Ecosystem Restoration:

A Case Study in the Owens River Gorge, California

By Mark T. Hill and William S. Platts

ABSTRACT

In 1991 the Los Angeles Department of Water and Power, in cooperation with Mono County, California, initiated a multiyear effort to restore the Owens River Gorge. The project aims to return the river channel, dewatered for more than 50 years, to a functional riverine-riparian ecosystem capable of supporting healthy brown trout and wildlife populations. The passive, or *natural*, restoration approach focused on the development of riparian habitat and channel complexity using incremental increases in pulse (freshet) and base flows. Increasing pulse and base flows resulted in establishment and rapid growth of riparian vegetation on all landforms, and the formation of good-quality microhabitat features (pools, runs, depth, and wetted width). An extremely complex, productive habitat now occupies the bottom lands of the Owens River Gorge. A healthy fishery in good condition has quickly developed in response to habitat improvement. Brown trout numbers have increased each year since initial stocking, 40% between 1996 and 1997. Catch rates increased from 0 fish/hr in 1991 to 5.8–7.1 fish/hr (with a maximum catch rate of 15.7 fish/hr) in 1996. Restoring the Owens River Gorge bridges the theoretical concepts developed by Kauffman et al. (1997) and the practical application of those concepts in a real-time restoration project.

The purpose of restoration is to shift ecosystems from a dysfunctional state to a functional state. A functional ecosystem exhibits self-sustaining natural processes and linkages among terrestrial, riparian, and aquatic components (Kauffman et al. 1997). In watershed-level ecosystems the riverine-riparian component plays a primary role by linking with terrestrial components to sustain total biodiversity, natural processes, and the movement of energy within and among watersheds (Stanford and Ward 1992). The lifeblood of the riverine-riparian system is the timing, quantity, and quality of flowing water, which influences quantity and quality of riparian habitat, fisheries and wildlife resources, and the way energy is transported among ecological components (Hill et al. 1991; Beschta 1997; Poff et al. 1997).

Restoring rivers is a linear process; riparian habitat strongly influences geomorphic processes and must develop ahead of in-channel habitat to maximize complexity and sustain habitat. The development of riparian systems is part of a directional sequence known as the *reversible process concept* (Amoros et al. 1987), within which the directional sequences are rejuvenated by erosion, deposition, and flood disturbance.

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Kauffman et al. (1997), in an overview of ecosystem restoration in the western United States, identify two primary causes of ecosystem dysfunction: land and water use practices. Watersheds affected by land use practices are those in which grazing and logging activities are improperly managed, while poor water use practices include stream diversion and flood control actions that degrade aquatic habitat. Kauffman et al. (1997) also identify several management strategies that correct degradation caused by land and water use activities but do not necessarily qualify as ecological restoration (i.e, preservation, creation, reclamation, rehabilitation, replacement, mitigation, and enhancement).

This paper presents a case study of riparian and stream restoration in the Owens River gorge that applies many of the concepts and approaches Kauffman et al. (1997) suggest. This empirical study shows that restoration can include most of the management strategies they identified. Our approach to restoring the gorge has used multiple flow regimes that are both *passive* (or *natural)* and *active* interventions (Kauffman et al. 1997).

During these initial years of restoration, incremental changes in annual pulse and base flows were used to establish riparian vegetation on landforms and develop complex habitat. This was the *active* phase of restoration and required manipulation of discharge from year to year. The *passive* restoration phase arrives when the river reaches functionality; final instream flows will then be established that sustain ecological processes. This passive phase also might be described as a *preservation* management strategy since the ecosystem would be intact and no additional diversion or dewatering would be allowed.

Restoration of the Owens River gorge has included management strategies that *create* additional wetlands, *reclaim* self-sustaining habitat to benefit endemic fish species, *rehabilitate* lost riverine-riparian vegetation types, *replace* native fish species with an exotic target species, *enhance* wetland habitat with the use of an historic stream barrier, and *mitigate* for hydropower generation. The associated study provides a bridge between theoretical concepts developed by Kauffman et al. (1997) and practical application of these concepts in a real-time restoration project.

