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PRIMARY RESEARCH PAPER

Effects of travertine and flow on leaf retention in Fossil Creek, Arizona

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Abstract Leaf retention is important in transferring energy from riparian trees to stream food webs. Retention increases with geomorphic complexity such as substrate coarseness, sinuosity, and the presence of debris dams. High discharge can reduce retention, particularly when streams lack physical trapping features. Travertine formations, caused by calcium carbonate deposition, can alter stream morphology. To date, however, we know of no study testing the effect of travertine on leaf retention. This study capitalized on a river restoration project in Fossil Creek, Arizona, where water was returned to the channel after a century of diversion. We examined how the fixed factors Flow (before and after restoration) and Morphology (travertine and riffle-pool sites) affected leaf retention. Leaf retention was higher in sites where travertine forms barriers across the river, relative to sites with riffle-pool morphology. Most leaves retained in travertine reaches were concentrated at the bottom of pools formed between dams. Although flow restoration did not alter retention rates across all sites, it diminished them at travertine sites, indicating an interaction between stream flow and morphology. We conclude that stream complexity and leaf retention are enhanced by travertine deposition but that high discharge can reduce the retentive capacity of in-stream structures.

Keywords Leaf retention · Flow restoration · Travertine · CPOM · Fossil Creek

Introduction

Leaf retention is important to in-stream ecosystem functioning, especially in small streams (orders 1–3) that are reliant on leaf litter as an important carbon source (Vannote et al., 1980). Leaf retention allows microbial colonization to occur, which is important because shredders preferentially consume leaves after the establishment of a well-developed microbial community (Graca, 2001).

Lamberti and Gregory (1996) defined four primary factors influencing leaf retention: (1) stream discharge, (2) substrate coarseness, (3) stream sinuosity, and (4) dams, including debris dams. Others have found a strong correlation between leaf retention and

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rooting (Tarragó et al., 2004). A synthesis of 40 published measurements determined that the two primary factors influencing leaf transport across streams were stream size and discharge (Webster et al., 1999). The most important internal structure for leaf retention is debris dams, especially during high discharges (Muotka & Laasonen, 2002).

Although debris dams are well-studied, travertine dams have not been examined in the context of leaf retention. Travertine, or calcium carbonate ($CaCO_3$), is a mineral precipitate deposited when turbulence-induced CO_2 out-gassing shifts the bicarbonate equilibrium, causing $CaCO_3$ to deposit in the stream channel (Barnes, 1965; Stumm & Morgan, 1970). Additionally, biological activity of macrophytes and epiphytes can govern travertine dam growth (Kempe & Emeis, 1985; Emeis et al., 1987; Pentecost, 2003). Spring-fed, karst streams with supersaturated levels of $CaCO_3$ (frequently 5–10 times saturation with respect to calcite), high CO_2 levels, and attributes promoting CO_2-outgassing (e.g., steep gradients and sufficient flow) have a unique geomorphology characterized by the presence of travertine dams or terraces (Lu et al., 2000, Malusa et al., 2003; Hammer et al., 2007). These channel-spanning dams can have a profound effect on stream morphology, effectively widening channel width and lowering stream velocity by creating large, upstream pools (see Pentecost et al., 2000; Malusa et al., 2003; Marks et al., 2006). Despite the influence of travertine on stream morphology and the distribution of particulate organic matter (Casas & Gessner, 1999; Miliša et al., 2006), no study has examined travertine as a mechanism of leaf retention.

We capitalized on a dam decommissioning project where flow was increased following a century of diversion, studying how flow interacts with travertine to affect leaf retention. This study compared leaf retention rates of travertine and riffle-pool stream reaches before and after restoration of flow, to test for the relative importance of stream morphology versus discharge in determining leaf retention rates. Three a priori hypotheses were tested: (1) leaf retention would decrease after restoration of full flows; (2) leaf retention would be higher at travertine sites than riffle-pool sites; and (3) leaf retention would increase with the abundance of coarse substrates. With fewer than 5% of dam removals accompanied by ecological studies (Hart et al., 2002), this restoration project represented a unique opportunity to study independent and interactive effects of travertine deposition and discharge on leaf retention.

