizona/New Mexico Plateau. The Mountains region, which lies along the southern border of the watershed, accounts for about 50% of the total study area. The region is characterized by mountainous terrain with pinion-juniper and oak woodlands at low to mid-elevations and ponderosa pine forests at high elevations. Most perennial streams identified in this study occur in the Mountains region, and therefore the majority of sites, ranging in land-surface elevations between 1,780 and 2,920 meters, were located in this ecoregion. The Plateau ecoregion, the other 50% of the study area, is characterized by desert vegetations at low elevations, grass and shrublands at mid-elevations, and pinion-juniper woodlands at high elevations. One probability site is located in this region at land-surface elevation of 1550 meters. All 32 sampling sites were, however, located above 5000 feet (1524 meters), and were thus categorized as "cold water" streams for the assessment.

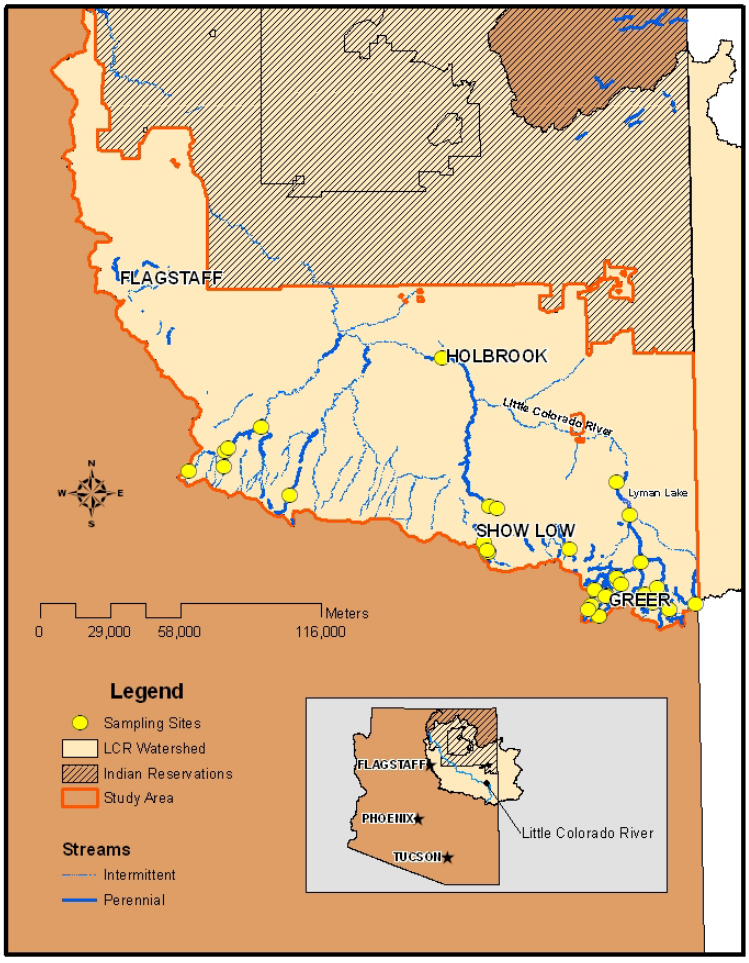

Figure 1. Little Colorado River watershed and study area sites sampled in 2007.

Methods

USEPA assisted ADEQ in developing a probabilistic study design which was used to select 30 perennial stream sites in the Little Colorado River (LCR) basin of Arizona. The target population of streams were all perennial flowing streams on non-tribal lands in the LCR basin, as identified on the Arizona updated perennial streams GIS map. The total perennial stream length within the LCR basin was approximately 2121 km which constituted the sampling frame from which a list of probability sites was derived. A total of 237 sites were evaluated through GIS and field reconnaissance. As a result 1754 km or 83% of the total stream length was determined to be "non-target" (i.e. non-perennial or non-wadeable reaches, streams on Indian land, or wrong water body types such as ditches, washes, wetlands, and lake shores). The remaining 367 km or 17% was determined to be "target" or flowing and wadeable, of which 99 km or 5% was inaccessible due to physical barriers or lack of access permission. The target, sampled stream category was therefore 268 km or 12% of the total stream length, represented by the 30 probability sites. Two handpicked sites, one reference and one stressed were also sampled, bringing the total number of sites sampled to 32. The handpicked "reference" site (LCLVL001.32) was found to have degraded site conditions and was kept as a study site instead of a reference site. Three reference sites and two stressed sites were selected from the random site list to determine whether the IBI results were in the same category using both methods. The site selection criteria were based on criteria described in the LCR watershed stream assessment and the technical support document for narrative biocriteria standard (Condon and others, 2009; ADEQ, 2007). A list of sites sampled during our study is presented in Appendix A.

Macroinvertebrates

Sample collection:

Macroinvertebrate samples were collected using ADEQ methods described in the Biocriteria Program Quality Assurance Program Plan (ADEQ, 2006) and USEPA's methods described in the EMAP Western Pilot Study Field Operations Manual for Wadeable Streams (Peck and others, 2006). For the ADEQ collection method, 3-minute timed kick samples were collected in riffle habitats using a D-frame dip net. The USEPA method involves sampling 1ft^2 sections along 11 stratified random transects along a study reach. Details of the two collection methods are presented in Table 1. Periphyton samples and fish community data were also collected following USEPA EMAP protocols and are only presented here for use in comparing biological responses to stressors, as measured by EMAP and ADEQ habitat methods. Periphyton and fish IBI results are presented in ADEQ's "Ecological assessment of streams in the Little Colorado River Watershed of Arizona" (Condon and others, 2009).

Table 1. A comparison of ADEQ and USEPA EMAP methods to collect macroinvertebrates in wadeable streams during the 2007 sampling in the LCR basin.

Parameter	ADEQ Method	USEPA-EMAP Method
Reach length	Minimum 100m	Minimum 150m
Habitat sampled	Riffle/run erosional habitat	Reach-wide, multi-habitat, erosional and depositional
Number of sub-samples	3	11
Area sampled	9ft^2/sub-sample (27 ft^2 or 2.6m^2 total)	1ft^2/sub-sample (11ft^2 or 1m^2 total)
Net mesh size	500 micron	500 micron
Sampling approach	Traveling kick net	Stationary box

Sampling effort	1 minute each riffle for 3 minutes total	30 seconds per transect for 5.5 minutes total
Preservation	99% Isopropanol	95% Ethanol
Index period	Spring (April-June), avoid high flows	No index period, avoid high flows
Macroinvertebrate identification	Genus level taxonomy, 500 count minimum, midges lumped to family level	Genus level taxonomy, 500 count minimum
Assessment tool	ADEQ cold water IBI	ADEQ cold water IBI

Laboratory Processing:

Laboratory processing and taxonomic identifications for both the ADEQ and EMAP samples were conducted at the Ecoanalysts, Inc. (Lester, 2001) laboratory in Moscow, Idaho. Data quality objectives for laboratory processing and taxonomic identifications were met (90% sorting efficiency and 90% taxonomic accuracy). ADEQ entered the taxonomic lists and abundance data into a proprietary Microsoft ACCESS database entitled the Ecological Data Application System (EDAS), to calculate the metrics and the ADEQ cold water Index of Biological Integrity (IBI) needed for statistical analysis. The ADEQ cold water IBI consists of seven metrics: total taxa richness, Diptera taxa richness, intolerant taxa richness, scraper taxa richness, percent composition by scrapers, percent composition by stoneflies, and Hilsenhoff biotic index. The reference metric thresholds and IBI scoring criteria are provided in the Biocriteria Implementation Procedures document (ADEQ, 2008). The ADEQ IBI was calculated for both datasets; the EMAP IBI was not used for this comparative analysis. Metric and IBI values for both EMAP and ADEQ datasets are included in Appendix B.

Statistical analysis:

ADEQ and EMAP macroinvertebrate sampling methods were compared using a “performance based methods system” (PBMS) recommended by USEPA (Barbour and others, 1999). These methods include evaluation of precision, bias and sensitivity to judge the comparability of different bioassessment methods. The precision of each sampling method was evaluated by comparing coefficients of variation (CV) among reference sites and the 30 samples to evaluate measurement error. Similar precision among metrics and ADEQ-IBI scores would indicate similarity of the two methods. Precision was measured using coefficients of variation (CV) and values < 20% were considered precise. We examined sampling bias by comparing CVs of different stream type classes; alpine meadows with a C or E Rosgen stream type channel (Rosgen, 1996) versus steeper gradient montane streams (A and B Rosgen stream type channels). Method sensitivity was evaluated by comparing study site data with reference site data as a function of the reference sites variation (Barbour and others, 1999).

ADEQ and EMAP derived IBI scores were compared using regression analysis and condition class assignments (IBI scoring categories) were compared between the two methods using Spearman’s rank correlation. For the regression analysis, if R^2 values were ≥0.8 the two methods were considered to yield similar results. In addition, an ANCOVA was run to compare slopes and origins of regressions between %riffle habitat and IBI scores. The condition class analysis identified the number of times each method produced the same IBI estimate of condition class. We also examined how well each method detected impairment along fine sediment stressor gradients (30% fines is the threshold above which samples are considered impaired) through scatterplots of IBI scores by %fines. Mann-Whitney significance tests were used to identify which metrics were significantly different between the ADEQ and EMAP samples which disagreed in assessment category.

Discriminant function analysis (DFA) was used to determine the most important of 16 stressor or habitat variables that distinguish among the IBI attainment categories (Table 2) for ADEQ and EMAP methods. We used Pearson’s correlation coefficient to examine pairs of variables and removed variables that were

autocorrelated; ten stressor variables were left for input into the DFA analysis. Since crayfish are known to be a biological stressor in the Little Colorado River basin (Condon and others, 2009), a categorical variable was developed to combine EMAP and ADEQ observations on crayfish abundance. EMAP methods made a quantitative count of crayfish abundance and ADEQ methods made qualitative estimates of abundance. These abundances were combined as follows: category 1 = EMAP count of 0 or ADEQ category 'absent'; category 2 = EMAP count of <100 or ADEQ category 'rare', category 3 = EMAP count of >100 count or ADEQ category 'common'. The multiple regression part of the analysis used a backward stepwise procedure for entering variables into the model. The resulting ten chemical, physical/habitat, and biological parameters were selected for this analysis to evaluate influence on bioassessment standard attainment categories. The 10 environmental variables included:

- Crayfish abundance category
- Reach-wide % fines (EMAP method)
- Canopy percent cover
- Pool, percent of reach
- Riffle, percent of reach
- ADEQ Habitat index score
- Laboratory total dissolved solids
- Riffle median particle size (D50)
- Embeddedness in riffles
- Water temperature

The three IBI scoring categories were:

- Passing or attaining the reference IBI score of 52 for cold water streams
- Inconclusive, with IBI score 46-51
- Failing or not meeting the minimum IBI score of 45 for cold water streams

Habitat

Sample collection: Paired habitat data were collected using the ADEQ Stream Ecosystem Monitoring (SEM) protocols (ADEQ, 2006b) and the EMAP habitat protocols (Peck and others, 2006; Kaufman and others, 1999). ADEQ habitat protocols were used to measure physicochemical variables for the reach as a whole, including current velocity, water chemistry, habitat complexity, substrate measurements of particle size distribution and embeddedness, overall channel stability and a riparian condition assessment. The ADEQ Habitat Assessment Score consisted of a sum of 5 categorical substrate and bank habitat attributes for an overall score of 20. The five attributes are: habitat quality/variety, longitudinal extent of riffle habitat, riffle embeddedness, sediment deposition, and bank stability. The EMAP protocol consisted of five habitat categories: thalweg profile, woody debris tally, channel and riparian vegetation characterization, assessment of channel constraint and major hydrological events. The thalweg profile consisted of measuring the maximum channel depth, classifying habitat and pool-forming features, and checking for the presence of backwaters, side channels and deposits of fine sediment at 10 to 15 equally spaced intervals between each of 11 cross-channel transects. EMAP uses the USEPA's Rapid Bioassessment Habitat Assessment protocol which consists of a sum of 10 categorical habitat attributes for an overall score of 200. The 10 variables are: substrate quality, embeddedness, velocity/depth regime, sediment deposition, channel flow status, channel alteration, frequency of riffles, bank stability, vegetative protection, and riparian vegetative zone width. Sixteen habitat variables were selected from the ADEQ and EMAP datasets for comparisons. These variables can be categorized into the 4 major groups; riparian vegetation, in-stream substrate and cover, and geomorphology (Table 2).

Table 2. Habitat attributes recorded at 32 sites in the LCR basin using ADEQ and EMAP methods, 2007.

Category	Attribute	ADEQ	EMAP
In-stream substrate	Median particle size (D50)	Reach-wide particle size count, 100 particles total, measured using modified Wolman, zig-zag method	5 particle measures at 21 transects (105 'particles' total, size estimated)
	Mean embeddedness of channel substrates	Collected concurrently with riffle particle size count (100 measurements)	55 measurements (5 at each of 11 cross sections)
	Percent fines (substrate that is <2mm in size)	Determined during the reach particle size count (100 measurements)	Determined during the particle size count (105 measurements)
In-stream cover	Percent algae cover on stream bottom	Visual estimate, single observation taken for the entire reach	Visual estimate taken for each transect (11 observations)
	Percent macrophyte cover on stream bottom		
	Visual-based habitat score	ADEQ Habitat Assessment Score - Sum of 5 categorical substrate and bank habitat attributes for an overall score of 20	USEPA's Rapid Bioassessment Habitat Assessment Score - Sum of 10 categorical habitat attributes for an overall score of 200
Riparian vegetation	Percent Canopy Density	Concave densiometer used to measure right bank, left bank, center upstream, center downstream, for a total of 12 measurements	Convex densiometer used to measure right bank, left bank, center upstream, center downstream, center Left, center Right at 11 transects, for a total of 66 measurements
	% Riparian cover - ground layer barren	Visual estimate, single observation taken for the entire reach	Visual estimate (22 measures for each) broken down into 4 groups
	% Riparian cover - Ground layer cover <0.5m		
	% Riparian cover - mid-layer cover 0.5-5m		
	% Riparian cover - canopy cover >5m		
Geomorphology	Bankfull width of channel	Width of channel at bankfull elevation	Measured at each transect (11 measurements)
	Bankfull height of channel	Mean bankfull depth of channel at bankfull elevation	
	Pool habitat, % of reach	Visual estimate made by pacing along the entire reach	100 visual measurements along 100m reach, unless reach was 150 m then 150 measurements were taken
	Riffle habitat, % of reach		
	Run/glide habitat, % of reach		

Statistical analysis:

ADEQ habitat data were entered into ADEQ's Microsoft ACCESS database (EDAS). The USEPA scanned and uploaded EMAP habitat data into their database and used the R statistical program to summarize or calculate variables (Appendix C). Univariate and multivariate statistical analyses were used to compare habitat parameters and examine their association to the biological indices. Descriptive statistics (mean, standard error, and the coefficient of variation {CV}) were calculated for each habitat variable. The CV was used to provide a dimensionless measure of spread in which scaling is relative to the mean. Pearson product-correlation coefficients were generated for each pair of similar metrics from

both protocols. The correlation coefficients and scatter plots were used to evaluate similarity between EMAP and ADEQ methods for each habitat variable. The closer the rho or r-value is to 1, the more similar are the two methods for a given variable; values near zero would indicate the two measures are not correlated to each other, and negative values that they are inversely related to each other.