Pre-restoration conditions in the Owens River Gorge

The Los Angeles Department of Water and Power, in cooperation with Mono County, is restoring the riverine-riparian ecosystem in the Owens River gorge, California (Figure 1). The river is bounded by Crowley Reservoir upstream and Pleasant Valley Reservoir downstream. The lower 16 km of the Owens River gorge (from the Upper Gorge power plant to the Control Gorge power plant) has been dewatered for hydroelectric purposes from 1953 to 1991, resulting in a dry river channel devoid of riparian vegetation and fish.

The Owens River gorge lies in a high desert plateau between the eastern Sierra Nevada Mountains to the west and the White Mountains to the east (Figure 1). The narrow, notched canyon has nearly vertical side walls averaging 240 meters high. Crowley Reservoir blocks sediment and gravel recruitment; colluvial inputs associated with infrequent landslides are the only source of new sediment material. The valley bottom is narrow in most places (<50 m) and widest (> 1,000 m) at the lower end, which is above the Control Gorge power plant. Gradient through the gorge averages 10 m/km. Because of its proximity to two mountain ranges, historic freshet flows in the gorge were extremely high and sudden. Historic flows have varied from more than 85 m^3/s in the spring to less than 5 m^3/s by late summer. Historic flows have created four principle landforms in the Owens River gorge: (1) terraces several meters above the streambed; (2) levees or incised streambanks; (3) floodplains adjacent to the channel; and (4) the channel itself.

A barrier placed in the river in the early 1950s just above the Control Gorge power plant to prevent fish migration from Pleasant Valley Reservoir into the fluctuating backwater areas also checks sediment movement and pooled flow from seeps and springs; this has resulted in a remnant wetland present throughout the half-century of dewatering.

Land uses that preceded water diversion for hydropower have included intensive mining, wood cutting, and livestock grazing. Early land use practices caused severe impacts to riparian vegetation and streambanks. Prior to dewatering, the central feature of the Owens River gorge ecosystem was the riverine-riparian system. The riparian zone was dominated by willows (*Salix* spp.) and, to a lesser extent, by cottonwood (*Populus* spp.) and associated tules (*Scirpus* spp. and *Typha latifolia*). The remnant wetland was the key habitat feature that supported most of the biodiversity in the gorge. Small galleries of cottonwood and tree willow were maintained in the seepage downstream of the three power plants and in the remnant wetland during the years of dewatering. These small remnant populations of cottonwood and willow provided the seed source for restoration.

Endemic fish species in the gorge have included endangered Owens tui chub (*Gila bicolor snyderi*) and the Owens speckled dace (*Rhinichthys osculus* ssp.), a candidate for threatened or endangered species listing under the Endangered Species Act; both species still occur in the river, primarily in the wetlands at the lower end of the gorge and in the reach designated as critical habitat for tui chubs between Crowley Reservoir and the Upper Gorge power plant.

Restoration goals

Goals of the restoration project were to maintain power production, rewater the river, recreate riparian habitat, and reestablish a healthy fish population (Brodt and Pettijohn 1995). Although native fish populations could be reestablished in the Owens River gorge, the

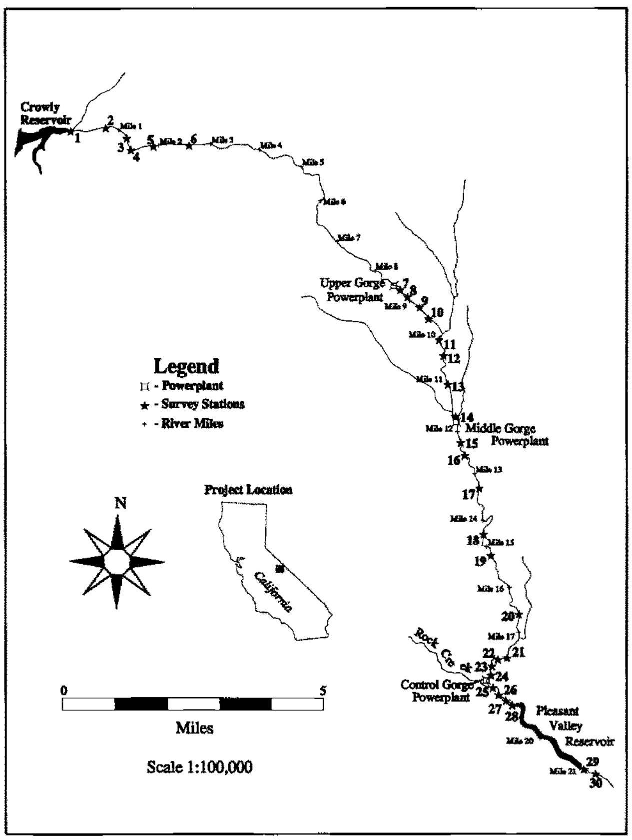

Figure 1 depicts the Owens River gorge, power plants, and sample sites by river mile.