Methods

Study site

Fossil Creek (34°18′21″N, −111°40′31″W) is a spring-fed first-order stream with atypically high flows for a headwater system. Perennial flow of Fossil Creek ($\sim$1,218 l s^{-1}) originates from a series of seven springs 22.4 km above the confluence with the Verde River, in Gila County, near Strawberry, Arizona. The riparian zone is characterized by regions of dense vegetation including Fremont cottonwood (*Populus fremontii* S. Wats.), narrowleaf cottonwood (*Populus angustifolia* James), Arizona alder (*Alnus oblongifolia* Torr.), box elder (*Acer negundo* L.), Gambel oak (*Quercus gambelii* Nutt.), Arizona sycamore (*Platanus wrightii* S. Wats), velvet ash (*Fraxinus velutina* Torr.), coyote willow (*Salix exigua* Nutt.), and Goodding's willow (*Salix gooddingii* Ball) (Leroy & Marks, 2006). Leaf input into the stream is mostly seasonal, occurring from late October through early January. During these periods, large, natural leaf packs can be seen aggregating on snags, log-jams, and debris dams often associated with travertine deposition (Compson, personal observation).

Flow was diverted from Fossil Creek for roughly a century through a flume system to produce hydroelectric power, reducing stream flow to 5.66 l s^{-1} below the Irving Power Plant (Fig. 1; Malusa et al., 2003; Marks et al., 2006). Historical accounts of pre-diversion conditions at Fossil Creek describe a series of travertine terraces and pools reaching up to 3 m and extending some 6.3 km downstream from the springheads (Malusa et al., 2003; Marks et al., 2006). Flow diversion restricted these features to a small (<1 km) reach of stream below the Irving Power Plant (Fig. 1; Overby & Neary, 1996). Deposition of travertine decreased gradually downstream, with no travertine terrace formation found 3 km below Irving. Below this point, the stream had a riffle-pool morphology typical of other similar sized streams in the region (Marks et al., 2006; Carter & Marks, 2007). Riffle-

