Stream Channel Morphology and Benthic Macroinvertebrate Community Associations in the San Pedro River and Verde River Basins of Arizona, 1999-2002

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Abstract

This study was conducted to evaluate relationships between channel geomorphology, stream order, riparian condition, habitat, and metrics describing the macroinvertebrate community at various scales. Macroinvertebrate samples were collected once and geomorphology surveys were conducted twice at 10 sites each in the San Pedro and Verde River basins during the period of 1999-2002. Significant taxa differences between tributary streams and large rivers were identified, with the greatest taxa richness occurring in tributary streams and shifts in species to more tolerant taxa in the larger rivers. Broad scale parameters such as watershed area and Pfankuch stability score were found to be important for basin comparisons of aquatic communities. However, at the scale of individual bioassessments, the macroinvertebrate community responds to substrate parameters such as particle size and embeddedness, which directly affect benthic habitat. The macroinvertebrate community was altered at low to moderate levels of percent fines (8% in the Verde River basin and 40-50% in the San Pedro River basin), and by moderately low embeddedness (30-50% in the San Pedro River basin). At these levels of sedimentation there was loss of taxa in the scraper feeding group and loss of percent composition by filterers. Replacement of sensitive taxa by sand tolerant taxa occurred especially in the larger streams and rivers. These findings reveal that the macroinvertebrates are responding to sedimentation, but that the sensitivity of the community may be different between hydrophysiographic provinces across Arizona.

In evaluating correlations of Rosgen stream type and benthic community structure, we determined that the greatest taxa richness and percent composition of mayflies and caddisflies occurred in stable “F” channels of the San Pedro River basin and in “C” channels of the Verde River basin where an intermediate disturbance effect is occurring. Increases in percent composition by Oligochaetes and Chironomidae occurred as expected where median particle sizes were smallest. Although this study found only one significant correlation of Proper Functioning Condition of riparian areas to a macroinvertebrate metric, the riparian community has a vital but indirect affect on the structure and function of the macroinvertebrate community.

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Preface

ADEQ is in the process of developing bioassessment tools. Indexes of biological integrity were developed for bioassessment of warm and cold water streams (Gerritsen and Leppo, 1998; Leppo and Gerritsen, 2000). However, we need tools for identifying sediment and channel stressors in order to understand one of the causes of biological impairment. This study proposed to relate geomorphological and habitat variables and channel stability assessments with biological condition, represented by macroinvertebrate bioassessments to further our understanding of the effects of the physical template upon the biota. The geomorphology surveys and stability assessments used in this analysis were conducted by ADEQ and by contract help from staff at Natural Channel Design, Inc. The macroinvertebrate collections and habitat assessments were conducted by ADEQ staff during the period of 1999 to 2002. Natural Channel Design, Inc., provided geomorphology data in a report on Verde River channel stability assessments (Moody et al., 2003) and ADEQ provided stability assessment data for the San Pedro River basin. All of the data and analyses were funded by a USEPA Wetlands Grant awarded in 1998.

Acknowledgments

This USEPA Wetlands Grant funded the research which was instrumental for developing methods to assess physical integrity in Arizona. This research project was the result of cooperative efforts between Natural Channel Design, Northern Arizona University, and ADEQ. We appreciate the quality technical reports that Tom Moody authored (Moody et al. 2003), which have laid the foundation for physical integrity assessments of Arizona streams. Our research on channel assessments and sediment transport would still be a decade away from us without the knowledge and assistance of Mr. Moody. This project could not have been conceived without the initial methods and training provided by Wildland Hydrology. Many thanks to Dave Rosgen for the geomorphology education and the methods for channel stability assessments. This study could not have been initiated without high quality macroinvertebrate taxonomic data. Thanks to Bob Wisseman for providing consistent taxonomy services during this study period.

A monumental field effort was required to install and resurvey the nearly 60 sites. Lin Lawson of ADEQ played a major role in identifying study sites and conducting initial surveys at 30 sites in the San Pedro River basin for the Bank erosion hazard index (BEHI) validation study and the stability assessment project. Lin Lawson's training and experience were invaluable for implementing these ambitious monitoring projects. My gratitude to several other staff, without whom the surveying and monitoring events could not have been completed. My deepest thanks go to ADEQ monitoring staff: Lee Johnson, Roland Williams, and Doug McCarty who conducted the lion's share of surveys and carried out surveys in the worst cold of winter 2002. Thanks to other field assistants who filled in when we really needed them: Sam Rector, Kyle Palmer, Linda Cline, Elizabeth Boettcher, and Jalyn Cummings. Thanks to Roland Williams and Lee Johnson for help with data entry and analysis. Many thanks also to managers Steve Pawlowski and Linda Taunt for supporting the intensive field and analytical effort required to produce this technical report.

I. Introduction

This project was intended to evaluate relationships between channel geomorphology, stream order, riparian condition, habitat and metrics describing the macroinvertebrate community at various scales. Several studies have shown that in-stream hydraulics affect the benthos at different scales (Statzner and Higler, 1986; Corkum, 1992; Carter et al. 1996). In-stream hydraulics, such as velocity and depth relate to the dimensions of the stream channel (Leopold et al., 1964). A classification system for identifying stream types by differences in channel dimension, pattern and profile was developed by Rosgen (1994). Rosgen's classification of stream types is based on measurements of entrenchment and width/depth ratios, sinuosity, slope and median particle size. Slope and particle size, in particular have been shown to influence macroinvertebrate community structure (Statzner and Higler, 1986; Growns and Davis, 1994). Channel hydraulics and benthic community structure are related to altitude and longitudinal distance along a stream channel (Vannote et al. 1980; Ward, 1986; Statzner and Higler, 1986; Carter et al., 1996). The altitude factor was controlled for by including only warm water streams in this study. Longitudinal changes were incorporated by including 3 sites each on the mainstem San Pedro and Verde Rivers. We have selected to study correlations of the biota with "stream size" instead of "stream order" because the latter is highly variable from basin to basin in Arizona due to a highly dendtritic hydrologic pattern in some basins, with perennial water only found in the greater stream orders. This study presents an analysis of relationships between Rosgen's stream channel classification, substrate indicators, stream size and various metrics of macroinvertebrate community structure within desert stream ecosystems of southern Arizona. Specific objectives of this study were to:

