A Survey of the Aquatic Community at Fossil Creek, AZ

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Executive Summary

There are few stream restoration projects in the Southwest that rival the size and complexity of the Fossil Creek Restoration. Fossil Creek is a spring fed stream in which water has been diverted for hydropower production for nearly a century. In 2005, the hydropower dam will be decommissioned returning full flow to Fossil Creek. In the fall of 2005 managers removed exotic fish from almost ten miles of the river. We initiated an extensive monitoring program in 2002 to determine the baseline conditions of the river prior to decommissioning. Here we describe six major trends 1) native fish densities decline dramatically below the hydropower dam due to both habitat alteration and exotic species; 2) the macroinvertebrate assemblage is diverse and differs among stream reaches due to differences in flow and travertine deposition. 3) two endemic invertebrates are concentrated above the diversion dam; 4) exotic crayfish have invaded from the Verde River and maintain large populations from the confluence upstream to the Irving Power Plant; smaller populations and isolated individuals are establishing up stream; 5) exotic fish have displaced native fish as top predators; and 6) the most productive areas in the stream are above the dam and directly below the Irving Power Plant where travertine dams are most prominent.

The trends reported here advance our understanding of river ecosystems showing how exotic species and flow alteration affect aquatic communities. We have shown that native fish densities, macroinvertebrate species assemblages, and food web structure are dramatically altered by these disturbances. To our knowledge, this is the largest ecological data set gathered prior to either a dam decommissioning or an exotic fish removal in the country. This baseline data will be instrumental in analyzing how the ecosystem will respond to restoration allowing scientists and managers to evaluate the full potential of river restoration.

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Chapter I: Overview

Exotic species, pollution, and human appropriation of fresh water have degraded streams and lakes around the world and contribute to the widespread losses of native species. Can ecosystem restoration projects help reverse these alarming trends? In Fossil Creek, Arizona, scientists and natural resource managers are working together to find out. Nearly a century ago, Arizona Public Service (APS) built a hydropower dam on Fossil Creek. Reduced flow caused by the dam and invasion by exotic fish have caused native fish populations to decline. APS, natural resource managers, and scientists hope their ambitious restoration plan can fix this damaged ecosystem.

The Restoration Plan has two parts. First, the reach of the creek immediately below the dam will be purged of exotic fish. Second, water will no longer be diverted for hydropower production, but instead will be allowed to flow in the natural stream channel. Return of full flows by decommissioning the dam is scheduled for the spring of 2005, though it's not yet decided whether the dam will be removed completely or only partially. Safety, liability, and aesthetic concerns argue for completely removing the dam, but there are ecological reasons to leave a portion of it in place. First, the dam is an effective barrier to exotic species migrating further up stream. Second, the dam prevents sediments from being unleashed into the stream. Third, the pool created by the dam has an extensive riparian zone that supports the largest known breeding population of lowland leopard frogs in the Coconino National Forest.

To eradicate exotic fish, in the fall of 2004 managers treated the river with a chemical that kills fish called Antimycin A. Prior to chemical treatment, native fish were removed and kept in holding tanks, to be released back into the stream once the exotics have been eradicated. The plan also included constructing a barrier at the downstream end of the chemical treatment to prevent reinvasion of exotic fish from the Verde River.

Restoring the Fossil Creek ecosystem will benefit freshwater resources in Arizona, enhancing visitors' aesthetic and recreational experiences and providing a native fishery in a region where native fish are increasingly rare. Equally important, the collaboration between managers and scientists in the design, execution, and monitoring of this ambitious restoration project can serve as a model for stream restoration. Of the hundreds of dam removal projects that have already occurred around the country, very few monitored the recovery of the ecosystem. Fewer still had enough baseline information to be able to articulate clear goals for ecosystem recovery. Did restoration really restore the ecosystem? Why, or why not? Unlike most dam removal projects around the country, it will be possible to answer these questions in Fossil Creek. The Stream Ecology and Restoration Group (SERG) at Northern Arizona University has been monitoring baseline conditions in Fossil Creek beginning in 1999. We received funding from the Heritage program to conduct a two year monitoring program beginning in 2002.

The renovations in Fossil Creek will create a large-scale experiment in river restoration with three treatments: 1) a reach above the dam experiencing natural flows and no exotic species; 2) a completely restored reach, with both removal of exotics and restoration of natural flows and 3) a partially restored reach, where flow is restored but exotic species will not be removed (Figure 1). Funding from the Heritage Program has helped us establish 16 sampling sites along the stream gradient. Figure 2 shows names and locations of sites we have sampled (see also specific sections for more details on sampling locations and dates). We sampled six core sites multiple times per year for two years generating data on fish and macroinvertebrate distributions. These core sites are 1) Springs, 2) Above Dam, 3) Below Dam, 4) Above Irving, 5) Below Irving, and 6) Below Sallie Mae Wash. Water quality was sampled at all of these core sites during some of the sample dates. Stable isotope studies were also conducted at the six core sites in August 2002 and repeated at the Below Sallie Mae Wash site in November 2003. In the first year, we also sampled the isolated pools above the springs and in year two we extended our sampling sites for select variables. Specific protocols and sample sites are presented within each section. We intend to monitor these sites following full flows to evaluate the effects of restoration on native species and their food webs. This report presents baseline data and is divided into seven sections: I) Overview, II) Native and Exotic Fish, III) Macroinvertebrates, IV) Exotic Crayfish, V) Water quality and VI) Food web structure and VII) Benthic biomass, VIII) In-stream vegetation.

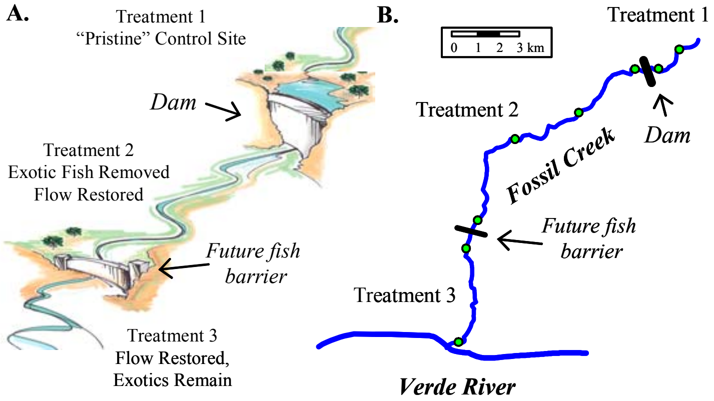


Figure 1. A. Schematic showing the Fossil Creek Restoration Project as a large-scale ecological experiment with three treatments. B. Map of Fossil Creek showing that our long term study sites, depicted as green dots, span all three treatments. See Figure 2 for a more detailed map.

We have provided Arizona Game and Fish Department with four additional deliverables: 1) A series of *Econotes from Fossil Creek*, which are one-page summaries of our research results. *Econotes* have been disseminated to management agencies, non-government organizations and the media. They have been positively received by representatives from management agencies including Arizona Game and Fish Department (AGFD), Bureau of Reclamation, United States Forest Service, and the United States Fish and Wildlife Service. Dave Weedman (AGFD) has offered to make them available on the AGFD website. 2) A manuscript that will be published in the *Journal of Geomorphology* on the effects of travertine on native food webs in Fossil Creek. 3) A list of titles of presentations at National and International Professional Meetings. 4) The project summary of a successful grant to the National Science Foundation to produce a PBS documentary on Fossil Creek entitled "Cascading Consequences". The Heritage program was acknowledged for their generous support on all of these deliverables.

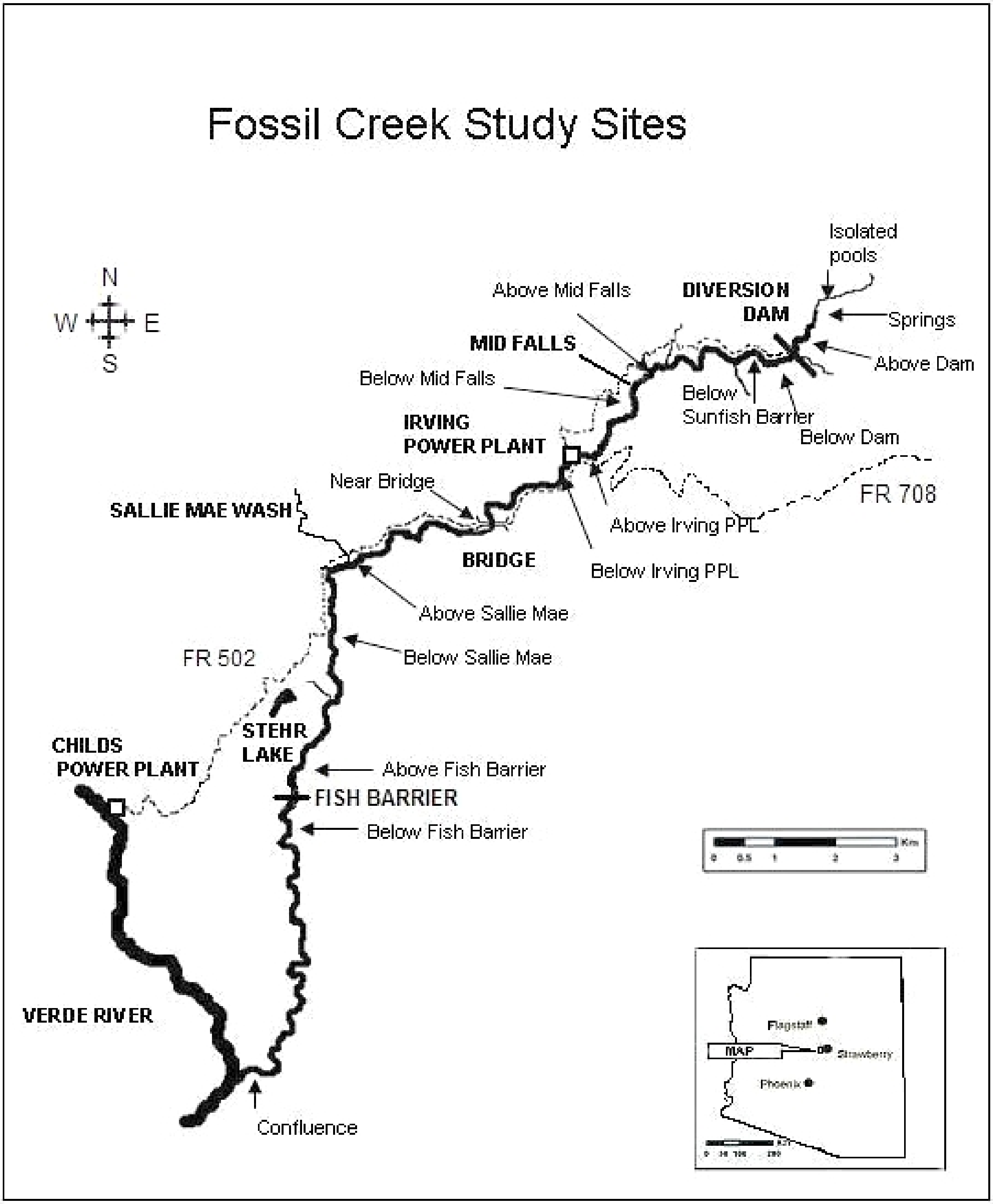


Figure 2. Map of Fossil Creek showing major landmarks and all sampling sites for Fish (see section II), Invertebrates (section III), Crayfish (section IV), Water Chemistry (section V) and Isotope for Food Webs (section VI). Study sites locations are indicated by arrows.

Chapter II. Native and Exotic Fish

Native fish are among the most threatened groups of organisms in the southwest, primarily because of water diversions and the introduction of exotic fish. Over half of Arizona's fish are listed as endangered or threatened. Fossil Creek provides an opportunity for preserving native fish because it is one of a few streams in Arizona retaining viable populations of six native fish species, including headwater chub, roundtail chub, speckled dace, longfin dace, desert sucker, and Sonora sucker. The federally endangered razorback sucker (*Xyrauchen texanus*) was inadvertently stocked into the up-stream springs of Fossil Creek although a viable population failed to establish perhaps because there is not sufficient habitat suitable for this large river fish (Barrett and Maughn 1995, EnviroNet 1998). Razorback suckers have not recently been collected from Fossil Creek other than Stehr Lake (Sponholtz unpublished data, Haden unpublished data) and likely no longer occur in the springs area.

The purpose of this research was to document the state of the Fossil Creek fish community before managers eliminate non-native species and APS restores flow. This data will provide a base line for assessing community changes in response to restoration. Much of the data contained in this final report has already been shared with Arizona Game and Fish Department, U. S. Fish and Wildlife Service, U. S. Forest Service and Bureau of Reclamation personnel during the planning process for piscicide treatment of the stream.

Methods

Fish collections were made during August 2002, December 2002, May 2003, August 2003, November 2003, February 2004, and May 2004. Earlier collections (Aug. '02 - May '03) were made using single pass backpack electrofishing, seine nets and trammel nets (Table 1). During the first year we sampled six core sites where we also sampled invertebrates, water quality and isotopes. These core sites are 1) Springs, 2) Above Dam, 3) Below Dam, 4) Above Irving, 5) Below Irving, 6) Below Sallie Mae Wash. After preliminary analysis of our data, we changed our protocol to include a mixture of snorkeling surveys and electrofishing/netting to generate better estimates of smallmouth bass and other species, which were under sampled using electrofishing and netting techniques. The new protocol was incorporated from May '03 through May 2004. We also expanded the number of sample sites to generate a more complete picture of the distribution of native and exotic fish along the stream gradient. Our first year data helped us establish the upstream boundaries of exotic sunfish and bass. During this period managers had developed a restoration plan that identified the site for barrier construction that was downstream from our initial sample sites. The additional sampling sites incorporated sections of the river that contained different mixes of sunfish and bass and extended our samples further downstream where exotics will not be removed. These samples are important because they will serve as base line data to quantify the effect of flow restoration decoupled from the exotic fish removal. We sampled the isolated pools at two times during year one but eliminated them from our protocol in year two to focus our efforts on areas of the stream that will be affected by restoration.

Collections were made in designated reaches of the stream ranging from 150 - 250 m length as well as isolated pools upstream of Fossil Springs. These reaches incorporated both a riffle and pool habitat. Each sample location was recorded using a handheld Global Positioning System unit. Electro-fished and netted fish were identified to species, weighed and measured for length. Fish sampled by snorkeling were visually categorized into three size classes (< 100 mm, 100 - 200 mm, and > 200 mm). Distribution of species and size classes were based on the mean of three independent snorkel surveys. Relative abundance data was based on visual counts by snorkeling because we were able to sample a higher number of fish and sites, while minimizing the bias towards any taxa. We used electrofishing data to analyze size class distributions since we were able to gather accurate data on length and weight. During May 2004 we were able develop methods for size classification during our visual surveys. These size class data are presented in Table 3 but were not included in the size class analysis presented below to avoid comparing samples collected with different methods.

We also synthesized data on the distribution of fish in Fossil Creek from several other sources to test how species composition has changed over the last decade. Arizona Game and Fish Department collected data at 5 different sites from 1994 through 1996 (Roberson et al. 1996). Tom Jones, of Grand Canyon University, collected fish data from 1997 through 1998. Pam Sponholtz, of the U. S. Fish and Wildlife Service, provided data collected from 1999 through 2001. We used data from all of these sources where common sites were sampled from 1996 - 2004. Cody Carter, of Northern Arizona University, provided snorkeling observational data from below the Irving Power Plant during 2001 and the NAU Stream Ecology and Restoration Group began conducting seasonal samples in August 2002, as part of this Heritage project. Fish sampling methods include backpack electrofishing, netting in deeper pools, seine netting, and snorkeling observations.

Data analysis

We used ordination techniques to analyze the structure of fish assemblages among the 15 different sites along Fossil Creek. Mean abundance (across all sample periods) of each taxa was double standardized to unit maxima and unit totals to mediate the effect of super abundant and rare species. Bray-Curtis distance measures were used in the ordination. We used the non-metric multidimensional scaling (NMDS) technique in the DECODA software package (Minchin 1989). The vector fitting technique of Kantvilas and Minchin (1989) was used to correlate habitat and water quality variables for each site with the fish communities for the eight sites where we generated both fish data and physical/chemical data (the six core sites, the isolated pools, and the confluence).

We tested for significant correlations between fish assemblages and the following 29 habitat and water quality variables: Distance to Verde River, Depth of pool, % bed rock, % boulder, % cobble, % sand, % gravel, % silt, frequency of occurrence for algae, detritus and travertine, base discharge, minimum water temperature, dissolved oxygen, total dissolved solids, salinity, specific conductance, pH, NH_3, NO_3, PO_4, SO_4, Mg, Ca, Na, K, Cl, and turbidity. The mean values for each variable for each site were used in the analysis. Although the correlations were generated from a subset of sites the results are relevant to all of the sites because the correlation is based on the relative position of the sites in the ordination. The strength of the correlation is shown by the correlation coefficient, “Max R”, and the significance of the correlation was tested by running 1000 iterations of the correlation routine with randomly assigned values to test for combinations that have higher correlation (Max R). The number of combinations with higher correlation than the original combination of data is divided by the total number of combinations to give a significance value (p). The methods for collecting water quality and habitat data are reported in the water quality and invertebrate sampling sections of this report.

Table 1. Sample locations and dates for fish sampling sites in Fossil Creek from August 2002 through May 2004. Letters refer to sample methods used: electrofishing (E), netting (N), and snorkel surveys (V).

Site description	AUG 02	DEC 02	MAY 03	AUG 03	N0V 03	FEB 04	MAY 04
Isolated pools above Springs	E/N	E/N					
Springs	E/N	E/N	E/N	V		V	V
Above Dam	E/N	E/N	E/N	V		V	V/E/N
Below Dam	E/N	E/N	E/N	V		V	V/E/N
Below Sunfish Barrier				V			E/N
Below Mid Falls				V			
Below Mid Falls				V			
Above Irving Power plant	E/N	E/N	E/N	V		V	V/E/N
Below Irving Power plant	E/N	E/N	E/N	V		V	V/E/N
Below Irving Power plant near bridge		E/N	E/N	V		V	V
Above Sallie Mae Wash				V		V	V
Below Sallie Mae Wash	E/N	E/N	E/N	V	E/N	V	V
Above Fish Barrier							E/N
Below Fish Barrier							E/N
Near confluence with Verde R.		E/N					E/N

Results and Discussion

Fossil Creek retains populations of fish native to the southwestern United States. Native fishes include: large minnows - headwater chub (*Gila nigra*), roundtail chub (*G. robusta*), small minnows - speckled dace (*Rhinichthys osculus*), longfin dace (*Agosia chrysogaster*), and suckers - desert sucker (*Pantosteous clarki*), and the Sonora sucker (*Catostomus insignis*). Non-native species have also made their way into the stream, probably moving upstream from the Verde River. Green sunfish (*Lepomis cyanellus*), smallmouth bass (*Micropterus dolemieu*) are the dominant invasive species. Flathead catfish (*Pylodictis olivaris*), channel catfish (*Ictalurus punctatus*) and yellow bullhead (*Ameiuris natalis*) also occur in the stream. The distribution of native and exotics are presented in Table 2, and the numbers observed of each species by size class is provided in Table 3.

Our findings indicate that, although portions of the stream contain intact native fish communities and no non-natives, green sunfish and smallmouth bass have likely expanded their distributions in the last decade, becoming dominant components of the community in most of the river (Figures 3 and 4). The total number of fish declines dramatically below the dam due to both flow reduction and the prevalence of exotic fish below the dam (Figure 3). The section of stream above the diversion dam contains only native fish (Figures 3and 5). Isolated pools above the springs area contained only desert suckers. In addition, a short (<1 km) reach immediately below the diversion dam contains only native fish. The upper limit of exotic green sunfish is a small barrier falls (~3 m high) roughly 1 km from the diversion dam (Figure 2 – labeled sunfish barrier). Exotic fish increase in relative abundance and number of taxa towards the confluence of the Verde River, supporting the hypothesis that they migrated upstream from the Verde River (Table 2). Green sunfish are abundant in the reach from the small barrier falls to the Irving power plant. Smallmouth bass were not found above a barrier falls at the Irving power plant during this study (Figure 5, Table 2). In contrast to bass and sunfish, the three exotic catfish were not found in the upper reaches of the stream. Yellow bullhead were found as far upstream as the recently constructed fish barrier (see sample site location Table 2), whereas flathead and channel catfish were only found near the confluence with the Verde River.

The invasion of smallmouth bass has been relatively rapid. The exact data of their introduction is not known and sampling prior to 1998 may not have detected them if they were present in low numbers or localized populations. Girmendonk and Young (1997) reported that a large flood during early 1995 destroyed an apparent barrier in the lower portion of the creek. Subsequent surveys by Jones and colleagues in1999, reported in Voeltz (2002), found increasing numbers of smallmouth bass and declining populations of roundtail chub below the Irving power plant. Continued monitoring by Northern Arizona University at the same sites has shown that smallmouth have since become the dominant species in this area in the following decade (Figures 4 and 5).

The prevalence of small-bodied native fish decreases in the presence of non-native fish, especially smallmouth bass. The abundance of dace and juvenile natives declined substantially at sites below Irving Power Plant (Figure 5). Snorkel surveys in May 2004 found schools of young-of-the-year suckers present in this reach, although only large adult suckers were observed during the fall of 2004.

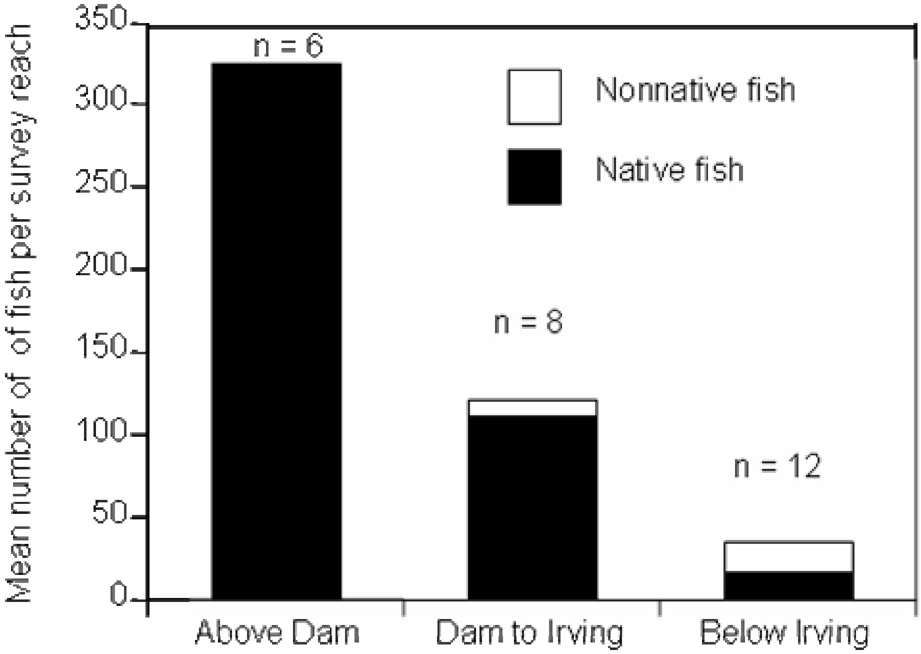


Figure 3. Native fish densities decline downstream in Fossil Creek as densities of exotic fish increase. Data are means of visual surveys conducted in August 2003, February 2004 and May 2004 of sites within each reach. Study sites are combined within the reaches. See Table 1 and Figure 2 for site names and locations. Native fish include speckled dace, headwater chub, roundtail chub, Sonora sucker, and desert sucker. Exotic fish are green sunfish and smallmouth bass.