California Department of Fish and Game selected brown trout (*Salmo trutta*) as the target species on which to build a healthy fishery. Regional and local emphasis on recreational fishing helped drive the decision for a brown trout fishery.

The primary objective in achieving these goals was the reestablishment of riparian habitat that functioned in concert with the river, wetlands, and upland habitats (i.e., the free energy exchange among habitats) by mimicking natural flow processes. Key to successful restoration in the Owens River gorge was development of riparian vegetation through good stream flow management.

Riparian areas in watersheds provide numerous ecological links between uplands and their aquatic ecosystems (Heede 1985; Gregory et al. 1991; Naiman et al. 1992) as well as create shade, cover, and organic debris (Large and Petts 1994). Riparian zones in the Owens River Gorge were the source of extremely important structural components of the aquatic ecosystem. Woody debris is often the dominant element in the physical structure of streams (Bisson et al. 1987), and when coarse, woody debris enters a stream, a critical role of the riparian forest is played (Swanson et al. 1976; Harmon et al. 1986; Maser et al. 1988). Riparian vegetation in the gorge also provided an important nutritional substrate for the aquatic ecosystem. Allochthonous inputs that dominate small streams are the main source of energy (Triska et al. 1982; Gregory et al. 1991). Riparian vegetation has been shown to exert significant control over fluvial processes and the determination of instream habitat via (1) flow resistance; (2) flow interruption by log jams; (3) interception and storage of sediment; (4) bank strengthening; and (5) concave bank bench deposition (Hicken 1984; Gregory and Gurnell 1988).

Disturbance regimes in stream ecosystems are important in shaping riparian zones and their vegetation (Gregory et al. 1991; Hill et al. 1991); establishing a disturbance regime was fundamental to recovering the Owens River Gorge. First and foremost, our method was to avoid mechanical intervention and provide the ecosystem with flows that allowed natural processes to occur. Passive or *natural* restoration must begin with flows that promote complex riverine-riparian habitat required to maintain a healthy fishery. Our approach was to allow riparian vegetation to respond to incremental increases in both base flows and pulse flows throughout many years before larger flows are permanently released in the gorge (Table 1). In the early stages of our efforts, we had to carefully match pulse flows with the ability of vegetation on landforms to trap and hold sediments. Due to Crowley Reservoir Dam, the gorge is starved for sediments, and the river system cannot afford to lose sediments necessary to build streambanks. Base flows in early stages of restoration had to match pulse flows to ensure that newly established riparian vegetation on landforms was maintained throughout the growing season.

Table 1 lists actual and target base and pulse flows in the Owens River Gorge from 1991 to 2000. (Target flows were established by agreement between Mono County and the Los Angeles Department of Water and Power).

Year	Base flow (cfs)		Pulse Flow (cfs)	
	Target	Actual	Target	Actual
1991	16	16	0	0
1992	16	16	0	0
1992	16	16	24	26
1994	16	16	24	32
1995	16	16	24	40
1996	26	26	39	60
1997	36	26	39	70
1998	46	36	69	90
1999	56	---	84	---
2000	65	---	98	---

Flow management

Reestablishment of the Owens River Gorge ecosystem was based on multiple stream flows that allowed natural processes to proceed for an extended time. Mechanical intervention such as pool digging, log placement, bank stabilization, and artificial plantings was possible, but such interventions are rarely successful (Beschta et al. 1995). Natural restoration was the most-feasible, least-costly approach (Platts and Rinne 1985) and depended on in-channel and out-of-channel flows that occurred at appropriate times (Hill et al. 1991).