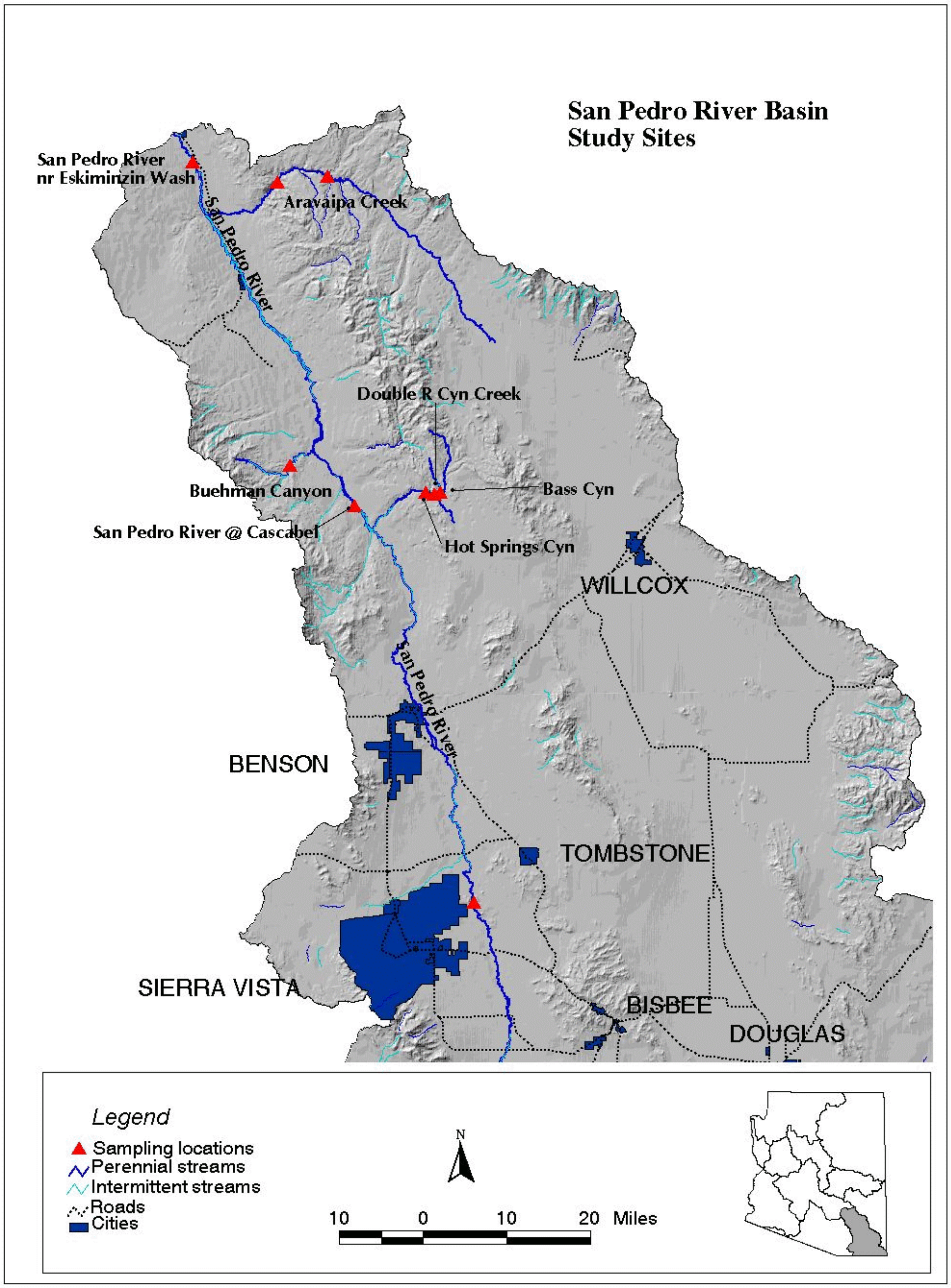
I. Determine how the benthic macroinvertebrate community correlates with stream size differences
II. Identify which scale of habitat parameters are most correlated with the macroinvertebrate community
III. Identify correlations between macroinvertebrate metrics and Rosgen stream types
IV. Analyze relationships among percent fines, embeddedness and benthic condition
V. Evaluate the macroinvertebrate community response to riparian condition

II. Study Areas

ADEQ selected two basins in different hydrophysiographic regions of Arizona for this study to examine whether relationships between the physical substrate and macroinvertebrates were similar. The San Pedro River basin is within the basin and Range Province and the Verde River basin is within the Central Highlands Province. Ten study reaches in the San Pedro River basin (Figure 1) and ten in the Verde River basin (Figure 2) were selected to encompass variability in stream size and Rosgen stream type in perennial streams (Table 1, Appendix A). Elevation was controlled for by sampling only warmwater streams occurring at <5000' elevations. The Babocomari River in the San Pedro River basin was dry during the spring macroinvertebrate collection period, so no samples were collected or analyzed.

Table 1. Study reaches on streams of the San Pedro River and Verde River basin.

basin	Stream reach	Stream Type	Strahler Stream Order
San Pedro	Aravaipa Creek (East) Upstream of Parsons Canyon	B4c	4
San Pedro	Aravaipa Creek (West) Near Woods Ranch	F4	4
San Pedro	Bass Canyon upstream of Double R Canyon confluence	B4c	3
San Pedro	Buehman Canyon upstream of Bullock Canyon confluence	C3	2
San Pedro	Double R Canyon upstream of Bass Canyon confluence	B5c	2
San Pedro	Hot Springs Canyon downstream of Wildcat Creek	F4	4
San Pedro	San Pedro River at Cascabel	B6c	5
San Pedro	San Pedro River downstream of Charleston Bridge	B4c	4
San Pedro	San Pedro River downstream of Eskiminzin Wash	C6	5
Verde	Beaver Creek downstream of Montezuma’s Castle	B4c	5
Verde	Oak Creek downstream of Page Springs	C3	4
Verde	Oak Creek at Red Rock State Park	B4c	4
Verde	Verde River upstream of Perkinsville Bridge	C4	4
Verde	Verde River at Riverfront Park	C5	5
Verde	Verde River upstream of West Clear Creek confluence	B5c	6
Verde	West Clear Creek at Campground	C4	5
Verde	West Clear Creek upstream of Bullpen Ranch	C3	5
Verde	Wet Beaver Creek at Campground	B4c	4
Verde	Wet Beaver Creek at Gage	B3c	4



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ure 1. Study sites in the San Pedro River basin, sampled 2000-2002.