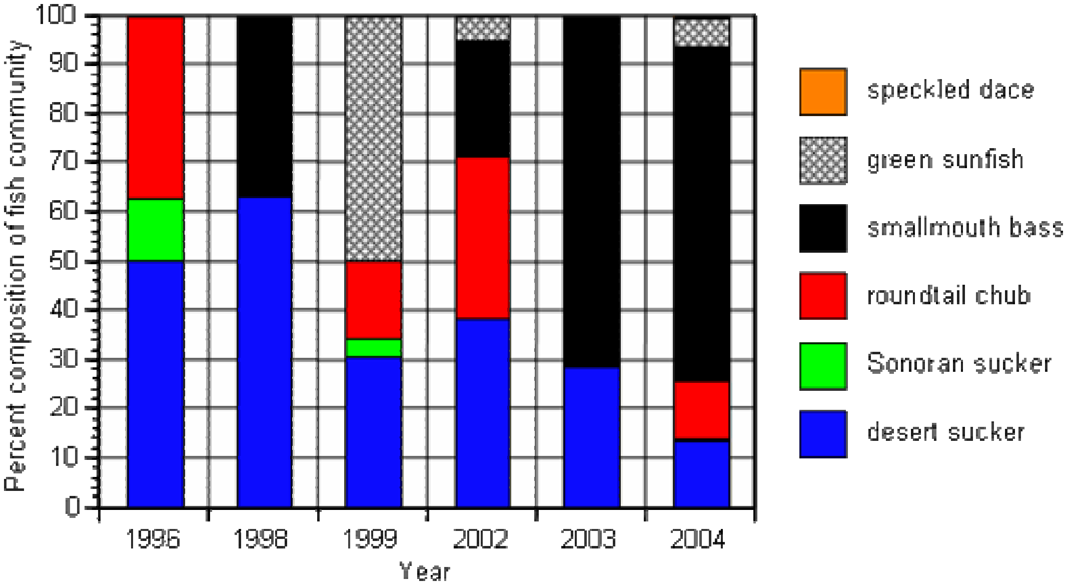
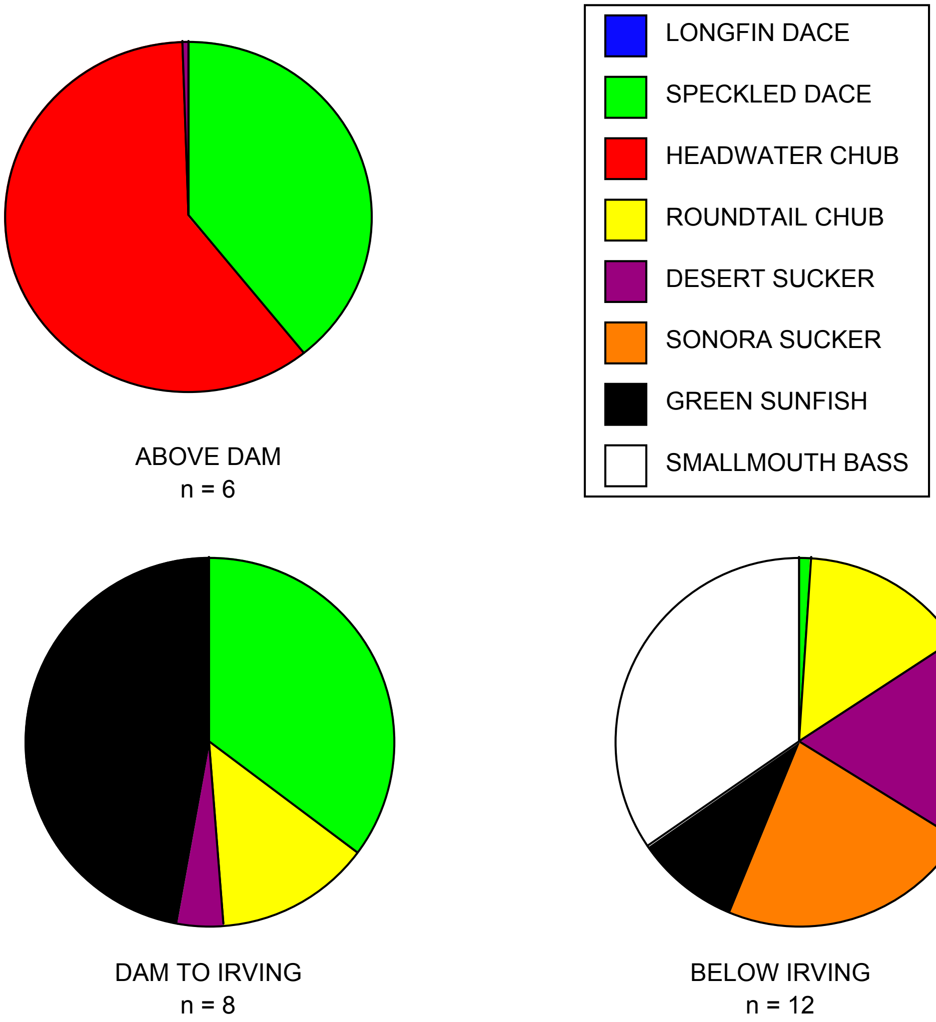


Figure 4. The relative abundance of non-native fish has increased over the last eight years. Fish were sampled below the Irving Power plant at two sites which have been monitored by Grand Canyon University and Northern Arizona University. Samples collected from 1996 through 1999 are electrofishing surveys conducted by Tom Jones of Grand Canyon University (n = 2). Samples from 2002 are electrofishing surveys conducted by Northern Arizona University (n = 3), and samples collected in 2003 and 2004 are snorkel surveys conducted by Northern Arizona University (n = 2).

Table 2. Distribution (presence/absence) of native and non-native fish species in Fossil Creek. Data are from current NAU sampling activities as well as past Arizona Game and Fish Department and Grand Canyon University sampling efforts. Distribution of headwater chub (*G. nigra)* below the diversion dam is unknown since distinguishing this species from roundtail chub (*G. robusta*) in the field is very difficult. For the purposes of this table all chubs below the diversion dam are considered roundtail chubs. Data were collected under the supervision of G. Allen Haden.

Taxon	Above Diversion Dam	Dam to Irving Power Plant	Irving to Verde River
headwater chub	X		
roundtail chub		X	X
speckled dace	X	X	X
longfin dace	X	X	
desert sucker	X	X	X
Sonora sucker		X	X
green sunfish		X	X
smallmouth bass			X
yellow bullhead			X
flathead catfish			X
channel catfish			X



ABOVE DAM
n = 6

DAM TO IRVING
n = 8

BELOW IRVING
n = 12

Figure 5. Fish community composition of Fossil Creek shows increased abundance of non-native fishes downstream of the diversion dam to the Verde River. Data were collected in August 2003, Feb 2004 and May 2004 by snorkel survey and represent mean relative abundance within each site sampled. Native species are in color, exotic species are in black and white. Please note that while Sonora sucker is present in the reach between Mid Falls and Irving it was detected by electrofishing and netting methods and does not show up in visual surveys in this reach. For specific sites sampled within each of these larger reaches refer to Table 2 and Figure 2.

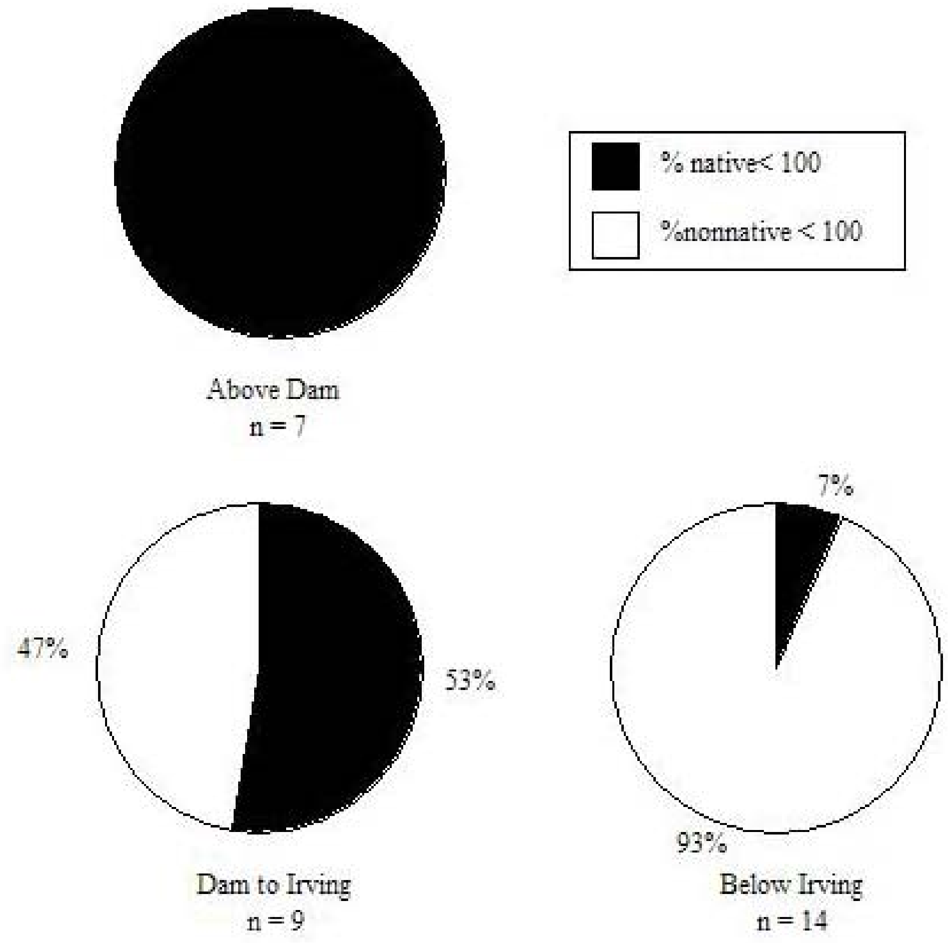


Figure 6. Fish community composition for fish <100 mm total length in Fossil Creek. Increasing relative abundance of non-native fishes is associated with a decline in small size classes of native fishes indicating poor recruitment of native fishes. Data were collected August 2002, December 2002 and May 2004 by electrofishing and represent mean composition of all sites within the reach during each sample period. For specific sites used please refer to Table 1.

Ordinations

Figure 7 presents the NMDS ordination which repartitions the multivariate data set into a two dimensional graph such that sites that are close to each other on this graph have similar fish assemblages where as sites that are further apart have more distinct assemblages. For example, the above dam site and the spring site have similar fish assemblages but both sites have very different assemblages from the Confluence. This analysis reveals seven distinct clusters 1) the isolated pools, 2) The two sites above the dam (springs site and above dam site), 3) the below dam site, 4) the area from the sunfish barrier to the midfalls region which encompasses the sunfish barrier site, and the above and below midfalls sites, 5) the above Irving site, 6) the area directly below Irving to the fish barrier which includes the below Irving site, the below bridge site, the below Sallie Mae site, and the sites above and below the fish barrier, and 7) the confluence site.

Ordination of fish communities combined with correlations of habitat and water quality indicated that the variation in fish communities only correlated with three of the 29 variables: distance from the Verde River, pH, and Na+. These three variables are plotted using a vector analysis onto the ordination graph (Figure 8). Distance from the Verde River is the main variable that describes the differences in fish communities among sites in Fossil Creek (Max R = 0.88, n =15, p = 0.001). The vector depicting distance from the Verde is fitted through the ordination space in the same direction as the majority of the variation among sites (Figure 8). Other environmental factors that were significantly correlated with the fish community are pH (Max R = 0.89, n = 8, p = 0.04) and Na (Max R = 0.92, n = 8, p = 0.02). Sodium (Na) is likely significant because the rather unique assemblage of fishes in the isolated pools (desert sucker only) is also associated with low sodium. The direction of the sodium vector parallels the distance on the graph that separates the isolated pools from the other sites. Other fish species are probably absent from the isolated pools because of barriers to dispersal rather than the lower sodium levels. PH is negatively co-correlated with distance from the Verde River because there is an increase in pH as CO2 levels decrease with distance from the springs. It is likely that pH is not a major driver of fish assemblage but correlates with fish variation because it follows the gradient of the river. Thus this data shows that water quality and microhabitat structure are not driving the differences in fish assemblages among the study reaches. The best predictor of fish assemblage is distance from the Verde Rive, supporting the widely believed hypothesis that the Verde River is the source of colonization. It appears that the main factor regulating fish communities in Fossil Creek is the ability of non-native fishes to gain access to the stream. In the case of Fossil Creek, fish community composition and native fish densities are more affected by the presence of exotic fish rather than abiotic disturbances caused by reduced flow.

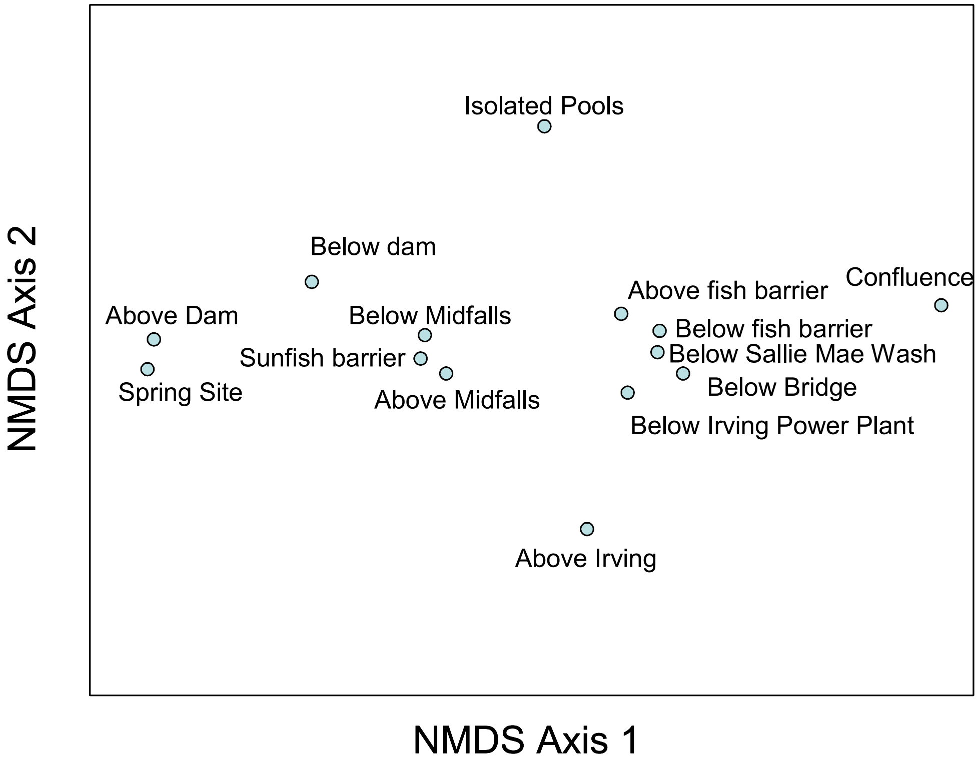


Figure 7. Non Metric Dimensional Scaling (NMDS) two-dimensional ordination of fish communities at 15 sites in Fossil Creek. The NMDS axes collapse multivariate data into a two dimensional space such that sites that are close to each other in this graph have similar fish assemblages where as sites that are further apart have more distinct assemblages. For example the Above Dam and Spring Site have similar fish communities that differ from the confluence site. Note that the site above Sallie Mae Wash site is in the exact same location as the Below Sallie Mae Wash site and has been left out of the figure.

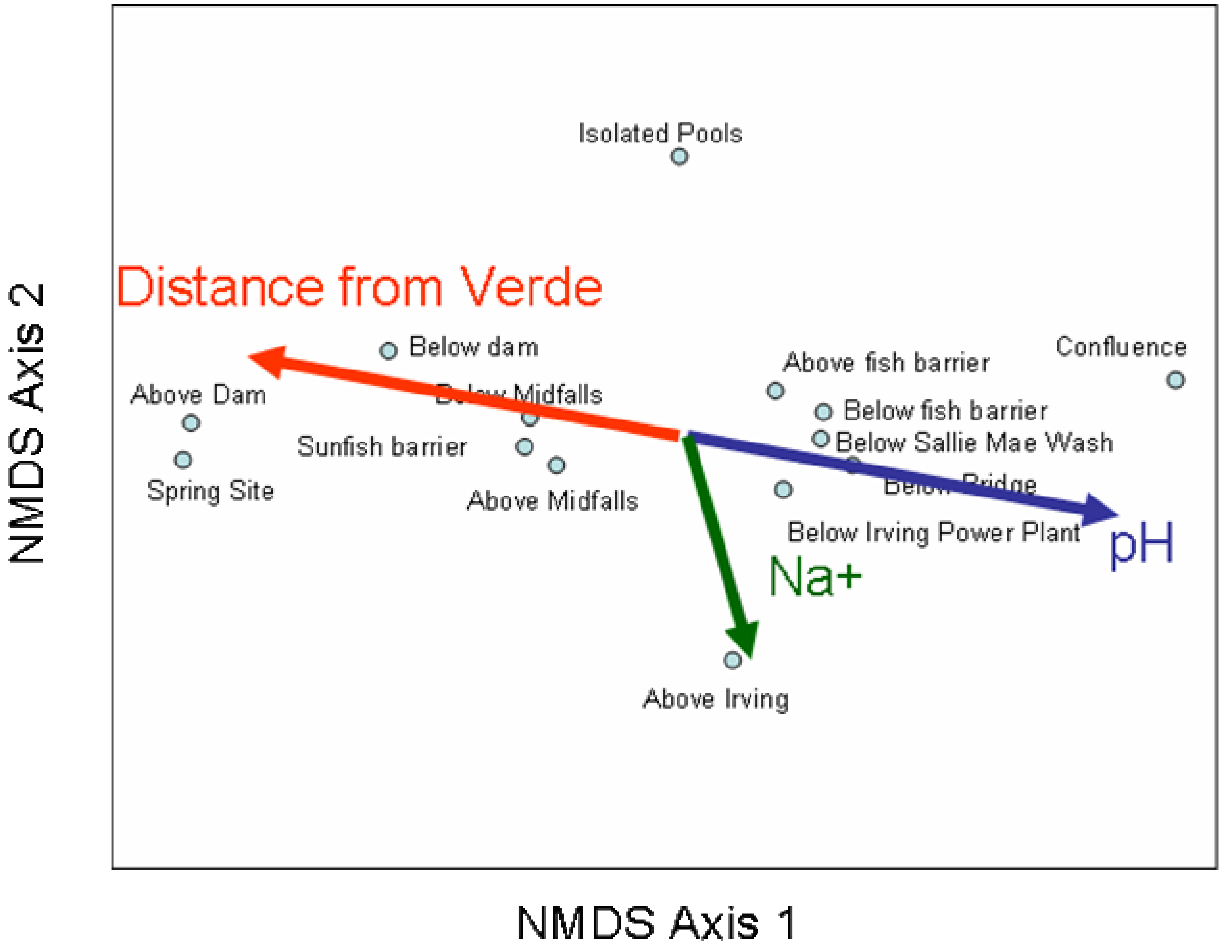


Figure 8: Vector analysis overlain on the NMDS ordination depicting vectors for the three variables that are correlated with differences in fish communities. Distance from the Verde River shows the best association with fish communities, pH decreases downstream and is also correlated with fish communities. Finally, sodium (Na) is correlated and appears to separate the isolated pools from the other sites and indicates both a unique fish community and lower sodium levels at the isolated pool site relative to other sites in the river.

Considerations for Management and further research

Our data document the distribution of native fish prior to eradication of exotics and return of full flow. This is one of the most comprehensive data sets for fish populations prior to either a dam decommissioning or an exotic fish removal. We have found that the native fish community still remains viable: large individuals (with reproductive potential) of both suckers and roundtail chub remain throughout the stream. The upstream reaches have abundant and intact native communities to provide immigrants to depopulated portions of the stream. The Verde River remains a likely source for reintroduction of exotic species after renovation and careful monitoring around the barrier and road access will be needed to detect re-invasion. We also found that the ephemeral portion of the stream above the springs is capable of supporting fish throughout the year. Several cohorts of desert sucker were able to survive in large disconnected pools during the summer of a record drought. Our sampling did not detect any non-native species above the dam.

This portion of stream should also be included in monitoring programs to detect possible reintroduction for stock tanks and other upstream sources.

The possibility that populations of *G. nigra* and *G. robusta* may be sympatric within Fossil Creek needs to be further studied once appropriate tools become available. None of our field crew felt qualified to identify the two species in the field, but we observed distinctly different looking chubs intermingled in the pools immediately below the diversion dam. As flows are returned to Fossil Creek and if the diversion dam is dismantled, there will be more opportunities for the two species to intermingle. Detailed ecological and genetic studies of this interaction may give insight into the speciation of *G. nigra* and other species within the Gila complex.

Fossil Creek is a unique and valuable case study for the conservation of native southwestern fishes. Population studies of native species in Fossil Creek after restoration will provide valuable insight into fish community dynamics without the stress of invasive species. As part of a complimentary study, our research team worked closely with the United States Fish and Wildlife Service to document the number of fish that were salvaged and reintroduced into the stream. We also generated additional populations estimates for all native and non-native fish species in sub-reaches of Fossil within the chemically treated area by combining estimates of the number of fish killed with the number of fish salvaged. These data combined with the data presented here will enable researchers to monitor the recovery of native fish.

Table 3. Data from fish collections and visual observations in Fossil Creek. Data presented are date, site, sample method, and number of each taxa/size class observed. Size classes are <100 mm (A), 100 – 200 mm (B), and > 200 mm (C). Sampling methods are either electrofishing and netting (EF/Net) or visual observation (Vis). * Size classes were not recorded during visual surveys in August 2003 and February 2004, numbers of individuals are reported in the middle of species columns for these samples.