Pulse and base flow principles

Pulse flows in the gorge built and irrigated landforms, redistributed sediments, scoured pools, and undercut banks. Landforms such as streambanks, floodplains, terraces, and channels in the gorge were platforms on which riparian vegetation (primarily willow and cottonwood) grew. Pulse flows created vortices that placed sediments onto landforms that, with out-of-channel irrigation, set the stage for seeding and germination of riparian plants; timing of pulse flows was critical. Pulse flows had to occur when willow and cottonwood seeds were at peak maturation in the gorge; pulse flows then dispersed seeds downstream onto landforms. Higher pulse flows each spring irrigated and deposited sediments and seeds successively higher on surrounding landforms. Landforms were the key to developing the riparian vegetation that is the primary component of fish habitat in the gorge. If bare landforms in the gorge were eroded by pulse flows that were too high, platforms for riparian plants would have been lost. Therefore, we had to build and strengthen landforms to such a degree that they could withstand increasingly higher pulse flows without eroding.

Riparian seedlings sent roots into the hyporheic zone following germination and continued growth created structural stability on landforms. Riparian vegetation nearest the channel edge matured in time, and as stream flows increased in the gorge, near-stream vegetation died and/or eventually fell into the stream, adding valuable nutrients and woody debris that enhanced habitat complexity. Vegetation that was higher on landforms matured, creating landforms that were structurally sound and erosion-resistant.

As a consequence of cycles of pulse flows and vegetation growth, the channel became increasingly complex and resistant to erosion at higher flows.

Pulse flows were the "disturbance regime," and base flows were the "stability regime" in the Owens River Gorge. Pulse flows set the stage for changes in the gorge, and base flows maintained and improved on the physical and biological changes initiated by pulse flows. Base flows followed pulse flows during the growing season, a critical time for all biological components of the gorge ecosystem. We established a stable hydrologic regime during the growing period to achieve maximum riparian growth and reproductive potential.

The three-dimensional nature of groundwater determined the level where the water table and soil moisture would rise under landforms. Elevation of the hyporheic zone depended on soil particle size, the longitudinal dimension from upstream flow, the lateral dimension extending beyond channel boundaries, and a vertical dimension that resulted from the out-of-channel flow moving downward into the soil and groundwater. The hyporheic zone was at a higher elevation than the actual stream surface. Higher water tables created by incrementally higher base flows allowed riparian vegetation to grow and stabilize landforms at successively higher elevations.

Riparian seedlings became established in relation to a specific hyporehic zone associated with a specific base flow. A stable base flow steadied the water table level, and successful riparian vegetation growth depended on adequate soil moisture content above the water table throughout early plant growth phases (seedling, sprout, young plant).

Too high of an annual base flow in the gorge would have inundated landforms and drowned newly germinated riparian plants. Willow and cottonwood seedlings would not grow in standing water of any depth, and without developed root systems to hold them in place, landforms could not have withstood successively higher pulse flows. As a result, we did not change base flows in the gorge until vegetation had adequately secured landforms.

Determining annual pulse and base flows

How much pulse flow was too much if the objectives were to retain sediments, build landforms, and promote riparian vegetation throughout the gorge? The river was monitored during 10-day pulse flow periods as the discharge slowly increased. Sites and landforms particularly sensitive to erosion and sediment transport were the monitoring indicators. Pulse flows were allowed to rise to the level where incipient bank erosion began and/or fine sediments were transported no more than 1.5 river bends. At the point of erosion and/or excess sediment transport, we halted pulse flow rise, held the maximum flow for another day, and slowly ramped down to a preselected base flow. As restoration efforts proceeded, pulse flows were not allowed to become too far ahead of the base flow's ability to maintain new riparian vegetation.

A target base flow was selected each year before the pulse flow period. Base flows were selected to match the previous year's "set" of riparian vegetation to maintain new vegetation growth on landforms. Therefore, base flows had to maintain the hyporehic zone without inundating landforms on which riparian vegetation had been established. Annual base flow was determined as a function of the previous year's riparian growth and the number of sprouts (willow and cottonwood) and their relative positions on landforms. The previous year's pulse flow ideally set new vegetation farther from the streambank and higher on landforms. A one-year lag period existed between pulse flows that stimulated riparian seeding, and germination and measurement of sprouts. Thus, base flows were often held constant for two or more years as a guarantee that landforms had been secured by vegetation before moving to higher flows. Monitoring cross-channel transects and woody species provided the best information on sprout height, plant age structure, and distance from the water's edge.