Several multivariate statistics were used to examine associations among the habitat and biological variables. Principal components analysis (PCA) was used to generate independent habitat gradients for each protocol. The gradients were related back to the biota to determine how well each set of habitat variables performed. PCA generates linear combinations of variables which are represented with principal component vectors. The first principal component (PC1) accounts for the greatest proportion of variance in the data and each successive orthogonal component accounts for next greatest proportion of the variance (in which the eigenvalues are >1). Contributions from the variables are expressed as loadings where the highest loadings are interpreted as the most significant. Only the first two principal components from the EMAP and ADEQ habitat data sets were compared since they accounted for a majority of the variation (cumulative variation = 77.8% and 64.7%, respectively).

Multiple linear regression (MLR) models of the relationships among habitat and biological variables were developed using a mixed stepwise procedure to choose a final model. Habitat variables that had skewed distributions were either logarithmic base-ten transformed or in the case of zero values one was added to the metric to retain the zero value after the transformation. In some cases where habitat variables were on different scales, variables were normalized by subtracting the mean and dividing by the standard deviation. To avoid the problems of multi-collinearity a screening process consisting of correlation analysis and PCA was conducted to remove redundant variables. PCA can be useful for identifying a parsimonious set of variables which can then be used in a stepwise multiple regression to develop a habitat model. In general ADEQ variables were only removed if more than 50% of the values were missing. The EMAP variables were reduced from 619 variables to 27. The MLR stepwise procedure alternates the forward and backward steps that uses the most significant term that satisfies probability to enter ($p = 0.05$) and removes the least significant term satisfying probability to leave ($p = 0.05$). Goodness of fit was determined using the coefficient of determination (R^2) and the Akaike's Information Criteria (AIC). The R^2 ranges from 0 to1 with 1 meaning that variables explain 100% of the variation within the response variable. AIC is a function of the number of observations and the sum of squared errors. The AIC statistic decreases with the goodness of fit but also increases with too many variables, which discourages over-fitting. The model with lowest AIC and highest R-squared was determined to be the best model.

Results

Macroinvertebrate Index and Metric Comparison

The precision of the ADEQ and EMAP macroinvertebrate collection methods were very similar (Table 3). The CV for the Index of Biological Integrity (IBI) scores among reference sites was equivalent for ADEQ and EMAP methods at 22% (Table 3). The CV for all 32 sites in the basin was much greater, at 44% and 47%, but similar for both methods. Average IBI scores were also very similar between ADEQ and EMAP methods for both reference and all sites. The CV of metric scores based on an average for the 7 cold water IBI metrics, also indicated similarity between ADEQ and EMAP methods, though with greater variation than the IBI score. The CVs were greatest for the metrics intolerant taxa richness, percent stoneflies, and percent composition by the scraper functional feeding group for both ADEQ and EMAP datasets indicating more variation in these metrics among all sites using either method (Table 5). In evaluating method precision, the two methods are very similar with comparable average IBI scores and reference site CV values.

Sensitivity of the two methods was evaluated. ADEQ and EMAP method sensitivity values were very similar (ADEQ = 1.74; EMAP= 1.83). Discriminatory power or sensitivity between the ADEQ and EMAP methods was comparable.

Method bias was evaluated by comparing CVs among different Rosgen stream types. There are many low gradient, alpine meadow channels (C & E type) as well as steeper gradient (A & B type) and large order low gradient stream types (Bc and C type channels) in the Little Colorado River basin. Method bias was evaluated in the dataset by comparing the CV between forested, high gradient and low gradient meadow streams. The CV of IBI scores for both types of channels and both methods was large, at 50% for meadow streams between methods and 40-50% for steeper gradient streams, similar to the overall CV for all 32 sites in the basin. There was an insufficient number of reference sites in each stream type (meadow vs. steeper gradient) to allow for examination of method bias between reference sites. However the fact that the overall CV of IBI scores for all meadow streams was similar to that of the steeper gradient streams is an indicator that method bias among stream types would not produce a significant difference in the macroinvertebrate community index.

Table 3. Comparison of ADEQ and EMAP methods using coefficients of variation among datasets.

Dataset	N	Mean ADEQ IBI Score	CV - ADEQ method	Mean EMAP IBI Score	CV - EMAP method
Reference sites, IBI Score	3	60	0.22	59	0.22
All sites, IBI Score	32	40	0.44	37	0.47
Reference sites, 7 metric average	3		0.38		0.38
All sites, 7 metric average	32		0.85		0.87
IBI score for meadow streams, C & E type channel	14	39	0.50	35	0.50
IBI score for high gradient streams >2% slope	15	43	0.40	42	0.50

Index of biotic integrity scores were assigned to three impairment scoring categories (Table 4) based on thresholds identified in ADEQ's Biocriteria Implementation Procedures document (ADEQ, 2008). The

agreement in group assignment between the ADEQ and EMAP methods was evaluated. Both methods categorized the three a-priori selected stressed sites as violating the IBI criterion, and categorized two of the three a-priori reference sites as meeting the IBI criterion. Overall, samples were classified into the same scoring categories by the two methods 82% of the time, and into different categories 18% of the time (Table 4) and classifications by the two methods were highly correlated (Spearman's rho=0.783 $p<0.001$).

Scoring category assignment did not match between the two methods for 6 sites (Lee Valley Creek, Milk Creek, two Hall Creek sites, E. Fork Little Colorado River, and Mineral Creek). The ADEQ IBI scores were greater in 5 of 6 cases; the EMAP IBI score was greater in the sample from Hall Creek (LCHAL004.59). Of those six, four samples scored near the biocriteria thresholds with IBI scores that differed only by a few points. Lee Valley Creek and Milk Creek samples had substantially different IBI scores between ADEQ and EMAP samples, with a point spread of 25 and 7 points, respectively. The macroinvertebrate metrics diptera taxa, intolerant taxa, and percent stoneflies were all significantly greater and the metric, Hilsenhoff biotic index was less in these 6 cases than in the remaining 26 samples as per the Mann Whitney 2-sample test ($p<0.05$). In addition, the habitat metrics percent canopy cover and percent riffle habitat were significantly greater and the metrics crayfish abundance, TDS, specific conductance, pH and hardness were all less in the 6 samples that did not agree in scoring category. These factors describe these 6 sites as being in better condition than the majority of sites in the LCR, but scored just a few points lower in EMAP-IBI score which resulted in a change in condition class from meeting to inconclusive. Lee Valley Creek and Mineral Creek are outlier cases in which the IBI score changed from meeting to violating the biocriteria standard and from inconclusive to violating the standard, respectively.

Table 4. Distribution of macroinvertebrate IBI scores across biocriteria attainment categories, for 32 samples from the Little Colorado River basin, spring 2007.

Scoring Category	IBI Score Range	ADEQ Samples	EMAP Samples	EMAP Results Agree with ADEQ results	EMAP Results disagree with ADEQ results
Meeting IBI criterion	≥52	10 (31%)	7 (22%)	6 (19%)	4 (12%)
Inconclusive	46-51	2 (6%)	3 (9%)	0	2 (6%)
Violating IBI criterion	≤45	20 (63%)	22 (69%)	20 (63%)	0

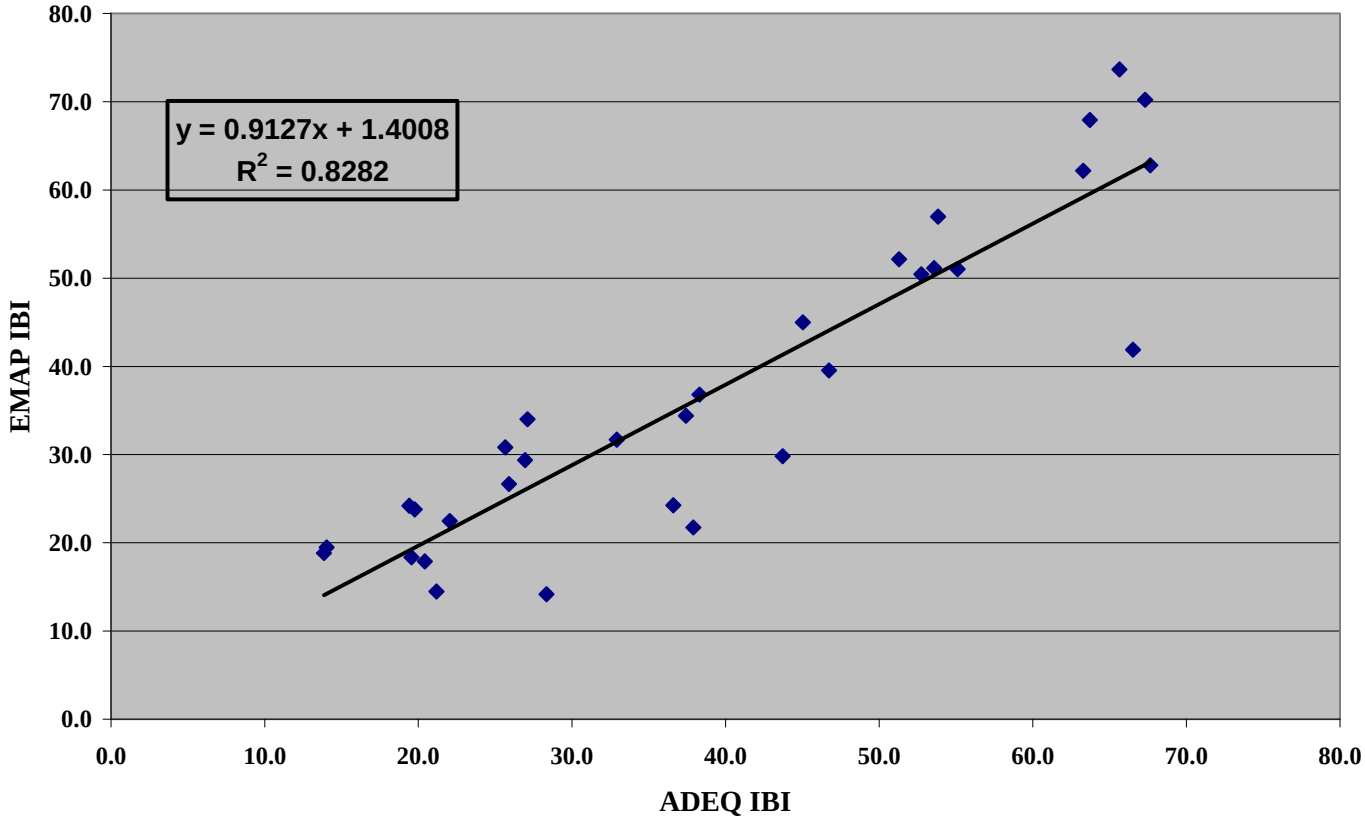

Figure 2. Relationship of ADEQ and EMAP collected macroinvertebrate samples, Little Colorado River basin sites (n=32), spring 2007.

Comparisons of 17 individual macroinvertebrate metrics plus the IBI scores were conducted to examine similarities between ADEQ and EMAP methods. The Pearson correlation coefficient (r) was used to determine the extent to which the ADEQ and EMAP metric and IBI values were correlated (Table 5). The IBI scores for ADEQ and EMAP samples were very highly correlated (r = 0.91; Figure 2). The mean IBI score for ADEQ samples was 40, and 37 for EMAP samples. The ADEQ-IBI score was greater than the EMAP-IBI score in 17 cases. There were differences among individual metrics. Four metrics measured by both methods were significantly correlated ($p<0.05$), including mayfly taxa richness, Hilsenhoff biotic index, intolerant taxa richness, and total taxa richness. Metrics not significantly correlated included all of the percent composition metrics (eg. percent composition by EPT, non-insects, stoneflies and tolerant taxa) and some functional feeding group metrics (percent filterers and percent scrapers).

Table 5. Descriptive statistics for macroinvertebrate metrics derived from ADEQ and EMAP data collection methods and Pearson's correlations (r) between the two methods for each metric, Little Colorado River basin sites, 2007. Significant correlation coefficients (α<0.05) are in bold type. Metrics of the ADEQ cold water IBI are marked with an asterisk.

Macroinvertebrate Metric	Method	Mean	Standard Deviation	CV	N	r
Baetidae (mayfly) percent composition	ADEQ	70.1	27.1	0.4	30	0.15
Baetidae (mayfly) percent composition	EMAP	51.0	35.2	0.7	32	
Diptera taxa richness*	ADEQ	5.4	2.1	0.4	32	0.07
Diptera taxa richness	EMAP	6.1	2.5	0.4	32	
Dominant taxon %composition	ADEQ	40.5	18.7	0.5	32	0.11
Dominant taxon %composition	EMAP	40.3	15.0	0.4	32	
Mayfly %composition	ADEQ	22.4	18.3	0.8	32	0.07
Mayfly %composition	EMAP	16.2	14.5	0.9	32	
Mayfly Taxa richness	ADEQ	4.0	2.1	0.5	32	**0.38**
Mayfly Taxa richness	EMAP	4.1	2.3	0.6	32	
EPT %composition	ADEQ	35.5	23.3	0.7	31	-0.08
EPT %composition	EMAP	23.2	16.3	0.7	32	
Filterer %composition	ADEQ	17.0	16.4	1.0	31	0.15
Filterer %composition	EMAP	10.2	11.3	1.1	32	
Hilsenhoff Biotic Index*	ADEQ	5.7	0.7	0.1	32	**0.35**
Hilsenhoff Biotic Index	EMAP	6.1	0.6	0.1	32	
Index of Biological Integrity	ADEQ	39.5	17.6	0.4	32	**0.91**
Index of Biological Integrity	EMAP	37.4	17.6	0.5	32	
Intolerant taxa richness*	ADEQ	1.3	1.4	1.0	32	**0.57**
Intolerant taxa richness	EMAP	1.3	1.7	1.3	32	
Non-insect %composition	ADEQ	16.5	20.3	1.2	32	-0.05
Non-insect %composition	EMAP	30.4	23.0	0.8	32	
Stonefly %composition*	ADEQ	7.0	13.3	1.9	32	0.07
Stonefly %composition	EMAP	3.6	5.6	1.6	32	
Scraper feeding group %composition*	ADEQ	10.1	12.9	1.3	32	0.24
Scraper feeding group %composition	EMAP	6.3	8.5	1.3	32	
Scraper taxa richness*	ADEQ	3.1	2.8	0.9	32	0.32
Scraper taxa richness	EMAP	2.9	3.0	1.0	32	
Tolerant %composition	ADEQ	16.5	18.5	1.1	32	0.28
Tolerant %composition	EMAP	26.1	16.9	0.7	32	
Tolerant taxa richness	ADEQ	5.4	1.9	0.4	32	0.30
Tolerant taxa richness	EMAP	6.1	2.4	0.4	32	
Total taxa richness*	ADEQ	21.2	7.1	0.3	32	**0.38**
Total taxa richness	EMAP	22.6	9.0	0.4	32	
Caddisfly taxa richness	ADEQ	3.0	2.3	0.8	32	0.25
Caddisfly taxa richness	EMAP	2.8	3.1	1.1	32	