Date	Site	Method	longfin dace	speckled dace		headwater chub			roundtail chub			desert sucker			Sonora sucker			green sunfish			smallmouth bass			yellow bullhead		channel catfish	flathead catfish
			A	A	B	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	B	C	A	C
Aug-02	ISOLATED POOL	EF/Net										11	10														
May-03	ISOLATED POOL	EF/Net										13	5														
Aug-02	SPRINGHEAD	EF/Net	17	1			10	2					2														
Dec-02	SPRINGHEAD	EF/Net		9	1	9	20						1														
May-03	SPRINGHEAD	EF/Net	3	5	1		12	1																			
Aug-03*	SPRINGHEAD	Vis		115			293						6														
Feb-04*	SPRINGHEAD	Vis		226			259						6														
May-04	SPRINGHEAD	Vis		49		98	51	8					1														
Aug-02	ABOVE DAM	EF/Net	7	4		4	19	2						4													
Dec-02	ABOVE DAM	EF/Net		10		1	3							1													
May-03	ABOVE DAM	EF/Net	2			1	1																				
Aug-03*	ABOVE DAM	Vis		64			443						3														
Feb-04*	ABOVE DAM	Vis		121																							
May-04	ABOVE DAM	EF/Net	50	68		23	46	3					4	5													
May-04	ABOVE DAM	Vis		52		126	33	2																			
Aug-02	BELOW DAM	EF/Net	46	2					38	14																	
Dec-02	BELOW DAM	EF/Net	7	49					3	2	2																
May-03	BELOW DAM	EF/Net	28	2					2	8			3														
Aug-03*	BELOW DAM	Vis		379						70			2														
Feb-04*	BELOW DAM	Vis		130						24			1														
May-04	BELOW DAM	EF/Net	37	141	1				35	64	2	2	37	4													
May-04	BELOW DAM	Vis		162					45	17	0	3	5	2													
May-04	SUNFISH	EF/Net	15	50					3	16	4		11	3				22	45								
Aug-03*	ABOVE MIDFALLS	Vis		3						11			6						29								
Aug-03*	BELOW MIDFALLS	Vis		14						10			3						10								
Aug-02	ABOVE IRVING PPT	EF/Net											1					8	14								

Table 3. Continued.

Date	Site	Method	longfin dace	speckled dace		headwater chub			roundtail chub			desert sucker			Sonora sucker			green sunfish			smallmouth bass			yellow bullhead		channel catfish	flathead catfish
			A	A	B	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	B	C	A	C
Dec-02	ABOVE IRVING PPT	EF/Net																8	2								
May-03	ABOVE IRVING PPT	EF/Net											3			2		22	8								
Aug-03*	ABOVE IRVING PPT	Vis											1						34								
Feb-04*	ABOVE IRVING PPT	Vis																	10								
May-04	ABOVE IRVING PPT	EF/Net											1			2	15	250	41	1							
May-04	ABOVE IRVING PPT	Vis										1						6	1								
Aug-02	BELOW IRVING PPT	EF/Net	1						1	1	8							1	1								
Dec-02	BELOW IRVING PPT	EF/Net									1						9	1	3								
May-03	BELOW IRVING PPT	EF/Net									2						3	5									
Aug-03*	BELOW IRVING PPT	Vis								9			3			14			19			9					
Feb-04*	BELOW IRVING PPT	Vis								18			1			21			7			7					
May-04	BELOW IRVING PPT	EF/Net									16			5			16	19	66	2		13	2				
May-04	BELOW IRVING PPT	Vis							7	11	9		6	13		2		31	3		2	6	1				
Dec-02	BELOW IRVING NEAR BRIDGE	EF/Net									1																
May-03	BELOW IRVING NEAR BRIDGE	EF/ Net									2								1								
Aug-03*	BELOW IRVING NEAR BRIDGE	Vis								4			1			4			5			27					
Feb-04*	BELOW IRVING NEAR BRIDGE	Vis								8			1			13			1			7					

Table 3. Continued.

Date	Site	Method	longfin dace	speckled dace		headwater chub			roundtail chub			desert sucker			Sonora sucker			green sunfish			smallmouth bass			yellow bullhead		channel catfish	flathead catfish
			A	A	B	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	B	C	A	C
May-04	BELOW IRVING NEAR BRIDGE	Vis								2	2		1	4				2			13	13	1				
Aug-03*	ABOVE SALLIE MAE WASH	Vis														1						9					
Feb-04*	ABOVE SALLIE MAE WASH	Vis											6			6											
May-04	ABOVE SALLIE MAE WASH	Vis		1					3	4	4		5	5	2	3	3	2			16	13	4				
Aug-02	BELOW SALLIE MAE WASH	EF/Net								1			4														
Dec-02	BELOW SALLIE MAE WASH	EF/Net								5			2	1		1		1			4	1					
May-03	BELOW SALLIE MAE WASH	EF/Net								2			5	1		1		1									
Aug-03*	BELOW SALLIE MAE WASH	Vis								1			5									5					
Nov-03	BELOW SALLIE MAE WASH	EF/Net								1	1			7		1	9	5	6		24	16	4				
Feb-04*	BELOW SALLIE MAE WASH	Vis											2			7						1					
May-04	BELOW SALLIE MAE WASH	Vis							1				1								1						
May-04	ABOVE BARR	EF/Net											4	7			3	21	15		8	12	4				
May-04	BELOW BARR	EF/Net											1	7			4	11	15		17	32	6				
Dec-02	NEAR CONFLUENCE	EF/Net																	1			3	1				1
May-04	NEAR CONFLUENCE	EF/Net																10	29		18	57	10	3	3	1	1

Chapter III. Aquatic Macroinvertebrates

Aquatic macroinvertebrates, or stream bugs, are a diverse group made up of various animals – mainly insects, snails, and worms. In aquatic ecosystems, these organisms are important in transferring energy and nutrients contained in algae and leaf litter to higher food levels, both aquatic (e.g. fish) and terrestrial (e.g. spiders, birds, and bats). The aquatic macroinvertebrates of Fossil Creek are no exception – they are a vital link in sustaining the native ecosystem. Our studies of the aquatic macroinvertebrates reveal an abundant and diverse collection of aquatic insects. Diversity enhances the flow of energy and nutrients, because different types of insects eat different foods.

Methods

Species composition and densities were monitored seasonally at each site (Table 4). Because pool habitats differ in their invertebrate assemblages from riffle habitats, we monitored these habitats separately using different sampling protocols. Crayfish were sampled separately using nets and minnow traps. Results of crayfish sampling are reported in the subsequent section and were not included in the macroinvertebrate community analysis although technically they are a macroinvertebrate.

Riffles were sampled using a Surber sampler, which uses a metal frame delineating a square foot. Substrate in this area is disturbed by scrubbing, causing all invertebrates to collect in a 250 μm mesh net. Invertebrates are separated from rocks and pebbles by elutriation. Associated substrates that represent energy sources (e.g. algae, moss, coarse particulate organic matter (CPOM)) were also collected, condensed into vials, and preserved with 95% ethanol. Pools were sampled with a core made of ABS plastic pipe (4 inch) driven into the substrates ("coring"). We inserted a trowel underneath the core to secure the sample, and transferred it to a bucket. Samples were elutriated and preserved in 95% ethanol. Five replicate samples were taken for both riffles and pools (n = 5 for each habitat type in each sampling period).

In the laboratory, samples from pools and riffles were visually sorted into trays for invertebrates and major energy sources. Energy sources were dried and set aside for energy budgets. Invertebrates were identified under a dissecting microscope to the lowest possible taxonomic group (usually genus or lower) using national and regional keys and enumerated (Usinger 1963, Edmunds et al. 1976, Stewart and Stark 1988, Pennak 1989, Thorp and Covich 1991, Merritt and Cummins 1996, Westfall and May 1996, Wiggins 1996). To allow comparison of pools and riffles, densities were standardized to numbers of individuals per square meter.

Data were analyzed using PC-ORD (version 4.02) to allow visualization of community patterns using Non-metric Multi Dimensional Scaling (NMDS). NMDS uses a distance matrix based on Sorenson-Bray Curtis dissimilarity index to group samples in a geometric space. Samples that are similar to each other are grouped together, while samples that are dissimilar are placed further apart. Clarke (1993) gives a complete description of NMDS. Significance and strength of *a priori* grouping in NMDS can be quantitatively determined using Multi-Response Permutation Procedure (MRPP). MRPP uses randomization to reallocate group membership to determine if distances in the NMDS distance matrix are stronger than would be expected by chance alone (using a p value of 0.05). Strength of grouping is indicated by the A statistic calculated in the MRPP routine. A ranges from 0 to 1, with values near 0 indicating complete overlaps of groups (i.e. the invertebrates in group 1 are identical to invertebrates in group 2); and values near 1 indicate perfect separation of groups (i.e. there are no shared invertebrates in group 1 and group 2). In ecological communities, an A of 0.1 or higher is considered strong grouping.

PC-ORD was also used to calculate diversity indices (Species Richness, Shannon's Diversity, Simpson's Diversity and Species Evenness). Species distributions were calculated for all species, and relative frequencies were calculated for each species at each site. Species presence at a site was assessed as rare, uncommon, common or abundant based on relative frequency.

Table 4. Sampling locations and dates for benthic macroinvertebrates in Fossil Creek from August 2002 through January 2004. Letters refer to habitat type sampled: P = Pools; R = Riffles.

	Sampling Dates					
Site Location	13-15 August 2002	4-5 December 2002	17 January 2003	5-6 May 2003	30 September/ 1 October 2003	30-31 January 2004
Isolated Pools	P	P		P		
Springs	R/P	R/P		R/P	R/P	R/P
Above Diversion Dam	R/P	R/P		R/P	R/P	R/P
Below Diversion Dam	R/P	R/P		R/P	R/P	R/P
Above Irving Power Plant	R/P	R/P		R/P	R/P	R/P
Below Irving Power Plant	R/P	R/P		R/P	R/P	R/P
Below Sallie Mae Wash	R/P	R/P		R/P	R/P	R/P
Confluence			R/P			

We measured substrate type, depth and velocity with every invertebrate sample. Immediately after taking the invertebrate sample, the major substrate types were recorded and classified according to a modified scheme of Platt et al. (1983). Depth was recorded, and velocity was measured with a Marsh-McBirney Model 201D Portable Water Current Meter. These measurements were taken alongside our invertebrate samples to provide insight into understanding the distribution and composition of invertebrate assemblages. Both invertebrate samples and habitat measurements were taken randomly along our study reaches. Thus these habitat measurements are intended to characterize the microhabitats found in the pools and riffles at each study site.

In addition to the substrate classifications of Platt et al. (1983), we further classified substrates into the following categories: Algae, Detritus, Moss, Roots, Travertine and Bedrock. Descriptions of each substrate categories are as follows:

Bedrock: Any hard lithified substrate that we considered permanently attached to the geological formation underlying the stream.

Boulder: Hard, lithified substrate (i.e. rocks) with a diameter greater than 250 mm.

Cobble: Rocks with a diameter between 50 and 250 mm.

Gravel: Rocks with a diameter between 5 and 50 mm.

Sand: Inorganic sediment with a diameter between 1 and 5 mm.

Silt: Sediment with a diameter below 1mm. . Often contains both organic and inorganic sediments. Distinguishing between sand and silt in the field is a subjective estimate of the researcher. Typically, if sediment felt "gritty" it was classified as sand, and if soft – it was classified as silt.

Algae: This category was reserved for copious amount of macroalgae (i.e. large filamentous green algae or cyanobacteria mats). Note that algae always co-occur with another substrate (e.g. cobble). Absence of algae in a sample does NOT indicate presence/absence of other algal forms (e.g. mixed periphyton, biofilms).

Detritus: This category included leaf litter, plant particles, pine cones, etc. Also referred to as Coarse Particulate Organic Matter (CPOM). This often occurs with other substrate types, but in some cases can be the only substrate.

Moss: Similar to the algae category, but only for aquatic bryophytes. This also co-occurs with other substrates.

Travertine: Substrates made up of deposited calcite, $CaCO_3$. In some cases, travertine was the sole substrate, generally in the form of large dams – but was also found as an armoring substrate upon other substrates (e.g. cobble).

Roots: These are substrates that contained roots from riparian vegetation.

Results

A total of 75,433 individuals representing 147 different taxonomic groups were collected over the course of the study (Table 5). Included in these collections are two invertebrates listed in the Heritage Data Management System (HDMS): the endemic Fossil Springsnail, *Pyrgulopsis simplex,* and the microcaddisfly, *Metrichia nigritta* (Table 6). *Metrichia nigritta* is the Page Springs Microcaddisfly, and is known only from Fossil Creek and Page Springs. Abundance of invertebrates varied from site to site and season to season in both pools and riffles (Table 7 and 8). Total numbers of invertebrates collected in all sites in 2002, 2003 and 2004 are presented in Tables 9 – 16. Our collections also included the Asiatic clam, *Corbicula fluminea*, an exotic bivalve. We found it in high densities close to the Verde River, and in lower densities below the Irving power plant. As the distribution of *C. fluminea* increases in Fossil Creek, it has the potential to alter energy processing dynamics of the stream by filtering out fine particulate organic matter. Competition of this filterer with another filterer, the blackfly, *Simulium*, could lead to consequences in higher food levels, since *Simulium* is a component of the diet in many fish species.

Invertebrate diversity tended to be highest in sites with travertine deposition – the Below Diversion Dam and Below Irving Power Plant (Table 17). Sites with lower species richness were Ephemeral Pools, Below Irving, and Confluence sites. In contrast to species richness, the other measures of diversity (e.g. Evenness, Shannon's and Simpson's Diversities) indicate that sites above the diversion dam (Above Diversion Dam and Springheads) are generally the most diverse.

Because a single ordination with multiple sites, seasons and habitat sites is cumbersome to understand, we ran a subset of the data in two separate ordinations: one for August 2002 riffles and one for August 2002 pools. Here we report the detailed results of this one sampling period to illustrate that invertebrate assemblages differed among sampling sites showing that different reaches of the river support different invertebrate assemblages. We attribute these differences to the unique physical and biogeochemical parameters at each site, including flow rate, travertine deposition, and temperature.

Riffle invertebrate assemblages collected in August 2002 showed clear groupings of sites using NMDS ordination (Figure 9). These groupings indicate that each habitat is distinct. Overall MRPP confirmed this analysis, showing that there is significant grouping. Pairwise MRPP confirmed that most sites were distinct, with the exception that the Springhead site does not significantly differ from the Above Diversion Dam site (Table 18). We also ran a MRPP using travertine deposition as a variable that showed significant differences between travertine sites and non-travertine sites ($A = 0.028$, $p = 0.00007$) (See Table 20 – 21 for habitat data). Ordination on data collected in August 2002 from pool invertebrate assemblages and the associated MRPP analysis also showed that most sites are significantly different from other sites (Figure 10, Table 19). Repeating ordinations on other subsets or on the whole database (all sites, all seasons) gave similar patterns of grouping and MRPP analysis gave similar results.

Discussion

Fossil Creek harbors a very diverse aquatic macroinvertebrate assemblage in comparison to many other southwest streams. A leading cause for this is habitat diversity, caused by differences in flow and travertine deposition. Because there is a large travertine deposition gradient, there are different invertebrate assemblages associated with each site. Additionally, the sites above the diversion dam are protected from exotic fish and crayfish which likely affect invertebrate assemblages through competition and predation.

The sites above the diversion dam are also the main sites where we find the two sensitive taxa. The Fossil Springsnail, *P. simplex*, is also found in the Above Power Plant site, although we hypothesize that these specimens represent a population washed in from a nearby spring (as of yet, unknown and unsampled) and are not a reproducing, established population. The microcaddisfly, *M. nigritta*, is found throughout the creek, but is most abundant above the diversion dam. Further encroachment of exotic species, especially crayfish and fish, will likely threaten both of these species.

Differences in invertebrate assemblages appear to be associated with variation in travertine deposition. High deposition rates in some reaches will exclude or limit certain insects, reducing competition for other insects. This can be seen in comparisons of the above dam reach with the below dam reach. The mayfly, *Thraulodes*, is found in high numbers above the dam in fast-flowing riffles with no travertine but is excluded by travertine deposition. This allows more tolerant organisms such as the mayfly, *Tricorythodes*, to flourish in the travertine areas due to their opercular gill coverings. Additionally, in the below Sallie Mae wash area, there is just enough travertine to armor the substrate, which appears to favor the Mayflies, *Baetodes* and *Baetis*, but not *Tricorythodes* or *Thraulodes*. The NMDS ordination of riffle assemblages reveals different invertebrate assemblages in travertine vs. non-travertine sites. This pattern is not seen in the pool assemblages, since riffles are the areas of highest travertine deposition because of out-gassing of CO_2.

Flow restoration will likely increase travertine deposition and alter the invertebrate assemblage. Effects of restoration on invertebrate assemblages should be based on previous assemblages in areas of similar travertine deposition, and not only on previous assemblages in that geographical location. Because there may be substantial distances between existing travertine assemblages and newly forming travertine areas, colonization of appropriate invertebrates (those capable of dealing with travertine) may be delayed.

The pools had lower species richness than riffles but higher overall abundance. Pool-dwelling invertebrates, especially oligochaetes, chironomids (midges), and certain mayfly genera, are probably a large source of food for fish. This is especially true in areas of travertine dam formation, which reduce riffles and form large pools behind travertine dams.

Invertebrate densities varied over time. Most densities in October 2003 were the lowest recorded for all sites, probably a result of seasonal spates that scour the substrates in both pools and riffles. This highlights the need for understanding year-to-year variability caused by seasonal changes in invertebrate assemblages and also from natural disturbance. Understanding natural variability allows better assessment of restoration actions, and also highlights the need for long-term monitoring following restoration.

This baseline data will be instrumental in evaluating how macroinvertebrates respond to restoration treatments. We are already using it to help determine the effect of Antimycin A, the chemical used to eradicate exotic fish in the fall of 2004. One of the unfortunate side effects of this chemical is that it can also kill some macroinvertebrates. We sampled invertebrates before and after the chemical treatment to determine which invertebrates were killed during the treatment. Preliminary data indicates that large numbers of macroinvertebrates were killed, but that some species were more susceptible than others. The baseline data presented in this report will help us evaluate how long it takes for macroinvertebrate assemblages to reestablish after this disturbance.

Table 5. Aquatic invertebrate’s distribution and relative frequencies along Fossil Creek. Frequencies calculated from % occurrence in samples within a site. Rare (R) are invertebrates occurring in less than 10%, Uncommon (U) invertebrates occur in 10% to 50% of samples, Common (C) occur in 50% to 75% of samples and Abundant (A) occur in 75% or more.

Order Family Genus	Isolated Pools	Springs	Above Dam	Below Dam	Above Power Plant	Below Power Plant	Below S.M. Wash	Near Verde
Acarina								
Various								
Various		R	R	U	R	R	U	
Amphipoda								
Crangonyctidae								
Crangonyx								U
Hyalellidae								
Hyalella		C				R		
Annelida								
Enchantrachyidae								
Unknown	R		R	R	R	R	R	
Hirudinea								
Eropellidae	R							
Helobdella fusca	R	R						
Nematopmorpha								
Paragordius	R							
Lumbriculidae								
Various								
Tubificidae								
Branchiura sowerbyi	R		R		U	U	U	
Various	A	C	U	U	U	U	C	C
Bivalvia								
Corbiculidae								
Corbicula fluminea						R	R	U
Sphaeriidae								
Pisidium	R	U	U	R	R	R	R	U
Coleoptera								
Curclionidae								
Unknown						R	R	
Dryopidae								
Helichus		R	R	R	R	R		
Postelichius		R			U	R	R	U
Dyticidae								
nr. Agabetes	R			R				
Hydroporous	R							
Laccophilus	R							
Liodessus						R		
Nebrioporous/ Stictotarsus	U	R		U				
Thermonectus nr. marmoratus	R							
Elmidae								
Dubriraphia		R	R	R		R		R
Heterelmis		U	U	R	R	R		
Hexacylloepus		R			R			
Huleechis		C	C	U	C	U	U	A
Macrelmis		U	U	R	R		R	
Neocylloepus					R	R		
Neoelmis		R			R		R	

Table 5 continued.

Order Family Genus	Isolated Pools	Springs	Above Dam	Below Dam	Above Power Plant	Below Power Plant	Below S.M. Wash	Near Verde
Gyrinidae								
Dineutus	R							
Gyrinus	R	R						
Haliplidae								
Haliplus				R				
Peltodytes	U					R		
Hydraenidae								
Octhebius				R				
Hydrophilidae								
Berosus	R				R			
Enochrus fucatus			R			R		
Tropisternus lateralis	R							
Tropisternus	R		R	R				
Laccobius							R	
Lutrochidae								
Lutrochus					R		U	R
Psephenidae								
Psephenus			R					U
Scirtidae								
Scirtes		R						
Staphylinidae								
Stenus				R				
Collembola								
Unknown								
Unknown							R	
Diptera								
Ceratopogonidae								
Bezzia/Palpomyia	R	U	U	U	U	R	U	U
Culicoides		R	R	U	C	U	U	U
Forciomyia				R		R		
Chironomidae								
Various	A	A	A	A	A	A	A	A
Culicidae								
Anopheles	R	R		R				
Culex			R					
Culiseta	R							
Dixidae								
Dixa				R				
Dixella		R		R				
Empididae								
Chelifera				U	U	R	R	C
Clinocera					R			
Hemerodromia			R	U	R	R	U	U
Muscidae								
Limnophora				R	R			
Psychodidae								
Pericoma				R	R	R		
Simuliidae								
Simulium		R	U	C	C	C	U	A
Stratiomyiidae								

Table 5 continued.

Order Family Genus	Isolated Pools	Springs	Above Dam	Below Dam	Above Power Plant	Below Power Plant	Below S.M. Wash	Near Verde
Caloparyphus		R		U	R	R	R	
Euparyphus			R	R	R	R		
Stratiomys			R					
Tabanidae								
Tabanus				R	U	R	R	U
Tipulidae								
Antocha					R			
Dicranota				U	U		R	
Paradelphomyia/ Psuedolimnophora		R						
Tipula		R		R	R	R		
Ephemeroptera								
Baetidae								
Baetis	R	C	C	C	C	C	C	C
Baetodes	R			U	U	U	C	C
Callibaetis	R	U		R	U	R	R	
Cameleobaetidius							R	
Caenidae								
Caenis	R	U	U	U	U			U
Ephemerellidae								
Ephemerella inermis								U
Serratella micheneri					R			
Leptophebiidae								
Thraulodes		U	C	U	U			
Tricorythodidae								
Leptohypes			R		R		R	
Tricorythodes		A	U	C	U	R	R	
Gastropoda								
Ancylidae								
Ferrissia			R					
Hydrobiidae								
Pyrgulopsis simplex		U	U		R			
Lymnaeidae								
Fossaria							R	
Physidae								
Physella	U	R	R	R	R	R	R	U
Planorbidae								
Gyralus	R		R	R				
Heliosoma	R							
Hemiptera								
Belostomatidae								
Abedus	C							
Belostoma				R				
Corixidae								
Graptocorixa abdominalis	R							
Neocorixa	R							
Trichocorixa	R							
Gelastocoridae								
Gelastocoris rotundatus							R	R
Gerridae								
Gerris							R	
Metrobates				R				
Hebridae								
Hebrus sobrinus				R	R			

Table 5 continued.