Z. T. Hill

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Riparian habitat condition in the Owens River Gorge in 1991 (upper photo), the first year of rewatering, and in 1996 at a base flow of 26 cfs.

Microhabitat data were not used to establish pulse and base flows. Pool development may be accelerated with flows that scour and undercut streambanks, and create short-term physical habitat for brown trout. However, these high-velocity flows also could cause significant loss of landforms that had not been secured by riparian vegetation, and in the long-term fish habitat could be reduced.

During 1991 and 1992 a base flow of 16 cfs was released into the gorge to fill depleted aquifers and stimulate vegetation growth. To avoid erosion of landforms not yet secured by vegetation, the first pulse flows were not applied until May 1993. Each year since 1993 increasingly larger pulse flows have been released in late May or early June (depending on the stage of riparian seed development) for approximately 10 days. Incremental changes in base flows usually followed larger pulse flows but depended on the extent of riparian development on landforms. After each pulse flow release, we monitored vegetation on landforms and microhabitat response (Hill et al. 1994). Analysis of monitoring data was used as an adaptive management tool to determine the magnitude of next year's pulse and base flows.

Monitoring methods

Sampling sites

We selected 30 sampling sites for annual monitoring throughout the gorge (Figure 1). Sites that allowed the entire gorge reach to be typified were selected above, between, and below power houses. The six uppermost sites (Crowley Reservoir to Upper Gorge power plant) were reference (i.e., control) sites; these sites experienced relatively steady flow conditions and were not influenced by pulse flows or incremental flow increases as were the lower test sites. Reference sites provided a measure of environmental events that may have influenced microhabitat and riparian vegetation but were not due to changes in flow regime. Sample sites 25 through 30 were excluded from analysis due to confounding effects of water level fluctuations above Pleasant Valley Reservoir. Sample site 7 also was excluded from the study because of construction activity below Upper Gorge power plant.

Riparian vegetation

Riparian habitat was monitored at each of the sampling sites using methods described by the U.S. Forest Service (1991). We identified vegetation types according to physiognomic class (i.e., aquatic, forested, shrub, herbaceous, and substrate) and named them within a physiognomic class by the dominant plants in the tree or shrub stratum and by hydric status (e.g., wet, mesic, dry) (Table 2).

Table 2 shows classification of vegetation types and plant species by physiogonomic class used to describe riparian habitat throughout the Owens River Gorge.

Physiogonomic class	Vegetation type	Representative species
Herbaceous	Marsh	*Typha latifolia* *Scirpus* spp.
Herbaceous	Wet meadow	*Carex nebrascensis* *Carex* spp. *Juncus balticus* *Agrostis* spp. *Muhlenbergi* spp.
Herbaceous	Mesic meadow	*Poa pratensis* *Carex douglasii* *Carex praegrasilis* *Argrostis* spp. *Distichlis spicata*
Shrub	Willow/ wet meadow	*Salix exigua/wet meadow species* *Salix laevigata/* *Salix lutea/* *Salix lasiandra/*
Shrub	Willow/ mesic meadow	*Salix exigua/mesic meadow species* *Salix laevigata/* *Salix lutea/* *Salix lasiandra/*
Shrub	Rose	*Rosa woodsii* *Ribes* spp. *Rhus trilobata*
Shrub	Rabbitbrush/ meadow	*Chrysothakmnus nauseosus* *Distichlis spicata*
Tree	Cottonwood/ mesic meadow	*Betula occidentalis/mesic meadow species* *Populus tremuloides* *Populus tricocarpa* *Fraxinus latifolia* *Celtis* spp.

Microhabitat

Microhabitat monitoring tracked changes in variables that influence fish, especially pools, riffles, substrate, canopy, bank conditions, and organic debris. We defined microhabitat using 19 stream variables that create site-specific habitat for fish and describe channel morphology (Table 3). Microhabitat was monitored at each gorge site with stream cross-sectional methods described by Platts et al. (1983).