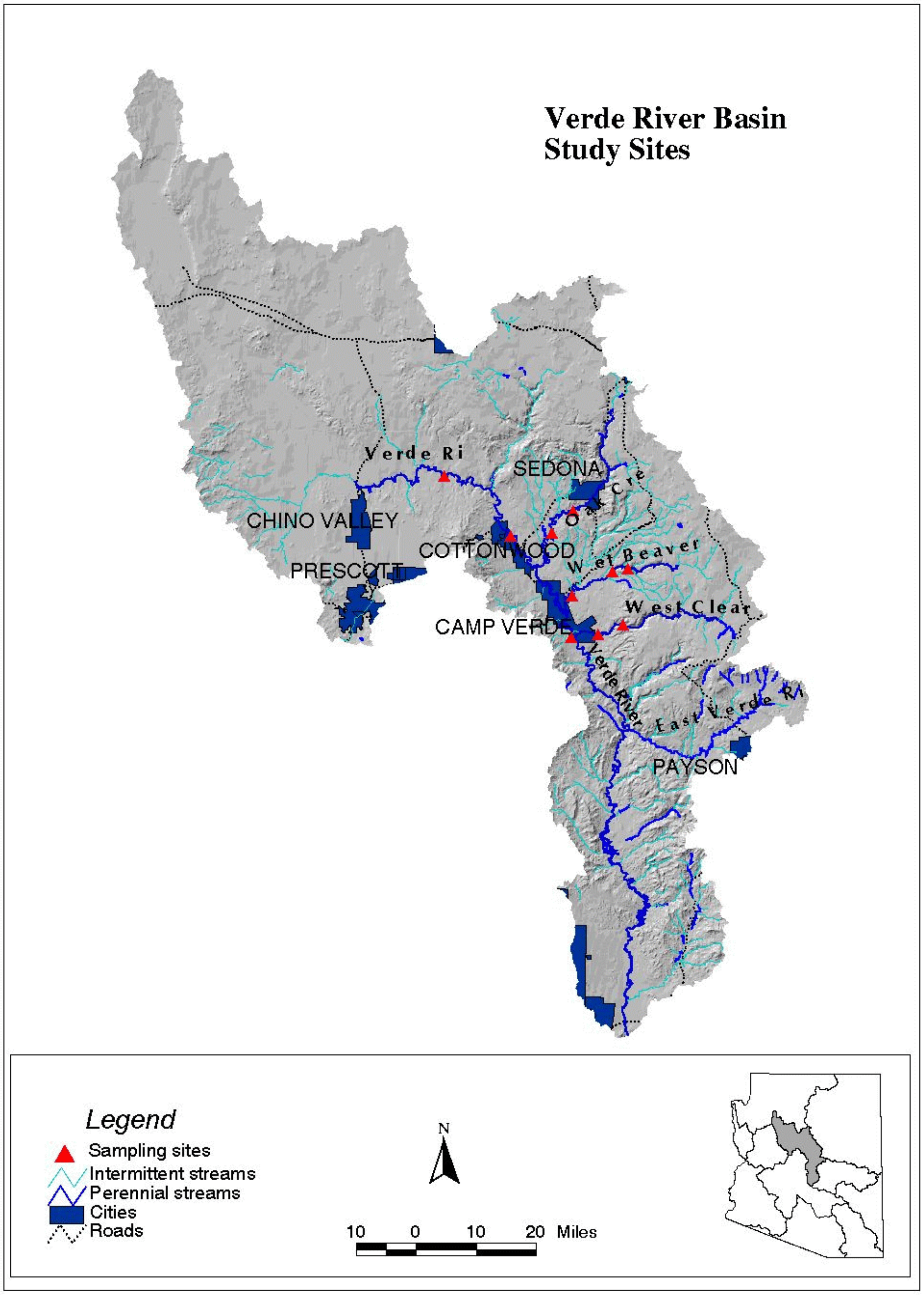

Figure 2. Study sites in the Verde River basin, sampled 1999-2002

III. Method of Approach

Biological - Macroinvertebrates were collected in the San Pedro River basin in 2000 and in the Verde River basin in 1999 (Appendix B). Macroinvertebrates were collected and taxonomically identified using ADEQ Biocriteria Program standard operating procedures (ADEQ, 2001). Sampling and analysis procedures were modeled after the USEPA's Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (Barbour et al., 1999). Metrics used in the Warm Water Index of Biological Integrity (Gerritsen and Leppo, 1998), were calculated based on a 500 count subsample with insects identified to genus or species level and with midges identified to family level. Additional functional feeding group and percent composition metrics were used in the analysis.

Physical - Geomorphological evaluations were conducted in the San Pedro River basin in 2000 and 2002 and in the Verde River basin in 1999 and in 2002 (Appendix C). Geomorphology surveys were collected following the Rosgen approach and using ADEQ Geomorphology surveying procedures (Spindler, 2003). In addition, habitat measurements including embeddedness, canopy cover (ADEQ, 2001), Proper Functioning Condition of Riparian Areas (USDI-BLM, 1998), Pfankuch Channel Stability Evaluation (Pfankuch, 1975) were collected concurrently with the macroinvertebrate samples. The Pfankuch Evaluation is a visual-based channel and bank stability assessment in which lesser scores mean good stability and greater scores mean poor stability. Rosgen's six-parameter "Sediment Supply Rating", hereafter called Rosgen's Stability Index is a more quantitative assessment of channel and bank stability.

Statistical methods - Taxa differences between large river sites and smaller order tributary streams were determined using a Kruscal-Wallis Significance Test on natural log transformed macroinvertebrate abundance data.

To characterize the physical habitat of the study sites, discriminant function analyses (DFA) were conducted to determine which substrate, reach, and watershed scale habitat parameters best differentiated large river from smaller tributary stream study sites. Three analyses per study basin were performed: one each for substrate, reach and watershed scale variables.

A Pearson Correlation Test was performed on macroinvertebrate metrics to identify which metrics are most correlated with stream type, percent fines and embeddedness. The nine metrics contained in the ADEQ Warm Water Index of Biological Integrity (IBI), along with additional functional feeding group metrics were included in the analysis. Metrics and habitat variables that were significantly correlated were further examined with regression plots.

IV Results and Discussion

The objective of this study was to investigate associations between geomorphological and habitat parameters and benthic community structure in two Arizona river basins, the San Pedro and the Verde River basins. The channel types were similar in the San Pedro and Verde River study sites, including Bc and C alluvial type channels, but the San Pedro River basin also contained naturally occurring entrenched F channel types as well. As one would expect, there were differences in macroinvertebrate community response to stream size, substrate, and stream type measures, which are the subject of this study.

A. Physical comparison of tributary streams and large rivers

San Pedro River basin

Study reaches of tributary streams included Rosgen B, C and F type channels with cobble to gravel and sand substrates, compared with B and C type channels with gravel to silt/clay substrates of the mainstem San Pedro River sites (Table 2). Drainage areas of tributary streams ranged from 5 to 514 mi^2 in size, an order of magnitude less than the mainstem San Pedro sites. Stream order ranged from 2-4 for tributary streams, whereas Strahler stream order ranged from 4-5 at the mainstem study reaches. The median particle size was gravel in tributary streams, 6 times greater than that of the San Pedro River sites. Average percent fines was 24% in tributary streams. Percent cobble was 25% in the tributary streams, 5 times greater than that of the mainstem San Pedro River sites. Mean embeddedness in tributary streams was 37%, one-third of the mainstem San Pedro River sites. The average riparian condition found at tributary streams was “Proper Functioning Condition”, whereas riparian condition at mainstem San Pedro River sites were “Functional-at-Risk”. Pfankuch stability scores were in the low to moderate sediment supply category at tributary study reaches, compared with high scores found at the mainstem San Pedro sites. Mean canopy density of the tributary streams was 68%, three times greater than in the mainstem San Pedro River sites (Table 2).

Verde River basin

Study reaches of both Verde tributary and mainstem streams included Rosgen Bc and C type channels. The average percent fines and percent cobble of tributary study reaches was comparable to mainstem Verde River reaches. However small cobble was the median particle size of tributary streams, whereas medium gravel was the median particle size of the mainstem Verde River study reaches (Table 3). Strahler stream order was similar among tributary and mainstem study reaches of the Verde River basin, although drainage areas of tributary study reaches (111 to 350 mi^2) were an order of magnitude smaller than the mainstem Verde River sites, ranging from 3200-4350 square miles. Mean embeddedness in tributary streams was 45 percent, also comparable to the mainstem Verde River. Pfankuch stability scores were similar for tributary and mainstem Verde River basin study reaches, all within the low to moderate sediment supply category by stream type. The average riparian condition, as indicated by the PFC score, was Functional at Risk-Upward trend in both tributary and mainstem Verde River study reaches. Mean canopy density of tributary streams was 37%, five times greater than in the mainstem Verde River sites (Table 3).

Table 2. Summary statistics for fluvial geomorphologic parameters of nine San Pedro River basin study sites, surveyed in 2002 (tributary streams n=6, San Pedro River sites n=3).

Geomorphic Parameter	Tributary Streams		San Pedro River sites	
	Mean	Range	Mean	Range
Drainage Area, mi^2	183	5-514	2392	1234-3790
Cross-section Area, ft^2	107	24-215	381	361-405
Bankfull Width, ft	16	20-133	181	114-296
Bankfull Max Depth, ft	3	2-5	6	5-6
Floodprone Width, ft	92	34-165	438	230-817
Sinuosity	1.4	1.1-1.9	1.2	1.1-1.3
Reach Slope, ft/ft	0.013	0.008-0.018	0.003	0.002-0.004
Riffle Slope, ft/ft	0.021	0.007-0.026	0.013	0.007-0.018
Median Particle Size, mm	37	1-71	6	1-15
Percent Fines	24	10-43	59	37-89
Percent Gravel	43	22-71	42	22-59
Percent Cobble	25	3-49	5	0-15
Percent Boulder	4	0-16	1	0-4
Percent Embeddedness	37	20-75	92	75-100
Pfankuch Score	70	54-90	98	75-130
Proper Functioning Condition of Riparian area	2	1-4	3	1-4
Elevation, ft	3505	2600-4134	3625	3035-3920
Percent Canopy Cover	68	41-98	20	14-32
Rosgen Stream Type	B4c, B5c, C3, F4		B4c, B6c, C6	
Strahler Stream Order	2-4		4-5	

PFC categories: 1-Proper Functioning Condition near PNC, 2-Proper Functioning Condition, 3-Functional At Risk-Upward, 4-Functional At Risk no trend, 5-Functional At Risk downward trend

Pfankuch scoring categories:

Scoring Category	B4	B5	B6	C3	C6	F4
Good	40-64	48-68	40-60	60-85	60-85	85-110
Fair	65-84	69-88	61-78	86-105	86-105	111-125
Poor	85+	89+	79+	106+	106+	126+

Table 3. Summary statistics for fluvial geomorphologic parameters of ten Verde River basin study sites, surveyed in 2001 (tributary streams n=7, Verde River sites n=3).