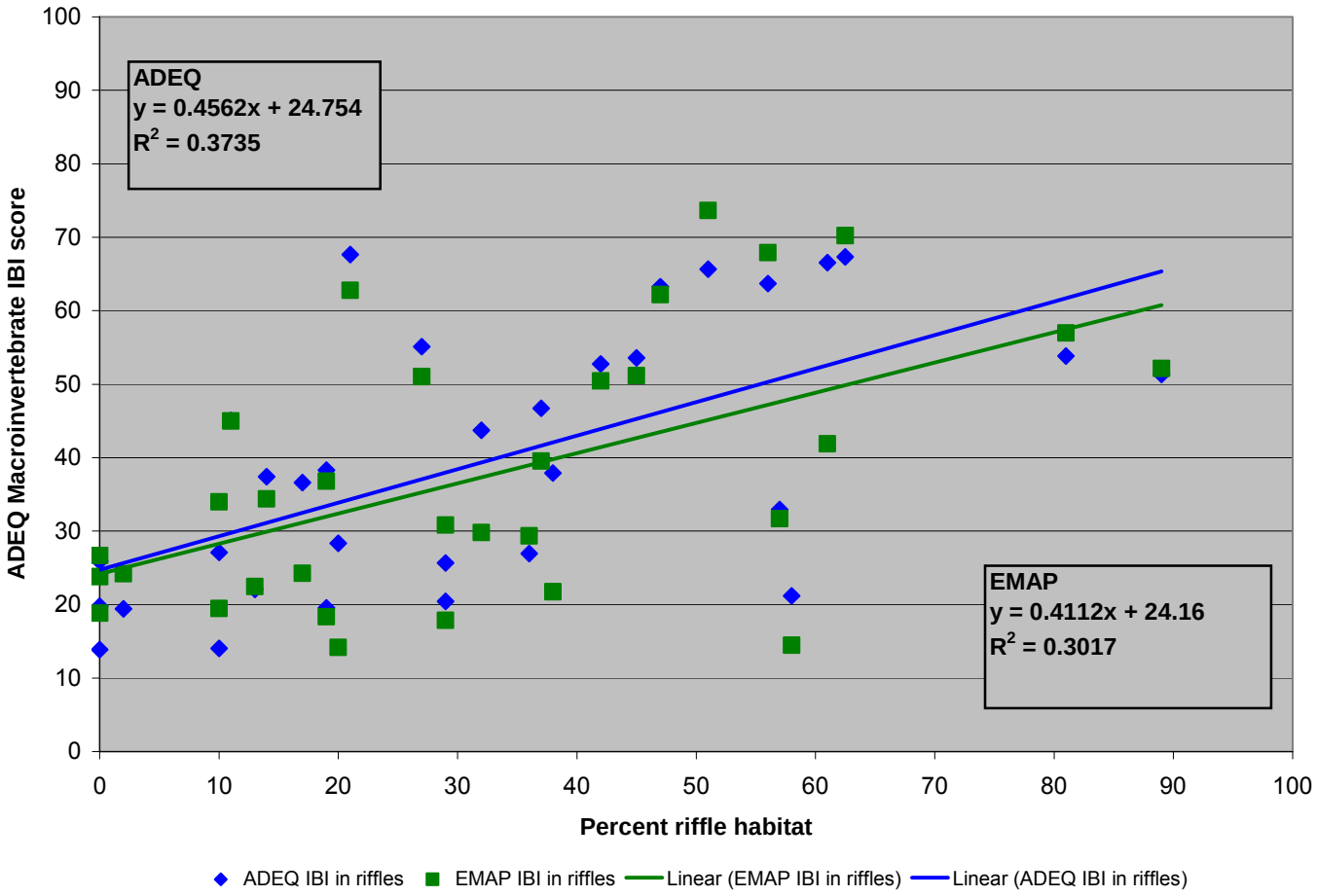

Figure 3. ADEQ and EMAP IBI Scores across a gradient of percent riffle habitat in the reach for 32 Little Colorado River basin sites, 2007.

The EMAP and ADEQ IBI scores were both significantly correlated to percent of riffle habitat (r=0.611 and r=0.549, p<0.001; Figure 3), and the regression line slopes and origins were not statistically different (ANCOVA) between the two methods. Measurements of percent riffle habitat within the study reach were similar for both EMAP and ADEQ reaches with a mean of 30% and 33%, respectively. With low percent riffle habitat, you would expect to find differences between the ADEQ riffle-based macroinvertebrate samples and the EMAP multi-habitat samples. However that was only true for the Milk Creek (montane stream type) sample where the %riffle habitat was 37% and the IBI score and metrics, such as %stoneflies, were greater in the ADEQ sample. Overall, the IBI scores related to %riffle habitat very similarly, despite the multi-habitat EMAP sampling approach.

EMAP and ADEQ IBI scores were plotted by % fine sediment (<2mm) in the stream bottom (reach-wide pebble count method) to determine how well the a-priori reference and stressed sites were categorized with respect to channel sediments (30% fines is the threshold above which sites are considered impaired). In the ADEQ scatterplot, 2 of 3 reference sites plotted below the 30% fines criterion and 2 of 3 stressed sites plotted above this threshold (Figure 4). In the EMAP scatterplot, 2 of 3 reference sites plotted below the 30% fines criterion and 3 of 3 stressed sites plotted above this threshold (Figure 5). The ADEQ method found only 10 samples having fine sediment values >30%, whereas the EMAP method found 17 samples with values >30%.

As expected, the ADEQ riffle %fines method portrays much less fine sediment on stream bottoms than either the reach-wide ADEQ or EMAP method (Figure 6). A riffle particle size count was only collected

with the ADEQ method for purposes of comparison to the new bottom deposits water quality standard. Six samples were exceeding the 30% fines bottom deposits criterion; one a-priori stressed sample, one a-priori reference sample and 4 other samples.

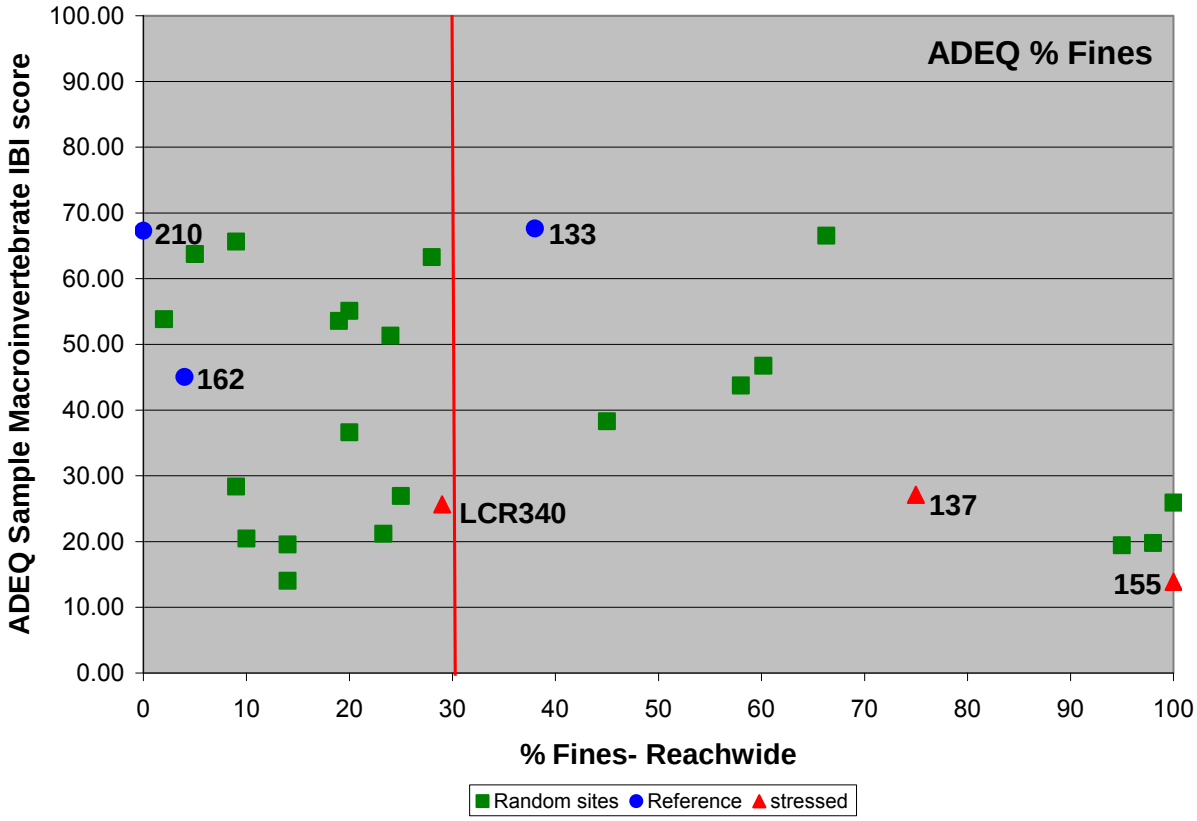

Figure 4. Distribution of ADEQ IBI scores across a gradient of stream bottom percent fine sediment, collected using a reach-wide pebble count method, for 30 sites in the Little Colorado River basin in 2007 (site ID numbers are displayed on graph for reference and stressed sites). The 30% fines threshold above which sites are considered impaired for riffle particle counts is shown for reference.

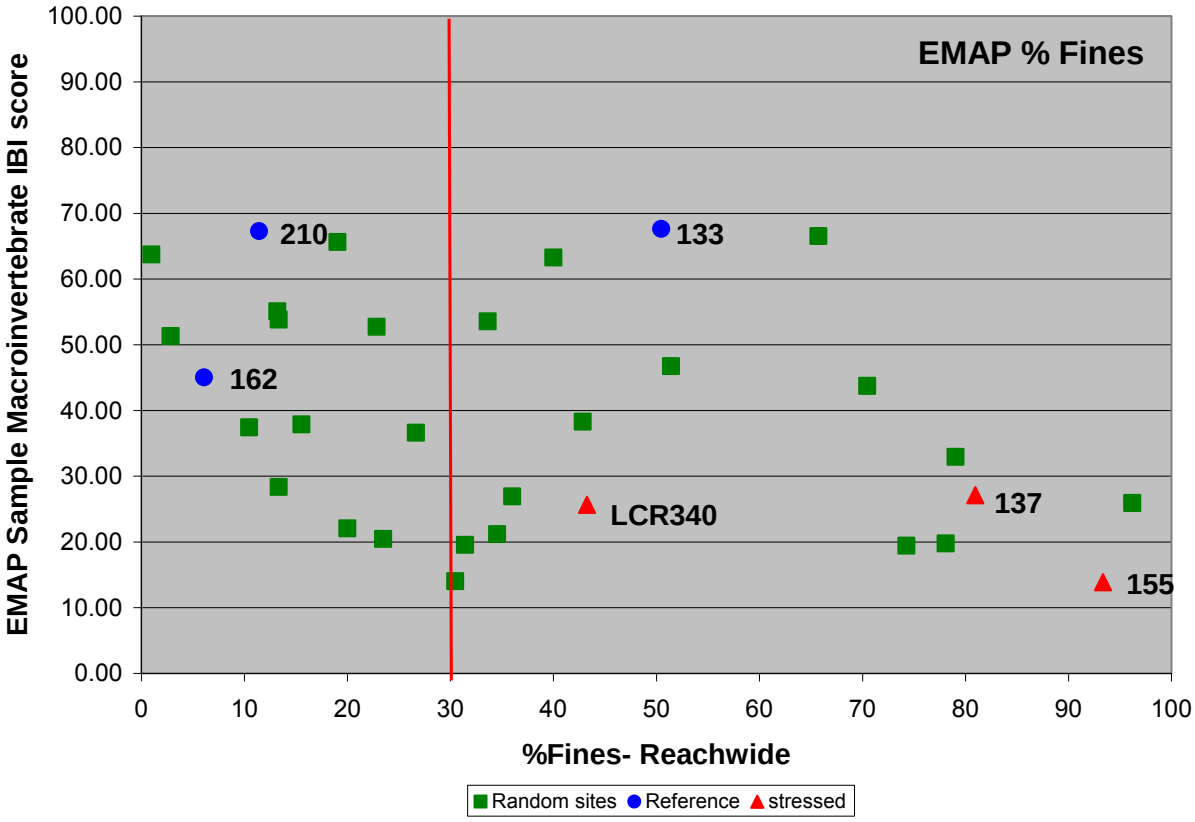

Figure 5. Distribution of EMAP IBI scores across a gradient of percent stream bottom fine sediment, collected using EMAP reach-wide pebble count method for 30 sites in the Little Colorado River basin in 2007 (site ID numbers are displayed on graph for reference and stressed sites). The 30% fines threshold above which sites are considered impaired for riffle particle counts is shown for reference.

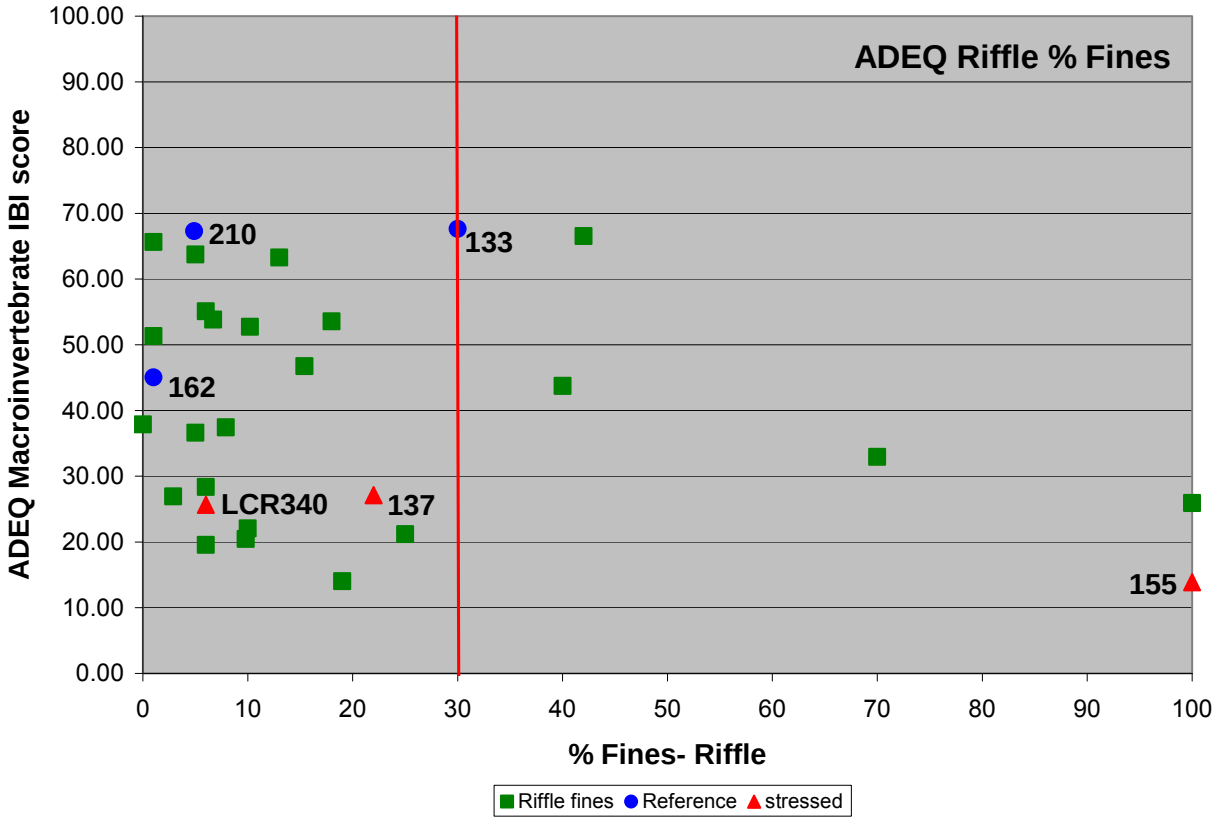

Figure 6. Distribution of ADEQ IBI scores across a gradient of percent stream bottom fine sediment, collected using the ADEQ riffle pebble count method (site ID numbers are displayed on graph for reference and stressed sites. The 30% fines threshold for riffle particle counts is shown for reference).