Order Family Genus	Isolated Pools	Springs	Above Dam	Below Dam	Above Power Plant	Below Power Plant	Below S.M. Wash	Near Verde
Naucoridae								
Ambrysus occidentalis		U	U	R				
Nepidae								
Ranatra brevicollis	R							
Notonectidae								
Buenoa	R							
Notonecta nr. hoffmani	R							
Veliidae								
Microvelia				R	R			
Rhagovelia distincta		R	R	U	R	U	R	
Lepidoptera								
Pyralidae								
Petrophila		U	U	U	U	U	U	C
Megaloptera								
Corydalidae								
Corydalus texanus		R	U	U	U	U	R	U
Odonata (Anisoptera)								
Gomphidae								
Erpetogomphus designatus		R	R	R	R		R	
Libelluilidae								
Brechmorhaga mendax		R	R		U		R	U
Libellula pantala	R							
Libellula saturata	R							
Pantala hymenaea	R							
Pseudoleon superbus	R							
Odonata (Zygoptera)								
Calopterygidae								
Hetareina americana		R	U	U		R	R	U
Hetareina vulnerata			R	R	R	R		
Coenagrionidae								
Argia immunda						R		
Argia plana					R	R		
Argia sedula	R							
Argia oenea		U						R
Argia lugens	R	U		R		U		
Argia			U	U	U	R		U
Enallamga		R			R	R		
Lestidae								
Archilestes grandis	U		R					
Ostracoda								
Various								
Various		U		U	U	R	R	U
Plecoptera								
Capniidae								
Capnia	R							
Perlodidae								
Isoperla				R			U	C
Trichoptera								
Calomatoceridae								
Phylloicus		R	R	R				
Glossosomatidae								
Culoptila			R					R
Protoptila			R		R			

Table 5 continued.

Order Family Genus	Isolated Pools	Springs	Above Dam	Below Dam	Above Power Plant	Below Power Plant	Below S.M. Wash	Near Verde
Helicopsychidae								
Helicopsyche mexicana		C		R				
Hydropsychidae								
Ceratopsyche venada		U	C	U	U	C	U	U
Chuematopsyche			U	R	U		R	U
Hydropsyche		U	C	U	U	C	U	U
Smicridea							R	
Hydroptilidae								
Hydroptila ajax				U	U		R	
Hydroptila artica				U	U		R	
Hydroptila				U	U		R	
Luecotrichia limpia			U	R			R	
Mayatrichia					R		R	
Metrichia nigritta		U	C	U	U	U	R	U
Neotrichia							R	
Ochrotrichia stylata				R				
Oxytheira		R						
Lepidostomitadae								
Lepidostoma			R					
Leptoceridae								
Nectopsyche		R	R	R				
Oecetis				R				
Limnephilidae								
Limnephilus	U			R	U			R
Odontoceridae								
Marilia flexuosa		R	U	R				
Philopotamidae								
Chimarra utahensis			U	U	U	R	R	C
Wormaldia				R		U		
Polycentropidae								
Cernotina			R					
Polycentropus halidus			R	U	U		R	U
Polyplectropus			R					R
Psychomyiidae								
Tinodes			R	U	U	R		
Turbellaria								
Tricladia								
Dugesia tigrina		C	U	U	U	R		U

Table 6. Distribution of HDMS invertebrates of Fossil Creek. These are “Species of Special Concern” as defined by the Fish and Wildlife Service. *Pyrgulopsis simplex* is also defined as “Sensitive” by the Bureau of Land Management and US Forest Service. See Tables 7 – 14 for numbers collected.

Scientific name	Common name	Distribution
Pyrgulopsis simplex	Fossil Springsnail	Springheads, above dam, above power plant
Metrichia nigritta	Microcaddisfly	All except isolated pools

Table 7. Average seasonal abundances of aquatic macroinvertebrates in pools of Fossil Creek per square meter. Numbers in parentheses are Standard Errors (n = 5). * indicates site not sampled. The final column is the average across all sampling periods.

Site	Aug-02	Dec-02	May-03	Oct-03	Jan-04	Average
Isolated Pools	54716 (49170)	5359 (1634)	13335 (3798)	*	*	25594 (17262)
Springhead	12420 (4306)	8991 (2713)	10261 (3442)	2642 (1169)	14046 (5994)	9672 (1773)
Above Dam	15977 (5095)	8661 (3590)	11811 (4431)	6858 (1498)	8966 (3491)	10455 (1689)
Below Dam	78359 (24362)	20599 (2222)	7239 (2118)	3988 (476)	13589 (3458)	24755 (7196)
Above Irving Power Plant	5944 (1576)	26314 (2046)	30812 (2987)	6350 (2074)	15011 (2807)	16886 (2288)
Below Irving Power Plant	2717 (794)	4622 (511)	3099 (1146)	2565 (479)	1880 (559)	2977 (355)
Below S.M. Wash	1473 (520)	17907 (4638)	5740 (271)	812 (262)	3023 (975)	5791 (1553)
Confluence	*	20650 (5876)	*	*	*	20650 (5876)

Table 8. Average seasonal abundances of aquatic macroinvertebrates in riffles of Fossil Creek per square meter. Number in parentheses are Standard Error (n = 5). * indicates site not sampled. The final column is the average across all sampling periods.

Site	Aug-02	Dec-02	May-03	Oct-03	Jan-04	Average
Springhead	6683 (4103)	4799 (1540)	3746 (807)	2104 (311)	1601 (334)	3787 (900)
Above Dam	828 (210)	1755 (314)	2494 (341)	376 (74)	1841 (364)	1459 (193)
Below Dam	8216 (2695)	12163 (4347)	8373 (2352)	2066 (766)	1383 (225)	6440 (1334)
Above Irving Power Plant	5604 (1846)	12533 (3289)	7483 (922)	8662 (4759)	8744 (4502)	8606 (1465)
Below Irving Power Plant	2457 (1359)	3920 (1068)	9966 (2238)	2407 (460)	3085 (586)	4256 (799)
Below S.M. Wash	1149 (536)	3472 (1045)	1198 (304)	559 (145)	1177 (376)	1511 (311)
Confluence	*	9304 (1486)	*	*	*	9304 (1486)

Table 9. Tally of invertebrates collected in Isolated Pools.

Year	Order	Lowest possible taxonomic group	Total
2002			
	Annelida		
		Eropellidae	1
		Tubificidae	177
	Coleoptera		
		nr. Agabetes	1
		Berosus	21
	Cladocera		
		Daphnia	60
	Diptera		
		Chironomidae	158
	Ephemeroptera		
		Callibaetis	10
	Gastropoda		
		Physella	10
		Gyralus	1
		Heliosoma	5
	Odonata		
		Pantala hymenaea	1
2003			
	Annelida		
		Enchantrachyidae	1
		Branchiura sowerbyi	21
		Tubificidae	17
	Bivalvia		
		Pisidium	3
	Coleoptera		
		Nebrioporous/Stictotarsus	5
	Diptera		
		Bezzia/Palpomyia	3
		Chironomidae	566
		Culiseta	2
	Ephemeroptera		
		Baetis	2
		Baetodes	1
		Callibaetis	2
		Caenis	3
	Gastropoda		
		Physella	3
	Trichoptera		
		Pupae	1

Table 10. Tally of invertebrates collected in Springhead reach

Year	Order	Lowest Possible Taxonomic Group	Total
2002			
	Amphipoda		
		Hyalella azteca	164
	Annelida		
		Enchantrachyidae	8
		Helobdella fusca	4
		Tubificidae	50
	Bivalvia		
		Pisidium	6
	Coleoptera		
		Helichus	1
		Nebrioporous/stictotarsus	2
		Dubriraphia	2
		Huleechis	612
		Macrelmis	4
	Diptera		
		Bezzia/Palpomyia	2
		Culicoides	6
		Chironomidae	549
		Dixella	1
		Paradelphomyia/Psuedolimnophora	1
	Ephemeroptera		
		Baetis	376
		Callibaetis	7
		Caenis	24
		Thraulodes	22
		Tricorythodes	393
	Gastropda		
		Pyrgulopsis simplex	77
		Physella	1
	Hemiptera		
		Ambrysus	6
	Lepidoptera		
		Petrophila	1
	Megaloptera		
		Corydalus	3
	Odonata		
		Anisoptera Early Instar	9
		Argia	5
		Zygoptera Early Instar	13
	Ostracoda		
		Ostracoda	87

Table 10 Continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Trichoptera		
		Helicopsyche mexicana	2804
		Hydropsyche	140
		Metrichia nigritta	130
		Oxytheira	1
		Nectopsyche	9
		Pupae	5
	Turbellaria		
		Dugesia tigrina	214
2003			
	Amphipoda		
		Hyalella azteca	89
	Annelida		
		Helobdella fusca	1
		Tubificidae	110
	Bivalvia		
		Pisidium	2
	Coleoptera		
		Helichus	5
		Postelichius	6
		Nebrioporous/Stictotarsus	4
		Heterelmis	2
		Hexacylloepus	1
		Huleechis	274
		Neoelmis	1
		Scirtes	1
	Diptera		
		Bezzia/Palpomyia	1
		Chironomidae	425
		Anopheles	1
		Simulium	1
		Caloparyphus	1
		Tipulidae	1
	Ephemeroptera		
		Baetis	906
		Callibaetis	3
		Caenis	4
		Thraulodes	20
		Tricorythodes	252
	Gastropoda		
		Pyrgulopsis simplex	9
	Hemiptera		
		Ambrysus occidentalis	5
	Hydracarina		
		Hydracarina	3

Table 10 Continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Lepidoptera		
		Petrophila	5
	Megaloptera		
		Corydalus	3
	Odonat		
		Gomphidae	2
		Argia	1
		Coenagrionidae	4
		Enallamga	1
	Ostracoda		
		Ostracoda	14
	Trichoptera		
		Helicopsyche mexicana	624
		Hydropsyche	25
		Metrichia nigritta	139
		Marilia flexuosa	1
	Turbellaria		
		Dugesia tigrina	61
2004			
	Amphipoda		
		Hyalella azteca	25
	Annelida		
		Helobdella fusca	1
		Tubificidae	205
	Bivalvia		
		Pisidium	3
	Coleoptera		
		Helichus	2
		Heterelmis	1
		Huleechis	114
		Macrelmis	3
	Copepoda		
		Copepoda	1
	Diptera		
		Bezzia/Palpomyia	4
		Culicoides	1
		Chironomidae	224
		Simulium	1
	Ephemeroptera		
		Baetis	28
		Caenis	2
		Thraulodes	29
		Tricorythodes	191
	Gastropoda		
		Physella	1

Table 10 Continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Hemiptera		
		Ambrysus occidentalis	6
		Rhagovelia brevicollis	2
	Lepidoptera		
		Petrophila	2
	Odonata		
		Hetareina	3
		Erpetogomphus	2
		Brechmorhaga mendax	1
		Argia	10
	Ostracoda		
		Ostracoda	56
	Trichoptera		
		Phylloicus	3
		Helicopsyche mexicana	280
		Hydropsyche	2
		Metrichia nigritta	1
	Turbellaria		
		Dugesia tigrina	33

Table 11. Tally of invertebrates collected in Above Dam reach.

Year	Order	Lowest Possible Taxonomic Group	Total
2002			
	Annelida		
		Enchantrachyidae	1
		Tubificidae	27
	Bivalvia		
		Pisidium	4
	Coleoptera		
		Helichus	1
		Dubriraphia	2
		Heterelmis	116
		Huleechis	64
		Macrelmis	13
		Psephenus	1
	Diptera		
		Bezzia/Palpomyia	5
		Culicoides	3
		Chironomidae	921
		Hemerodromia	1
		Simulium	63
		Euparyphus	1
	Ephemeroptera		
		Baetis	175
		Caenis	75
		Thraulodes	187
		Leptohypes	3
		Tricorythodes	31
	Gastropoda		
		Ferrissia	2
		Pyrgulopsis simplex	2
	Hemiptera		
		Ambrysus	3
		Rhagovelia	2
	Lepidoptera		
		Petrophila	14
	Megaloptera		
		Corydalus	8
	Odonata		
		Anisoptera Early Instar	3
		Hetareina	1
		Erpetogomphus	1
		Argia	1
		Zygoptera Early Instar	8
	Ostracoda		
		Ostracoda	140

Table 11 Continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Trichoptera		
		Phylloicus	1
		Protoptila	2
		Chuematopsyche	21
		Hydropsyche	56
		Luecotrichia	16
		Metrichia negritta	62
		Lepidostoma	1
		Nectopsyche	4
		Marilia flexuosa	1
		Chimarra utahensis	5
		Polycentropus halidus	3
		Polyplectropus	3
	Turbellaria		
		Dugesia tigrina	19
2003			
	Annelida		
		Enchantrachyidae	3
		Megadrilli	1
		Branchiura sowerbyi	2
		Tubificidae	40
	Bivalvia		
		Pisidium	13
	Coleoptera		
		Heterelmis	25
		Huleechis	139
		Macrelmis	40
		Tropisternus	1
		Psephenus	1
	Diptera		
		Bezzia/Palpomyia	1
		Chironomidae	493
		Simulium	84
	Ephemeroptera		
		Baetis	425
		Caenis	8
		Thraulodes	117
		Tricorythodes	69
	Gastropoda		
		Pyrgulopsis simplex	5
		Physella	2
		Gyralus	1
	Hemiptera		
		Ambrysus occidentalis	2
	Hydracarina		
		Hydracarina	3

Table 11 Continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Lepidoptera		
		Petrophila	32
	Megaloptera		
		Corydalus	4
	Odonata		
		Argia	10
	Ostracoda		
		Ostracoda	132
	Trichoptera		
		Culoptila	1
		Hydropsyche	107
		Metrichia	149
		Marilia flexuosa	4
		Chimarra utahensis	3
		Cernotina	1
		Polycentropus halidus	3
		Pupae	3
	Turbellaria		
		Dugesia tigrina	38
2004			
	Annelida		
		Tubificidae	80
	Bivalvia		
		Pisidium	4
	Coleoptera		
		Dubriraphia	3
		Heterelmis	45
		Huleechis	136
		Macrelmis	15
	Diptera		
		Bezzia/Palpomyia	14
		Chironomidae	399
		Simulium	3
	Ephemeroptera		
		Baetis	26
		Caenis	8
		Thraulodes	280
		Tricorythodes	27
	Hemiptera		
		Ambrysus occidentalis	1
		Rhagovelia distincta	3
	Lepidoptera		
		Petrophila	2
	Megaloptera		
		Corydalus texanus	1

Table 11 Continued

Year	Order	Lowest Possible Taxonomic Group	Total
	Odonata		
		Argia	10
	Trichoptera		
		Culoptila	1
		Hydropsyche	46
		Metrichia negritta	20
		Marilia flexuosa	2
		Tinodes	1
		Pupae	1

Table 12 Tally of invertebrates collected in Below Dam reach.

Year	Order	Lowest Possible Taxonomic Groups	Total
2002			
	Annelida		
		Enchantrachyidae	13
		Tubificidae	54
	Bivalvia		
		Pisidium	7
	Coleoptera		
		Postelichius	9
		nr. Agabetes	2
		Nebrioporous/Stictotarsus	5
		Dubriraphia	1
		Heterelmis	3
		Huleechis	33
		Tropisternus	1
	Diptera		
		Bezzia/Palpomyia	31
		Culicoides	17
		Chironomidae	6824
		Anopheles	1
		Dixa	2
		Dixella	1
		Chelifera	4
		Hemerodromia	12
		Pericoma	1
		Simulium	3368
		Caloparyphus	26
		Euparyphus	1
		Dicranota	20
		Tipula	7
	Ephemeroptera		
		Baetis	847
		Baetodes	139
		Callibaetis	4
		Caenis	157
		Thraulodes	4
		Tricorythodes	138
	Gastropoda		
		Physella	6
	Hemiptera		
		Metrobates	1
		Hebrus	2
		Microvelia	2
		Rhagovelia distincta	18
	Lepidoptera		
		Petrophila	18
	Megaloptera		
		Corydalus texanus	6

Table 12 Continued.

Year	Order	Lowest Possible Taxonomic Groups	Total
	Odonata		
		Anisoptera Early Instar	8
		Hetareina	1
		Argia	81
		Zygoptera Early Instar	9
	Ostracoda		
		Ostracoda	384
	Plecoptera		
		Isoperla	2
	Trichoptera		
		Helicopsyche mexicanus	5
		Chuematopsyche	38
		Hydropsyche	5
		Hydroptila	40
		Luecotrichia limpia	2
		Metrichia nigritta	13
		Nectopsyche	9
		Oecetis	5
		Chimarra utahensis	40
		Wormaldia	12
		Polycentropus halidus	101
		Tinodes	25
		Pupae	1
	Turbellaria		
		Dugesia tigrina	13
2003			
	Annelida		
		Tubificidae	19
	Coleoptera		
		Postelichius	1
		Nebrioporous/Stictotarsus	4
		Huleechis	22
		Macrelmis	2
		Haliplus	2
	Copepoda		
		Copepoda	1
	Diptera		
		Bezzia/Palpomyia	9
		Culicoides	3
		Chironomidae	2300
		Chelifera	1
		Limnophora	2
		Simulium	2154
		Caloparyphus	1
		Euparyphus	4
		Tabanus	1

Table 12 Continued.

Year	Order	Lowest Possible Taxonomic Groups	Total
	Ephemeroptera		
		Baetis	191
		Baetodes	5
		Callibaetis	2
		Thraulodes	3
		Tricorythodes	25
	Hemiptera		
		Belostoma	3
		Hebrus	2
		Ambrysus occidentalis	1
		Rhagovelia distincta	2
	Hydracarina		
		Hydracarina	7
	Lepidoptera		
		Petrophila	2
	Megaloptera		
		Corydalus texanus	4
	Odonata		
		Argia	16
		Coenagrionidae	4
	Ostracoda		
		Ostracoda	7
	Trichoptera		
		Hydropsyche	72
		Hydroptila	1
		Nectopsyche	1
		Marilia flexuosa	1
		Chimarra utahensis	1
		Tinodes	16
	Turbellaria		
		Dugesia tigrina	11
2004			
	Annelida		
		Tubificidae	49
	Bivaliva		
		Pisidium	2
	Coleoptera		
		Huleechis	12
	Diptera		
		Bezzia/Palpomyia	9
		Culicoides	4
		Chironomidae	746
		Chelifera	15
		Hemerodromia	4
		Simulium	138
		Caloparyphus	11

Table 12 Continued.

Year	Order	Lowest Possible Taxonomic Groups	Total
		Dicranota	12
	Ephemeroptera		
		Baetis	44
		Caenis	20
		Thraulodes	2
		Tricorythodes	10
	Gastropoda		
		Gyralus	1
	Lepidoptera		
		Petrophila	9
	Megaloptera		
		Corydalus texanus	3
	Odonat		
		Hetareina	1
		Erpetogomphus	2
		Argia	2
	Trichoptera		
		Phylloicus	5
		Hydropsyche	6
		Hydroptila	1
		Limnephilus	1
		Chimarra utahensis	1
		Tinodes	14
	Turbellaria		
		Dugesia tigrina	2

Table 13 Tally of invertebrates collected in Above Irving Power Plant reach.

Year	Order	Lowest Possible Taxonomic Group	Total
2002			
	Annelida		
		Enchantrachyidae	26
		Branchiura sowerbyi	77
		Tubificidae	135
	Bivalvia		
		Pisidium	2
	Coleoptera		
		Helichus	4
		Postelichius	34
		Heterelmis	13
		Hexacylloepus	19
		Huleechis	106
		Macrelmis	2
		Neocylloepus	38
		Neoelmis	2
		Lutrochus	1
	Diptera		
		Bezzia/Palpomyia	4
		Culicoides	28
		Chironomidae	4808
		Chelifera	13
		Hemerodromia	4
		Limnophora	5
		Pericoma	1
		Simulium	1675
		Caloparyphus	8
		Euparyphus	1
		Tabanus	2
		Antocha	1
		Dicranota	18
	Ephemeroptera		
		Baetis	1320
		Baetodes	144
		Callibaetis	4
		Caenis	16
		Thraulodes	1
		Leptohypes	4
		Tricorythodes	38
	Gastropoda		
		Physella	7
	Hemiptera		
		Microvelia	1
		Rhagovelia distincta	8
	Lepidoptera		
		Petrophila	30

Table 13 continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Megaloptera		
		Corydalus texanus	29
	Odonata		
		Anisoptera Early Instar	37
		Hetareina	15
		Brechmorhaga mendax	13
		Argia	31
		Zygoptera Early Instar	8
	Ostracoda		
		Ostracoda	17
	Trichoptera		
		Protoptila	1
		Chuematopsyche	16
		Hydropsyche	91
		Hydroptila	10
		Metrichia nigritta	24
		Limnephilus	7
		Chimarra utahensis	38
		Polycentropus halidus	22
		Tinodes	7
		Pupae	8
	Turbellaria		
		Dugesia tigrina	25
2003			
	Annelida		
		Enchantrachyidae	2
		Branchiura sowerbyi	41
		Tubificidae	178
	Coleoptera		
		Postelichius	2
		Heterelmis	1
		Hexacylloepus	10
		Huleechis	103
		Neocylloepus	3
	Diptera		
		Bezzia/Palpomyia	11
		Culicoides	19
		Chironomidae	1948
		Clinocera	1
		Simulium	3195
		Caloparyphus	1
		Euparyphus	1
		Tabanus	4
		Antocha	1

Table 13 continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Ephemeroptera		
		Baetis	2537
		Baetodes	93
		Callibaetis	10
		Caenis	37
		Serratella micheneri	1
		Thraulodes	5
		Leptohypes	1
	Gastropoda		
		Pyrgulopsis simplex	1
	Hemiptera		
		Rhagovelia distincta	3
	Hydracarina		
		Hydracarina	4
	Lepidoptera		
		Petrophila	20
	Megaloptera		
		Corydalus texanus	15
	Odonata		
		Gomphidae	6
		Brechmorhaga mendax	4
		Argia	6
		Coenagrionidae	9
	Ostracoda		
		Ostracoda	7
	Plecoptera		
		Isoperla	1
	Trichoptera		
		Hydropsyche	29
		Hydroptila	4
		Mayatrichia	18
		Metrichia nigritta	7
		Chimarra utahensis	8
		Polycentropus halidus	1
		Tinodes	7
	Turbellaria		
		Dugesia tigrina	7
2004			
	Annelida		
		Tubificidae	26
	Coleoptera		
		Helichus	1
		Huleechis	10
		Berosus	2
		Lutrochus	2
	Copepoda		

Table 13 continued.

Year	Order	Lowest Possible Taxonomic Group	Total
		Copepoda	1
	Diptera		
		Bezzia/Palpomyia	2
		Culicoides	8
		Chironomidae	968
		Chelifera	1
		Simulium	2443
		Tabanus	1
		Dicranota	11
		Tipula	2
	Ephemeroptera		
		Baetis	671
		Baetodes	30
		Callibaetis	30
		Caenis	12
		Tricorythodes	1
	Hemiptera		
		Rhagovelia distincta	1
	Lepidoptera		
		Petrophila	2
	Megaloptera		
		Corydalus texanus	4
	Odonata		
		Erpetogomphus	2
		Argia	17
		Enallamga .	1
	Ostracoda		
		Ostracoda	1
	Plecoptera		
		Isoperla	4
	Trichoptera		
		Hydropsyche	8
		Hydroptila	12
		Metrichia nigritta	5
		Limnephilus	17
		Chimarra utahensis	16
		Tinodes	4
		Pupae	3

Table 14. Tally of invertebrates collected in Below Irving Power Plant reach.