Geomorphic Parameter	Tributary Streams		Verde River sites	
	Mean	Range	Mean	Range
Drainage Area, mi^2	233	111-350	3683	3200-4350
Cross-sectional Area, ft^2	244	148-339	390	243-475
Bankfull Width, ft	90	66-110	172	70-260
Bankfull Max Depth, ft	5	4-6	5	5
Floodprone Width, ft	174	140-220	427	380-500
Sinuosity	1.2	1.1-1.3	1.2	1.1-1.3
Reach Slope, ft/ft	0.009	0.003-0.016	0.003	0.002-0.005
Riffle Slope, ft/ft	0.024	0.012-0.045	0.015	0.006-0.025
Median Particle Size, mm	71	25-105	12	2-26
Percent Fines	7	0-17	10	5-12
Percent Gravel	27	16-43	31	24-44
Percent Cobble	46	9-66	49	40-63
Percent Boulder	11	2-17	1	0-2
Percent Embeddedness	45	25-75	42	25-50
Largest Particle size, mm	703	390-1100	297	200-440
Pfankuch Stability Score	54	46-65	70	62-79
Proper Functioning Condition Score (PFC)	3	1-5	3	3-4
Elevation, ft	3599	3190-4025	3384	3053-3820
Percent Canopy Cover	37	11-59	8	2-14
Stream Type	B3c, B4c, C3, C4		B5c, C4, C5	
Strahler Stream Order	4-5		4-6	

PFC categories: 1-Proper Functioning Condition near PNC, 2-Proper Functioning Condition, 3-Functional At Risk-Upward, 4-Functional At Risk no trend, 5-Functional At Risk downward trend

Pfankuch scoring categories:

Scoring Category	B3	B4	C3	C4	C5
Good	40-60	40-64	60-85	70-90	70-90
Fair	61-78	65-84	86-105	91-110	91-110
Poor	79+	85+	106+	111+	111+

B. Benthic macroinvertebrate comparison of tributary streams and mainstem rivers

Comparisons of taxa differences between the tributary and mainstem rivers were made with Kruscal-Wallis Significance Tests, to explore how benthic macroinvertebrates are correlated with stream size differences. Overall taxa richness was one-third greater in the San Pedro than in the Verde River basin, with 94 taxa and 67 taxa, respectively (Appendix B). This may be due in part to the influence of neo-tropical species found in southern Arizona. In the San Pedro, 89 taxa were identified from tributary streams and 55 taxa were found in the mainstem San Pedro River samples. In the Verde River basin, 59 taxa were identified from tributary streams and 40 taxa found in the three Verde River mainstem samples. Clearly the large-order, mainstem rivers do not have the biological diversity of the mid-order tributary streams. This pattern is consistent with that of the River Continuum Concept (Vannote et al., 1980) which predicts that the maximum taxa richness will occur in mid-order streams having high environmental variability.

There were many taxa that were distributed widely across each basin. Ubiquitous taxa that occurred in tributary and mainstem San Pedro River study reaches included the mayflies *Fallceon quilleri, Thraulodes*, and *Tricorythodes*; the caddisflies *Cheumatopsyche, Helicopsyche, Hydropyche, Hydroptila, Metrichia* and *Nectopsyche*; the beetle *Microcylloepus*; and the damselflies *Argia* and *Brechmorhoga mendax*. In the Verde River basin, cosmopolitan taxa included the mayflies *Acentrella insignificans, Baetis tricaudatus, Leptohyphes, Serratella*, and *Tricorythodes;* the caddisflies *Cheumatopsyche, Hydropsyche, Hydroptila*, and *Smicridea*; the beetle *Microcylloepus*; the water moth *Petrophila*; the Dobsonfly *Corydalus cornutus*; and the crustaceans *Corbicula, Physella*, and *Orconectes*. There were several taxa ubiquitous across both basins that included the mayfly *Tricorythodes*, the caddisflies *Cheumatopsyche, Hydropsyche, Hydroptila;* the beetle *Microcylloepus*, the Dipterans Ceratopogonidae and Tabanidae; and the Oligochaeta and Turbellaria.

Taxa that were indicative of tributary streams of both basins included the Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa *Acentrella, Baetodes, Baetis tricaudatus, Caenis, Fallceon quilleri, Serratella, Thraulodes, Cheumatopsyche, Chimarra, Hydroptila, Leucotrichia, Ochrotrichia, and Smicridea* (Table 4). There were some notable differences in community composition of these tributary streams with some taxa; *Baetis notos, Callibaetus, and Epeorus* and the stoneflies *Sweltsa* and *Anacroneuria;* only occurring in tributary streams of the San Pedro River basin, and *Isonychia* only found in the Verde River basin. *Baetis tricaudatus* was found at more sites in the Verde River basin than in the San Pedro River basin and *Fallceon quilleri* and *Thraulodes* were more widespread in the San Pedro River basin. Several caddisfly taxa were abundantly found in tributaries of the San Pedro River basin but not in the Verde River basin: *Brachycentrus, Lepidostoma, Oecetis, Phylloicus, Polycentropus, and Wormaldia*. The caddisfy *Cheumatopsyche* was most widespread and dominant in abundance in tributary streams of the Verde River basin. These taxa differences between the tributary streams of the two basins were probably due to the larger median particle sizes and increased percent of cobble habitat found in all Verde River basin streams, compared with the median particle size of gravel in the mainstem San Pedro River, and due to the presence of neo-tropical taxa in southern Arizona.

The mainstem river taxa that were similar in the two basins included several taxa: *Acentrella, Fallceon quilleri, Cheumatopsyche, Hydroptila, Ochrotrichia, Smicridea*, the Hemipteran

Ambrysus, the Megalopteran *Corydalus cornutus*, the leeches and flatworms. Taxa distinct at San Pedro River sites were the mayflies *Thraulodes and Caenis* while the Verde River sites included the mayflies *Isonychia, Serratella,* and the caddisflies *Chimarra* and *Leucotrichia*. Minnow-like *Isonychia* larvae are usually found in riffle areas of streams and rivers and are good swimmers. The spiny crawler, *Serratella*, occurs in lotic and lentic habitats with considerable wave action (McCafferty and Provonsha, 1981). These taxa are considered common to large river habitats.