Discriminant function analysis (DFA) was used to determine the most important of 16 environmental variables that distinguish among the IBI attainment classes. The DFA identified two (EMAP model) to four (ADEQ model) important environmental stressors. In the ADEQ model, the DFA selected 4 environmental stressors for the first discriminant function (%Riffle habitat, crayfish abundance, riffle median particle size class, and embeddedness in riffles) and the model accounted for 99% of the dispersion among parameters (Figure 7). In the EMAP model, the DFA selected only two variables for the first discriminant function (%canopy cover and %riffle habitat) and the model accounted for 85% of the total dispersion among the parameters (Figure 8). The DFA scatterplots in Figure 7 and 8 display the clear separation of samples meeting or exceeding biocriteria standards with either the ADEQ or EMAP datasets but with somewhat differing environmental parameters. Both models selected %riffle habitat as an important variable for separating out samples meeting or exceeding the biocriteria standard.

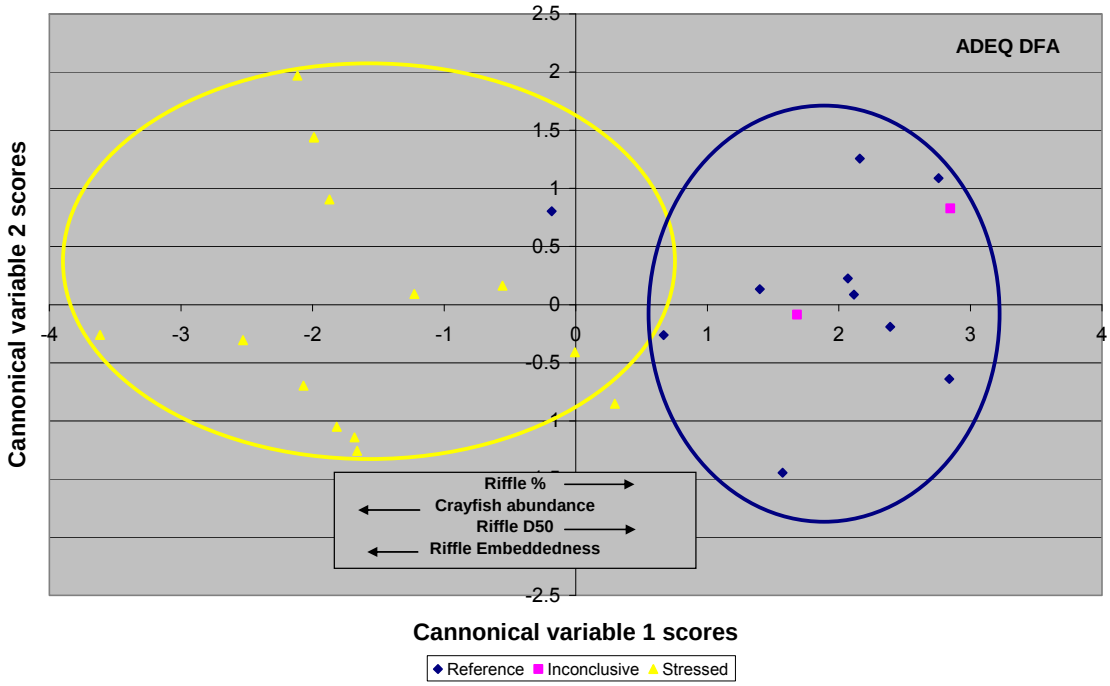

Figure 7. Distribution of ADEQ IBI scores in multivariate space, relative to the environmental variables selected as significant in a discriminant function analysis, Little Colorado River sites collected in spring 2007.

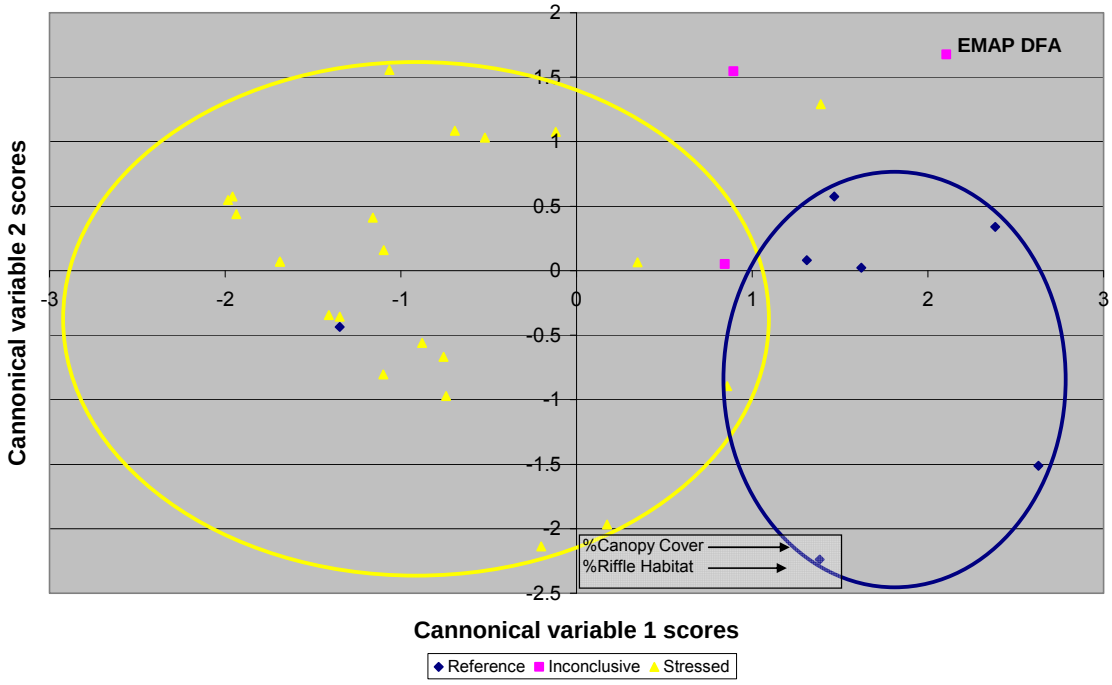

Figure 8. Distribution of EMAP IBI scores in multivariate space, relative to the environmental variables selected as significant in a discriminant function analysis, Little Colorado River sites collected in spring 2007.

Habitat Metric Comparison - Univariate Statistics

Descriptive statistics of habitat attributes sampled with the EMAP and ADEQ methods and correlations (Pearson's correlation coefficient, r) between the two methods for each attribute are given in Table 6. Riparian vegetation attribute measures were similar between the two methods. However, the ADEQ method estimated the percentage of riparian vegetation at the lower, mid, and upper canopy levels to be approximately 12% higher than the EMAP estimates. The EMAP and ADEQ understory and mid-story cover variables were moderately correlated (r = 0.66 and 0.62, respectively), but there was poor correlation between EMAP and ADEQ upperstory vegetation estimates (r = 0.35). EMAP estimates of canopy cover measured with a densiometer and barren ground estimates were greater than the ADEQ estimates (16% and 6.6% respectively). Canopy cover might have been greater than those of ADEQ because of differences in densiometer methods (convex versus concave mirrored instrument). Despite the method differences the canopy estimates were highly correlated (r = 0.88).

Most of the geomorphology related habitat measures (percentage of riffle, run, and pool) were similar between ADEQ and EMAP methods (the greatest mean difference = 3.88 %). The glide and riffle habitat metrics were moderately correlated between methods, whereas the percent of pool present within a stream and the bankfull width were highly correlated between the two methods. The ADEQ estimates were generally greater for bankfull width (mean difference = 2.67 m), probably due to different methods of bankfull estimation between ADEQ and EMAP. ADEQ used Arizona-derived "regional curves" in addition to field indicators, to help identify bankfull elevation, whereas EMAP protocol used field indicators only (Moody and others, 2003). Bankfull height was the only geomorphology variable that was not significantly correlated between the two methods.

In-stream substrate measures of percent fine substrate, embeddedness and the D50 particle size were significantly correlated between the two methods (r = 0.93, 0.70, and 0.90 respectively). The ADEQ mean values were greater for percent embeddedness and the D50 median particle size, whereas the EMAP mean value for percent fine substrate was greater than the ADEQ mean value (Table 6).

For in-stream cover, the two methods produced similar algal cover estimates (Table 6). However, estimates of macrophyte cover were not significantly correlated, but the means were similar (both 0.1).

The EMAP and ADEQ qualitative rapid habitat bioassessments were very similar between sites (r=0.80 and mean difference = 1.34). The standard errors and CVs were much less for this metric than most metrics, probably because it was a combination of 5 (ADEQ) to 10 (EMAP) metrics, rather than just one metric.

Table 6. Descriptive statistics for habitat attributes measured with ADEQ and EMAP data collection methods and Pearson's correlations (r) between the two methods for each attribute, at sites sampled in the Little Colorado River basin during 2007. Significant (p<0.01) correlation coefficients are in bold type.

Habitat attribute	Protocol	Mean	Standard error	CV	N	*r*	*p*
Riparian Vegetation							
Canopy cover, densiometer	EMAP	44.5	5.7	71.3	31	**0.88**	**<0.0001**
Canopy cover, densiometer	ADEQ	28.6	5.1	98.4	31		
Percent barren ground cover	EMAP	18.1	3.1	96.3	31	**0.62**	**0.0002**
Percent barren ground cover	ADEQ	11.5	2.8	138.2	31		
Percent riparian lower story	EMAP	52.3	4.6	49.2	31	**0.66**	**<0.0001**
Percent riparian lower story	ADEQ	65.0	5.6	47.5	31		
Percent riparian midstory	EMAP	14.8	1.5	55.9	31	**0.62**	**0.0002**
Percent riparian midstory	ADEQ	26.4	4.2	89.3	31		
Percent riparian upperstory	EMAP	4.9	1.2	141.8	31	0.35	0.0510
Percent riparian upperstory	ADEQ	17.5	3.8	121.2	31		
Geomorphology							
Percent pool	EMAP	23.6	4.5	106.3	31	**0.73**	**<0.0001**
Percent pool	ADEQ	22.7	4.6	113.6	31		
Percent riffle	EMAP	29.5	3.5	65.8	31	**0.53**	**0.0024**
Percent riffle	ADEQ	33.3	4.2	69.5	31		
Percent glide/run	EMAP	43.8	4.5	57.0	31	**0.52**	**0.0025**
Percent glide/run	ADEQ	45.5	4.9	59.5	31		
Bankfull height	EMAP	0.4	0.1	27.8	11	0.09	0.7952
Bankfull height	ADEQ	0.3	0.0	77.9	11		
Bankfull width	EMAP	7.1	1.1	68.1	21	**0.73**	**0.0002**
Bankfull width	ADEQ	9.8	1.6	73.9	21		
In-stream substrate							
Percent fine substrate	EMAP	38.1	5.2	69.2	26	**0.93**	**<0.0001**
Percent fine substrate	ADEQ	34.3	6.1	90.1	26		
Percent embeddedness	EMAP	40.8	3.4	46.0	30	**0.70**	**<0.0001**
Percent embeddedness	ADEQ	49.0	4.4	49.3	30		
Median particle size	EMAP	20.5	5.3	123.3	23	**0.90**	**<0.0001**
Median particle size	ADEQ	25.9	5.7	105.9	23		
In-stream Cover							
Percent algae cover	EMAP	0.1	0.0	188.5	30	**0.55**	**0.0018**
Percent algae cover	ADEQ	0.2	0.0	125.6	30		
Percent macrophyte cover	EMAP	0.1	0.0	130.3	31	0.15	0.4100
Percent macrophyte cover	ADEQ	0.1	0.0	74.5	31		
Overall Habitat Assessment							
Rapid habitat visual assessment	EMAP	14.5	0.6	23.0	31	**0.80**	**<0.0001**
Rapid habitat visual assessment	ADEQ	15.9	0.7	15.5	31		

The relationship between an individual habitat metric and an IBI can be an indicator of the metric's ability to explain the biotic condition. Overall the correlations of habitat metrics and the macroinvertebrate IBI were fairly similar between the ADEQ and EMAP methods. Three habitat metrics (canopy cover, percent riffle, and visual habitat assessment) were significantly and positively correlated with the macroinvertebrate IBI for both the ADEQ and EMAP data collection methods (Table 7). Three other metrics (percent pool, bankfull width, and percent algal cover) were significantly and negatively correlated with the macroinvertebrate IBI for the EMAP method but not for the ADEQ method.

Overall the associations between habitat variables and the aquatic vertebrate IBI score were fairly similar between the ADEQ and EMAP methods (Table 7). For both collection methods, three habitat metrics (percent canopy cover, percent riffles, and the visual habitat assessment) were significantly and positively correlated with the aquatic vertebrate IBI and one metric (percent fines) was significantly and negatively correlated with the aquatic vertebrate IBI. Four other habitat variables were correlated with the aquatic vertebrate IBI derived from one or the other data collection methods. Riparian mid-story cover was significantly and positively associated with the ADEQ derived vertebrate IBI and percent embeddedness was significantly and negatively associated with the ADEQ derived IBI. Percent pool and percent algal cover were significantly and negatively associated with the EMAP derived aquatic vertebrate IBI.