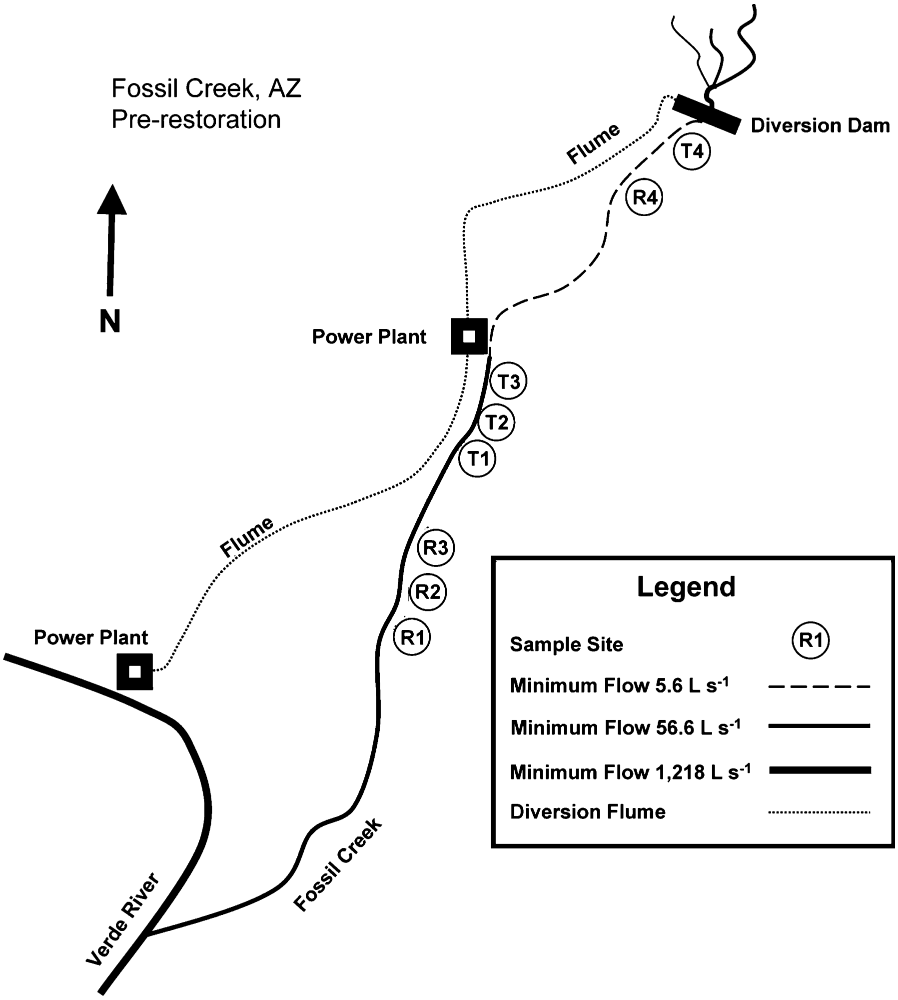

Fig. 1 Site map of Fossil Creek, Arizona. Sites T1–T3 were travertine sites, located just below the Irving Power Plant and sites R1–R3 were riffle-pool sites approximately 2 km downstream from Irving. Sites T4 and R4 were alternate travertine and riffle-pool sites where only coarse wood, velocity, and discharge measurements were taken

pool sites were dominated by cobble and boulder, with some gravel, silt, and bedrock (Marks et al., 2006; Carter & Marks, 2007).

Study design

Full flow was restored to Fossil Creek on June 18, 2005. This experiment was conducted ~9 months prior to and ~3 months after flow restoration during periods when the creek was at base flow. Post-restoration trials were conducted shortly after restoration to isolate the effects of increased flow on current dams. Three travertine sites were located just below the now defunct Irving Power Plant where a portion of Fossil Creek's water was diverted back into the stream channel, and three riffle-pool sites were located 4–5 km downstream from Irving (Fig. 1).

The limited area (<1 km) below the Irving Power Plant where travertine dams occurred prevented us from having more replication in our study. Our ability to replicate temporally was limited because the power plant was decommissioned within 1 year of the final decision to close down the facility, preventing us from collecting multiple years or seasons of pre-restoration data. These constraints are common in restoration projects where scientists are required to make tradeoffs between ideal study designs and the ned for assessing management actions (Muehlbauer et al., 2009; Bernhardt et al., 2005; Pollard & Reed, 2004). Additionally, geomorphic conditions are difficult to replicate and are usually confounded by multiple variables, including stream size, gradient, and discharge. Although travertine and riffle-pool sites were pseudo-replicated, this design allowed us to compare reaches with strikingly different geomorphologies where stream size, gradient, and discharge were similar (Marks et al., 2006; Carter & Marks, 2007).

Leaf retention

Experimental methods were adapted from Lamberti and Gregory (1996). Senescent pear (*Pyrus calleryanus*) and gambel oak (*Quercus gambelii*) leaves were used because of their unique morphology and absence in the Fossil Creek drainage. While our visual quantification method required us to use leaves foreign to Fossil Creek, we chose to use leaves that are found in other local river drainages (e.g., Oak Creek, Arizona) with a similar relative shape and size to leaf-forms found at Fossil Creek. Leaves (2000 per site) were soaked in de-ionized water for 24 h prior to release to achieve neutral buoyancy. These pre-soaked leaves appeared to have similar buoyancies as other leaves in the water column at the time of their release (Compson, personal observation).

Seine nets were set at the downstream end of each reach to collect leaves in-transit. Nets were placed either 100 or 200 m downstream from the top of the reach. Leaves were released and collected in nets after 1–3 h. All retention data were standardized to times of 1 hour and reach lengths of 100 m. We varied times and reach lengths because Lamberti and Gregory (1996) recommend that at least 10% of leaves should be collected at the end of each reach, which could be only achieved at each site using different times and reach lengths. In all cases, our experimental trials were stopped only after leaf accumulation in the nets had noticeably dropped off, suggesting that most leaves had either been collected or stabilized and retained (Compson, visual observation). In order to calculate the dominant retention features at each site, reaches were subdivided into 10 equal sections and all leaves were counted according to what feature trapped them. These values were totaled for each reach and standardized to the total number of retained leaves we observed. Leaves not included in these calculations were either lost or not retained (captured in nets at the end of each experiment).