Table 4. Macroinvertebrate taxon abundances for tributary stream versus mainstem river study reaches of the San Pedro and Verde River basins, 1999-2000 (All listed taxa had a preference for that stream size at a Kruscal-Wallis significance of $p<0.05$ or as indicated: R=Rarely found among streams in that size class, C=commonly found, A=abundantly found, – = absent)

Taxon	San Pedro River basin		Verde River basin	
	Tributary	Mainstem	Tributary	Mainstem
Ephemeroptera				
Acentrella	C	C	A	A
Baetodes	R	--	R	R
Baetis notos	R	--	--	--
Baetis tricaudatus	R	--	A	A
Caenis	R	R	R	--
Callibaetus	R	--	--	--
Epeorus	R	--	--	--
Fallceon quilleri	A	A	R	A
Isonychia (p<0.077)	--	--	C	A
Serratella	C	--	C	A
Thraulodes	A	C	R	--
Trichoptera				
Brachycentrus	R	--	--	--
Cheumatopsyche (p<0.067)	C	C	A	R
Chimarra	A	--	C	R
Hydroptila (p<0.07)	C	A	C	A
Leucotrichia	R	--	R	R
Neotrichia (p<0.088)	C	--	--	--
Ochrotrichia (p<0.068)	C	R	R	C
Oecetis (p<0.09)	A	--	--	--
Phylloicus	C	--	--	--
Polycentropus	C	--	--	--
Smicridea	R	C	C	A
Other Taxa				
Coleoptera - Postelichus	--	C	--	--
Coleoptera - Psephenus (P<0.068)	--	--	C	--
Diptera - Empididae	R	R	A	--
Hemiptera - Ambrysus	--	C	C	C
Hirudinea	--	R	--	R
Megaloptera - Corydalus cornutus (p<0.09)	R	C	A	C
Turbellaria	C	C	C	A

B. Benthic macroinvertebrate comparison of tributary streams and mainstem rivers (continued)

Further statistical analyses were undertaken to identify the important environmental variables at the substrate, reach and watershed scales, which might influence biological differences between tributary and mainstem rivers. Kruscal-Wallis Significance Tests were conducted to reduce the number of habitat variables to consider in the discriminant function analysis (DFA) to only those which identified a significant difference. Those important habitat variables were then plugged into the discriminant function analysis to determine how the macroinvertebrate communities of small streams and mainstem rivers in the Verde River and San Pedro River basins responded to substrate, reach and watershed scale variables. The mainstem San Pedro and Verde Rivers in the southwest have large drainage areas, bankfull widths and extreme high flows, however baseflows of <10 cfs were common in the San Pedro River, compared with baseflows of <1 cfs in tributaries to the San Pedro River. Baseflows of 20-80 cfs were measured in the mainstem Verde River, compared with baseflows of 7-20 cfs in the tributaries during the study period. Our "large" rivers in Arizona present a different image than those of eastern rivers such as the Connecticut River.

San Pedro River DFA analysis

At the substrate scale, two variables accounted for 97% of the variation in the DFA. Embeddedness and maximum depth were found by the stepwise regression to be the most important substrate parameters differentiating tributary streams from the San Pedro River. The three San Pedro River sites generally were described by higher embeddedness and higher maximum bankfull depth in riffles, than the tributary streams. At the reach scale, four variables accounted for 96% of the variation in the DFA. Pfankuch Score, maximum bankfull riffle depth, bankfull width, and reach water slope were determined by a stepwise regression to be the most important reach scale parameters differentiating between tributary streams and the San Pedro River sites. Smaller order streams were generally found to have greater geomorphic stability scores, greater slope, but lower maximum bankfull depth than the San Pedro River sites. At the watershed scale, four parameters accounted for 99% of the variability in the DFA. Water surface slope, PFC, watershed area, and elevation were determined by the stepwise regression to be the most important watershed scale parameters differentiating between tributary streams and the San Pedro River. Smaller order streams were generally found to have greater slope, more stable riparian areas, and smaller watershed areas than the San Pedro River sites.

Verde River DFA analysis

At the substrate scale, one variable accounted for 80% of the variability in the DFA. The median particle size (D50) was the most significant substrate parameter. The three mainstem Verde River sites generally were described by gravel rather than cobble median particle size found in the tributary streams. At the reach scale, three variables accounted for 98% of the variability in the DFA. Floodprone width, Pfankuch score, and water slope were determined by the stepwise regression to be the most powerful variables at the reach scale. Smaller order streams were generally found to have greater slopes and Pfankuch scores, but smaller floodprone widths than the Verde River sites. At the watershed scale, three parameters, watershed area, elevation, and stream type, were determined by the stepwise regression to be the most important watershed scale parameters, accounting for 99% of the variability. The tributary streams were generally found to have smaller watershed areas and slightly higher elevations compared with the mainstem Verde River sites.

Across all scales, the variables which best distinguished tributary streams from the mainstem San Pedro River included: percent fines, embeddedness, maximum riffle depth, bankfull width, Pfankuch score, watershed area, and water surface slope. Across all scales there were only four variables which best distinguished between tributary streams and mainstem rivers in the Verde River basin: median particle size, floodprone width, Pfankuch score, and watershed area. This is a result of the similar size and proximity of the tributary streams and the Verde River. Watershed area and Pfankuch stability score were common to both basins, indicating the importance of broad scale to reach scale parameters when making comparisons between basins.

Comparisons across basins

At the substrate scale, embeddedness and the maximum bankfull depth in riffles differentiated the macroinvertebrate community of the San Pedro River basin. The median particle size best discriminated the macroinvertebrate community of large and small streams of the Verde River basin. Insects of the EPT group inhabit cobble surfaces and the interstitial spaces around and beneath gravel and cobble substrates. The abundance of insects, especially the EPT taxa, declines when sediment fills in riffle habitats (Waters, 1995). Riffle embeddedness of more than 33% resulted in a 50% decline in insect abundance and when the streambed was cleaned of fine sediment, mayflies and stoneflies increased in abundance eightfold (Bjornn et al. 1977). McClelland and Brusven (1980) also found that the EPT taxa preferred cobble and gravel substrate best and that most species respond negatively to increasing amounts of sand and embeddedness. Median particle size of the riffle substrate is obviously an important factor distinguishing the habitat, substrate conditions and macroinvertebrates of large river and small streams. Benthic macroinvertebrate abundance is positively correlated with an increasing gradient of particle sizes, with the greatest abundance occurring where the larger particle sizes are present (Waters, 1995). This finding was substantiated in the current study. Since the median particle size is greater in moderately steep tributary streams than in the low sloped channels of the mainstem San Pedro and Verde Rivers, we found greater biological diversity in the benthic macroinvertebrate community of the tributary streams where the largest particle sizes were found.

At the reach scale, Pfankuch stability score and reach slope best discriminated between tributary and mainstem river reaches in both basins. Small streams in unperturbed watersheds tend to be more stable ecosystems than intermediate sized streams, which experience constant change in discharge and bed movement (Minshall, 1983). The San Pedro River is intermediate in size, ranging in stream order from 4-6, and has experienced the lowest base-flows in many years but also a 10-year flood event during the study period of 2000-2002. In contrast, most of the tributary streams of the Verde River basin had only near bankfull flows (1-1.5 year flood event). The San Pedro River experiences an order of magnitude greater flow disturbances than the smaller tributary streams and has a median particle size in the sand-gravel range which is heavily scoured and redeposited during high flow events. It experiences ecosystem expansion and contraction with its highly variable flows (Stanley et al. 1997). Our findings are supported by Minshall's (1983) theory that intermediate-sized streams tend to be more disturbed than smaller stable streams. The flashy hydrology of Arizona's desert streams leads to more disturbance of the stream channel, resulting in greater Pfankuch stability scores and a more tolerant benthic community at the reach scale.