Year	Order	Lowest Possible Taxonomic Group	Total
2002			
	Amphipoda		
		Hyalella azteca	1
	Annelida		
		Enchantrachyidae	44
		Branchiura sowerbyi	13
		Tubificidae	106
	Bivalvia		
		Corbicula fluminea	1
		Pisidium	1
	Coleoptera		
		Helichus	1
		Postelichius	5
		Heterelmis	2
		Huleechis	35
		Neocylloepus	1
	Diptera		
		Bezzia/Palpomyia	3
		Culicoides	54
		Forciomyia	1
		Chironomidae	1517
		Chelifera	2
		Hemerodromia	9
		Pericoma	7
		Simulium	566
		Caloparyphus	14
		Euparyphus	1
		Tabanus	2
		Tipula	10
	Ephemeroptera		
		Baetis	166
		Baetodes	33
		Callibaetis	1
		Rhagovelia	2
	Lepidoptera		
		Petrophila	40
	Megaloptera		
		Corydalus texanus	3
	Odonata		
		Anisoptera Early Instar	9
		Hetareina	2
		Argia immunda	7
		Argia plana	1
		Enallamga	2
		Zygoptera Early Instar	11
	Ostracoda		
		Ostracoda	1

Table 14 continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Trichoptera		
		Hydropsyche	215
		Metrichia nigritta	14
		Chimarra utahensis	3
		Wormaldia	91
		Pupae	1
	Turbellaria		
		Dugesia tigrina	15
2003			
	Annelida		
		Branchiura sowerbyi	43
		Tubificidae	14
	Bivalvia		
		Pisidium	1
	Coleoptera		
		Dubriraphia	1
		Heterelmis	1
		Huleechis	43
	Diptera		
		Bezzia/Palpomyia	1
		Culicoides	1
		Chironomidae	742
		Hemerodromia	1
		Simulium	3099
		Euparyphus	1
	Ephemeroptera		
		Baetis	586
		Baetodes	118
		Callibaetis	1
	Gastropoda		
		Physella	2
		Rhagovelia distincta	3
	Hydracarina		
		Hydracarina	3
	Lepidoptera		
		Petrophila	104
	Megaloptera		
		Corydalus texanus	5
	Ostracoda		
		Ostracoda	2
	Trichoptera		
		Hydropsyche	704
		Metrichia nigritta	27
		Wormaldia	1
		Tinodes	5

Table 14 continued.

Year	Order	Lowest Possible Taxonomic Group	Total
2004			
	Annelida		
		Branchiura sowerbyi	12
		Tubificidae	7
	Coleoptera		
		Curclionidae	1
		Huleechis	19
	Diptera		
		Culicoides	1
		Chironomidae	249
		Simulium	399
	Ephemeroptera		
		Baetis	157
		Baetodes	10
		Tricorythodes	1
	Hemiptera		
		Rhagovelia distincta	1
	Lepidoptera		
		Petrophila	22
	Odonata		
		Argia	1
	Trichoptera		
		Hydropsyche	275
		Wormaldia	1

Table 15 Tally for invertebrates collected in Below Sallie Mae Wash reach.

Year	Order	Lowest Possible Taxonomic Group	Total
2002			
	Annelida		
		Enchantrachyidae	7
		Branchiura sowerbyi	79
		Tubificidae	45
	Bivalvia		
		Pisidium	2
	Coleoptera		
		Postelichius	5
		Huleechis	161
		Macrelmis	1
		Lutrochus	70
		Terrestrial Beetle	2
	Collembola		
		Collembola	1
	Diptera		
		Bezzia/Palpomyia	4
		Culicoides	4
		Chironomidae	1049
		Chelifera	3
		Hemerodromia	23
		Simulium	130
		Caloparyphus	1
		Tabanus	1
		Dipteran Pupae	1
	Ephemeroptera		
		Baetis	555
		Baetodes	405
		Callibaetis	3
		Cameleobaetidius	1
		Leptohypes	1
		Tricorythodes	2
	Gastropoda		
		Fossaria	1
	Hemiptera		
		Gelastocoris rotundatus	1
		Rhagovelia distincta	5
	Lepidoptera		
		Petrophila	92
	Megaloptera		
		Corydalus texanus	3
	Odonata		
		Anisoptera Early Instar	6
		Zygoptera Early Instar	1
	Ostracoda		
		Ostracoda	1

Table 15 continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Plecoptera		
		Isoperla	3
	Trichoptera		
		Chuematopsyche	10
		Hydropsyche	12
		Smicridea	12
		Luecotrichia	1
		Mayatrichia	4
		Metrichia nigritta	7
		Neotrichia	2
		Chimarra utahensis	5
		Polycentropus halidus	1
2003			
	Annelida		
		Tubificidae	31
	Bivalvia		
		Corbicula fluminea	2
	Coleoptera		
		Curclionidae	1
		Huleechis	14
		Neoelmis	2
		Laccobius	1
		Lutrochus	3
	Diptera		
		Bezzia/Palpomyia	4
		Culicoides	2
		Chironomidae	354
		Chelifera	1
		Simulium	138
	Ephemeroptera		
		Baetis	344
		Baetodes	56
		Callibaetis	1
		Tricorythodes	1
	Hemiptera		
		Gerris	1
	Hydracarina		
		Hydracarina	3
	Lepidoptera		
		Petrophila	3
	Megaloptera		
		Corydalus texanus	1
	Odonata		
		Gomphidae	2
		Brechmorhaga mendax	3
		Coenagrionidae	1

Table 15 continued.

Year	Order	Lowest Possible Taxonomic Group	Total
	Plecoptera		
		Isoperla	1
	Trichoptera		
		Hydropsyche	33
		Hydroptila	3
		Mayatrichia	1
		Metrichia nigritta	1
		Chimarra utahensis	1
2004			
	Annelida		
		Tubificidae	29
	Coleoptera		
		Huleechis	9
		Lutrochus	9
	Diptera		
		Culicoides	5
		Chironomidae	143
		Hemerodromia	1
		Simulium	2
		Caloparyphus	1
		Tabanus	1
		Dicranota	1
	Ephemeroptera		
		Baetis	376
		Baetodes	17
	Gastropoda		
		Physella	1
	Odonata		
		Anisoptera Early Instar	1
		Hetareina	1
	Ostracoda		
		Ostracoda	1
	Plecoptera		
		Isoperla	7
	Trichoptera		
		Hydropsyche	16

Table 16. Tally of invertebrates collect in Confluence reach.

Year	Order	Lowest Possible Taxonomic Group	Total
2003			
	Amphipoda		
		Crangonyx	7
	Annelida		
		Tubificidae	59
	Bivalvia		
		Corbicula fluminea	1
		Pisidium	37
	Coleoptera		
		Postelichius	1
		Dubriraphia	5
		Huleechis	108
		Lutrochus	2
		Psephenus	8
	Diptera		
		Bezzia/Palpomyia	6
		Culicoides	44
		Chironomidae	2430
		Chelifera	31
		Hemerodromia	5
		Simulium	1250
		Tabanus	2
	Ephemeroptera		
		Baetis	121
		Baetodes	26
		Caenis	2
		Ephemerella inermis	6
	Gastropoda		
		Physella	2
	Lepidoptera		
		Petrophila	65
	Megaloptera		
		Corydalus texanus	3
	Odonata		
		Hetareina	4
		Brechmorhaga mendax	13
		Zygoptera Early Instar	8
	Ostracoda		
		Ostracoda	6
	Plecoptera		
		Isoperla	12
	Trichoptera		
		Culoptila	1
		Chuematopsyche	88
		Hydropsyche	55
		Metrichia nigritta	2
		Limnephilus	1

Table 16 continued.

Year	Order	Lowest Possible Taxonomic Group	Total
		Chimarra utahensis	354
		Polycentropus halidus	2
		Polyplectropus	1
	Turbellaria		
		Dugesia tigrina	21

Table 17. Aquatic macroinvertebrate diversity measurements for Fossil Creek.

	Species Richness	Evenness	Shannon's Diversity	Simpson's Diversity
Isolated Pools	49	0.500	0.624	0.320
Springs	51	0.617	1.243	0.580
Above Dam	55	0.662	1.399	0.624
Below Dam	77	0.432	0.905	0.423
Above Power Plant	63	0.397	0.865	0.390
Below Power Plant	69	0.597	0.935	0.476
Below S.M. Wash	46	0.628	1.027	0.501
Near Verde	50	0.439	1.081	0.482

Table 18. MRPP pairwise comparisons for August 2002 riffle invertebrate assemblages. Overall MRPP significance was $p = 0.00001$, $A = 0.1144$. Top numbers are the p value, and the number in the parentheses is the effect size, A. Only the Above Dam – Springhead comparison is not significant. (n = 5 for each site)

	Above Dam	Above Power Plant	Below Dam	Below Power Plant	Below S.M. wash	Spring-head
Above Dam	-	0.001 (0.09)	0.001 (0.179)	0.003 (0.075)	0.002 (0.073)	0.087 (0.025)
Above Power Plant		-	0.003 (0.087)	0.016 (0.04)	0.001 (0.052)	0.001 (0.065)
Below Dam			-	0.002 (0.107)	0.001 (0.105)	0.001 (0.149)
Below Power Plant				-	0.021 (0.034)	0.004 (0.039)
Below S.M. wash					-	0.001 (0.040)
Spring-head						-

Table 19. MRPP pairwise comparisons for August 2002 pool invertebrate assemblages. Overall MRPP significance was $p = 0.000001$, $A = 0.1514$. Top numbers are the p value, and the number in the parentheses is the effect size, A. (n = 5 for each site)

	Isolated Pool High	Isolated Pool Low	Springhead	Above Dam	Below Dam	Above Power Plant	Below Power Plant	Below S.M. Wash
Isolated Pool High	-	0.026 (0.166)	0.006 (0.15)	0.007 (0.131)	0.005 (0.162)	0.006 (0.096)	0.613 (-0.012)	0.007 (0.087)
Isolated Pool Low		-	0.004 (0.143)	0.003 (0.132)	0.004 (0.145)	0.004 (0.084)	0.005 (0.189)	0.006 (0.111)
Springhead			-	0.005 (0.071)	0.001 (0.099)	0.002 (0.075)	0.002 (0.16)	0.004 (0.095)
Above Dam				-	0.099 (0.024)	0.116 (0.022)	0.003 (0.135)	0.005 (0.077)
Below Dam					-	0.002 (0.083)	0.002 (0.178)	0.002 (0.128)
Above Power Plant						-	0.024 (0.063)	0.312 (0.008)
Below Power Plant							-	0.011 (0.069)
Below S.M. Wash								-

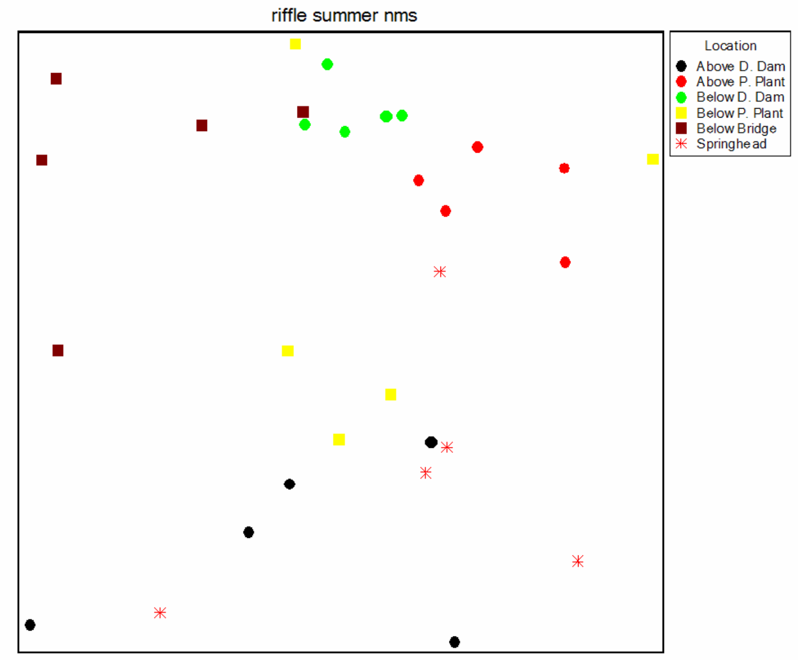


Figure 9. NMDS ordination of August 2002 riffle invertebrate assemblages. For clarity, only 2 dimensions of a 3 dimensional solution are shown. Note that in the figure legend, Below Bridge is synonymous with Below Sallie Mae Wash.

Table 20. Substrate and depth for samples collected in pool habitats. See text for specifics on how data were collected and definitions of substrate types. Substrate types are presented as percent occurrence in our sampling location, over all sampling periods (Percent occurrence = number of times substrate found/total number of samples). Total number of samples is given in parentheses after sample site. Note that substrate types are not mutually exclusive (e.g. it is possible to have silts overlaying a layer of bedrock), so that percent totals can sum to be greater than 100.

	Substrate Type (%)										
	Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Algae	Detritus	Moss	Travertine	Average Depth (cm)
Isolated Pools (15)	7	0	0	7	7	86	0	7	0	0	41
Springhead (30)	47	0	30	13	7	10	3	7	0	0	70
Above Dam (30)	3	0	20	10	7	73	3	3	3	0	80
Below Dam (25)	8	16	24	20	0	36	8	4	0	0	26
Above Irving Power Plant (25)	20	0	0	28	24	52	12	4	0	0	27
Below Irving Power Plant (30)	17	0	0	13	27	80	0	3	0	0	92
Below Sallie Mae Wash (30)	0	0	3	13	67	63	0	3	0	0	35
Confluence (5)	0	0	0	100	0	0	0	0	0	0	26

Table 21. Substrate, depth and current velocity for samples collected in riffle habitats. See text for specifics on how data were collected and definitions of substrate types. Substrate types are presented as percent occurrence in our sampling location. (Percent occurrence = number of times substrate found/total number of samples). Total number of samples is given in parentheses after sample site. Note that substrate types are not mutually exclusive (e.g. it is possible to have silts overlaying a layer of bedrock), so that percent totals can sum to be greater than 100.

	Substrate Type (%)												
	Bedrock	Boulder	Cobble	Gravel	Sand	Silt	Algae	Detritus	Moss	Travertine	Roots	Average Depth (cm)	Average Velocity (m/s)
Springhead (30)	23	7	77	7	0	3	0	0	7	0	0	26	0.41
Above Dam (30)	0	0	100	7	0	0	0	0	0	0	7	44	1.03
Below Dam (25)	0	0	0	0	0	0	0	0	0	100	0	3	0.27
Above Irving Power Plant (25)	28	4	56	24	0	0	4	4	0	20	0	7	0.39
Below Irving Power Plant (30)	0	0	0	0	0	0	0	0	0	100	0	2	0.71
Below Sallie Mae Wash (30)	0	10	90	7	3	0	0	0	0	57	0	17	0.47
Confluence (5)	0	20	100	20	0	0	0	0	0	0	0	15	0.48

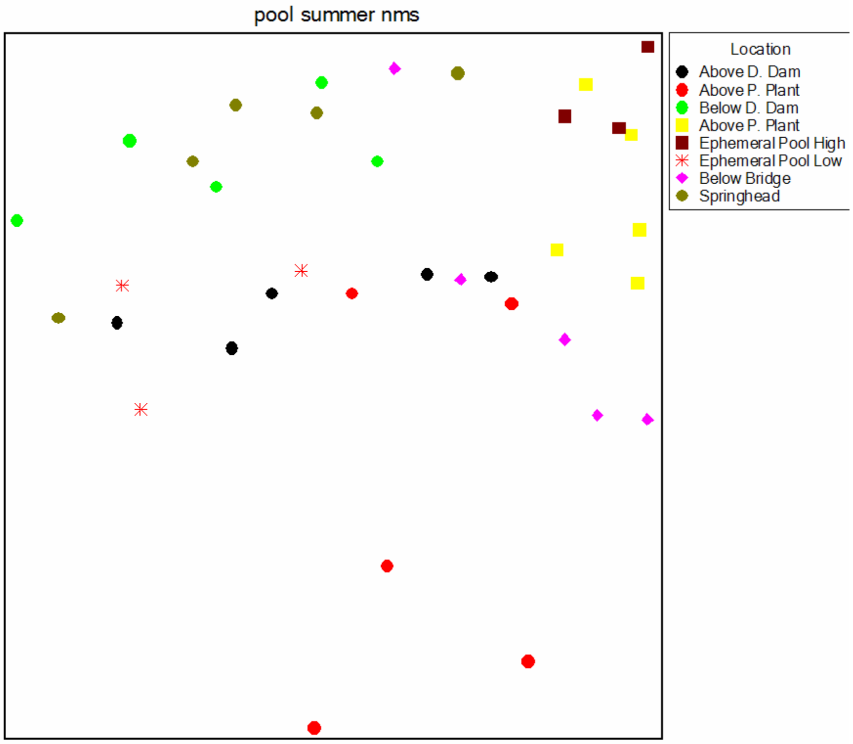


Figure 10. NMDS ordination of August 2002 pool invertebrate assemblages. For clarity, only 2 dimensions of a 3 dimensional solution are shown. Note that in the figure legend, Below Bridge is synonymous with Below Sallie Mae Wash.

Chapter IV. Exotic Crayfish

Crayfish are notorious for invading freshwater ecosystems and initiating aggressive and complex interactions with native species. Arizona has no native crayfish, but two exotic species were introduced by the Arizona Game and Fish Department and the U.S. Fish and Wildlife Service in the 1970s to control aquatic weeds, for sports fish forage and as bait, *Orconectes virilis* and *Procambarus clarkii*. *Orconectes virilis* was first observed in Fossil Creek during the 1990s. Currently, crayfish are migrating upstream from the Verde River but have not yet established stable populations near the dam, although individual crayfish have been found directly below the dam on a few occasions.

Preliminary evidence in 2003, from trapping, indicated that the crayfish were migrating up-steam from the Verde River, although the population had not yet established close to the dam. Seasonal sampling revealed that crayfish are active from March through November. During the winter they are dormant in most parts of the stream but remain active in areas where their densities are very high (near the confluence with the Verde River). We conducted a series of mark-recapture studies in 2004 designed to provide a measure of crayfish densities that can be repeated in subsequent years. The density of adult crayfish in Fossil Creek ranges from 0.05 crayfish/sq. meter at a distance 4.7 km downstream of the dam to 1.17 crayfish/sq. meter at a distance of 18.5 km downstream (Figure 11). The biomass of crayfish at the furthest downstream site was 4.4 grams/sq. meter.

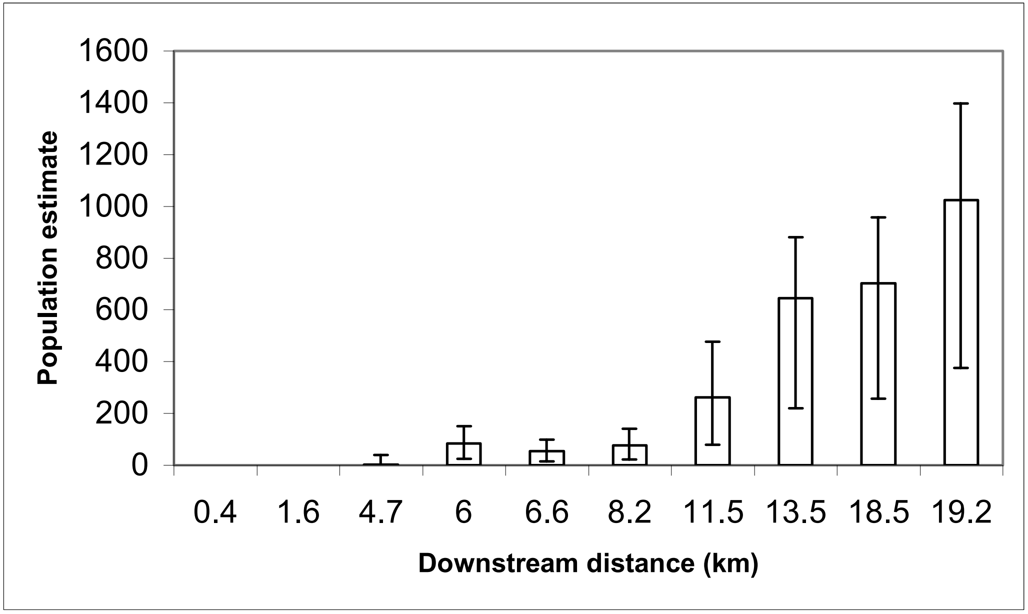


Figure 11. Crayfish population size (# per reach) as a function of distance downstream from the Fossil Creek Springs. Samples collected by Ken Adams.

The crayfish in Fossil Creek eat a wide range of food materials, including leaf litter, algae, and macroinvertebrates, but they prefer macroinvertebrates, a primary food source for native fish. This indicates that the crayfish have the potential to compete with native fish populations for food, and can negatively affect primary producers and consumers.

Exotic crayfish will not be affected by the Antimycin treatment. Ironically, crayfish farmers in the southeastern U.S. use Antimycin A to rid their ponds of bass because it does not harm crayfish. Stable isotope and bass gut analyses indicate that exotic bass prey upon crayfish and compete with them for macroinvertebrates. Bass may thus be controlling crayfish densities, such that removal of bass will release crayfish from competition and predation (see Foodweb Structure, section VI).

There are no approved chemical methods for eradicating crayfish, so the only way of removing them is through manual trapping and netting, which is labor-intensive and will reduce, but likely will not eliminate, crayfish. Jim Walters, in collaboration with the USFWS, has been trapping crayfish from a portion of the creek. We are beginning to collaborate with Mr. Walters to evaluate how his removal efforts are effecting crayfish populations.

Management Recommendations and Further Research

Although crayfish populations are expanding in Fossil Creek, they are still lower than in many southwestern streams. Because of the potential for crayfish to respond positively to restoration, we recommend that managers closely monitor crayfish in Fossil Creek. We also recommend that manual trapping be continued. We will be studying the efficacy of different trapping techniques in Fossil Creek.

Chapter V: Water Quality

The Fossil Creek drainage is one of the largest tributary drainages of the Verde River. Maximum elevation ranges from 2213 m along the Mogollon Rim to 777 m at the confluence with the Verde River. The only perennial source of flow with in the drainage originates at Fossil Springs at an elevation of 1304 m. However, the drainage above the springs does contain pools which remain wetted throughout the entire year, as evidenced by standing water during the summer drought of 2002.