Physical parameters

Physical parameters were measured across 10 equidistant, longitudinal transects at each site. Width, depth, and velocity measurements were taken at five points across each transect. Velocity was taken with a 201D water current meter from Marsh-McBirney. Substrate type was qualitatively determined at each point across each transect according to Platts et al. (1983): boulder (>250 mm), cobble (50–250 mm), gravel (5–50 mm), sand (1–5 mm), silt (<1 mm), bedrock, and detritus. Travertine was included as an additional substrate type. Substrates were divided into coarse (boulder, cobble, and travertine) and fine (gravel, sand, silt, bedrock, and detritus) categories. Percent coarse and percent silt were calculated as the proportion of these substrate categories compared to the total substrate cover at each transect. These values were averaged across transects to give a single value per site.

Additionally, gradient, coarse wood volume (m^3/m stream), and travertine dam volume (m^3/m stream) were calculated. Gradient was measured using a tripod by Allen Precision Co., a Lecia level, and a TopCon stadia rod. Coarse wood was measured using a modified method from Kershner et al. (2004), where all measurable pieces (i.e., pieces that were completely visible and reachable) were quantified and unmeasurable pieces (e.g., standing dead trees, travertine-covered logs, wood embedded in the stream bank) were estimated. Estimator bias was accounted for at each site by calibrating estimates to actual measurements.

Quantification methods:

Discharge (Q) was calculated as follows:

$$Q = \sum ((w/5)(d)(v)), \qquad (1)$$

where w (m) was the width of the entire channel at a given cross-section, d (m) was the depth at one of the five equidistant points, and v (m/s) was the velocity at the corresponding equidistant point. Velocity measurements were averaged across each transect and each reach. Discharge (m^3/s) values were calculated at each transect and averaged to compare to each reach. Substrates were analyzed as the percentages of coarse substrate, as defined above, calculated as the number of equidistant points along each transect where a coarsely defined substrate occurred versus the total substrate composition.

Retention for each site was determined using a negative exponential model:

$$P_d = P_o * \mathrm{e}^{-kd}, \tag{2}$$

where P_o was the initial number of leaves released, P_d was the number of leaves still in transport at distance d, d was the distance downstream from the release point, and k was the instantaneous retention rate. Using the variables P_o, P_d and d, k was calculated for each site.

Travertine dam volume was quantified by measuring the length (L) of the dam and then taking five equidistant measurements of the following variables: height in front of the dam (H_{F}), height behind the dam (H_{B}), and width (W). Average dam volume, $\mathrm{DV_A}$ (m^3), was then calculated using an adapted equation for a trapezoid:

$$\mathrm{DV_A} = \left(\left(\left(\sum(0.5(H_{\mathrm{F}}+H_{\mathrm{B}})*W)\right)\Big/5\right)*L\right). \tag{3}$$

For comparative purposes, dam volumes were standardized to reach length and reported in m^3 of travertine per m of stream (m^3/m).

Statistical analyses were conducted using JMP-IN software (1989–2003) (Academic version 5.1, SAS Institute, Inc., Cary, North Carolina, USA). A repeated-measures ANOVA was used to compare retention rates (k), velocity, % coarse substrate, % silt, and retention features using the fixed factors Flow (before and after restoration) and Morphology (travertine or riffle-pool sites). A two-way ANOVA was used to compare coarse wood for the fixed factors Flow (before and after restoration) and Morphology (travertine or riffle-pool sites) because data were not collected at the same sites before and after restoration. A paired Student's t-test using equal variance was used to compare gradient between travertine and riffle-pool sites before restoration. Data for coarse wood were ln-transformed to meet the assumptions of normality and equal variance. Wilcoxon/Kruskal–Wallis rank sum tests (1-way test, chi-square approximation) were used to compare the retention features Algae, Eddy, Settled, and Travertine, which could not be transformed to meet the assumptions of normality and equal variance.

Results

Leaf retention

Both flow restoration (Flow) and travertine (Morphology) imparted a significant effect on leaf retention rates (repeated-measures ANOVA, F-ratio: 21.71, P-value: 0.005) (Table 1). The interaction term between the two factors of the model (Flow × Morphology) was significant, indicating that the effect of increased flow on leaf retention differed at travertine and riffle-pool sites (Table 1). Travertine sites retained more leaves than riffle-pool sites before restoration, although the retentive ability of travertine diminished after restoration (Fig. 2). Flow restoration did not reduce the retentive ability of riffle-pool sites to the same degree (Fig. 2). Although travertine sites had a higher proportion of leaves retained directly on dams (chi-square: 6.14, df: 1, P-value: 0.013), the majority of leaves at these sites settled out in pools behind dams. This indicates that travertine dams increase retention by creating large pools with low velocity (Fig. 3). The dominant retentive features of travertine and riffle-pool sites were snags, and the importance of this feature increased after flow restoration (Table 2; Fig. 3). Less than 10% of leaves were trapped directly by travertine dams (Fig. 3). In contrast, a greater proportion of leaves were caught on boulders and roots at riffle-pool sites (Fig. 3; Table 2).