For the periphyton IBI, four habitat metrics had significant correlations with the IBI for both the ADEQ and EMAP methods. There were significant positive correlations with median particle size and the visual habitat assessment score, and significant negative associations between the percent fines and percent embeddedness metrics with the periphyton IBI. Two other metrics (bankfull height and percent glide) were significantly and negatively associated with only the ADEQ derived periphyton IBI.

Table 7. Pearson correlations(r) between habitat attribute measures and Indexes of biological integrity for both EMAP and ADEQ collection methods, Little Colorado River basin sites, 2007 (values in bold are significantly correlated (p<0.05); all other values and dashed lines represent insignificant correlations).

HABITAT VARIABLE	Method	Macroinvertebrate IBI		Vertebrate IBI		Periphyton IBI	
		r	N	*r*	N	*r*	N
Riparian Vegetation		--	--	--	--	--	--
Canopy Cover, Densiometer	EMAP	**0.59**	30	**0.52**	18	--	--
Canopy Cover, Densiometer	ADEQ	**0.62**	30	**0.56**	18	--	--
Percent Riparian Midstory	EMAP	--	--	0.44	18	--	--
Percent Riparian Midstory	ADEQ	--	---	**0.53**	18	--	--
Geomorphology		--	--	--	--	--	--
Percent Pool	EMAP	**-0.44**	30	**-0.49**	18	--	--
Percent Pool	ADEQ	-0.16	30	-0.22	18	--	--
Percent Riffle	EMAP	**0.59**	30	**0.54**	18	--	--
Percent Riffle	ADEQ	**0.53**	30	**0.65**	18	--	--
Percent Glide/Run	EMAP	--	--	--	--	-0.30	31
Percent Glide/Run	ADEQ	--	--	--	--	**-0.50**	31
Bankfull Height	EMAP	--	--	--	--	-0.50	11
Bankfull Height	ADEQ	--	--	--	--	**-0.64**	11
Bankfull Width	EMAP	**-0.53**	21	--	--	--	--
Bankfull Width	ADEQ	-0.32	21	--	--	--	--
In-stream Substrate		--	--	--	--	--	--
Percent Fine Substrate	EMAP	-0.40	26	**-0.64**	16	**-0.77**	26
Percent Fine Substrate	ADEQ	-0.35	26	**-0.53**	16	**-0.75**	26
Percent Embeddedness	EMAP	--	--	-0.31	17	**-0.75**	30
Percent Embeddedness	ADEQ	--	--	**-0.65**	17	**-0.48**	30
Median Particle Size	EMAP	--	--	0.53	13	**0.49**	31
Median Particle Size	ADEQ	--	--	0.50	13	**0.48**	23
In-stream Cover		--	--	--	--	--	--
Percent Algae Cover	EMAP	**-0.45**	29	**-0.56**	18	--	--
Percent Algae Cover	ADEQ	-0.28	29	-0.31	18	--	--
Habitat Visual Assessment	EMAP	**0.47**	30	**0.55**	18	**0.65**	31
Habitat Visual Assessment	ADEQ	**0.36**	30	**0.47**	18	**0.63**	31

Habitat Metric Comparison - Multivariate Habitat Comparison

Principal Components Analysis (PCA) was used to evaluate the correlation of combined habitat gradients for each of the two data collection methods. This analysis enables an evaluation of which combination of habitat gradients best accounted for the variance among the sampling sites. Since the habitat variables were collected using different methods, a comparison of the PCA results allows for a comparison of the variable sets between ADEQ and EMAP methods.

EMAP PCA

For the EMAP model, principal component #1 (PCA1) accounted for 53% of the total variation and was considered as a substrate and riparian cover gradient (Figure 9). Principal component #2 (PCA2) accounted for another 25% of the variation and was considered a hydrology gradient. The EMAP PCA1 had high positive loadings for bed stability, large substrate, and percent canopy cover. PCA1 was driven by sites Benton Creek (AZ0663-141, abbreviated as 141), Hall Creek (109), and South Fork Little Colorado River (065), which had high values for all these variables. Sites that had highly embedded substrates and sites that were dominated by fine substrates describe sites at the other end of this gradient, including Riggs Creek (098), Rudd Creek (130), Lee Valley Creek (LCLVL001.32), and Little Colorado River (145). The EMAP PCA2 had high positive loadings for slope and fast water. The other end of the gradient had a high negative loading for residual pool volume. The residual pool volume is defined by Kaufmann and others (1999) as a portion of the stream that would contain water even at zero discharge. This habitat variable is based upon thalweg depths and reach slope. The EMAP fast water and elevated slope gradient was represented by the sites with large values for these variables such as Benton Creek (141) and Milk Creek (050). Sites with slower waters and greater residual pool volumes at the other end of the gradient were represented by sites East Clear Creek (151), Clear Creek (088), and East Clear Creek (063).

ADEQ PCA

The ADEQ principal component #1 (PCA1) was defined as a substrate and flow gradient and accounted for 41% of the total variation, and principal component #2 (PCA2) was defined as a hydrology gradient with a 'bare ground' component and accounted for 25% of the variation (Figure 10). ADEQ PCA1 had a high negative loading for embeddedness, represented by highly embedded stream sites such as Rudd Creek (130) and the Little Colorado River (145) on the high end of the gradient. Large substrate size (high positive loading for D50) also affected PCA1, which was influenced by sites Chevelon Canyon (183) and Clear Creek (088). ADEQ PCA2 had high positive loadings for percent riffle habitat, represented by sites South Fork Little Colorado River (210), South Fork Little Colorado River (065), and Mineral Creek (077). The other end of this gradient represents a loss of riffle habitat and less bank stability with high negative loadings for percent pool and bare ground along the stream banks. This was driven by the following sites: Clear Creek (088), Coyote Creek (137), East Clear Creek (151), and the Little Colorado River (155).

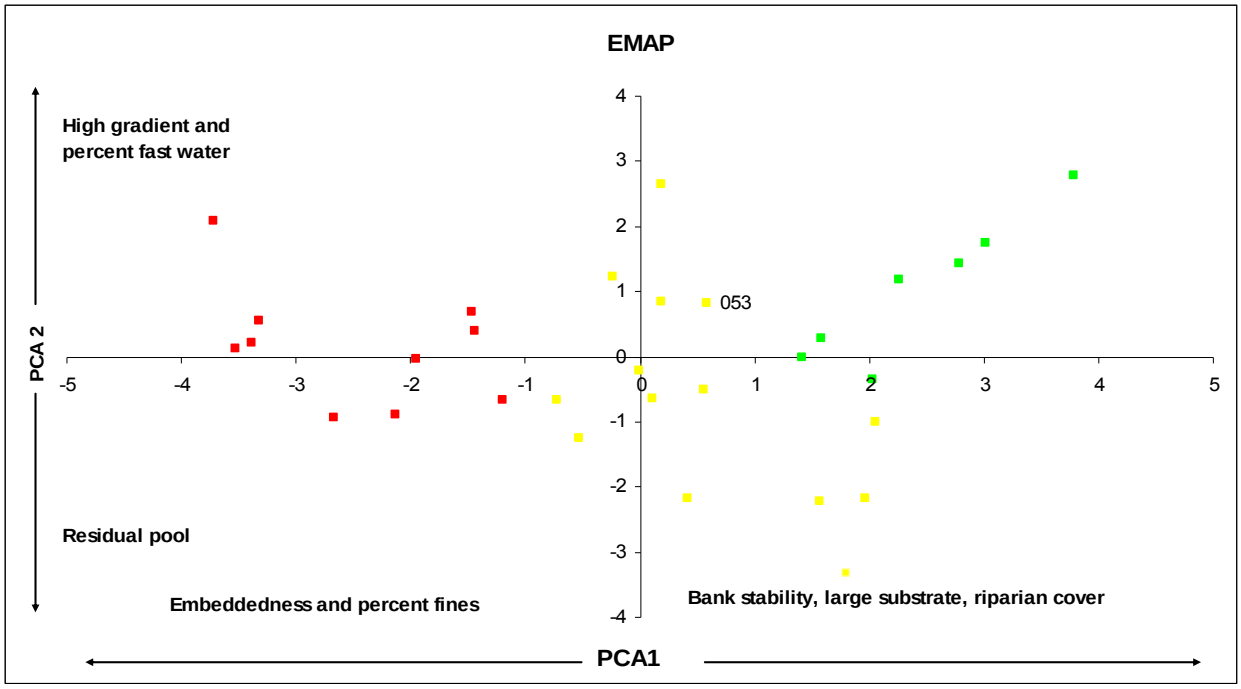

Figure 9. Plot of PCA scores for each site sampled in the Little Colorado River watershed during 2007 along the first two PCA axes derived from EMAP habitat data (green circle=reference site, red triangle=stressed site, yellow square=random site).

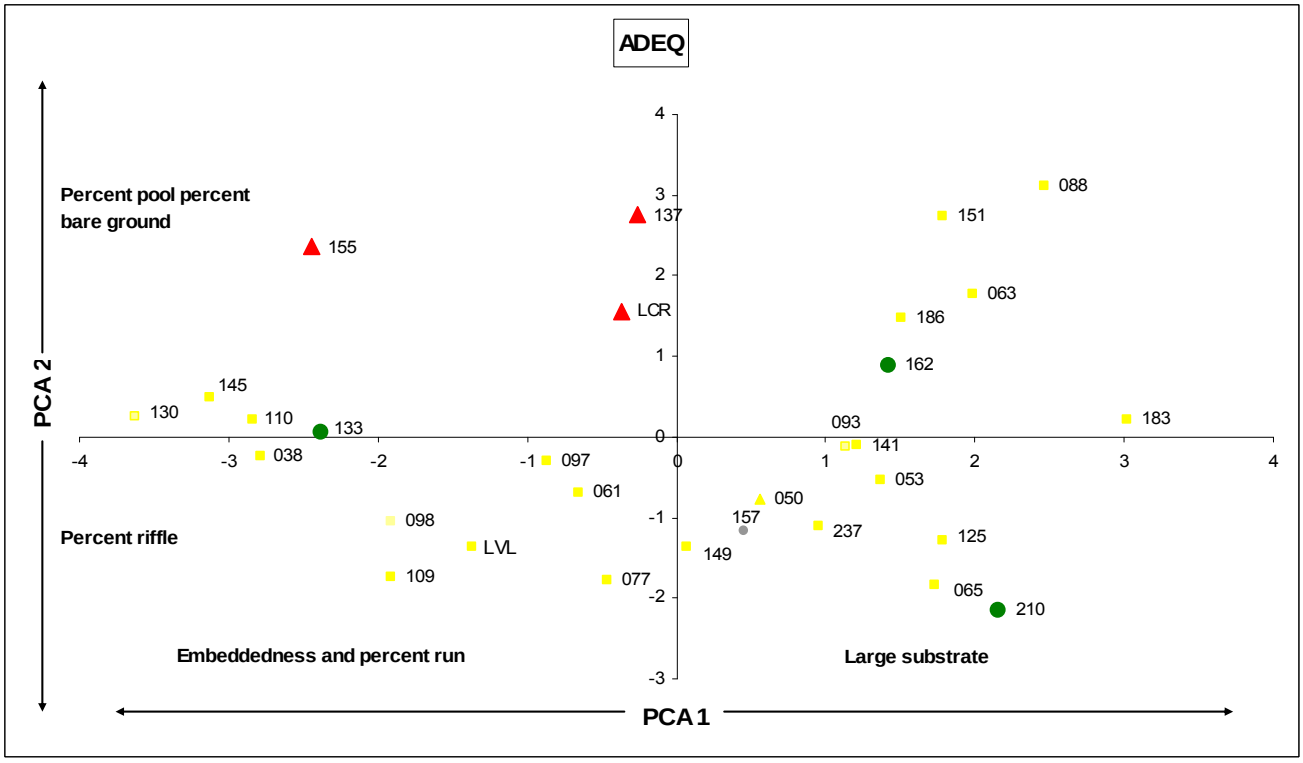

Figure 10. Plot of PCA scores for each site sampled in the Little Colorado River watershed during 2007 along the first two PCA axes derived from ADEQ habitat data(green circle=reference site, red triangle=stressed site, yellow square=random site).

Habitat Comparison - Multiple Linear Regression Models

Macroinvertebrate-habitat models

Multiple linear regression models were developed to identify the combination of habitat variables that best explain the distribution of IBI scores (Table 8, Figure 11) for the ADEQ and EMAP datasets. The final EMAP macroinvertebrate-habitat model accounted for 56% of the variation in the macroinvertebrate IBI. The model revealed that the EMAP derived macroinvertebrate IBI was positively related to percent coarse gravel in the substrate and canopy cover, and negatively related to channel morphology (width x depth). In other words, as streams within the basin become wider and deeper the macroinvertebrate biological integrity decreases and as percentages of coarse gravel and canopy cover increase the macroinvertebrate biointegrity increases. The final model constructed with the ADEQ habitat data explained 70% of the variation in the macroinvertebrate IBI. The model predicts that the macroinvertebrate IBI increases with increasing riffle habitat and greater canopy density. Both EMAP and ADEQ models essentially identified coarse stream bottom substrate and riparian canopy cover over the stream as important habitat variables to the macroinvertebrate community.

Aquatic vertebrate-habitat models

The final EMAP aquatic vertebrate-habitat model explained 76% of the variation in the aquatic vertebrate IBI. The habitat variables in the final model included percentage of coarse gravel in the substrate, residual pool volume and percent glide habitat (Table 8). The aquatic vertebrate IBI was negatively related to the percent residual pool volume and positively related to the percent glide habitat and percent of coarse gravel substrate. The final ADEQ model explained 62% of the variation in the aquatic vertebrate IBI, and included the variables percent embeddedness and percent pool habitat. The vertebrate IBI was inversely related to both attributes (i.e., as embeddedness increased and percent pool habitat increased, the vertebrate IBI decreased). Both models indicated that substrate and variety of macro-habitats were important determinants of the fish community composition and IBI score.

Table 8. Habitat attributes included in the final multiple regression models of biological assemblage IBIs using ADEQ and EMAP data collected from Little Colorado River basin streams during 2007. All non-bolded habitat variables are significant at the p<0.05 level, bolded variables are significant at p<0.01.

Biological assemblage	ADEQ Method			EMAP Method		
	R^2	Number of samples	Significant attributes (model coefficient)	R^2	Number of samples	Significant attributes
Periphyton	None	None	None	0.61	31	**Bank angle (-10.48)** **Riparian disturbance (-14.27)** **% Coarse gravel (+9.76)**
Macroinvertebrates	0.70	27	**% Riffle habitat (+0.34)** **% Canopy cover (+0.32)**	0.56	31	%Coarse gravel (+0.50) %Canopy density (+0.17) **Channel cross-section area (-14.42)**
Vertebrates (fish)	0.62	19	**% Embeddedness (-46.86)** % Pool habitat (-5.3)	0.76	19	**% Residual pool volume (-1.04)** **% Coarse gravel (+0.95)** % Glide habitat (+0.29)

Periphyton-habitat model

The final EMAP periphyton-habitat multiple regression model accounted for 61% of the variation in the periphyton IBI (Table 8). The final habitat variables included in the model were the riparian disturbance metric, bank angle and percentage of coarse gravel in the substrate. The periphyton IBI was negatively related to the riparian disturbance metric and bank angle, and positively related to percent coarse gravel substrates. There was no significant multiple regression model for the ADEQ habitat variables with the periphyton IBI, thus no results are presented for this relationship in Table 8.