At the watershed scale, elevation and drainage area had the strongest influence on macroinvertebrate community composition in both the San Pedro and Verde River basins. Since elevation co-varies with temperature (Growns and Davis, 1994) and temperature regime affects aquatic life histories, elevation therefore also influences macroinvertebrate community structure (Carter et al., 1996; Spindler 2001). Drainage area was also an important determinant of benthic communities between tributary streams and the mainstem rivers. Drainage area is logically correlated with Rosgen stream type and valley type. Smaller order streams have A or B type channels and moderately steep colluvial valleys, and larger order rivers have C type meandering alluvial streams with gentle valley slopes and well developed floodplains. Large river valleys have naturally lower slope and higher sinuosity, with reduced shear stress and smaller substrate size (Rosgen, 1994). Taxa differences result from slope and substrate changes as channels change from B to C type channels, such as increases in Oligochaetes, Hirudinea, and Chironomidae in the gentle gradient meandering streams (Ward, 1986). Although these taxa are considered indicators of impaired streams, they are a natural component of low gradient streams. Drainage area and elevation therefore are good broad scale predictors of benthic response to stream size.

C. Macroinvertebrate metric response to in-stream and reach level habitat

Deposited sediment on streambeds has a profound effect on the benthic macroinvertebrate community (Waters, 1995). Increases in fine sediment results in loss of gravel and cobble substrate and loss of riffle and pool habitat in streams. In both the San Pedro and Verde River basins, sedimentation influences on the macroinvertebrate community were detected. In the San Pedro River basin, effects on the metrics, percent predators, percent scrapers, and percent caddisflies, were documented at 40-50% fines (Figures 2a-2c, respectively). This contrasts with results from the Verde River basin, where a negative effect on the percent filterers was demonstrated at 8% fines (Figure 3a). Our results also contrast with those of Relyea et al. (2000) who documented changes in the macroinvertebrate community as a result of increases in fines of 20-35%. This range of effects over the two study basins suggests that the effects of percent fines in stream substrates may vary considerably by hydro-physiographic province. However additional study on genus or species level tolerances to percent fines is needed to supplement the limited number of samples reported in this study.
Loss of habitat is the primary reason for loss of these functional feeding groups in the San Pedro

and the Verde River basins. Many predators in the Hemiptera and Coleoptera orders of insects inhabit shallow, slow moving water at the margins of streams, where fines are readily deposited. As a result of habitat preference, they are more susceptible to degradation of habitat by fines. The percent scrapers metric increased with percent fines, as a result of composition by an Elmid beetle *Microcylloepus* and the caddisfly *Helicopsychidae*, highly tolerant organisms, found in the San Pedro River basin. These highly tolerant taxa are adapted to sand and algae dominated substrates and represent a shift in community structure and function associated with excess sediment. Two sand-dominated San Pedro River sites contained these taxa in abundance. The unexpected increase in percent caddisflies with increasing percent fines was due to a shift towards Hydropsychidae and Hydroptilidae caddisfly families, which prosper in a habitat rich in filamentous algae mats, at one San Pedro River site. When that sand-dominated site is removed from the dataset, there is no significant positive correlation of percent caddisflies and percent fines. Further study of sediment correlations should utilize individual taxa rather than broad metrics to avoid such problems. Though filterers feed from suspended organic particles, as with all benthic organisms their density may be decreased due to loss of diverse habitat and reduction of interstitial space (Lenat et al. 1979). The loss of percent filterers in the Verde River basin paralleled the loss of the caddisflies *Cheumatopsyche, Chimarra, and Hydropsyche,* which were much more abundant in streams and in the Verde River, having low percent fines in riffle substrates.

Embeddedness of cobble and large gravel occurs when fine sediments fill in the interstitial spaces. So embeddedness is another measure of habitat loss. Whereas percent fines is a measure of substrate homogeneity, embeddedness is a more direct measure of loss of interstitial habitable space. A reduction in number of caddisfly taxa between 30-50% embeddedness was identified in the San Pedro River basin (r^2=0.66, Figure 2d). Effects on the macroinvertebrate community at a similar percentage was also reported by Bjornn et al (1977), who documented severe effects on macroinvertebrate abundance at greater than one-third embeddedness. No significant correlations were detected for macroinvertebrate metrics in the Verde River basin, probably because visual based embeddedness estimates were made instead of measurement of 30+ particles, which was the protocol used at San Pedro River sites. Further study is needed to determine the effect of embeddedness on metrics and individual taxa.

Other evidence of changes in benthic community structure and function due to sediment impacts were found in the San Pedro River basin. Mayfly taxa richness responded positively to percent gravel levels of >35% in substrates of San Pedro study reaches (Figure 2e), indicating the importance of heterogeneous gravel-cobble substrate (Minshall, 1984). Caddisfly and Diptera taxa richness were inversely correlated to Pfankuch score (Figures 2f and 3b). These metrics decreased in response to increases in Pfankuch scores (greater scores indicate poor conditions), an indicator of the overall channel stability. The importance of channel stability to macroinvertebrate community condition was further reinforced by the correlations between scraper taxa richness and PFC and Rosgen's Stability Index in the Verde River basin. Scraper taxa richness decreased as PFC and Rosgen Stability Index increased (Figures 3c and 3d), indicating the importance of a healthy riparian community with stable banks and a stable channel. These results demonstrate the importance of conducting geomorphology surveys and evaluating overall channel stability for identifying reference condition and conducting sediment studies.

PFC category was only significantly correlated with one metric, scraper taxa richness in the Verde River basin (Figure 3c). There were no other correlations of PFC with the macroinvertebrates in the Verde or San Pedro River basins. This lack of correlations doesn't mean that a healthy riparian community is not important for healthy biota. Corkum (1992) found that macroinvertebrate composition was associated with site-specific factors such as riparian vegetation and land use. The importance of the riparian community is demonstrated indirectly through benthic correlations with percent fines in the substrate (Lenat et al, 1979). When riparian vegetation is lacking, a number of channel changes occur including an increase in bank erosion rate and a shift to a bi-modal particle size distribution, due to delivery of a substantial amount of fine sediment to the stream channel (Rosgen, 1996). Clearly, changes in riparian vegetation cover directly impact stream channel processes and indirectly affect the macroinvertebrate community. Additional studies utilizing quantitative measures of riparian vegetation and cover, rather than a categorical PFC score are recommended to accurately identify relationships between riparian condition, stream stability, and benthic condition.