Physical factors

Prior to restoration travertine sites differed from riffle-pool sites in multiple physical factors. Average water velocity was significantly lower in travertine reaches relative to riffle-pool reaches despite nearly identical discharge rates (Table 1; Fig. 2). Travertine reaches have long, flat sections of deep pools punctuated by dramatic steps formed by travertine dams. In contrast, riffle-pool sites were high-velocity, low-volume reaches with single, riffle-dominated channels and more constricted channel widths. Although travertine and riffle-pool sites showed no differences in their proportions of coarse substrates before restoration (Table 1), boulder and cobble dominated riffle-pool sites, whereas travertine sites were composed primarily of travertine structures. Additionally, average silt loads were higher in

Table 1 Repeated-measures ANOVA table for retention rates (k), velocity, % coarse substrates, and % silt substrates for the fixed factors flow (before or after flow restoration) and morphology (travertine or riffle-pool)

Variable	Source	DF	Sum of squares	Mean square	F-ratio	P-value
k	*Analysis of variance*					
	Model	7	0.0014	0.00021	21.71	0.0050
	Error	4	0.000038	0.000010		
	C. Total	11	0.0015			
	Effect tests					
	Flow	1	0.00026		27.18	0.0065
	Morphology	1	0.00080		84.21	0.00080
	Site[Morphology]	4	0.00019		5.070	0.073
	Flow * Morphology	1	0.00019		20.28	0.011
Velocity	*Analysis of variance*					
	Model	7	0.20	0.030	3.99	0.10
	Error	4	0.028	0.0070		
	C. Total	11	0.22			
	Effect tests					
	Flow	1	0.057		8.20	0.046
	Morphology	1	0.12		17.42	0.014
	Site[Morphology]	4	0.016		0.58	0.70
	Flow * Morphology	1	0.000034		0.0049	0.95
% Coarse	*Analysis of variance*					
	Model	7	1133.75	161.96	10.02	0.021
	Error	4	64.66	16.17		
	C. Total	11	1198.41			
	Effect tests					
	Flow	1	7.12		0.44	0.54
	Morphology	1	11.94		0.74	0.44
	Site[Morphology]	4	1113.68		17.22	0.0087
	Flow * Morphology	1	1.012		0.063	0.81
% Silt	*Analysis of variance*					
	Model	7	1232.33	176.048	5.64	0.057
	Error	4	124.82	31.20		
	C. Total	11	1357.15			
	Effect tests					
	Flow	1	499.11		16.00	0.016
	Morphology	1	359.048		11.51	0.028
	Site[Morphology]	4	289.19		2.32	0.22
	Flow * Morphology	1	84.99		2.72	0.17

travertine compared to riffle-pool sites before restoration probably because silt settled out in the low-velocity pools (Table 1; Fig. 2).

Immediately after restoration, morphological differences between travertine and riffle-pool sites were less pronounced. Increased discharge after restoration lead to inundation of most dams in the main channel, leaving many of the pre-restoration dams in the secondary and tertiary channels elevated above the water level. Velocity increased with flow restoration (Table 1), but remained higher in riffle-pool sites (Fig. 2). Restored flows dramatically increased silt loads (Table 1; Fig. 2), and mean silt loads were higher in travertine than riffle-pool sites (Fig. 2).