Fossil Springs is a series of at least 5 major springs that combine to provide approximately 1.29 m^3s^{-1} flow to the stream (Monroe 2002). The spring waters are saturated with CO_2 and calcium carbonate $CaCO_3$. As CO_2 out gasses from the stream water, $CaCO_3$ is precipitated in the form of travertine. However since the 1908 the stream has been diverted near it's source for hydropower production at Irving and Childs. During periods of base flow only about 0.0006 m^3s^{-1} is in the stream between the diversion dam and Irving power plant while the remainders is diverted through a flume to Irving. At Irving the stream is once again diverted through a conduit to the Childs powerplant. However, 0.06 – 0.15 m^3s^{-1} is allowed back into the streambed from this point to the confluence with the Verde River. During periods of spate any flow in excess of 1.29 m^3s^{-1} is allowed back into the channel at the diversion dam. Flow from the flume can also be routed from the flume back into the stream approximately 500 m upstream from the Irving powerplant during periods when the Irving powerplant is not operating. Irving powerplant also has the ability to capture streamflow (up to ~ 1.14 m^3s^{-1}) and divert it back into the conduit to Childs powerplant. The various diversion strategies in combination with the unique water quality from Fossil Springs provide an interesting backdrop for water quality patterns in the present day stream.

The purpose of this research was to document basic water quality patterns and their variability in conjunction with other ongoing ecological studies of Fossil Creek. This information will provide a baseline to compare with water quality changes caused by flow restoration and dam removal activities. It will also provide basic information to managers planning and implementing restoration activities.

Methods

Water quality surveys were conducted during the same sampling periods as benthic and fisheries sampling. Specifically we sampled water quality parameters during August 2002, December 2002, April 2003, September 2003, December 2003, May 2004 and October 2004.

A Hydrolab Surveyor 4™ was used to take basic water quality parameters at each sample period. These included: temperature (°C), dissolved oxygen (mg l^{-1}), specific conductivity (µS cm^{-1}), salinity (ppt) and total dissolved solids (g l^{-1}) and pH. For the first year of the study we also collected major cations and anions, (Ca, Mg, K, Cl, Na), sulfate (SO_4) as well as basic nutrients (NH_3, NO_3-N, PO_4). Samples were collected as 3 replicates and mean data were used. Water quality analysis was carried out at Northern Arizona University Instrument Lab using a Technicon 3 autoanalyzer and a Dionex ion chromotograph. During the summer of 2002 we conducted a longitudinal sample for dissolved CO_2 and alkalinity (mg $CaCO_3$ l^{-1}).

Results

Water quality data are reported in Tables 22 –29. The major influences on water quality of Fossil Creek are the spring source and diversion by the hydroelectric facility. Interestingly most water quality variables changed directionally with the distance from the springs up until the Irving Power Plant. At this point water which had been diverted from the springs is returned to the river. The water directly below the Power Plant is more similar to water closer to the springs in some variables including temperature and CO_2 concentrations. We noted a consistent pattern of change with increasing distance from the springs. Although sites differed based on their location from the springs and from the Irving Power plant there was little variation in most parameters within a site (Tables 22 – 29). Samples were intentionally gathered during base flow to study seasonal variation in water quality that is separate from the high flow events that occur primarily during snow melt and summer monsoons.

The two variables that differ most dramatically among sites and are likely dictating differences in decomposition and algal accrual are temperature and dissolved CO_2 (Marks et al. In press, see appendix). Water temperature is an important driver of aquatic ecology. Fish and invertebrate growth rates as well as decomposition rates are a function of temperature. (Sweeny 1984, Allan 1995). The area of Fossil Creek immediately below the springs is characterized by warm, stable temperatures. Temperature varies seasonally at the downstream sites with the exception of the area immediately below the Irving Power Plant. Water released from the flume has a very short travel time from the springs and does not interact much with the atmosphere, moderating temperature variation. This 'thermal refuge" provides a small area where biological activity remains high compared to the rest of the stream during cold winter months.

The increase in flow to the stream below the Irving Power plant also drives travertine formation. Currently there are two major reaches of travertine formation in Fossil Creek. The first is immediately below the diversion dam and the second is immediately below the outlet to the Irving plant where water from the flume is released back to the stream. High levels of dissolved CO_2 at the springs and above the diversion dam keep $CaCO_3$ in solution and travertine deposition is minimal in these sites. However, the reduced flow below the diversion dam outgases CO_2 quickly and travertine formation is evident for a short reach below the dam. The amount of travertine deposited in this reach is limited since the total volume of water released below the dam and consequently the total volume of $CaCO_3$ is small. Diverted water does not completely outgas CO_2 during travel in the flume and water released back into Fossil Creek at Irving still has the potential to carry dissolved $CaCO_3$. Additionally there are minimal surface areas for travertine formation in the flume although APS employees report that there is deposition on available surfaces. Once in the streambed, CO_2 levels begin to equilibrate with the atmosphere depositing travertine in the form of travertine dams. The amount of travertine deposited and the length of this travertine forming reach (~1.5 km) is proportional to the larger volume of water released below the powerplant (Malusa 2003). Travertine formation has important implications for stream morphology, detritus retention, fish habitat and invertebrate communities (Marks et al., In Press, see appendix). It is likely that the area below the Irving Power Plant will no longer have active travertine formation once flows are restored (Malusa 2003). However, this short reach provides insight into how travertine formation will affect the ecosystem of the upper portion of the stream after flow restoration.

Water that is currently diverted into the flume will flow over the dam. Geomorphologists predict that this will re-establish a ten kilometer reach of the stream characterized by large travertine dams and associated pools (Malusa 2003 and Marks et al, in press).

Table 22. Water quality parameters and collection dates for “Isolated Pool” Site in Fossil Creek. For site locations, see Figure 2.

Site	Parameter	8/13/02	12/5/02	5/6/03	mean
Isolated Pool	Temperature (°C)	22.73	5.23	17.35	15.10
	Dissolved O_2 % sat.	51.47	93.00	106.27	83.58
	Dissolved O_2 (mg l^{-1})	3.46	9.23	7.87	6.85
	Dissolved solids (g l^{-1})	0.28	0.28	0.23	0.27
	pH	7.45	8.07	8.21	7.91
	Conductance (□S cm^{-1})	441.63	442.17	363.90	415.90
	NH_3 (mg l^{-1})	0.24	0.02	0.03	0.14
	PO_4 (mg l^{-1})	0.02	0.55	0.07	0.30
	Salinity (ppt)	0.22	0.22	0.18	0.21
	NO_3-N (mg l^{-1})	0.04	0.55	<0.02	0.35
	Mg (mg l^{-1})	24.77	22.13	20.30	22.40
	Ca (mg l^{-1})	55.33	51.33	44.67	50.44
	Na (mg l^{-1})	7.97	4.93	5.47	6.12
	K (mg l^{-1})	6.40	1.00	1.40	2.93
	Cl (mg l^{-1})	3.57	4.43	5.97	4.66
	SO_4 (mg l^{-1})	2.70	2.03	1.73	2.16
	CO_2 (mg l^{-1})		12.67		12.67
	Alkalinity ($CaCO_3$ mg l^{-1})				
	NTU		4.30		4.30

Table 23. Water quality parameters and collection dates for “Springhead” Site in Fossil Creek. For site locations, see Figure 2.

Site	Parameter	8/13/02	12/4/02	5/6/03	10/16/03	1/31/04	Mean
Springhead	Temperature (°C)	21.56	21.20	21.31	21.22	20.90	21.24
	Dissolved O_2 % sat.	84.90	97.83	94.67	71.30	66.23	82.99
	Dissolved O_2 (mg l^{-1})	5.83	6.78	6.46	5.83	4.57	5.90
	Dissolved solids (g l^{-1})	0.33	0.48	0.45	0.46	0.46	0.44
	pH	6.78	6.86	7.17	7.27	7.44	7.10
	Conductance (□S cm^{-1})	521.17	756.17	702.03	713.17	710.93	680.69
	NH_3 (mg l^{-1})	0.03	<0.02	<0.02	0.02	< 0.02	0.03
	PO_4 (mg l^{-1})	0.04	0.05	0.08	0.16	0.09	0.08
	Salinity (ppt)	0.40	0.39	0.36	0.37	0.37	0.38
	NO_3-N (mg l^{-1})	0.11	0.11	0.10	0.12	0.15	0.12
	Mg (mg l^{-1})	40.27	34.33	35.43			36.68
	Ca (mg l^{-1})	100.20	85.87	89.30			91.79
	Na (mg l^{-1})	11.63	9.93	10.60			10.72
	K (mg l^{-1})	2.00	1.40	1.70			1.70
	Cl (mg l^{-1})	6.21	8.40	8.60			7.74
	SO_4 (mg l^{-1})	24.67	23.33	23.93			23.98
	CO_2 (mg l^{-1})		48.33				48.33
	Alkalinity ($CaCO_3$ mg l^{-1})						
	NTU		1.93		0.38		1.15

Table 24. Water quality parameters and collection dates for “Above Dam” Site in Fossil Creek. For site locations, see Figure 2.

Site	Parameter	8/14/02	12/4/02	5/703	10/15/03	1/31/04	mean
Above Dam	Temperature (°C)	21.55	21.12	21.13	21.34	21.00	21.23
	Dissolved O_2 % sat.	100.43	107.30	101.03	78.67	70.73	91.63
	Dissolved O_2 (mg l^{-1})	6.90	7.46	6.91	6.42	4.88	6.51
	Dissolved solids (g l^{-1})	0.49	0.48	0.45	0.45	0.45	0.46
	pH	7.02	7.06	7.45	7.17	7.50	7.24
	Conductance (□S cm^{-1})	771.10	749.80	698.73	704.73	705.57	725.99
	NH_3 (mg l^{-1})	0.03	<0.02	0.03	0.02	< 0.02	0.03
	PO_4 (mg l^{-1})	0.04	0.04	0.09	0.02	0.08	0.06
	Salinity (ppt)	0.40	0.39	0.36	0.36	0.36	0.37
	NO_3-N (mg l^{-1})	0.14	0.11	0.12	0.12	0.10	0.14
	Mg (mg l^{-1})	41.93	31.27	35.37			36.19
	Ca (mg l^{-1})	109.33	77.13	88.93			91.80
	Na (mg l^{-1})	12.17	9.07	10.60			10.61
	K (mg l^{-1})	2.20	7.87	1.67			3.91
	Cl (mg l^{-1})	6.25	8.13	8.87			7.75
	SO_4 (mg l^{-1})	24.74	24.47	24.60			24.60
	CO_2 (mg l^{-1})		40.00				40.00
	Alkalinity ($CaCO_3$ mg l^{-1})		132.17				132.17
	NTU		2.32		0.38		1.35

Table 25. Water quality parameters and collection dates for “Below Dam” Site in Fossil Creek. For site locations, see Figure 2.

Site	Parameter	8/14/02	12/4/02	5/7/03	10/15/03	1/31/04	2/29/04	3/29/04	4/30/04	Mean
Below Dam	Temperature (°C)	23.00	13.53	17.16	19.44	13.78	18.39	19.42	19.09	17.65
	Dissolved O_2 % sat.	94.00	105.13	111.60	83.30	61.13			124.20	93.11
	Dissolved O_2 (mg l^{-1})	6.32	8.55	8.29	7.00	4.91			8.83	7.13
	Dissolved solids (g l^{-1})	0.44	0.43	0.40	0.41	0.41	0.42	0.40	0.39	0.42
	pH	7.89	8.11	8.15	7.79	8.51	8.45	8.12	8.18	8.12
	Conductance (□S cm^{-1})	459.73	674.13	625.73	642.60	639.90	654.80	619.60	613.60	611.91
	NH_3 (mg l^{-1})	0.05	<0.02	0.03	0.04	0.05				0.04
	PO_4 (mg l^{-1})	0.03	0.03	0.04	0.04	0.07				0.04
	Salinity (ppt)	0.36	0.35	0.32	0.33	0.33	0.34	0.32	0.31	0.34
	NO_3-N (mg l^{-1})	0.08		0.03	0.07	0.10	0.10	0.04	0.06	0.07
	Mg (mg l^{-1})	41.80	35.13	35.47						37.47
	Ca (mg l^{-1})	85.20	74.40	75.53						78.38
	Na (mg l^{-1})	12.10	10.07	10.73						10.97
	K (mg l^{-1})	2.20	1.40	1.60						1.73
	Cl (mg l^{-1})	5.73	8.27	8.03						7.34
	SO_4 (mg l^{-1})	23.79	20.63	22.80						22.41
	CO_2 (mg l^{-1})		23.33							23.33
	Alkalinity ($CaCO_3$ mg l^{-1})									
	NTU		1.39		0.93					1.16

Table 26. Water quality parameters and collection dates for “Above Power Plant” Site in Fossil Creek. For site locations, see Figure 2.

Site	Parameter	8/15/02	12/5/02	5/6/03	10/16/03	1/30/04	2/29/04	3/29/04	4/30/04	mean
Above power plant	Temperature (°C)	22.07	8.10	14.77	17.92	6.81	9.09	16.94	17.35	13.64
	Dissolved O_2 % sat.	98.07	103.77	102.60	87.57	60.37			118.20	92.21
	Dissolved O_2 (mg l^{-1})	6.67	9.57	8.01	7.61	5.70			8.75	7.59
	Dissolved solids (g l^{-1})	0.40	0.41	0.34	0.35	0.36	0.35	0.35	0.35	0.37
	pH	7.92	8.05	8.38	7.97	8.36	8.62	8.37	8.38	8.20
	Conductance (□S cm^{-1})	627.63	644.10	524.73	549.47	556.50	548.10	541.30	548.50	573.77
	NH_3 (mg l^{-1})	0.03	<0.02	0.02	0.03	<0.02				0.03
	PO_4 (mg l^{-1})	0.08	0.05	0.08	0.10	0.07				0.07
	Salinity (ppt)	0.32	0.33	0.27	0.28	0.28	0.28	0.28	0.28	0.29
	NO_3-N (mg l^{-1})	0.02	0.12	<0.02	0.04	0.05	<0.02	<0.02	<0.02	0.06
	Mg (mg l^{-1})	50.60	35.73	35.03						40.46
	Ca (mg l^{-1})	56.90	47.67	48.13						50.90
	Na (mg l^{-1})	16.90	12.60	13.60						14.37
	K (mg l^{-1})	2.90	1.73	2.10						2.24
	Cl (mg l^{-1})	7.15	10.80	9.33						9.09
	SO_4 (mg l^{-1})	20.11	14.60	11.30						15.34
	CO_2 (mg l^{-1})		18.00							18.00
	Alkalinity ($CaCO_3$ mg l^{-1})									
	NTU		2.27		2.92					2.60

Table 27. Water quality parameters and collection dates for “Below Power Plant” Site in Fossil Creek. For site locations, see Figure 2.

Site	Parameter	8/15/02	12/5/02	5/6/03	10/16/03	1/30/04	2/29/04	3/29/04	Mean
Below power plant	Temperature (°C)	23.04	20.04	20.27	22.01	20.12	18.68	21.34	20.92
	Dissolved O_2 % sat.	110.63	114.27	100.03	95.53	58.20			95.73
	Dissolved O_2 (mg l^{-1})	7.39	8.09	6.98	7.25	4.12			6.77
	Dissolved solids (g l^{-1})	0.48	0.47	0.43	0.44	0.44	0.43	0.44	0.45
	pH	7.86	7.81	8.15	7.85	8.29	8.35	8.12	8.04
	Conductance (□S cm^{-1})	749.30	730.50	679.27	688.80	687.23	674.60	689.10	703.12
	NH_3 (mg l^{-1})	0.03	<0.02	0.03	0.03	<0.02			0.03
	PO_4 (mg l^{-1})	0.05	0.04	0.10	0.12	0.08			0.08
	Salinity (ppt)	0.39	0.38	0.35	0.35	0.35	0.35	0.36	0.36
	NO_3-N (mg l^{-1})	0.09	0.46	0.11	0.12	0.10	0.10	0.11	0.16
	Mg (mg l^{-1})	41.90	34.87	35.00					37.26
	Ca (mg l^{-1})	100.83	84.93	85.80					90.52
	Na (mg l^{-1})	12.17	10.53	10.83					11.18
	K (mg l^{-1})	2.13	1.53	1.63					1.77
	Cl (mg l^{-1})	5.67	9.07	8.13					7.62
	SO_4 (mg l^{-1})	24.39	24.60	23.47					24.15
	CO_2 (mg l^{-1})		19.33						19.33
	Alkalinity ($CaCO_3$ mg l^{-1})								
	NTU		2.57		0.83				1.70

Table 28. Water quality parameters and collection dates for “Below Sallie Mae Wash” Site in Fossil Creek. For site locations, see Figure 2.

Site	Parameter	8/12/02	12/5/02	10/16/03	1/30/04	5/6/03	mean
Below Sallie Mae Wash	Temperature (°C)	22.76	12.46	17.67	9.48	19.17	15.88
	Dissolved O_2 % sat.	110.03	113.07	92.33	61.17	111.50	97.62
	Dissolved O_2 (mg l^{-1})	7.39	9.43	8.05	5.44	7.95	7.65
	Dissolved solids (g l^{-1})	0.33	0.36	0.32	0.33	0.32	0.33
	pH	8.33	8.23	8.32	8.43	8.50	8.37
	Conductance (□S cm^{-1})	514.03	563.90	503.00	522.08	500.90	520.86
	NH_3 (mg l^{-1})	0.02	<0.02	0.02	0.03	<0.02	0.03
	PO_4 (mg l^{-1})	0.04	<0.02	0.02	0.03	0.03	0.03
	Salinity (ppt)	0.26	0.29	0.25	0.27	0.25	0.26
	NO_3-N (mg l^{-1})	<0.02		0.03	0.02	<0.02	0.02
	Mg (mg l^{-1})	41.17	36.33			35.43	37.64
	Ca (mg l^{-1})	22.73	51.20			46.53	40.16
	Na (mg l^{-1})	12.93	10.73			11.23	11.63
	K (mg l^{-1})	2.20	1.47			1.70	1.79
	Cl (mg l^{-1})	6.54	8.47			8.13	7.71
	SO_4 (mg l^{-1})	23.79	24.40			24.00	24.06
	CO_2 (mg l^{-1})		30.67				30.67
	Alkalinity ($CaCO_3$ mg l^{-1})						
	NTU		1.53	1.89			1.71

Table 29. Water quality parameters for "Fossil Creek Confluence" Site in Fossil Creek for 17 January 2003. For site locations, see Figure 2.

Site	Parameter	1/17/03
Fossil Ck confluence	Temperature (°C)	8.81
	Dissolved O_2 % sat.	101.23
	Dissolved O_2 (mg l^{-1})	9.18
	Dissolved solids (g l^{-1})	0.33
	pH	8.15
	Conductance (□S cm^{-1})	511.83
	NH_3 (mg l^{-1})	0.03
	PO_4 (mg l^{-1})	0.03
	Salinity (ppt)	0.26
	NO_3-N (mg l^{-1})	0.03
	Mg (mg l^{-1})	35.87
	Ca (mg l^{-1})	40.07
	Na (mg l^{-1})	13.07
	K (mg l^{-1})	5.00
	Cl (mg l^{-1})	9.00
	SO_4 (mg l^{-1})	23.23
	CO_2 (mg l^{-1})	20.83
	Alkalinity ($CaCO_3$ mg l^{-1})	
	NTU	1.16

Chapter VI. Foodweb Structure Using Stable Isotopes

Stable isotopes are a useful tool for delineating food web interactions. By serving as energy tracers, stable isotopes can detect competitive and predator/prey interactions between species. Isotope studies, which integrate energy flow among trophic levels over time, provide a more complete and temporally integrated picture of trophic structure than do field diet studies which provide only a snapshot of what an organism ingested immediately prior to being sampled. On a practical note, stable isotopes can be analyzed from a small fin clip of a fish without sacrificing the animal for diet studies. We used stable isotopes to determine: 1) whether the diets of exotic and native species overlap, 2) if trophic position of native fish changes in the presence of exotic fish (Green Sunfish and Small-mouth Bass) are preying on native fish and invertebrates, 3) compare food web topology in different reaches of Fossil Creek that vary in flow and the presence of exotic species. This will help managers determine which exotic species are likely to be most harmful to native species.

Stable isotopes of different elements provide distinct information. Carbon (C) and Hydrogen (H) indicate the base of the food web (e.g. algae vs. detritus vs. submerged aquatic vegetation) at any higher trophic level, because the isotopic composition of carbon changes very little with trophic level. By contrast, the isotopic composition of nitrogen (N) becomes enriched with each transfer up the food chain, and thus provides a quantitative marker for the functional trophic level of an organism. Thus species with similar isotope values for C, N, and H have strongly overlapping diets and are likely to be competing for food. Similar isotope values for C and H but different N values indicate predator/prey relationships. In contrast, species with different isotope values are likely using different food resources. Identifying pairs of exotic and native species with similar isotope values will help focus research and management actions on species that are most likely to be affecting one another.

Methods

We collected samples for stable isotope analysis in five study sites (Springhead, Above dam, Below dam, Above Irving, Below Irving, and Below Sallie Mae Wash in August 2002. In addition we re-sampled the Below Sallie Mae Wash site in November 2003 to increase the sample size at this site. Samples were oven dried at 70 ºC. Algae and detritus were ground using a Wiley Mill. Fish fins and macroinvertebrate samples were ground using liquid N_2 and a mortar and pestle. Subsamples were weighed and packed into tin capsules for stable isotope analysis at the Colorado Plateau Stable Isotope Laboratory, using continuous-flow stable-isotope ratio mass spectrometry. Values for Carbon and Nitrogen are presented in Table 30**.** Invertebrate samples were identified and categorized into functional feeding groups. In a few instances there were no data available on certain genera or species and these taxa are reported separately. Figure 12 presents food web diagrams that combine data into three major reaches 1) Above the dam combines samples collected at the spring head and directly above the dam, 2) The dewatered reach combines samples collected at the below dam and above Irving reach, and 3) The below Sallie Mae Wash site. These three reaches represent the three areas in the river with distinct flow regimes (full flow, dewatered seepage flow, and partial return of flow. Data collected at the below Irving site were not combined with the below Sallie Mae Wash site because the high carbonate levels at this site resulted in unique carbon isotopes reflected in the food base samples. In contrast carbon isotopes of food base samples taken from sites that were combined were not statistically different as determined by Analysis of Variance. Because we could not combine the Below Power Plant samples with the Sallie Mae Wash samples we re-sampled the Sallie Mae Wash site in November 2003 to collect adequate sample sizes of all abundant taxa in each group.