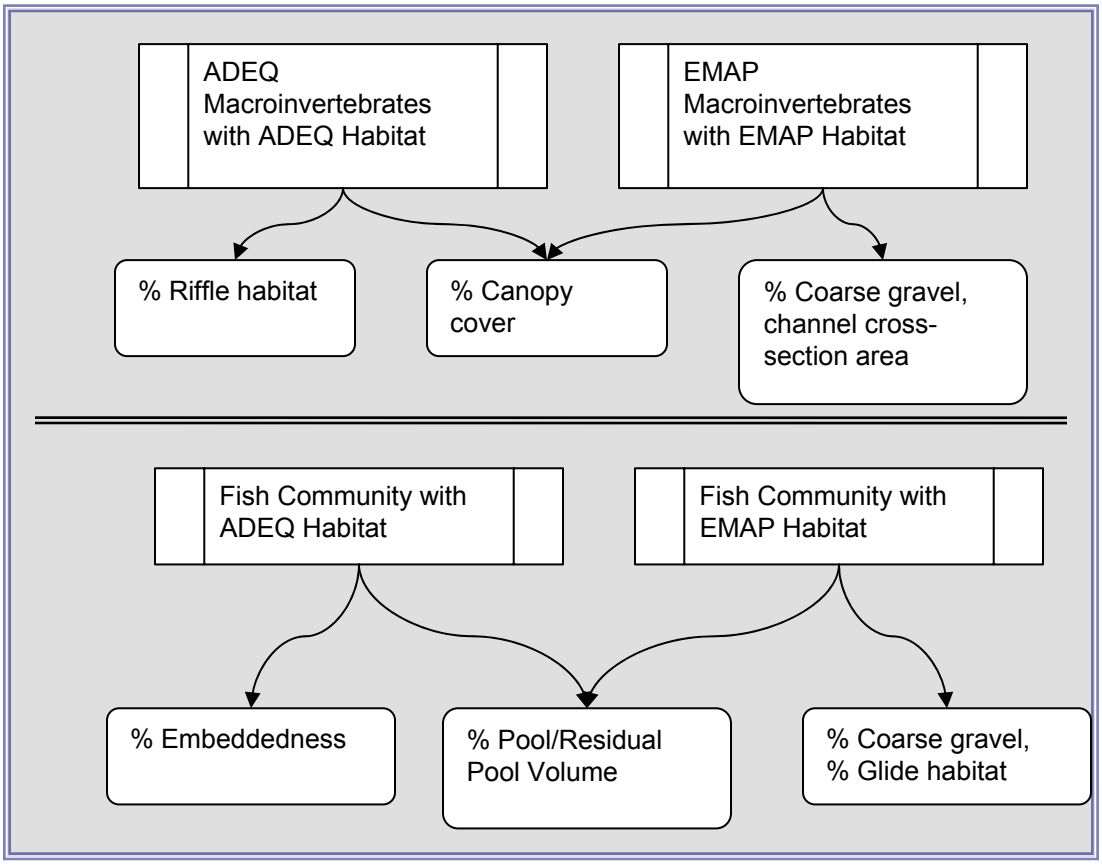

Figure 11. Comparison of multiple regression model parameters identified using both ADEQ and EMAP Habitat and macroinvertebrate datasets.

Discussion

Macroinvertebrate Method Comparisons

ADEQ has developed an Arizona-based, empirically derived macroinvertebrate IBI biocriteria standard and associated sampling methodology, following USEPA's Rapid Bioassessment Protocols (Barbour and others, 1999). After a decade of research and a multi-year standards review process, the biocriteria standard was established in the Surface Water Quality Standards in January 2009 (ADEQ, 2009). This gives ADEQ the ability to conduct site-specific biological assessments for the 305b surface water quality assessment report, as well as other uses. Since 2000, USEPA has been developing a new protocol for conducting assessments of ecological condition, for the purpose of standardizing procedures and aggregating ecological assessments into a national water quality assessment. Pilot projects were conducted across the U.S. with the Western Ecological Monitoring and Assessment Program implemented from 2000-2004. The new protocol differs from the 1999 protocol by 1) using a probabilistic study design consisting of randomly selected sites on perennial, wadeable streams, 2) collecting direct measurements of aquatic life using a stratified, multi-habitat sampling approach, and 3) collecting intensive physical habitat measurements for the purpose of identifying and ranking relative importance of chemical, physical and biological stressors affecting aquatic life condition. This EMAP protocol has been through a rigorous review process and provides for a comprehensive ecological assessment of the nation's streams. However, the EMAP protocol differs from approaches that states have typically used in the past. Arizona, like other states, has used a riffle-based macroinvertebrate protocol and a targeted sampling approach for bioassessments. Several studies have examined the effect of sample type on bioassessment results. Gerth and Herlihy (2006) found that similar bioassessment results were obtained using either a riffle-based or multi-habitat sampling approach in the Western EMAP regional survey conducted in 12 western states. Herbst and Silldorff (2004) found in a California comparison of three survey approaches that even substantially different methods of field collection, laboratory processing, and data analysis yielded similar, effective discrimination of impaired biological conditions, and that existing data could be integrated with future data collected using a unified standard approach. In Arizona, a riffle-based protocol has been used to develop biocriteria, whereas the EMAP protocol utilizes a multi-habitat or reach-wide sample collection approach (Table 1 & 2). A comparison of the two bioassessment approaches was needed to allow use of the EMAP protocol for integration into Arizona's portion of the national (305b) assessment as well as for targeted in-state bioassessments for 303d determinations of standards violations and impaired aquatic life conditions.

Several analytical approaches were used to compare macroinvertebrate and habitat metrics. The average metric and IBI precision (expressed as mean coefficient of variation value) showed that the two methods are highly comparable (Table 3). The precision among reference site IBI scores and metric values was the same for either method and near the data quality objective of 20% variability. The precision among all study site IBI scores and metric values was also very similar, indicating similar amounts of variation in the datasets. There was a slight method bias in sampling steeper gradient streams, with more variance in the EMAP method than the ADEQ method, presumably due to the greater variance in macro-habitats in step-pool stream types with gradients >2%. Overall both methods produced similar IBI score coefficients of variation for all stream types, indicating a similar amount of variance using either method. In addition, the sensitivity analysis showed that the discriminatory power of each sampling method, calculated with the ADEQ-IBI, was also very similar.

Rehn and others (2007) found that broad-scale condition assessments were nearly identical between reach-wide and riffle based methods in California. In our study, the two methods classified IBI scores similarly into the categories of meeting, inconclusive or violating the biocriteria thresholds. The a-priori reference and stressed sites were classified into the same categories by either method and overall the samples were classified into the same scoring category by either method in 82% of the samples (Table 4). In the 6 samples that did not match in scoring category, 4 samples were near the threshold for

meeting the biocriterion, but just a few points different with the ADEQ score greater than the EMAP score. These differences occurred in steeper gradient streams with greater canopy cover and less TDS and greater crayfish abundance. The percent stonefly composition, diptera taxa, intolerant taxa were all significantly greater and the Hilsenhoff tolerance index was less in these 6 cases than the other 26 cases where the IBI scoring category matched between datasets. While these few cases revealed some differences in macroinvertebrate attributes between methods, the IBI score, being a composite of 7 metrics, smoothed out these differences resulting in a highly significant correlation (r=0.91) between the two methods.

Comparison of various macroinvertebrate metrics revealed that only 4 of 18 metrics and the IBI scores were significantly correlated between methods (Table 5). The four metrics that were significantly correlated were taxa richness measures and the tolerance index. Attributes which were different included the composition metrics and functional feeding group metrics which would be predicted to be different in samples from riffles + pools versus from riffles alone. For example, stoneflies are generally more abundant in well oxygenated riffle habitats than pools and they would be expected to be greater in ADEQ than EMAP samples. Non-insects and tolerant taxa would be expected to be present in greater abundance in more degraded habitats typified by pool or run, sand-dominated multi-habitat samples. These findings suggest that 1) some of the metrics could be different between methods due to the difference in habitats sampled and 2) the IBI score, being a combination index, factors out the variability associated with individual metrics and as a result is more significantly correlated between methods.

Since the difference in %riffle habitat was variable among the multi-habitat EMAP samples, correlations between the IBI and %riffle habitat were examined (Figure 3). The mean percentage of riffle habitat for the study reaches was approximately 30-40%. With the low percentage of riffle habitat, one would expect to find differences between the ADEQ riffle-based macroinvertebrate samples and the EMAP multi-habitat samples. However, both the EMAP and ADEQ IBI scores were significantly correlated to each other and to percent riffle habitat, regardless of sampling methodology. One would expect the percent riffle habitat, and thus IBI scores in warm water streams to be less than %riffle and IBI scores in cold water streams. However, the percent riffle habitat is not significantly different between warm and cold water streams (p=0.134) at 34% and 38% respectively, according to data in ADEQ's EDAS database. It is predicted that the IBI scores using either ADEQ or EMAP sampling methodology in warm water streams would also result in similar scoring categories.

There were some differences in distribution of ADEQ and EMAP IBI scores over a range of % fine sediment in stream bottom reaches (Figures 4-6). Overall the % fine sediment in the stream bottom values were greater in the EMAP samples than in the matched ADEQ samples. The ADEQ method found only 10 samples having fine sediment values >30% (the ADEQ bottom deposits riffle-based criterion for cold water streams) versus 17 for EMAP. There were no significant differences in the mean % fine substrate values overall between methods, however there was a difference between meadow streams. The ADEQ riffle %fines method displayed much lower %fines values than either the reach-wide ADEQ or EMAP method. The riffle %fines value was the appropriate measure to compare to the new ADEQ bottom deposits standard; six samples were exceeding the 30% fines bottom deposits criterion.

In a multivariate analysis of the macroinvertebrate IBI and habitat parameters using both ADEQ and EMAP datasets, %riffle habitat was the parameter most significantly correlated with IBI score that was identified by both EMAP and ADEQ methods (Figure 7-8). Substrate variables, such as %embeddedness and riffle D50 particle size, biological variables such as crayfish abundance, and reach variables such as % canopy cover were also found to be important to the distribution of reference to stressed samples. Percent riffle habitat is an important habitat factor for macroinvertebrates, constituting the amount of clean, aerated substrate that is habitable for stream-bottom dwellers. It is also inversely related to %fine sediment and embeddedness in the stream bottom, which can negatively affect the macroinvertebrate community.

Habitat Measurement Comparisons

Habitat is a primary determinant of stream-biota community structure and function; however there are multiple methods and attributes used by different state and federal agencies. Sampling methods developed to measure habitat attributes contain considerable variance and error within and between protocols (Roper and others, 2002, Whitacre and others, 2007). Natural stream heterogeneity from differences in the physiographic-climatic characteristics can increase the total variance in the habitat attributes measured. Together natural variability and protocol differences can make it difficult to identify and explain the relations between biota and habitat. There is a need to understand biological responses to habitat conditions but also to understand similarities and differences between sampling protocols for translating and combining datasets. The EPA developed habitat sampling protocols for the Western EMAP which were implemented on a national level from 2000 to 2004 (Kauffman and others, 1999). Since then several studies have attempted to address inconsistencies between sampling protocols (Faustini and Kaufmann, 2007; Whitacre and others, 2007; Roper and others, 2002). The EPA is encouraging states to adopt regionally consistent EMAP-protocols for future ecological assessments (USEPA, 2006). We compared and evaluated EMAP and ADEQ habitat protocols and biological responses to those habitat variables to determine the extent of similarities or differences in the habitat metrics and biological responses between methods.

The habitat measurements generated from EMAP and ADEQ methods were on average similar and significantly correlated (Table 6). Thirteen of 16 habitat measures were significantly correlated ($p<0.01$). The visual-based percentage estimates (percent riffle and pool habitats, vegetative cover and percent canopy cover, and substrate measures of percent fine substrate and embeddedness) were all remarkably similar, given the different field methods. The measurements of percent canopy cover were significantly correlated between the two methods despite different field instruments (convex vs. concave densiometers) and number of measurements (ADEQ=12, EMAP=66). The percent riffle and pool habitats were significantly correlated although these parameters were measured and calculated differently; with the ADEQ method using direct distance measures of habitat lengths (100 measurements, 1m apart), whereas the EMAP method calculated habitat lengths from thalweg profiles (100-150 measurements, 1-1.5m apart). Substrate measures were significantly correlated as well, though these measures were also measured and calculated differently. The ADEQ method used a modified Wolman, zig-zag particle size count, recording data in 16 size classes throughout all habitats in the reach (100 measurements). The EMAP method calculated percent fines and embeddedness from the thalweg profile and 11 transect measurements (105 measurements), recording data in 10 broad size classes. The visual-based rapid habitat assessment scores were also highly correlated between the two methods. These measures were also different but comparable, with the EMAP habitat index consisting of 10 habitat parameters on a 0-20 scale and the ADEQ habitat index consisting of 5 habitat parameters in common with EMAP index on a 1-4 scale. These results indicate that similar habitat measures can be obtained using two different field sampling protocols. In addition, many of these habitat parameters, important to benthic macroinvertebrate habitat, were significantly correlated, thus the data are interchangeable for analysis purposes.

Several studies have examined variability of visual-based field results using different field staff. Faustini and Kaufmann (2007) showed that the EMAP visual estimates can be highly variable for certain size classes but also stated that these types of visual estimates have adequate accuracy for regional assessments. Whitacre and others, (2007) reported that EMAP visual estimates of substrate had the lowest precision but also found that an experienced crew could have high precision. During this study different combinations of trained sampling crews were used. Both ADEQ and EMAP teams in our study included at least one experienced crew member. Sampling error due to difference in sampling crews was not specifically addressed in this study however the high degree of correlation between both biological and habitat metrics suggest that sampling error was minimal.

Multiple components of habitat structure influence stream biota. A principal components analysis identified combinations of habitat variables and gradients which best accounted for the variation among EMAP samples and among ADEQ samples (Figures 9-10). The principle components were similar and

highly correlated between EMAP and ADEQ analyses. Principle component #1 for both methods was identified as a substrate condition with the less disturbed endpoint represented by sites with larger substrates, more flow and more canopy cover and the other endpoint consisting of sites that have greater embeddedness and percentages of fine sediment (≤sand). Principle component #2 for both methods was identified as a hydrology/macro-habitat gradient, with the reference endpoint represented by sites with greater slope, faster water and more %riffle habitat and the stressed endpoint consisting of sites having high residual pool volume and greater area of bare ground on stream banks.