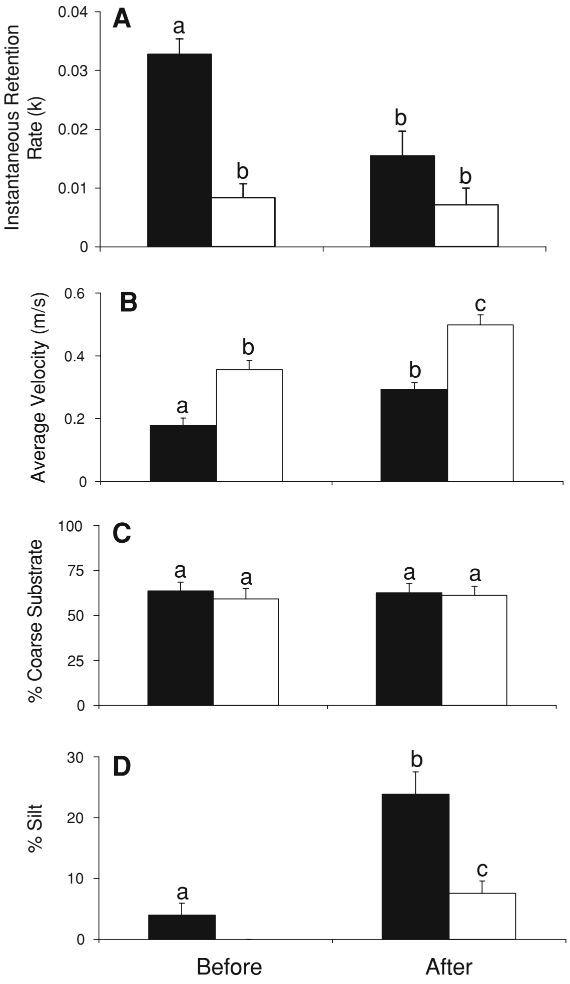

Fig. 2 Pre- and post-restoration conditions for travertine (*black*) and riffle-pool (*white*) sites. Error bars indicate +1SE. Differing lower case letters indicate significant differences ($P < 0.05$). **A** Instantaneous retention rates (k). **B** Average velocity (m/s). Values indicate means across reaches. **C** Percent coarse substrates. **D** Percent silt

Relatively similar standardized travertine dam volumes were quantified at all travertine sites before restoration. Travertine dam volumes have not visually changed since restoration, so post-restoration measurements have not been taken.

Other factors

Coarse wood was likely the largest factor besides travertine influencing leaf retention. Coarse wood volume standardized to reach length was 0.078 ± 0.040 m^3/m at travertine sites and 0.0049 ± 0.0081 m^3/m at riffle-pool sites before restoration and 0.078 ± 0.026 m^3/m at travertine sites and 0.0066 ± 0.0024 m^3/m at riffle-pool sites after restoration. Coarse wood volume was greater at travertine than riffle-pool sites (*F*-ratio: 38.21; DF: 1, 8; *P*-value: 0.00030) but was not affected by flow restoration (*F*-ratio: 0.19; DF: 1, 8; *P*-value: 0.68). Lack of a significant interaction term (*F*-ratio: 0.0033; DF: 1, 8; *P*-value: 0.96) indicates that travertine was the sole factor affecting coarse wood volume. Gradient did not differ between travertine (7.18 ± 1.75) and riffle-pool (8.17 ± 2.30) sites (*t*-test: 0.34, DF: 4, *P*-value: 0.75). Dam volume standardized to reach length was 1.33 ± 0.21 m^3/m.

Discussion

This study shows that flow and travertine interact to affect leaf retention. Travertine dams increase retention primarily by creating deep pools with low water velocity where leaves settle to the bottom or are caught on snags. Few leaves were found trapped on the travertine dams themselves, suggesting that the direct effect of travertine on entrapping leaves is small. Travertine dams are similar to debris dams in that they increase leaf retention and reduce velocity (Pentecost et al., 2000, Miliša et al., 2006; Hammer et al., 2007) but are less important in directly retaining leaves. Travertine does, however, entrap large amounts of coarse wood, which in turn serves as substrate for further travertine deposition. Travertine also causes coarse wood to settle out between dams, creating snags and log-jams which also retain leaves in travertine reaches.

The decrease in retention after restoration at travertine sites was likely due to subsequent increases in velocity and depth. Prior to restoration much of the flow was trapped behind dams, leaving large sections of dams above the water surface. With increased flow, some dams became submerged, with water flowing over the entire length of the dams, decreasing their impact on water velocity. This decrease in leaf retention at travertine sites is likely a short-term effect, because travertine deposition is increasing with flow restoration (Parnell, unpublished data). Increased travertine deposition in the form of "plating," new dams, and increased dam volumes was observed within 6 months after restoration of flows (Compson, personal observation).