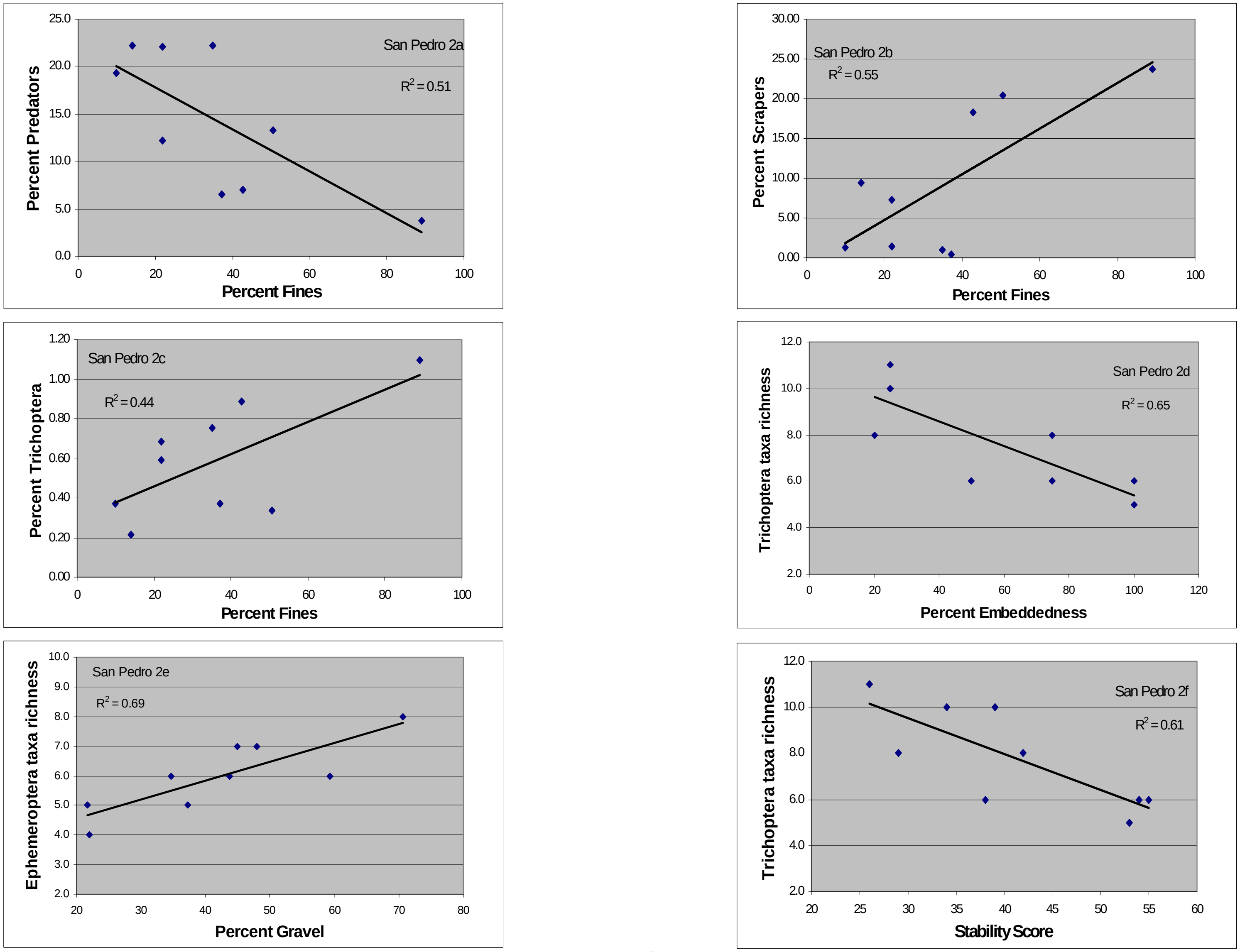

Figure 3. Macroinvertebrate metric response to substrate and reach level habitat parameters, in the San Pedro River basin, 2000 {2a) Percent predators vs. percent fines, 2b) Percent scrapers vs. %fines, 2c) Percent Trichoptera vs. %fines, 2d) Trichoptera taxa richness vs. %embeddedness, 2e) Ephemeroptera taxa richness vs. %gravel, and 2f) Trichoptera taxa richness vs. Pfankuch stability score}.

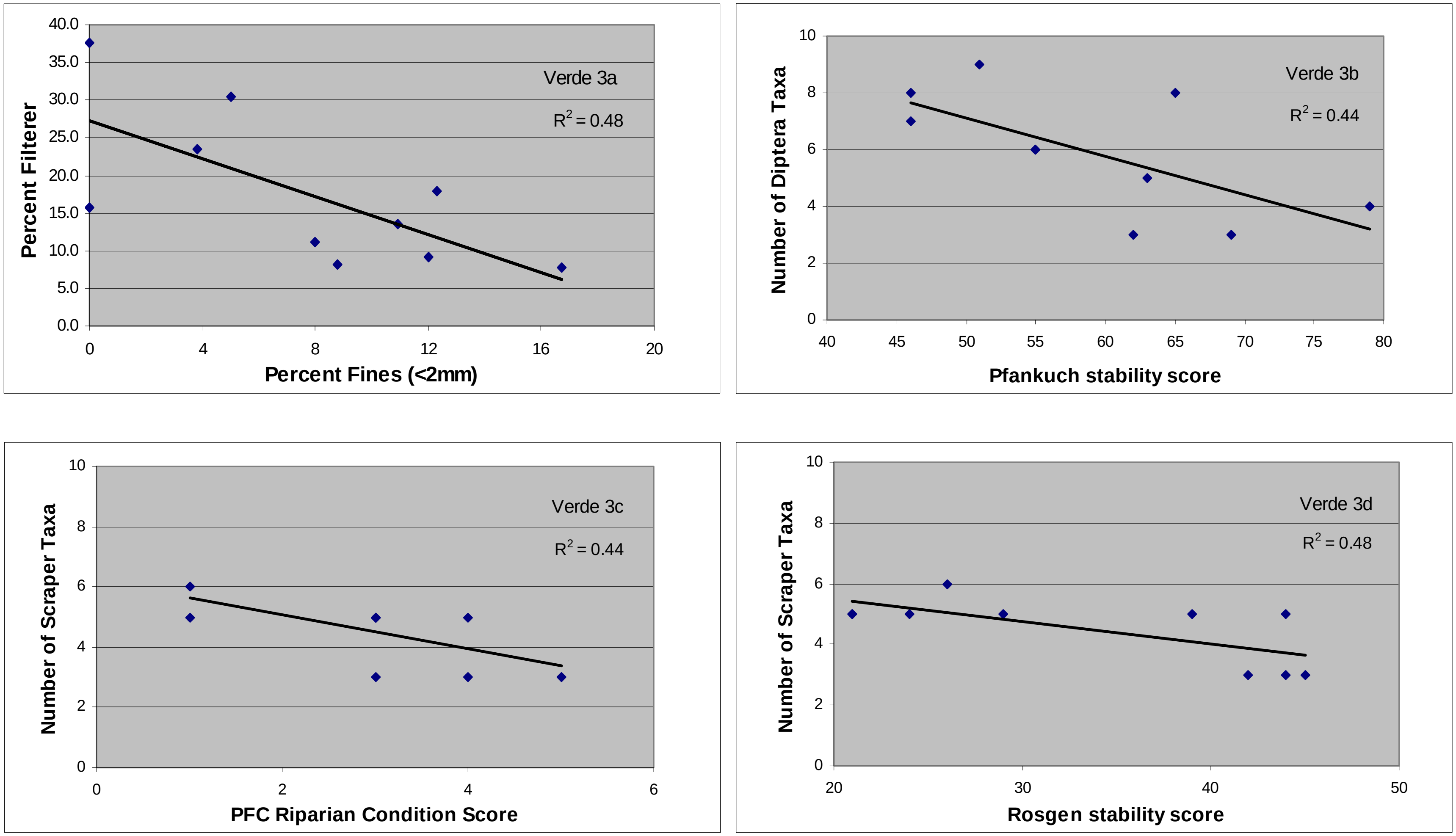

Figure 4. Macroinvertebrate metric response to substrate and reach level habitat parameters, in the Verde River basin, 1999 {3a) Percent filterers vs. percent fines, 3b) Diptera taxa richness vs. Pfankuch stability score, 3c) Scraper taxa richness vs. PFC Score, 3d) Scraper taxa richness vs.

Rosgen stability score}.

D. Benthic macroinvertebrate response to stream type

Rosgen stream type is determined using stream gradient, particle size and stream size variables. Since these geomorphic variables produce the physical template upon which the macroinvertebrate community develops, one would expect to detect different biological responses to stream type. We looked for significant differences in macroinvertebrate response to stream type through box plots of four types of metrics: taxa richness, percent composition of functional feeding groups, percent composition by different indicator groups, and dominance and tolerance metrics.