The EMAP and ADEQ methods provide data for several general physical habitat attributes which are important influences in stream ecology, such as stream size, channel gradient, channel substrate size, habitat complexity, riparian vegetation cover, anthropogenic alterations, and channel-riparian interactions (Peck and others, 2006 and ADEQ, 2006b). Although these are all important variables in a properly functioning stream ecosystem, the stream bottom substrate conditions provide the habitable space for macroinvertebrates and thus have a direct impact on measures of macroinvertebrate condition. Stream bottom characteristics are often cited as controls on the species composition of macroinvertebrate, periphyton, and fish assemblages in streams (Hynes, 1972; Cummins, 1974, Platts and others, 1983). In addition to bedform (riffles and pools), substrate size influences the hydraulic roughness of the channel, the water velocity, and the available interstitial space available for colonization (Kaufmann and others, 1999).

The PCA analyses in this study identified these same combinations of flow, substrate, and macro-habitat parameters as the critical stream attributes affecting macroinvertebrate conditions and IBI scores. The multiple linear regression models for both ADEQ and EMAP methods explained a high proportion of the variance in the IBI scores for all three assemblages: algae, macroinvertebrates, and fish (Table 8). As in the PCA analysis, the combination of habitat metrics that best explained the macroinvertebrate IBI distribution consisted of substrate and canopy cover variables. Percent riffle habitat from the ADEQ method corresponded with percent coarse gravel and channel cross section area variables from the EMAP method. The percent canopy cover metric was the same between both methods. These two variables reflect the importance of substrate conditions for macroinvertebrate diversity and the importance of the riparian vegetation in reducing stream temperature, providing leaf litter inputs and stabilizing banks and erosion rates that lead to excess fine sediment in the stream bottom.

The habitat metrics explaining the fish IBI distribution were similar for the two methods and consisted of a negative correlation with percent pool habitat and correlations with substrate measures; negative correlation with percent embeddedness for ADEQ method and positive correlation with percent coarse gravel for the EMAP method (Table 8). While pool habitat is important for fish communities, some non-natives are better suited to exploit this habitat and out-compete native fish, especially during periods of low flow or intermittency (Propst and others, 2008).

The periphyton IBI distribution was best explained by the EMAP variables describing channel disturbance (bank angle and riparian disturbance) and substrate (%coarse gravel). The correlation of the riparian disturbance parameter to the periphyton IBI suggests that the periphyton IBI could be sensitive to anthropogenic activities. The bank angle metric is likely a surrogate measure for unstable banks and excess sediment in the streambed, explaining its importance in the model. The percentage of coarse gravel indicates the importance of substrate size to algal growth (Table 8).

Although the habitat measures that ADEQ collected were very similar to the EMAP measures, there are several combination metrics, which EMAP employs which were significantly correlated with biological assemblage condition, but there were no ADEQ variables by which to make comparisons. Relative bed stability, residual pool volume, riparian disturbance, and in-stream cover were some combination metrics for which we detected biological responses. The individual habitat metrics typically have a low signal to noise ratio especially in larger scale assessments (Kaufmann and others, 1999). Individual metrics may not account for the variation in the stream biota as well as EMAP combined metrics or a set of metrics identified by multivariate models (Kaufmann and others, 1999). These combination metrics could be useful for future analyses of habitat parameters most affecting biological assemblage condition.

Conclusions

These results indicate that the two sampling methods for macroinvertebrates and habitat data are highly comparable in terms of bioassessment and habitat/stressor results. While the bioassessment category was not identical for all sites, overall the assessments were significantly correlated, providing similar bioassessment results for the 32 cold water streams used in this study of the Little Colorado River basin. These data can be combined within a study or used interchangeably in either ADEQ or USEPA assessments.

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Appendix A: Sample Sites in the Little Colorado River Basin

EPA Site ID	ADEQ Site ID	Stream Name and Location	Latitude (Dec. Deg)	Longitude (Dec. Deg)	Elevation (ft)	Drainage Area (mi2)
AZ06631-037	LCHAL008.83	Hall Creek Below the Wilderness Area Boundary	33.9725	-109.521	9280	2.3
AZ06631-038	LCMRS043.17	Morrison Creek 0.8 Mile Below Confluence With Coyote Creek	33.97013	-109.055	8440	2.9
AZ06631-050	LCMLK001.18	Milk Creek Southwest Corner of Section 34	33.95183	-109.173	8000	4.3
AZ06631-053	LCHAL010.20	Hall Creek Downstream of Hall Creek Headwaters	33.95694	-109.536	9580	1.4
AZ06631-061	LCSIL041.04	Silver Creek End of Queen Creek Place	34.34425	-109.977	6060	105
AZ06631-063	LCECL021.13	East Clear Creek Just East of FH095 And FH496 Intersection	34.55078	-111.161	6500	95
AZ06631-065	LCSLR001.42	South Fork LCR Above South Fork Campground	34.0707	-109.41	7620	25
AZ06631-077	LCMIN018.05	Mineral Creek Above Forest Service Road #404	34.17992	-109.618	8070	6.3
AZ06631-088	LCCLE063.52	Clear Creek Downstream of Willow Creek Confluence	34.64472	-110.999	6000	313
AZ06631-093	LCSHL026.50	Show Low Creek Above Morgan Wash	34.20833	-110.001	6480	69
AZ06631-097	LCLCR342.03	Little Colorado River Above Airport Road	34.12788	-109.299	6940	133
AZ06631-098	LCRIG004.87	Riggs Creek Above Riggs Reservoir	33.97598	-109.247	8160	2.5
AZ06631-109	LCHAL004.59	Hall Creek East of Geneva Reservoir	34.02778	-109.506	9000	6.8
AZ06631-110	LCSHL031.05	Show Low Creek Below Porter Cr And Billy Cr Confluence	34.17166	-109.983	6660	63
AZ06631-125	LCLCR360.06	Little Colorado River 1/4 Miles East of the Greer Post Office	34.00803	-109.454	8330	14
AZ06631-130	LCRUD003.45	Rudd Creek at Sipe Wildlife Area	34.03335	-109.23	7640	18
AZ06631-133 MR	LCELR007.19	East Fork LCR Above F.S. Rd #113 Crossing	33.92979	-109.489	9460	2.3
AZ06631-137 MS	LCCOY000.71	Coyote Creek at Richville Valley	34.30638	-109.346	6060	227
AZ06631-141	LCBEN002.57	Benton Creek Near Pat Knoll Cabin	33.98538	-109.291	8600	2.5
AZ06631-145	LCLCR311.31	Little Colorado River South of Salado	34.42601	-109.402	5840	780
AZ06631-149	LCSIL043.84	Silver Creek Below AGFD Hatchery	34.33587	-109.939	6103	99
AZ06631-151	LCECL018.17	East Clear Creek 3/4 Mile Upstream From Kinder Crossing Trail	34.56419	-111.147	6460	101
AZ06631-155 MS	LCLCR211.73	Little Colorado River North of Mclaws Bend	34.89681	-110.181	5070	7945

EPA Site ID	ADEQ Site ID	Stream Name and Location	Latitude (Dec. Deg)	Longitude (Dec. Deg)	Elevation (ft)	Drainage Area (mi2)
AZ06631-157	LCELR000.13	East Fork LCR 500 Feet Above West Fork Confluence	34.00199	-109.457	8410	14
AZ06631-162 MR	LCBRB006.74	Barbershop Canyon Creek Below Merritt Draw Confluence	34.49442	-111.165	6950	3.2
AZ06631-183	LCCHC081.26	Chevelon Canyon At Telephone Ridge Above Horse Trap Canyon	34.38736	-110.872	6500	59
AZ06631-186	LCSHL029.75	Show Low Creek Near Lakeside	34.17944	-109.987	6610	68
AZ06631-210 MR	LCSLR003.72	South Fork LCR Below Joe Baca Draw	34.04889	-109.39	8100	17
AZ06631-237	LCRUD007.23	Rudd Creek Above Benton Creek Confluence	34.01097	-109.281	8100	5.1
NA MS	LCLCR340.02	Little Colorado River, Downstream of Eagar WWTP Ponds	34.15177	109.295	6900	130
NA	LCLVL001.32	Lee Valley Creek Upstream of the Wilderness Boundary	33.93944	109.509	9440	1.1

MR = Macroinvertebrate reference site, MS = Macroinvertebrate stressed site

Appendix B: Macroinvertebrate Metrics and Index of Biological Integrity Scores for sites sampled in the Little Colorado River Basin, 2007

Site ID	Method	Habitat	Sample Date	CF	Total Taxa	Diptera Taxa	Intol Taxa	HBI	%Pleco	%Scraper	Scraper Taxa	IBI
AZ06631-037	ADEQ	Riffle	06-05	1.5	21	6	2	5.77	6.24	4.91	2	39.74
AZ06631-037	EMAP	Multi-habitat	06-05	4.1	22	6	2	5.79	5.94	3.42	2	39.37
AZ06631-038	ADEQ	Riffle	05-23	7.4	16	1	1	4.69	60.83	12.65	2	43.72
AZ06631-038	EMAP	Multi-habitat	05-24	9.6	14	4	0	6.14	9.14	5.22	1	29.82
AZ06631-050	ADEQ	Riffle	05-22	4.5	26	7	2	5.56	3.83	12.77	4	46.73
AZ06631-050	EMAP	Multi-habitat	05-22	14.0	25	10	1	5.84	0.59	4.54	2	39.54
AZ06631-053	ADEQ	Riffle	06-07	2.2	21	7	3	4.79	11.09	15.21	2	52.75
AZ06631-053	EMAP	Multi-habitat	06-07	4.0	26	10	4	5.65	4.41	8.81	1	50.43
AZ06631-061	ADEQ	Riffle	04-24	6.0	13	4	0	5.82	0.00	0.00	0	20.44
AZ06631-061	EMAP	Multi-habitat	04-24	1.7	13	3	0	6.33	0.00	0.00	0	17.87
AZ06631-063	ADEQ	Riffle	05-03	4.7	21	5	2	5.60	0.92	14.47	1	36.60
AZ06631-063	EMAP	Multi-habitat	05-02	1.7	17	4	1	6.68	0.20	1.97	1	24.26
AZ06631-065	ADEQ	Riffle	05-24	10.7	32	6	2	5.45	2.78	9.26	10	53.84
AZ06631-065	EMAP	Multi-habitat	05-21	8.0	34	6	4	5.79	0.57	9.64	10	56.98
AZ06631-077	ADEQ	Riffle	06-26	16.0	31	8	3	5.66	6.90	14.52	3	53.57
AZ06631-077	EMAP	Multi-habitat	06-29	15.5	33	9	1	6.01	4.70	19.16	4	51.15
AZ06631-088	ADEQ	Riffle	05-07	3.6	15	5	0	5.99	0.00	0.00	0	22.06
AZ06631-088	EMAP	Multi-habitat	05-07	1.0	17	4	0	6.29	0.00	1.26	1	22.48
AZ06631-093	ADEQ	Riffle	04-16	7.1	16	4	0	6.47	0.00	0.55	1	21.42
AZ06631-093	EMAP	Multi-habitat	04-17	7.3	14	4	0	6.66	0.00	0.18	1	20.08
AZ06631-097	ADEQ	Riffle	04-11	19.2	18	3	1	6.38	0.52	2.08	3	26.94
AZ06631-097	EMAP	Multi-habitat	04-12	4.4	24	3	1	6.75	0.86	2.06	5	31.14
AZ06631-098	ADEQ	Riffle	05-10	11.3	22	7	1	6.31	1.78	0.39	2	32.93
AZ06631-098	EMAP	Multi-habitat	05-10	11.3	21	10	0	6.42	2.61	0.00	0	31.69
AZ06631-109	ADEQ	Riffle	06-04	13.7	24	6	3	5.56	16.38	0.69	3	51.31

Site ID	Method	Habitat	Sample Date	CF	Total Taxa	Diptera Taxa	Intol Taxa	HBI	%Pleco	%Scraper	Scraper Taxa	IBI
AZ06631-109	EMAP	Multi-habitat	06-04	11.8	23	7	2	5.59	22.86	1.79	3	52.15
AZ06631-110	ADEQ	Riffle	04-17	21.3	11	3	0	7.57	0.00	0.00	0	14.04
AZ06631-110	EMAP	Multi-habitat	04-16	3.0	14	4	0	6.91	0.00	0.18	1	19.47
AZ06631-125	ADEQ	Riffle	06-05	16.8	30	8	3	5.43	1.13	52.26	8	65.65
AZ06631-125	EMAP	Multi-habitat	06-06	12.8	41	8	5	5.30	3.64	30.60	10	73.62
AZ06631-130	ADEQ	Run	05-23	6.6	13	4	0	6.23	0.00	0.00	0	19.42
AZ06631-130	EMAP	Multi-habitat	05-23	5.6	16	7	0	6.33	0.00	0.00	0	24.19
AZ06631-133	ADEQ	Riffle	06-13	36.6	26	5	3	5.10	26.49	29.73	7	68.34
AZ06631-133	EMAP	Multi-habitat	06-13	13.4	36	5	4	5.54	13.02	19.92	5	63.13
AZ06631-137	ADEQ	Riffle	04-10	31.9	15	8	0	6.07	0.00	0.18	1	27.11
AZ06631-137	EMAP	Multi-habitat	04-11	8.5	17	11	0	6.27	0.00	0.56	3	34.00
AZ06631-141	ADEQ	Riffle	05-09	8.7	33	8	4	4.46	12.21	6.49	5	63.71
AZ06631-141	EMAP	Multi-habitat	05-09	5.8	38	9	5	4.97	9.57	8.33	6	67.92
AZ06631-145	ADEQ	Run	04-09	12.0	12	6	0	6.98	0.00	0.00	0	19.77
AZ06631-145	EMAP	Multi-habitat	04-10	4.1	15	7	0	6.34	0.00	0.00	0	23.79
AZ06631-149	ADEQ	Riffle	06-28	4.0	16	2	0	6.52	0.00	1.75	4	22.97
AZ06631-149	EMAP	Multi-habitat	06-27	12.0	14	1	0	7.18	0.00	1.72	2	16.69
AZ06631-151	ADEQ	Riffle	05-02	13.7	20	5	0	5.66	0.00	3.14	2	28.35
AZ06631-151	EMAP	Multi-habitat	05-01	1.8	12	2	0	7.15	0.00	0.00	0	14.16
AZ06631-155 (1)	ADEQ	Edge	04-24	1.0	19	7	0	6.09	0.00	0.00	0	25.90
AZ06631-155 (1)	EMAP	Multi-habitat	04-25	1.0	8	5	0	6.23	0.00	0.00	0	18.84
AZ06631-155 (2)	ADEQ	Run	05-15	1.0	4	2	0	6.06	0.00	0.00	0	13.87
AZ06631-155 (2)	EMAP	Multi-habitat	05-14	1.0	15	8	0	6.28	0.00	0.41	1	26.67
AZ06631-157	ADEQ	Riffle	06-12	14.0	25	5	4	5.40	2.90	18.15	8	55.10
AZ06631-157	EMAP	Multi-habitat	06-12	6.4	27	6	2	5.39	6.28	13.91	6	51.02
AZ06631-162	ADEQ	Riffle	06-18	1.7	29	7	0	5.61	0.55	22.95	5	45.04
AZ06631-162	EMAP	Multi-habitat	06-20	1.0	33	6	0	5.74	0.59	23.12	5	45.00
AZ06631-183	ADEQ	Riffle	06-19	5.3	26	7	1	5.99	0.00	6.17	5	39.62