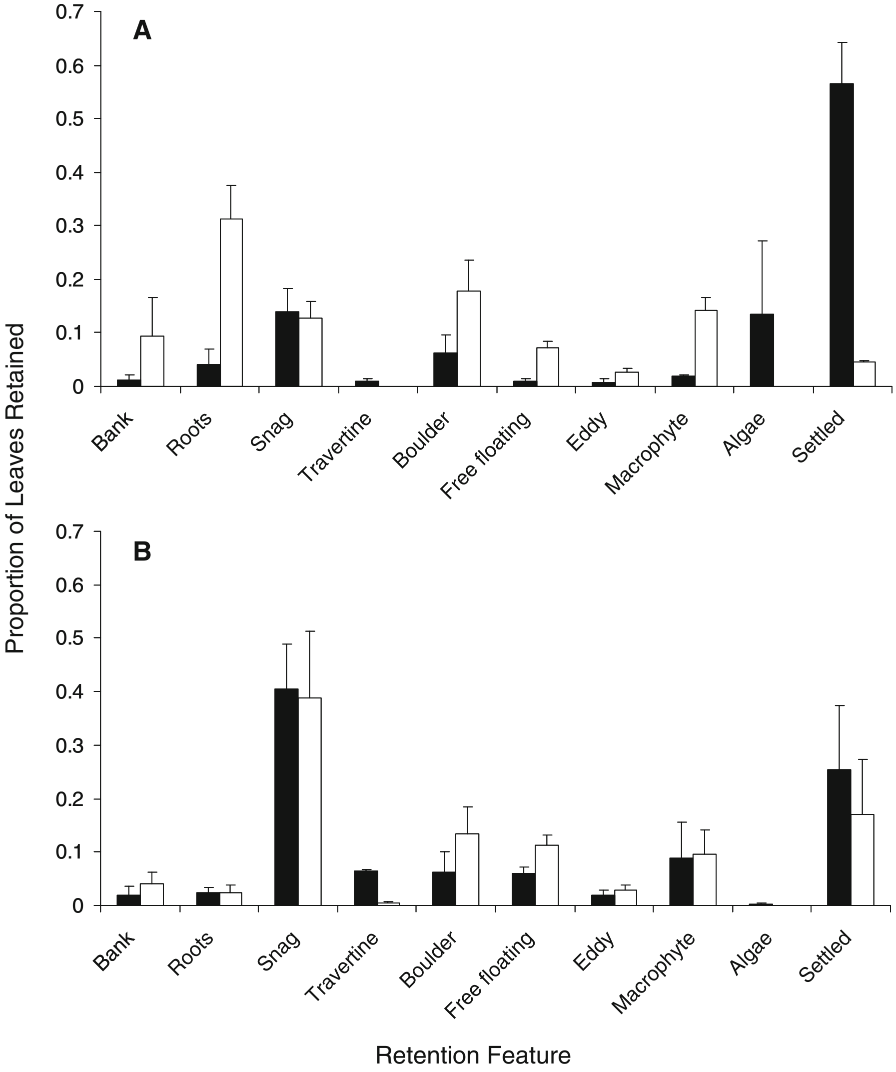

Fig. 3 Leaf retention features **A** before and **B** after restoration of Fossil Creek, AZ, in travertine (*black*) and riffle-pool (*white*) reaches. Mean and standard errors represent proportions of total leaves (per site) retained by each feature

Contrary to our prediction, leaf retention at riffle-pool sites was not reduced by increased flow. Although higher discharge values are generally associated with lower leaf retention rates (Raikow et al., 1995; Brookshire & Dwire, 2003), the effects of discharge interact with stream geomorphology and other retention features, such as snags, which are more important in high flow conditions. The lack of response at riffle-pool sites may have been due to the few retention features (especially debris dams) other than boulders at these sites. This makes sense in context of the relatively low retention rates seen before (0.008 ± 0.002) and after (0.007 ± 0.002) flow restoration compared to the mean retention rate found for leaves in the literature (0.12 ± 0.036) (calculated from Jones & Smock, 1991; Ehrman & Lamberti, 1992; Raikow et al., 1995; Schade & Fisher, 1997; Brookshire & Dwire, 2003; Hoover et al., 2006). Many previous studies were conducted in smaller streams with discharges lower than the pre-restoration rates at Fossil Creek. Retention rates therefore may be more sensitive to changes in discharge in smaller streams. These findings have implications for restoration projects where land managers are concerned that organic matter will decline with flow restoration. Our results suggest that increased flows will not always lead to decreases in leaf retention.