San Pedro River basin

The sensitive Ephemeroptera, Plecoptera, and Trichoptera (EPT) metric responded to differences in Rosgen stream type in the San Pedro River basin, though not in the manner one would expect. Mayfly taxa richness was different among stream types, with significantly greater numbers in the F channel types than in the Bc channel types. Mayfly taxa richness, caddisfly taxa richness and percent composition by caddisflies were greatest in the F4 and F5 channel types of Aravaipa Creek and Hot Springs Canyon and least in the B4c and B5c channels of the San Pedro River basin. This finding is contrary to what one would expect; that the macroinvertebrates would be impaired in what is generally thought of as impaired F channels. However, the F channel is the natural stable stream type for the canyon constrained Aravaipa Creek while Hot Springs Canyon is evolving from an F to a C type channel and has been fairly stable during the several drought years of this study. Though these stream types have a median particle size of gravel and sand, cobble habitat was present in these stream types. The extent of cobble habitat in riffles is underestimated when using the zig-zag method of pebble counts which includes bank material within the bankfull channel. As mentioned previously, clean cobble gravel substrates are preferable for development of a benthic community rich in EPTs.

There were no significant differences in percent composition metrics by stream type. However, Chironomidae and Oligochaetes responded as expected to stream type and particle size, occurring at greatest abundance in stream types B5c and B6c, which had the smallest median particle size. This is the classic response of the macroinvertebrates to increasing sediment; a change in composition from mayflies, stoneflies, and caddisflies to Oligochaetes and burrowing chironomids (Lenat et al. 1979). The percent Chironomidae and Oligochaetes are generally poor quality indicators which corresponds with the low stability assessments determined for these channels, using Rosgen assessment methods.

While there were no significant differences for functional feeding groups among channel types, the collector-gatherer metric was greatest in the B4c and B5c channels, while the percent scraper metrics was least in this stream type. The percent filterers metric had minimal values for the B6c channel type and the percent predators metric was lowest in the F4 and F5 stream type.

There was no significant difference in the percent most abundant taxon metric, the Hilsenhoff Biotic Index (HBI) metric or the Warm Water Index of Biological Integrity (IBI). However, the Warm Water IBI score was greatest for the F4 and F5 stable canyon channels of the San Pedro River basin.

Verde River basin

Different patterns were found in the Verde River basin dataset, consisting of B3-B5 and C3-C5 stream types. Mayfly, caddisfly, and total taxa richness were found to be greatest in the C4 and C5 channel types, the lowest gradient streams with gravel and sand median particle sizes. These stream types have larger valleys, naturally lower slopes and higher sinuosities which reduce stream power and deposit smaller substrates (Rosgen, 1996). These streams occurred in two Verde River mainstem sites and the lower West Clear Creek site. EPT taxa richness was greatest at these unlikely channels because of an intermediate disturbance effect and due to the fact that most of the mayfly and caddisfly taxa present were tolerant to highly tolerant species. Statzner and Higler (1986) indicate that maximum taxa richness occurs where large changes in stream slope create areas of high in-stream hydraulic variability. The hydraulics are variable in these Verde River channels due to the large size of the channel and to tributary inputs just upstream of the sampled reaches. This variability creates an intermediate disturbance effect, yielding increased diversity (Collins, S.L and S.M Glenn, 1997). There was increased richness of EPT taxa at these sites. However these taxa were tolerant to highly tolerant, consisting of the mayflies *Acentrella insignificans* and *Tricorythodes* and the caddisflies *Cheumatopsyche, Hydroptila, and Hydropsyche*. Though there was increased taxa richness at these mainstem river sites, the taxa present were primarily tolerant ones as indicated by the high HBI scores for these samples.

The percent composition by caddisflies metric was significantly greater for the C4 and C5 channels than for the other channel types. There were no significant differences for the percent mayflies, percent Chironomidae, or percent Oligochaete metrics by stream type. The functional feeding group, percent scrapers was significantly greater in the C4 and C5 channels, compared with the other channel types. The percent filterers was greatest for the C3 type channel, and the percent predators was greatest for the C4 and C5 channel types. The percent dominant taxon metric was significantly greater in the B4c and B5c channel types. The Hilsenhoff Biotic Index was least in the B4c and B5c channels. The Warm Water IBI score was significantly greater in the C4 and C5 channel types.

V. Conclusions

It is important to understand associations between biota and the physical substrate in order to parse out natural from anthropogenic effects on benthic macroinvertebrate communities. This study evaluated the response of benthic macroinvertebrates to stream size, in-stream habitat and Rosgen stream type.
The benthic macroinvertebrate community responded differently to stream order between

tributary streams and the mainstem San Pedro and Verde Rivers. Tributary streams have greater taxa richness than the mainstem rivers. In particular, the EPT taxa are richer in the tributary streams. Some taxa found in the mainstem rivers are specific to that habitat, such as the mayfly *Isonychia*. There has not been any evidence to date that the Warm Water Index scores are presenting any anomolous bioassessments for the large river communities. However further investigation of the applicability of the Warm Water Index for large rivers should be conducted to determine whether development of a separate large river index is warranted.

Scale is an important factor when considering the design of ecological studies. This research indicates that reach and watershed scale parameters are important when making comparisons between basins, since parameters such as watershed area and Pfankuch stability score were common to both the San Pedro and Verde River basins in distinguishing between tributaries and rivers. However at the level of individual bioassessments, the macroinvertebrate community is directly related to substrate parameters such as particle size and embeddedness, which directly affect benthic habitat.

There were several other effects of in-stream habitat on the macroinvertebrates. Structural changes in the macroinvertebrate community were evident in the loss of caddisfly taxa due to embeddedness and due to decreases in overall stream stability. Functional changes occurred in the form of loss in abundance of the filterers and number of scraper taxa. Loss in the filterers functional feeding group occurred at only 10-20% fines in the substrate. Some taxa found in the tributary streams were replaced by more tolerant taxa in the mainstem rivers, such as the shift in caddisflies towards Hydropsychidae and Hydroptilidae families, which are abundantly found in a habitat rich in filamentous algae mats and percent sandy substrate. These changes in the macroinvertebrate community aid the understanding of sediment impacts on aquatic life.

Although no impaired Warm Water Index scores occurred in either dataset, these data indicate that changes in the benthic community may be occurring at percent fines in the 40-50% range. This result contrasts with other published findings of impairment occurring at 20-35% fines. Further study of correlations of macroinvertebrates to percent fines should be conducted with a statewide dataset to fully examine the range of impairment across hydro-physiographic provinces in Arizona. Such a study might consist of development of a biocondition gradient, utilizing a statewide database of macroinvertebrate genus and species data over a range of environmental conditions, to identify harmful levels of sediment for aquatic life in Southwestern perennial streams.

Rosgen stream type was associated with shifts in the macroinvertebrate community. The median particle size, slope, and other hydraulic parameters shape the channel and habitat available for the macroinvertebrate community. We found the greatest EPT taxa richness and percent composition in stable “F” channels of the San Pedro and in “C” channels of the Verde River basin where an intermediate disturbance effect occurs. Increases in Oligochaetes and Chironomidae occurred as expected where median particle sizes were smallest, having the greatest percentages of fines.

Although this study found only one significant correlation of PFC to a macroinvertebrate metric, this finding does not mean that the riparian area is insignificant. The riparian vegetation provides bank stability, clean substrates, adequate canopy cover for temperature control, refugia during floods, and organic matter to the stream. Thus the riparian community indirectly contributes to a healthy macroinvertebrate community. However the PFC is not an adequate measurement for statistical analyses, because the it is qualitative in nature. Further study of correlations between *quantitative* riparian measures and macroinvertebrate structure and function using a large dataset, should be conducted to improve this analysis.

The influence of fluvial geomorphology on aquatic communities should not be underestimated. Fluvial processes govern the flow regime, channel and substrate composition, and riparian and bank stability in streams. This study joins many others, which have determined that the benthic macroinvertebrate community is directly influenced by substrate conditions such as percent fines and embeddedness. Further study of correlations between individual macroinvertebrate taxa and percent fines and embeddedness with a larger database is recommended for a better understanding of sediment impacts to benthic organisms across a broad scale of stream conditions.

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