The $\delta^{13}C$ values revealed that there were not large differences in $\delta^{13}C$ between algae and detritus in this system. This is a common problem in stable isotope studies. This lead our research team to collaborate with stable isotope experts to develop a novel technique using stable isotopes to differentiate allochthanous from autochthanous food sources. Although not funded directly by the Heritage grant we include some of these results below (Trend 4). **This is a major contribution to the field of stable isotopes and food web studies and will be published in a high profile journal.**

Results

Our results reveal four major trends in food web structure. ***Trend 1) Exotic fish are displacing native fish as top predators.*** Where both bass and sunfish are present, the trophic positions (determined by $\delta^{15}N$) of key native fishes are reduced, and macroinvertebrates exhibit a lower range in both $\delta^{13}C$ and $\delta^{15}N$, suggesting increased resource competition in the disturbed habitat (Figure 12). ***Trend 2) Reduced flow compresses macroinvertebrate functional feeding groups. In pristine streams macroinvertebrates feed on different resources where different functional feeding groups rely on different sources of energy***. A larger variety of resources generally sustains more diverse communities. The food web topology generated from stable isotope data above the dam show distinct functional feeding groups. In contrast there is little differentiation between functional feeding groups in the two reaches below the dam where flow is reduced. Note the scale of the axis is similar in all three diagrams. The actual values of $\delta^{13}C$ in the food base differ among the sites, which simply means that the values of $\delta^{13}C$ differ in either dissolved CO_2 or CO_2 in the atmosphere. This is typical of spring fed streams and does not affect the food web analysis. ***Trend 3) Bass control crayfish through predation and competition.*** Stable isotope and bass gut contents reveal that exotic bass eat crayfish. Both bass and crayfish also consume macroinvertebrates. Thus, removal of bass could undermine restoration by inadvertently causing crayfish populations to explode (Figure 13). In contrast, if roundtail chub populations quickly rebound then they may replace bass as top predators controlling crayfish populations. Monitoring crayfish densities following restoration will allow us to test how crayfish respond to exotic fish removal and return of full flows. As part of a complimentary research program we will be testing the efficacy of different trap types on crayfish populations. As part of a concurrent study we showed that roughly a third of the bass had crayfish in their guts and that crayfish constituted 17% of bass gut contents by weight (Adams et al. in review).

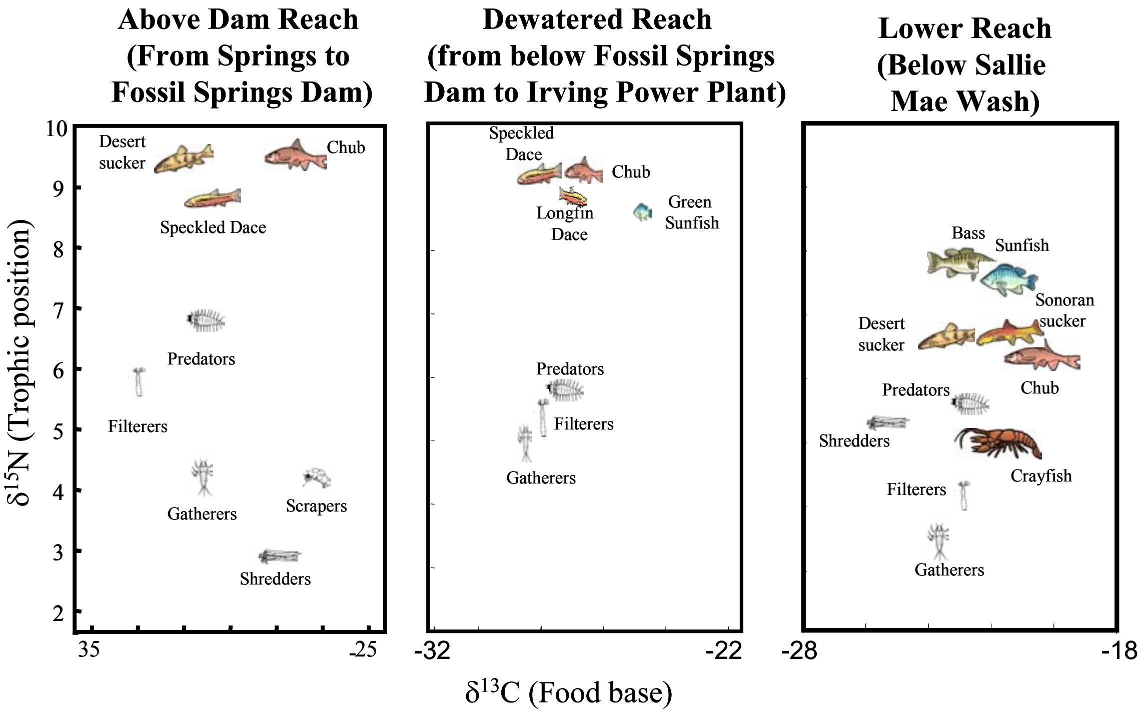


Figure 12. Stable isotope food webs for three reaches in Fossil Creek before decommissioning. Data were collected in fall of 2002 and 2003. X-axis shows δ^{13}C values vs. Vienna-Pee Dee Belemnite, and Y-axis show δ^{15}N vs. Vienna Air. Organisms with similar δ^{13}C values rely on similar food bases (e.g. algae vs. detritus), and organisms with similar $\delta\ ^{15}$N values occupy the same trophic levels. In the Lower Reach, native chub and suckers are replaced by exotic bass and sunfish as top predators. Macroinvertebrates occupy distinct niches above the dam but overlap in resource use below the dam, as shown by substantial compression of macroinvertebrate δ^{13}C values below the dam (1.45‰) compared to above the dam (5.98‰), suggesting a narrower food base caused by habitat degradation from reduce flow. This provides the first opportunity to test if fish can regain trophic position following an exotic fish removal.

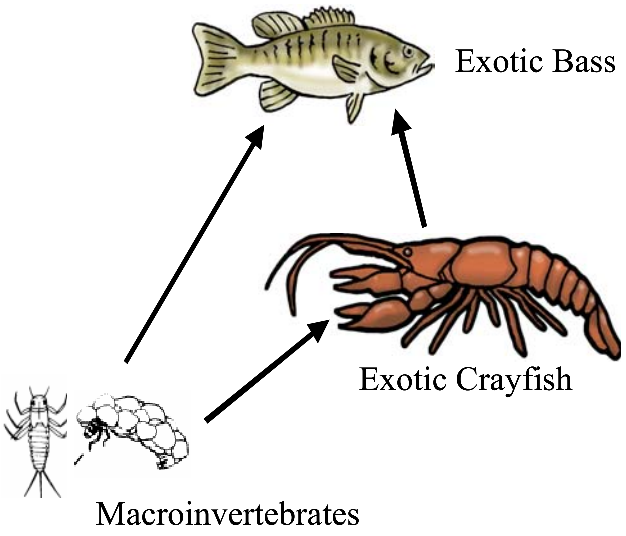


Figure 13. Stable isotope and diet studies suggest that exotic bass compete with and prey upon exotic crayfish. Removal of bass could release crayfish, undermining restoration of the native food web.

Trend 3) Both fish and macroinvertebrates depend more on detritus below the dam. Healthy streams are fueled by both algal productivity and leaf litter detritus that falls into the stream. Both food sources are important, because they provide different nutrients for fish and macroinvertebrates and are available during different seasons. We used two source mixing models for stable isotopes of carbon and hydrogen to calculate the relative importance of algae versus detritus above and below the dam. These results show that fish and macroinvertebrates are depending more on detritus below the dam where flow diversion reduces habitat for algae (Figure 14). The extensive riparian habitats above and below the dam likely provide comparable detrital inputs. This is one of the reasons why fish densities are markedly lower below the dam than above it.

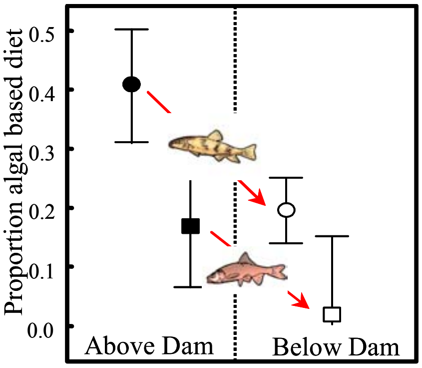


Figure 14. Hydrogen stable isotope analysis (δ D) indicates that the dam reduces the reliance of native suckers and chub on algal-based production. Values are means and 95% confidence intervals determined using the Isosource model (Phillips and Gregg 2001). Mean δ D values were -275‰ for algae and -145‰ for leaf litter.

Discussion

The stable isotope research is novel and important because: 1) By documenting food web structure prior to restoration of full flows and removal of exotic fish we have generated powerful baseline data to test how food web structure responds to restoration. To our knowledge this is the only study that generates sufficient baseline data on food web structure prior to a large restoration project to test whether restoration has the intended effects. By repeating this analysis after return of full flows – Fossil Creek will serve as a national case study for understanding how entire food webs respond to restoration. All other restoration studies rely on responses of individual taxa and do not show how species interactions change. 2) The data reveal a shift in trophic position of native fish in the presence of exotic fish. Although exotic fish are implicated for out competing native fish, this is one of the first studies to show that native fish are forced to feed lower on the food chain in the presence of exotic fish. 3) We use stable isotopes to show compression of macroinvertebrate functional feeding groups in a disturbed stream. Although the importance of macroinvertebrates to aquatic food webs is well documented it is difficult to evaluate their feeding habitats because their small size precludes gut analysis. Our study shows how a century of disturbance can change the food web position of these important taxa. 4) We present a novel use of stable isotopes for differentiating between algal and detrital resources and use this to show how a century of disturbance reduces algal biomass and forces higher trophic levels to rely more on detritus.

The food web analysis provides a mechanistic explanation for the decline in native species below the dam. Although exotic fish are often implicated as replacing native fish as top predators, the stable isotope analysis demonstrates a quantifiable shift in trophic structure caused by exotic species. Our analysis also shows how exotic crayfish are functioning in the food web. Because bass have already been eradicated from a large section of the stream it is important that crayfish are monitored closely. Manual removal may be the only option for keeping crayfish densities low before native fish are able to re-establish larger populations in the treated region below the dam. The best case scenario is that native chub replace bass as top predators, controlling crayfish populations. The coexistence of bass and crayfish in southwestern streams is not unique. Most of the other tributaries in the upper Verde Watershed have substantial populations of both these exotic species. The successful removal of exotic fish from Fossil Creek will open the door to other eradication programs in Arizona. Monitoring crayfish responses in Fossil Creek, where we have already established baseline conditions, will enable managers to evaluate the indirect effects of chemical treatment on crayfish.

The shift towards a more detrital based food web below the dam is probably attributed to poor habitat conditions where flow has been reduced. This is consistent with our observations of a more lush and diverse algal assemblage above the dam. Reduced flow limits the availability of this important resource contributing to lower fish densities below the dam. By repeating the stable isotope analysis post restoration we will be able to test whether food web structure can be restored by reversing the major disturbances.

Table 30. Stable Isotope Values for Fish, Food base, and Macroinvertebrates collected during surveys of Fossil Creek for different locations and sampling periods.

Above Dam **August 2002**		**$\delta^{13}C$**			**$\delta^{15}N$**	
Taxon	***Mean***	***n***	***SE***	***Mean***	***n***	***SE***
Fish						
Longfin Dace	-30.52	24	0.26	8.66	24	
Mountain Desert Sucker	-30.27	5	0.69	8.70	5	0.13
Roundtail chub	-28.58	28	0.32	9.13	28	0.20
Speckled dace	-30.39	5	0.33	8.63	5	0.15
						0.23
Food base						
Cyanobacteria	-37.60	2	0.32	3.29	2	
Course Particulate Organic Matter	-27.62	4	0.60	0.72	4	0.01
Epiphytes/mixed periphyton	-32.75	5	2.08	4.26	5	1.15
Fine Particulate Organic Matter	-27.99	2	1.89	2.33	2	0.44
Chlorophyta/green filaments	-34.85	8	1.47	3.49	8	1.84
Macrophytes	-34.56	3	1.38	4.63	3	0.35
Bryophytes	-34.12	6	0.67	3.95	6	0.30
						0.44
Macroinvertebrates						
Collector/Filterers	-33.21	4	1.30	5.79	4	
Collector/Gatherers	-30.77	18	0.91	4.42	18	0.34
Leptoceridae (caddisfly)	-36.71	3	0.94	5.11	3	0.18
Predators	-30.29	30	0.34	6.59	30	0.34
Scrapers	-33.91	6	2.13	4.41	6	0.17
Shredders	-28.45	7	1.27	3.28	7	0.43
Thraulodes - mayfly	-32.76	3	0.87	4.51	3	0.72
						0.61

Table 30 continued.

Below Power Plant **August 2002** ***Taxon***	$\delta^{13}C$ ***Mean***	***n***	***SE***	$\delta^{15}N$ ***Mean***	***n***	***SE***
Fish						
Green Sunfish	-25.88	2	1.28	8.88	2	0.50
Longfin Dace	-26.12	1	0.00	8.88	1	0.00
Roundtail Chub	-25.95	9	0.79	8.75	9	0.21
Food base						
Course Particulate Organic Matter	-28.03	2	0.36	1.10	2	1.85
Epiphytes/Mixed Periphyton	-28.36	2	0.03	2.75	3	0.10
Chlorophyta/green filaments	-24.66	2	0.90	3.76	3	0.39
Macrophytes	-26.28	2	1.29	3.37	3	1.33
Macroinvertebrates						
Collector/Filterers	-27.14	2	0.15	5.57	2	0.69
Collector/Gatherers	-24.60	5	1.39	5.01	5	0.52
Predators	-25.95	8	0.54	6.11	8	0.26
Scraper	-25.80	2	1.11	5.69	2	0.88
Shredder	-37.55	1	0.00	2.86	1	0.00
Eldmidae - beetle	-25.50	1	0.00	1.79	1	0.00
Piercer/grazer	-25.21	1	0.00	2.86	1	0.00

Table 30 continued.

Below Sallie Mae Wash **August 2002**		$\delta^{13}C$			$\delta^{15}N$	
Taxon	***Mean***	***n***	***SE***	***Mean***	***n***	***SE***
Fish						
Mountain Desert Sucker	-23.22	4	0.24	4.76	4	0.14
Roundtail Chub	-21.90	1		6.88	1	
Food base						
Course Particulate Organic Matter	-28.25	5	0.21	-1.16	5	0.23
Epiphytes/Mixed Periphyton	-22.62	5	1.27	0.25	5	0.26
Fine Particulate Organic Matter	-24.02	2	1.16	0.12	3	0.12
Bryophytes	-29.32	1		1.33	1	
Macroinvertebrates						
Collector/Filterers	-22.27	1		1.85	1	
Collector/Gatherers	-26.07	6	2.03	2.76	6	0.56
Predators	-24.81	2	0.58	3.38	2	0.23
Elmidae - beetle	-20.19	1		2.48	1	
Scraper	-22.16	3	1.90	1.63	3	0.74
November 2003						
Crayfish	-22.10	10	0.21	4.89	10	0.14
Macroinvertebrates						
Midges	-26.77	2	1.50	4.98	2	0.20
Collector/Gatherers	-23.90	8	1.25	3.92	8	0.89
Corbicula	-23.72	3	0.46	4.42	3	0.10
Dryopidae - beetle	-24.84	1		2.01	1	
Filters	-22.25	4	0.90	4.13	4	0.25
Grazers	-23.73	5	1.06	4.05	5	0.78
Lutrochus - beetle	-25.24	3	0.27	2.54	3	0.40
Oligochaetes	-22.26	4	0.61	2.62	4	0.40
Predators	-23.36	16	0.30	5.57	16	0.18
Fish						
Sonora sucker	-21.23	9	0.23	6.55	9	0.23
Round tail chub	-20.96	2	2.24	6.41	2	0.06
Green Sunfish	-21.87	11	0.14	7.54	11	0.16
Small mouth bass	-21.99	10	0.19	8.44	10	0.18
Small mouth bass <150	-22.93	20	0.14	7.43	20	0.12
Mountain Desert Sucker	-23.32	9	0.15	6.83	9	0.18

Table 30 continued (Below Sallie Mae Wash, November 2003 continued).

Food Base						
Cyanobacteria	-28.44	3	0.21	5.59	3	0.45
Cladophora glomerata - Chlorophyta	-30.03	3	0.24	2.72	3	0.62
Course Particulate Organic Matter	-29.30	3	0.03	-1.68	3	0.52
Diatom mat/mixed periphyton	-20.75	3	0.17	4.19	3	0.59
Fine Particulate Organic Matter	-23.95	3	0.29	2.39	3	0.37
Chlorophyta/ *Zygnematales*/green filaments	-25.61	3	0.09	3.74	3	0.30
Vaucheria sp.	-30.87	3	0.10	2.34	3	0.57

Table 30 continued.

Dewatered Zone **August 2002** ***Taxon***	δ^{13}C ***Mean***	 ***n***	 ***SE***	δ^{15}N ***Mean***	 ***n***	 ***SE***
Fish						
Speckled dace	-27.98	2	1.06	9.18	2	0.02
Roundtail Chub	-26.99	25	0.12	9.26	25	0.05
Longfin dace	-26.96	26	0.14	8.85	26	0.15
Green sunfish	-24.77	13	0.21	8.60	13	0.17
Macroinvertebrates						
Predators	-27.51	19	0.28	5.85	16	0.22
Collector/Filterers	-27.76	8	0.30	5.49	8	0.30
Collector/Gatherers	-28.62	16	0.97	4.89	16	0.30
Food base						
Bryophytes	-31.78	3	0.11	2.15	3	0.03
Cladophora glomerata - Chlorophyta	-30.27	3	0.10	3.08	3	0.06
Course Particulate Organic Matter	-27.33	12	0.26	-0.26	12	0.32
Epiphytes/Mixed Periphyton	-24.49	6	0.83	3.21	6	0.48
Fine Particulate Organic Matter	-20.09	6	0.28	1.45	6	1.01
Chlorophyta/green filaments	-24.56	6	0.50	3.53	6	0.96
Macrophytes	-28.84	3	0.02	5.22	3	0.06
Vaucheria sp.	-34.52	6	0.26	3.93	6	0.36

Chapter VII: Benthic Biomass – The distribution of organic matter

Overview

The distribution of different pools of organic matter in the benthic or bottom substrates of streams serves as the food base for fish and other mobile organisms that feed on the substrates. Organic matter can be divided into three major categories autochthonous material that is produced in the stream and includes algae, bryophytes (moss and liverworts), and aquatic macrophytes, 2) Detritus which is non-living organic material (leaf litter, sticks etc.) and 3) macroinvertebrates. By comparing the amount of organic material at different sites and across seasons we can glean which habitats are most productive. Benthic productivity is important to many stream organisms including fish and tadpoles. In addition, benthic productivity can be important for riparian species such as frogs, lizards, birds and spiders that feed on aquatic insects when they emerge from the stream.

Methods

We categorized food/energy resources into 3 categories: 1) Algae – autochthonous energy, including moss and aquatic macrophytes; 2) Detritus, or Coarse Particulate Organic Matter (CPOM) – allocthtonous energy, including leaves, twigs, pine cones, etc. and 3) Aquatic invertebrates – primary consumers and secondary consumers. Collections were done using Surber and Core samples for riffles and pools, respectively as described in chapter 3.

Samples were sorted into the 3 above categories in the laboratory. We measured Ash Free Dry Mass (AFDM) using standard methods (Greenburg et al. 1992, Minshall 1996). Samples were dried in crucibles at 70 degrees Celsius until they attained a constant weight and were then ashed in a furnace at 650 degrees Celsius for 1 hour, and reweighed. The difference between the two weights was recorded as the AFDM, and is a direct measure of the amount of organic material in a sample. Weights were standardized to grams per square meter.

Statistical analysis was performed using JMP-IN data analysis software (version 4.02). Overall differences in categories as a function of date/site/habitat type were done on transformed (log10 + 1) data using a Multivariate Analysis of Variance (MANOVA). If significant, standard Analysis of Variance was performed on individual response variables (Algae AFDM, Detritus AFDM, Invertebrate AFDM) using site, date, and habitat types as factors. Note that although all analyses were performed on transformed data to meet required assumptions, any figures use raw gram per meter square data to illustrate true differences.

Results

The MANOVA showed significant overall effect (Exact F = 25.24, p <0.0001, df = 12, 324) indicating that there are at least one significant difference in the model. To elucidate where the difference(s) were, we performed one-way ANOVAs where graphs of the data indicated there may be differences. In doing this, several patterns emerged. First, pools had higher resources of all 3 categories of food/energy resources (Figure 15a-c). Second, the highest levels of algae were in the area above the diversion dam (including the springs) (Figure 16a). Third, Algal resources tended to be highest in spring/summer sampling periods than fall/winter periods (Figure 16b). Finally, invertebrate biomasses were the highest in the fall and winter months (Figure 16c). Averages biomass of all categories sampled in all seasons, locations and habitat types are presented in Table 31.

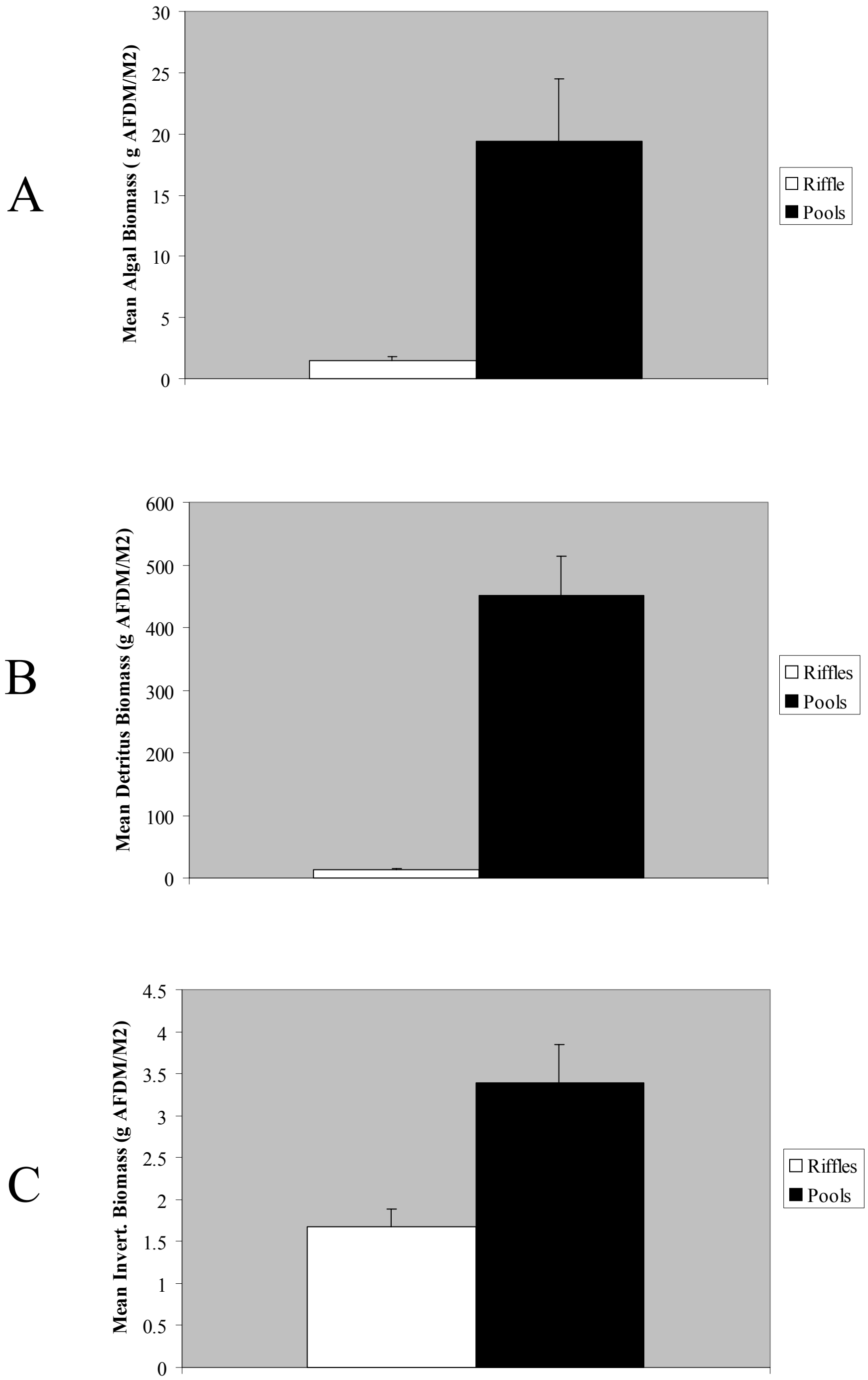


Figure 15. Mean values of the three categories of organic material (algae, detritus, and invertebrates) are all higher in pools than riffles.