Table 2 Repeated-measures ANOVA table for leaf retention features for the fixed factors flow (before or after flow restoration) and morphology (travertine or riffle-pool)

Variable	Source	DF	Sum of squares	Mean square	*F*-ratio	*P*-value
Bank	*Analysis of variance*					
	Model	7	0.022	0.0031	3.65	0.23
	Error	2	0.0017	0.00086		
	C. Total	9	0.024			
	Effect tests					
	Flow	1	0.00052		0.60	0.52
	Morphology	1	0.0059		6.87	0.12
	Site[Morphology]	4	0.013		3.86	0.22
	Flow * Morphology	1	0.0020		2.31	0.27
Boulder	*Analysis of variance*					
	Model	7	0.055	0.0078	25.86	0.038
	Error	2	0.00060	0.00030		
	C. Total	9	0.055			
	Effect tests					
	Flow	1	0.0045		15.04	0.061
	Morphology	1	0.014		47.18	0.021
	Site[Morphology]	4	0.032		26.67	0.037
	Flow * Morphology	1	0.00033		1.087	0.41
Free floating	*Analysis of variance*					
	Model	7	0.016	0.0022	5.16	0.17
	Error	2	0.00086	0.00043		
	C. Total	9	0.016			
	Effect tests					
	Flow	1	0.0050		11.56	0.077
	Morphology	1	0.0040		9.31	0.093
	Site[Morphology]	4	0.0026		1.49	0.44
	Flow * Morphology	1	0.000077		0.18	0.71
Macrophyte	*Analysis of variance*					
	Model	7	0.045	0.0064	1.16	0.54
	Error	2	0.011	0.0055		
	C. Total	9	0.056			
	Effect tests					
	Flow	1	0.00030		0.055	0.84
	Morphology	1	0.019		3.35	0.21
	Site[Morphology]	4	0.030		1.34	0.47
	Flow * Morphology	1	0.016		2.95	0.23
Roots	*Analysis of variance*					
	Model	7	0.14	0.019	8.95	0.10
	Error	2	0.0043	0.0022		
	C. Total	9	0.14			
	Effect tests					
	Flow	1	0.040		18.68	0.050
	Morphology	1	0.036		16.39	0.056

Table 2 continued

Variable	Source	DF	Sum of squares	Mean square	*F*-ratio	*P*-value
	Site[Morphology]	4	0.0067		0.77	0.63
	Flow * Morphology	1	0.035		16.22	0.057
Snag	*Analysis of variance*					
	Model	7	0.30	0.043	15.24	0.063
	Error	2	0.0057	0.0028		
	C. Total	9	0.31			
	Effect tests					
	Flow	1	0.27		94.58	0.010
	Morphology	1	0.0020		0.72	0.49
	Site[Morphology]	4	0.14		12.04	0.078
	Flow * Morphology	1	0.00057		0.20	0.70

Because leaf retention increases detrital stocks, fungal biomass, and macroinvertebrate densities (Laitung et al., 2002; Muotka & Laasonen, 2002; Laasonen et al., 1998), the short-term decrease in leaf retention we observed at travertine sites may have a profound impact on macroinvertebrate colonization dynamics. We anticipate, however, that the current dams will increase in size, regaining their ability to reduce velocity and trap leaves in pools. One of the primary goals of the Fossil Creek flow restoration was to return travertine deposition to pre-diversion levels. Restoration of flow is expected to increase travertine deposition to 11,923 kg d^{-1} (Malusa et al., 2003) resulting in an approximate 10-fold increase in travertine habitat (Marks et al., 2006). Since travertine supports higher primary productivity, faster leaf decomposition rates, and higher macroinvertebrate species richness at Fossil Creek (Marks et al., 2006), we predict that an increase in travertine deposition and subsequent enhancement of leaf retention will result in an ecologically successful restoration outcome (sensu Palmer et al., 2005). The unique geomorphology of Fossil Creek combined with restoration of flow offers an important opportunity to study in real-time how changing geomorphology affects leaf retention and other ecosystem processes (Marks, 2007).

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