Site ID	Method	Habitat	Sample Date	CF	Total Taxa	Diptera Taxa	Intol Taxa	HBI	%Pleco	%Scraper	Scraper Taxa	IBI
AZ06631-183	EMAP	Multi-habitat	06-18	2.7	16	4	0	6.75	0.00	5.31	2	23.55
AZ06631-186	ADEQ	Riffle	06-27	2.7	27	7	0	5.78	0.49	2.76	5	37.42
AZ06631-186	EMAP	Multi-habitat	06-26	1.0	27	6	1	6.49	0.19	1.52	5	36.13
AZ06631-210	ADEQ	Riffle	06-21	6.0	32	5	3	4.83	11.57	30.97	8	67.31
AZ06631-210	EMAP	Multi-habitat	06-21	12.8	38	8	4	5.40	7.43	19.17	10	70.21
AZ06631-237	ADEQ	Riffle	06-27	6.0	26	4	1	4.86	21.56	35.16	6	63.28
AZ06631-237	EMAP	Multi-habitat	06-28	10.0	32	7	2	5.40	16.55	19.06	5	62.18
LCLCR340.02	ADEQ	Riffle	04-18	42.0	20	2	1	6.15	0.55	2.01	2	25.67
LCLCR340.02	EMAP	Multi-habitat	04-18	16.0	23	6	1	6.80	0.00	0.57	3	30.83
LCLVL001.32	ADEQ	Riffle	06-13	9.1	24	9	3	4.60	37.94	23.40	3	66.81
LCLVL001.32	EMAP	Multi-habitat	06-13	2.8	28	6	2	5.78	9.96	2.34	2	44.31

(CF=correction factor, Intol taxa=intolerant taxa with tolerance value<3, HBI=Hilsenhoff Biotic Index, %Pleco=percent composition by stoneflies, %Scraper= percent composition by scraper functional feeding group, Scraper taxa=scraper taxa richness, IBI=cold water Index of biological integrity score)

Appendix C: ADEQ and EMAP Habitat Variables, Little Colorado River Basin, 2007

Site ID	Method	D50 (mm)	%Embeddedness	%Fines	%Algae	%Macrophyte	Habitat Score	%Canopy Density	%Barren	%Riparian <0.5 m	%Riparian 0.5-5 m	%Riparian >5 m	Bankfull Width (ft)	Bankfull Height (ft)	%Pool	%Riffle	%Run
AZ06631-037	ADEQ	3.0	43.0	45.0	0.5	0.5	18.0	0.0	0.0	100.0	0.0	0.0			6.0	19.0	75.0
AZ06631-037	EMAP	2.3	79.7	42.9	0.0	0.0	158.0	9.8	0.5	81.0	0.9	0.7	0.9	0.3	10.7	30.7	58.7
AZ06631-038	ADEQ	0.5	74.0	58.0	0.5	0.5	17.5	8.0	5.0	100.0	0.0	10.0			0.0	32.0	68.0
AZ06631-038	EMAP	0.3	71.6	70.5	0.0	0.5	111.0	29.0	25.0	65.5	14.2	22.3	3.8	0.4	0.7	44.7	54.7
AZ06631-050	ADEQ	0.1	38.0	60.2	0.5	13.0	18.5	72.0	0.0	20.0	20.0	60.0	10.1		15.0	37.0	48.0
AZ06631-050	EMAP	0.0	47.9	51.4	0.0	0.0	138.0	86.6	31.5	54.0	17.7	26.0	3.5	0.3	2.7	46.7	35.3
AZ06631-053	ADEQ		38.0		0.5	13.0	17.0	90.0	10.0	40.0	15.0	80.0	5.0		35.0	42.0	23.0
AZ06631-053	EMAP	17.0	43.6	22.9	0.0	2.3	159.0	91.7	55.1	9.1	4.8	9.1	2.5	0.4	18.7	32.0	44.0
AZ06631-061	ADEQ		36.0	10.0	38.0	13.0	19.0	7.1	0.0	100.0	25.0	0.0	64.2	0.7	2.0	29.0	69.0
AZ06631-061	EMAP	68.2	36.9	23.5	0.0	31.4	169.0	12.4	6.0	62.7	16.2	2.3	8.6	0.3	0.0	41.0	54.0
AZ06631-063	ADEQ	25.0	29.0	20.0	13.0	0.5	16.0	12.0	20.0	30.0	40.0	10.0			66.0	17.0	17.0
AZ06631-063	EMAP	21.4	42.4	26.7	1.8	5.0	157.0	31.6	48.4	19.7	9.2	0.9	10.9	0.3	68.0	14.0	18.0
AZ06631-065	ADEQ	81.0	32.6	2.0	13.0	0.5	20.0	28.0	0.0	50.0	60.0	5.0			3.0	81.0	16.0
AZ06631-065	EMAP	49.4	28.2	13.3	0.0	13.4	161.0	78.9	31.9	38.1	29.9	16.1	6.7	0.6	7.0	65.0	9.0
AZ06631-077	ADEQ	25.0	32.0	19.0	13.0	13.0	16.5	46.5	0.0	100.0	40.0	30.0	14.0		0.0	45.0	55.0
AZ06631-077	EMAP	13.2	36.5	33.6	0.0	12.7	171.0	84.6	3.9	69.7	19.0	1.5	3.5	0.3	4.0	32.0	64.0
AZ06631-088	ADEQ		44.0		63.0	0.5	17.0	14.0	40.0	10.0	25.0	15.0			73.0	13.0	14.0
AZ06631-088	EMAP	109.2	35.0	20.0	0.9	2.3	164.0	40.2	42.8	21.8	14.4	0.5	16.2	0.7	70.0	14.0	16.0
AZ06631-093	ADEQ	54.5	31.0	14.0	38.0	0.5	16.0	41.5	0.0	50.0	50.0	50.0	32.8	0.7	33.0	19.0	48.0
AZ06631-093	EMAP	39.8	38.0	31.4	40.2	4.1	145.0	23.4	6.4	73.1	18.6	5.9	9.4	0.3	33.0	35.0	32.0
AZ06631-097	ADEQ	26.2	23.0	25.0	0.5	0.5	15.0	4.5	10.0	90.0	2.0	5.0	50.0	1.2	13.0	36.0	51.0
AZ06631-097	EMAP	10.2	62.0	36.0	2.7	4.1	106.0	5.2	8.6	45.0	13.3	3.6	18.8	0.5	10.0	38.0	50.0
AZ06631-098	ADEQ		77.6		0.5	13.0	13.0	35.0	5.0	95.0	5.0	10.0	20.0		0.0	57.0	43.0
AZ06631-098	EMAP	0.0	78.8	79.0	0.0	5.0	106.0	28.7	7.2	63.1	3.0	4.3	3.0	0.1	0.0	0.0	100.0

Site ID	Method	D50 (mm)	%Embeddedness	%Fines	%Algae	%Macrophyte	Habitat Score	%Canopy Density	%Barren	%Riparian <0.5 m	%Riparian 0.5-5 m	%Riparian >5 m	Bankfull Width (ft)	Bankfull Height (ft)	%Pool	%Riffle	%Run
AZ06631-109	ADEQ	102.7	21.0	24.0	0.5	0.5	20.0	60.0	5.0	50.0	15.0	35.0	19.4	0.6	26.0	89.0	32.0
AZ06631-109	EMAP	100.1	23.2	2.9	0.0	0.5	179.0	81.7	34.7	17.8	11.8	12.4	4.1	0.4	9.3	46.0	36.0
AZ06631-110	ADEQ	12.0	56.0	14.0	88.0	13.0	12.0	0.0	5.0	95.0	0.0	0.0	64.9	0.2	0.0	10.0	90.0
AZ06631-110	EMAP	17.3	50.8	30.5	52.7	3.2	149.0	14.4	15.8	53.1	16.7	3.0	10.3	0.3	70.0	12.0	18.0
AZ06631-125	ADEQ	54.5	21.0	9.0		0.5	19.5	55.5	5.0	40.0	70.0	5.0	86.0	0.4	15.0	51.0	34.0
AZ06631-125	EMAP	33.0	34.5	19.0	0.0	5.0	192.0	53.1	3.2	49.7	25.1	0.0	9.5	0.5	3.0	36.0	54.0
AZ06631-130	ADEQ	0.0		95.0	0.5	0.5	7.0	0.0	0.0	100.0	0.0	0.0	15.0	0.5	0.0	2.0	98.0
AZ06631-130	EMAP	0.0	70.9	74.3	0.0	16.4	104.0	4.5	2.5	91.4	17.4	0.0	1.7	0.4	0.0	4.7	94.7
AZ06631-133	ADEQ	3.8	61.0	38.0	0.5	38.0	13.5	0.0	0.0	100.0	0.0	5.0	12.5		14.0	21.0	65.0
AZ06631-133	EMAP	1.8	60.9	50.5	0.0	12.5	177.0	10.4	1.6	89.1	3.0	0.7	3.5	0.4	18.7	44.0	34.0
AZ06631-137	ADEQ	1.6	40.5	75.0	0.5	0.5	12.5	0.0	50.0	60.0	5.0	0.0	34.0	3.1	47.0	10.0	43.0
AZ06631-137	EMAP	0.3	91.4	81.0	3.6	4.6	106.0	12.4	33.0	17.6	15.9	0.5	4.4	0.4	62.0	22.0	16.0
AZ06631-141	ADEQ	50.5	29.0	5.0	0.5	0.5	19.0	60.5	40.0	60.0	25.0	25.0	11.0	1.0	14.0	56.0	30.0
AZ06631-141	EMAP	57.7	12.0	1.0	0.0	2.3	171.0	87.3	19.2	23.6	8.9	10.5	3.1	0.2	9.5	77.3	12.0
AZ06631-145	ADEQ	0.1	83.0	98.0	13.0	0.5	7.0	30.0	10.0	80.0	20.0	0.0			0.0	0.0	100.0
AZ06631-145	EMAP	0.0	96.1	78.1	22.5	0.5	66.0	67.4	5.0	61.6	23.4	1.4	3.4	0.9	22.7	5.3	72.0
AZ06631-149	ADEQ	36.0	28.0	23.3	13.0	13.0	19.0	0.0	0.0	100.0	30.0	0.0	40.0		0.0	58.0	42.0
AZ06631-149	EMAP	5.1	23.9	34.5	8.5	21.7	151.0	11.8	8.9	63.1	2.3	2.1	13.0	0.3	0.0	32.0	67.0
AZ06631-151	ADEQ	30.0	29.0	9.0	13.0	13.0	17.0	1.0	40.0	40.0	10.0	10.0	31.7	1.6	73.0	20.0	7.0
AZ06631-151	EMAP	22.5	28.3	13.3	19.1	5.9	162.0	46.9	49.0	24.2	10.6	0.5	12.4	0.3	73.0	13.0	14.0
AZ06631-155 (1)	ADEQ		83.0	100.0	0.5	0.5	6.0	1.3	50.0	50.0	50.0	5.0			0.0	0.0	100.0
AZ06631-155 (1)	EMAP	0.2	99.2	96.2	0.0	0.0	70.0	23.4	53.8	15.8	8.4	0.2	31.1	1.1	18.0	0.0	77.0
AZ06631-155 (2)	ADEQ		83.0	100.0	0.5	0.5	8.0	0.5	30.0	10.0	60.0	3.0			28.0	0.0	72.0
AZ06631-155 (2)	EMAP	0.1	99.2	93.3	0.0	0.0	72.0		50.5	18.0	6.1	0.9	28.9	1.0	28.0		

Site ID	Method	D50 (mm)	%Embedded-ness	%Fines	%Algae	%Macrophyte	Habitat Score	%Canopy Density	%Barren	%Riparian <0.5 m	%Riparian 0.5-5 m	%Riparian >5 m	Bankfull Width (ft)	Bankfull Height (ft)	%Pool	%Riffle	%Run
AZ06631-157	ADEQ	28.0	21.0	20.0	13.0	13.0	17.0	66.0	5.0	95.0	40.0	60.0			18.0	27.0	55.0
AZ06631-157	EMAP	35.6	49.3	13.2	0.0	3.4	171.0	80.0	0.5	89.3	31.4	0.3	8.5	0.5	13.0	61.0	23.0
AZ06631-162	ADEQ	29.0	25.0	4.0	13.0	0.5	16.5	31.0	5.0	60.0	40.0	10.0	23.0		72.0	11.0	17.0
AZ06631-162	EMAP	48.8	36.8	6.1	0.0	0.4	129.0	66.3	21.8	60.3	20.5	15.7	7.1	0.5	32.7	15.3	52.0
AZ06631-183	ADEQ		24.0		0.5	13.0	19.8	37.5	10.0	30.0	60.0	15.0	79.0		46.0	38.0	16.0
AZ06631-183	EMAP	90.0	17.9	15.5	10.9	0.0	176.0	52.3	11.1	17.0	21.6	0.9	15.7	0.7	70.0	13.0	14.0
AZ06631-186	ADEQ		45.0		0.5	0.5	19.0	33.5	20.0	50.0	60.0	40.0	30.0		70.0	14.0	16.0
AZ06631-186	EMAP	54.5	17.9	10.5	25.9	0.0	143.0	49.5	8.4	66.1	20.0	4.5	8.4	0.4	50.0	24.7	20.7
AZ06631-210	ADEQ		27.0	0.0	38.0	13.0	20.0	78.5	0.0	35.0	80.0	20.0	17.7	0.9	0.0	62.5	37.5
AZ06631-210	EMAP	52.0	39.2	11.4	0.0	7.5	187.0	85.4	6.7	57.6	29.2	1.6	4.9	0.4	4.7	48.7	35.3
AZ06631-237	ADEQ	20.0	30.0	28.0	0.5	0.5	18.0	64.5	0.0	80.0	20.0	30.0	13.0		37.0	47.0	16.0
AZ06631-237	EMAP	4.8	53.6	40.0	0.0	1.4	160.0	93.6	4.5	84.9	19.0	1.6	1.9	0.3	13.3	33.3	53.3
LCLCR340.02	ADEQ	13.0	58.0	29.0	13.0	0.5	11.0	0.0	20.0	5.0	5.0	5.0			24.0	29.0	47.0
LCLCR340.02	EMAP	8.6	51.7	43.3	26.1	21.4	94.0	3.7	15.2	46.6	8.3	0.5	9.2	0.5	21.0	24.0	55.0
LCLVL001.32	ADEQ	0.3	44.0	66.3	0.5	0.5	15.0	9.0	0.0	100.0	5.0	1.0			0.0	61.0	39.0
LCLVL001.32	EMAP	0.0	81.1	65.7	0.0	36.4	145.0	14.2	0.2	89.3	5.5	0.9	2.2	0.3	17.3	8.0	74.7