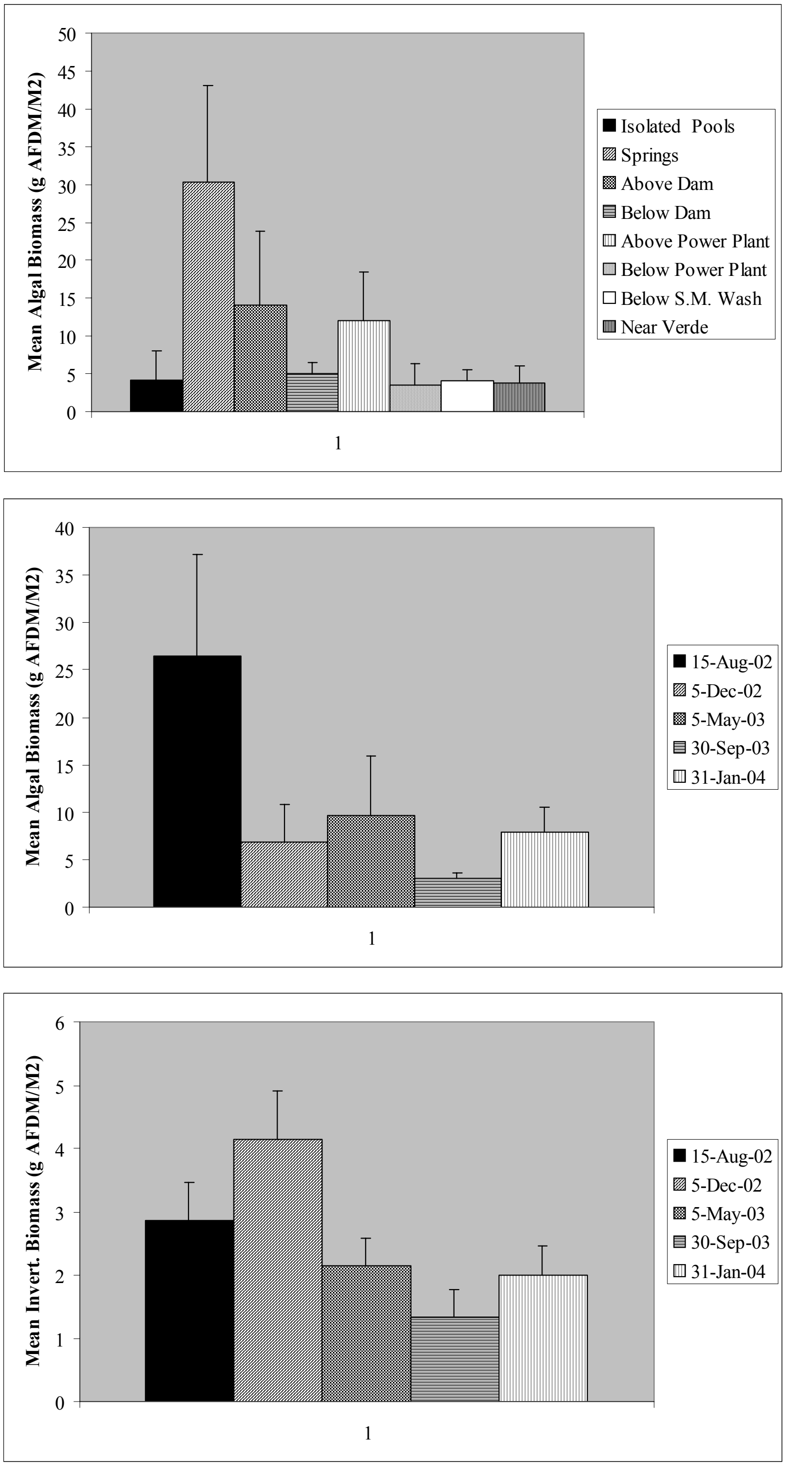


Figure 16. Trends across sites and seasons in benthic organic matter show: a) algal biomass is highest in the two sites above the dam and decreases at all sites below the dam except for the below Irving site in the travertine dam zone; b) algal biomass is highest in the summer, and c) invertebrate biomass is highest in the winter.

Discussion

The energy sources of Fossil Creek are not distributed equally. Most of the energy, in primary producers, detritus and invertebrates is concentrated pools relative to riffles. This is a direct result of pools acting as depositional zones. Slower velocities allow for the settling out of floating CPOM and also fine particulate organic matter, creating sinks of organic matter. In addition sediments that concentrate in pools provide substrate for aquatic macrophytes and algae. Our data is a measurement of standing crop, and should not be interpreted in terms of production. Algae (especially diatoms) in riffle areas may actually have higher production, but grazing invertebrates and high turnover result in low standing mass.

Algal biomass was highest in areas above the diversion dam. This area benefits in having full flows, allowing for a wider stream cross-section with a larger area of the stream exposed to direct sunlight in comparison to reduced flows, with a riparian zone that can cover the entire streambed. This is inline with the River Continuum Concept which predicts increased primary productivity in wider rivers (Vannote et al. 1980). Higher light levels also explain why we observed the highest algal biomasses in spring/summer months. Longer daylight periods coupled with more direct light increases photosynthesis and primary productivity.

We hypothesize that higher biomasses and insect numbers in fall and winter invertebrates are due to over-wintering stages of aquatic insects. Many insect lifecycles involve a period of growth in winter periods where they “fatten up” and go through several instars, before they metamorphoses into adult terrestrial stages in the spring and summer months. This is especially true of the larger insects, such as the Dobsonfly, *Corydalus texanus*. These large insects can explain higher biomasses in winter months.

Table 31. Ash Free Dry Mass averages at site, seasons and habitat type. Benthic standing mass estimates by sample date of algae, detritus, and invertebrates within pool and riffle habitats at sample sites in Fossil Creek. Data are AFDM g m^{-2} means with standard error in parentheses.

Site	Habitat Type	AFDM Category	15 August 2002	5 December 2002	5 May 2003	30 September 2003	31 January 2004
Isolated Pool	Pool	Algae	0.9231 (0.9231)	13.0431 (13.0431)	0.0000 (0.0000)		
Isolated Pool	Pool	Detritus	943.3416 (163.6535)	839.9386 (374.0466)	1900.7054 (1183.5858)		
Isolated Pool	Pool	Invertebrates	8.0341 (3.7660)	1.3461 (0.6820)	1.4101 (0.2987)		
Springhead	Pool	Algae	188.0219 (70.7904)	0.0000 (0.0000)	81.4161 (81.4161)	8.0998 (3.2702)	16.1533 (8.0610)
Springhead	Pool	Detritus	154.9100 (62.0070)	200.5760 (69.7281)	214.2863 (152.4270)	491.9163 (476.4556)	203.2875 (99.8252)
Springhead	Pool	Invertebrates	2.4405 (1.1037)	6.5070 (2.5456)	3.6402 (1.8727)	0.4281 (0.0773)	3.9348 (2.5563)
Springhead	Riffle	Algae	2.4281 (1.7225	0.2986 (0.2399)	5.1119 (5.1119)	1.1379 (0.9372)	0.3745 (0.2181)
Springhead	Riffle	Detritus	67.0119 (43.4028)	6.9515 (1.6626)	16.9272 (11.4217)	17.9683 (11.7986)	8.8598 (3.1140)
Springhead	Riffle	Invertebrates	2.0082 (0.5597)	1.9602 (1.0506)	0.1919 (0.0987)	0.4361 (0.1765)	0.6459 (0.2642)
Above Dam	Pool	Algae	108.3874 (94.3109)	0.0000 (0.0000)	24.5761 (16.4500)	5.7899 (1.7982)	0.9697 (0.7888)
Above Dam	Pool	Detritus	376.4818 (225.788)	204.8185 (102.1331)	1028.1897 (783.2889)	933.7306 (380.1478)	889.5771 (296.8784)
Above Dam	Pool	Invertebrates	4.2926 (1.8385)	1.3321 (0.4929)	7.4994 (3.7757)	0.7637 (0.1199)	3.6132 (2.6419)
Above Dam	Riffle	Algae	0.5630 (0.2688)	0.0000 (0.0000)	0.0384 (0.0384)	0.0059 (0.0028)	0.5870 (0.2569)

Table 31 continued.

Site	Habitat Type	AFDM Category	15 August 2002	5 December 2002	5 May 2003	30 September 2003	31 January 2004
Above Dam	Riffle	Detritus	6.2299 (2.9587)	23.9854 (9.6075)	8.8638 (2.60440)	4.6896 (1.2046)	5.3787 (2.3210)
Above Dam	Riffle	Invertebrates	0.9751 (0.5703)	0.7798 (0.3032)	0.9934 (0.6016)	0.0714 (0.0211)	1.1852 (0.5562)
Below Dam	Pool	Algae	17.3932 (10.0547)	7.4994 (4.8321)	11.6756 (6.3750)	5.3843 (2.7772)	0.5253 (0.3799)
Below Dam	Pool	Detritus	54.6691 (31.2359)	502.4027 (136.0424)	16.8857 (10.6748)	69.2001 (31.7577)	505.1485 (221.2501)
Below Dam	Pool	Invertebrates	9.0599 (5.2026)	3.2577 (1.3419)	1.8638 (0.8554)	0.5444 (0.2123)	5.0810 (3.4766)
Below Dam	Riffle	Algae	0.4091 (0.1873)	4.4196 (3.6673)	2.0278 (1.2913)	0.0079 (0.0052)	1.3930 (0.0691)
Below Dam	Riffle	Detritus	4.1271 (1.5560)	51.1180 (20.2756)	2.9644 (0.6945)	15.4960 (4.1613)	2.1453 (1.7828)
Below Dam	Riffle	Invertebrates	0.6891 (0.3721)	2.5680 (0.9919)	2.5115 (0.8641)	0.3006 (0.1136)	0.2901 (0.0442)
Above Irving PPT	Pool	Algae	0.0000 (0.0000)	58.7753 (58.7753)	0.5271 (0.5271)	1.2417 (0.6830)	39.7730 (21.9896)
Above Irving PPT	Pool	Detritus	546.9615 (456.4342)	494.0046 (265.1719)	71.6579 (13.0930)	53.4766 (25.7342)	382.4767 (104.7363)
Above Irving PPT	Pool	Invertebrates	0.5801 (0.1268)	14.3229 (7.5052)	1.4500 (0.3380)	1.8409 (1.0887)	1.2620 (0.5783)
Above Irving PPT	Riffle	Algae	1.8660 (1.4095)	11.5942 (3.3048)	0.0000 (0.0000)	0.0104 (0.0048)	6.5333 (5.9126)
Above Irving PPT	Riffle	Detritus	8.0266 (3.0153)	16.4470 (6.0365)	22.7851 (15.1206)	13.5240 (10.6722)	10.9335 (4.4069)
Above Irving PPT	Riffle	Invertebrates	2.8227 (0.2461)	3.5472 (0.9007)	0.8781 (0.2709)	5.4187 (4.4968)	3.3079 (1.2591)

Table 31 Continued.

Site	Habitat Type	AFDM Category	15 August 2002	5 December 2002	5 May 2003	30 September 2003	31 January 2004
Below Irving PPT	Pool	Algae	27.7439 (27.7439)	0.0000 (0.0000)	0.0000 (0.0000)	3.4520 (0.8959)	0.0621 (0.0621)
Below Irving PPT	Pool	Detritus	634.5217 (157.3673)	499.6372 (47.5393)	72.4575 (26.1048)	1119.5258 (409.9393)	731.5029 (271.3800)
Below Irving PPT	Pool	Invertebrates	0.9646 (0.2030)	2.0234 (1.0000)	0.2597 (0.0785)	1.1795 (0.5926)	1.9840 (1.6192)
Below Irving PPT	Riffle	Algae	2.4167 (2.4144)	0.0000 (0.0000)	1.7907 (1.3562)	0.0044 (0.0025)	0.0717 (0.0327)
Below Irving PPT	Riffle	Detritus	22.4690 (18.4133)	7.2168 (1.2715)	5.4746 (2.1440)	5.0862 (1.0154)	8.2043 (4.5132)
Below Irving PPT	Riffle	Invertebrates	2.3243 (1.6729)	1.3310 (0.4246)	6.6904 (1.4165)	1.5819 (0.3456)	1.2560 (0.4099)
Below Sally Mae	Pool	Algae	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	10.8966 (3.0276)	29.0146 (10.3802)
Below Sally Mae	Pool	Detritus	459.3570 (386.5910)	123.4126 (29.7074)	32.7299 (12.3217)	29.7238 (12.5841)	67.5785 (28.0245)
Below Sally Mae	Pool	Invertebrates	1.1297 (0.4321)	12.5679 (5.1667)	0.6109 (0.1952)	3.3687 (2.2798)	1.2037 (0.7485)
Below Sally Mae	Riffle	Algae	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0144 (0.0040)	0.1663 (0.1068)
Below Sally Mae	Riffle	Detritus	9.1775 (3.6948)	8.6365 (2.5703)	6.2845 (5.4987)	2.14309 (1.1295)	1.6508 (0.6698)
Below Sally Mae	Riffle	Invertebrates	0.8439 (0.5555)	1.3157 (0.6294)	0.1610 (0.0518)	0.1035 (0.0299)	0.2809 (0.0827)
Confluence	Pool	Algae		4.5124 (4.5124)			
Confluence	Pool	Detritus		97.2628 (45.6299)			

Table 31 continued.

Site	Habitat Type	AFDM Category	15 August 2002	5 December 2002	5 May 2003	30 September 2003	31 January 2004
Confluence	Pool	Invertebrates		4.7647 (2.6074)			
Confluence	Riffle	Algae		3.1835 (1.5825)			
Confluence	Riffle	Detritus		14.5465 (6.5142)			
Confluence	Riffle	Invertebrates		4.7340 (1.2342)			

VIII. Stream Vegetation Surveys

We conducted stream vegetation surveys during August 2002 at the six core sites and the isolated pools. We established 175 meter plots at each study site by establishing a central transect at each site. An additional six transects were conducted in 15 meter intervals above the central transect and four additional transects were conducted at 15 meter intervals below the central transect for a total of ten transects. The width of the stream was measured for each transect and the widths of different vegetation types were recorded along each transect. Dominant riparian vegetation was also documented for each site. Table 32 shows the combined widths of the ten transects and the amount of in-stream vegetation at each site. These results indicate that there is much more moss growing in the stream at the two sites above the dam (Springs Site, Above Dam Site) relative to all sites below the dam. Second, green algae (Chlorophyta) are present throughout the river but are more concentrated at the two sites above the dam and the Below Irving Site. This is consistent with other results that indicate higher algal biomass and productivity above the Fossil Springs dam and in areas with travertine dams (Below Irving). Aquatic plants are also more abundant at the two sites above the dam and the Below Irving Site. The two must abundant aquatic macrophytes are cattails and watercress. Table 33 documents the presence of major vegetation types in the riparian zone. This is a qualitative analysis designed to generate a list of dominant vegetation and likely misses rare taxa. These species lists indicate a diverse riparian assemblage at all sites except the isolated pools.

Increased flow will reduce riparian plants in areas that will be inundated with water as base flow increases. Because this is a run of the river dam, however, plants whose distributions are mostly set by flood events will likely be unaffected. There are no published data indicating the relative importance of stream water versus groundwater to riparian plants in the Fossil Creek watershed. The return of flows should make stream water more available to some plants that tap into it as their main source of water and will likely increase riparian vegetation in the long run. As travertine dams increase, establishing pools and backwaters we anticipate more habitat for aquatic and riparian vegetation.

Table 32. In-stream vegetation. Results of transect surveys at six core sites. Data presented are totals for ten transects at each site estimating the amount of benthic substrate covered by each vegetation type. Transects spanned 175 meters length of stream and were distributed 15 meters apart. Data collected by Chas Jones.

	Species	Springs	Above Dam	Below Dam	Above Irving	Below Irving	Below Sallie Mae
	Total width (cm)	11040	12330	7180	4300	16146	7329
Moss	*Didymodon tophaceus*	6	0	19	0	24	43
	Bryum sp. 2	0	0	0	0	0	11
	Mnium blytii	0	0	0	12	0	0
	Pohlia sp.	0	0	19	0	0	0
	Hygrohypnum luridum	6	0	0	0	0	0
	Fontinalis hypnoides	2132	987	0	0	0	0
	Filicinum cratoneuron	5	0	0	0	0	0
Algae	Periphyton	429	1954	1140	570	2205	1179
	Vaucheria	68	10	40	0	3	15
	Cladophora	1907	80	1100	15	364	45
	Chara	0	0	0	5	140	0
	Spirogyra	0	0	0	3	1233	0
	Rhizoclonium	0	0	420	0	0	0
Plants							
Aquatic	*Rorrippa nasturium*	997	918	7	15	761	1
	Typha domingensis	2	623	1	78	880	0
	Scirpus sp.	0	15	0	80	13	0
	Aquatic grass sp. 1	10	0	21	0	0	0
	Aquatic grass sp. 2	0	0	14	0	0	0
	Potamogetan #2	0	0	10	0	0	0
	Potamogetan #1	0	5	0	0	0	0
	Poaceae sp. 3	0	0	5	0	4	0
Fringe	*Adiantum capillus-veneeris*	108	0	0	0	0	0
	Sedge sp. 1	0	595	0	0	0	0
	Equisetum arvensis	0	0	0	10	15	0
	Bromus sp.	30	0	24	0	10	16
	Mimulus gutata	0	0	0	0	60	0
	Asteraceae sp. 1	0	25	0	0	0	0
Woody	*Pseudosasa japonica*	0	0	0	0	520	0
	Roots	337	3	120	63	160	204

Table 33. Dominant Riparian and Aquatic Plants. The presence of a taxon at each of the seven sites sampled is indicated by a "1". The final row presents the total number of dominant species at each site. Data collected by Chas Jones.

	Latin Name	**Common Name**	**Ephemeral Pools**	**Springs**	**Above Dam**	**Below Dam**	**Above Irving**	**Below Irving**	**Below Sallie Mae Wash**
Aquatic plants	Asteraceae sp. 1					1			
	Bromus sp.			1		1	1	1	1
	Lemna sp.	Duck weed		1					
	Mimalis gutatta	Monkey flower		1		1		1	
	Potamogetan #1(broad leaf)				1				
	Potamogetan #2 (narrow leaf)					1			
	Rorrippa nasturtium	Watercress				1		1	
	Scirpus sp.	Bulrush			1	1	1	1	1
	Typha domingensis	Narrow-leaved cattail		1	1	1	1	1	1
		Aquatic grass sp. 1		1		1			
		Aquatic grass sp. 2				1			
		Sedge sp. 1			1				
Fringe plants	*Adiantum capillus-veneris*	Maiden Hair		1	1	1	1	1	1
	Aquilegia sp.	Columbine		1					
	Equisetum arvensis	Horsetail					1	1	1
	Equisetum hymenales	Horsetail						1	1
	Juncus sp.					1			
	Juncus torreyi Coville	Torrey Rush							1
	Juncus articulatus L.	Jointed Rush							1
	Lobelia cardinalis	Cardinal flower		1				1	1
	Paspalum dilatum								1
	Phleum sp.			1		1		1	1
	Poaceae sp. 3					1		1	
	Pseudosasa japonica	Arrow Bamboo		1		1		1	1
	Scirpus maritimus var. paludosus								1

Table 33, continued.

	Latin Name	**Common Name**	**Ephemeral Pools**	**Springs**	**Above Dam**	**Below Dam**	**Above Irving**	**Below Irving**	**Below Sallie Mae Wash**
Woody plants	*Almus Rhombifolia*	River Alder		1	1	1	1	1	1
	Celtis sp.	Hackberry					1	1	
	Fraximus anomelus	Ash	1	1	1	1	1	1	1
	Fraximus velutina	Ash		1					
	Juglaus nigra	Black walnut		1			1	1	
	Pinus ponderosa	Ponderosa Pine	1						
	Platanus wrightii	Sycamore	1	1		1	1	1	1
	Populus fremontii	Cottonwood sp.			1	1	1	1	1
	Prosopis velutina	Mesquite	1						
	Quereous sp.	Oak					1		
	Salix sp.	Willow	1		1	1	1	1	1
	Tamarix sp.	Salt Cedar							1
Other riparian plants	*Artemisin* sp.							1	
	Berberis fremonitii						1		
	Beutoleua curtiperdula							1	
	Brickelia sp.					1	1	1	
	Cynadou didactylon	Bermuda grass			1		1	1	
	Medicago setiva	Alfalfa		1		1	1		
	Melilotus officianalis	Sweet clover					1	1	
	Pantheus sicus tricuspidata	Virginia Creeper		1					
	Rhammus calforanica	Coffee Berry			1				
	Rhus radians	Poison Ivy		1					
	Rhus Trilobata	Smooth sumac						1	
	Rubus sp.	Black berry		1					
	Vitis arizonica	Grapes		1		1	1		1
Other	Roots			1	1	1	1	1	1

Table 33, continued.

	Latin Name	Common Name	Ephemeral Pools	Springs	Above Dam	Below Dam	Above Irving	Below Irving	Below Sallie Mae Wash
Moss	*Bryum* sp. 2	Moss D							1
	Bryum sp. 3	Moss K				1			
	Bryum weigglii					1			
	Didymodon sp. 2	Moss C							1
	Didymodon Tophaceus	Moss A		1		1	1	1	1
	Filicinum cratoneuron	Moss M		1	1				
	Fontinalis hypnoides	Moss L		1	1				
	Hygroablystegium tenax	Moss J				1			
	Hygroamblystegium tenax var. spinifolium	Moss G						1	
	Hygrohypnum luridum	Moss H						1	
	Mnium blytii	Moss E & I					1		1
	Pohlia sp.	Moss F				1		1	1
Algae	*Chara*		1				1	1	
	Cladophora glomerata			1	1	1	1	1	1
	Coleochaete			1					
	Mixed Periphyton			1	1	1	1	1	1
	Rhizoclonium	Algae A & D				1		1	1
	Spirogyra	Algae B & C					1	1	
	Vaucheria	Algae E		1	1	1	1	1	1
Total number			6	28	17	32	27	36	30

* "1" indicates the presence of a species at that site

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