Fish populations

Fish were monitored by direct underwater observation in the late summer (typically in August during the nonmigatory residence phase of brown trout). Underwater observation by snorkeling is a quick, inexpensive, and nondestructive census method that is not limited by deep, clear, nonconductive water. Several studies (e.g., Hicks and Watson 1985; Zubik and Fraley 1988; Thurow 1994) have shown snorkeling to be an unbiased census technique. Underwater methods followed those described by Thurow (1994), with electrofishing calibration using methods described by Hillman et al. (1992). In addition to snorkel surveys, we performed controlled creel surveys (Platts and Hill 1997) in the spring and fall to assess catch rates.

Table 3 describes statistics of continuous macrohabitat variables measured at reference and test sites in 1993 and 1997 in the Owens River Gorge. Probability values of the Wilcoxin Signed Rank test are given.

	Reference sites 1 through 6					Test sites 8 through 24				
	1993		1997			1993		1997		
Variable	Mean	SE	Mean	SE	P-value	Mean	SE	Mean	SE	P-value
Channel width (m)	9.13	0.66	9.15	0.71	0.312	10.45	1.03	10.66	0.99	0.002
Wetted width (m)	3.87	0.47	3.94	0.49	0.610	8.08	0.87	8.30	0.74	0.002
Riffle width (m)	0.39	0.27	0.36	0.06	0.051	1.75	0.39	0.63	0.18	0.000
Run width (m)	2.25	0.38	2.11	0.33	0.118	3.18	0.45	5.80	0.50	0.000
Pool width (m)	1.23	0.34	1.47	0.36	0.020	3.16	0.97	1.86	0.52	0.483
Boulder substrate (m)	0.90	0.27	0.97	0.28	0.070	2.08	0.30	2.66	0.29	0.000
Cobble substrate (m)	0.97	0.29	0.68	0.18	0.001	1.50	0.35	0.81	0.19	0.000
Gravel substrate (m)	0.34	0.19	0.49	0.18	0.002	0.80	0.23	1.03	0.17	0.000
Fine substrate (m)	1.66	0.49	1.80	0.47	0.129	3.67	1.03	3.78	0.76	0.001
Right bank angle (deg)	115.42	2.33	126.22	2.02	0.082	118.89	1.60	126.08	1.47	0.028
Left bank angle (deg.)	109.58	2.74	125.78	1.91	0.208	122.38	1.57	124.97	1.55	0.051
Average depth (m)	0.35	0.32	0.37	0.31	0.005	0.34	0.28	0.40	0.25	0.000
Thalweg depth (m)	0.48	0.42	0.52	0.47	0.001	0.48	0.36	0.62	0.36	0.000
Right bank vegetation overhang (m)	0.44	1.92	0.20	1.24	0.013	0.28	0.67	0.28	0.78	0.033
Left bank vegetation overhang (m)	0.25	0.88	0.24	1.27	0.168	0.43	1.46	0.46	1.50	0.517
Canopy cover (%)	13.64	1.57	13.33	1.72	0.000	25.67	1.65	26.00	1.52	0.000
Organic debris (%)	19.11	1.77	30.11	1.67	0.000	32.12	1.44	20.92	1.01	0.000
Right bank undercut (m)	0.05	0.35	0.04	0.08	0.001	0.05	0.30	0.02	0.20	0.000
Left bank undercut (m)	0.07	0.42	0.05	0.09	0.002	0.04	0.23	0.04	0.32	0.811

Riparian and channel habitat complexity

Relatively low pulse flows were used intentionally to provide seed transport, germination, and hyporheic zone recharge while minimizing scour effects such as erosion and sediment transport. The effects on microhabitat and channel features from low pulse flows and the incremental increase in base flow can be seen in Table 3. Except for canopy cover and organic debris (due to vegetation growth), reference sites did not exhibit any significant changes in microhabitat variables (Table 3). Most microhabitat features at the test sites changed significantly ($P < 0.001$) from 1993 to 1997 (Table 3). These changes were the result of a combination of some scour during pulse flows and increasing the base flow from 16 cfs in 1993 to 26 cfs in 1996. While most of the microhabitat changes were statistically significant, the magnitude of the changes were small. Microhabitat features such as pool and run width, and thalweg and average depth—all dependent on high-flow scour—exhibited significant but not dramatic change. The higher water surface level in 1996 caused a significant decrease in riffle and pool width as run width increased (Table 3).

Microhabitat is a direct measure of fish habitat conditions and geomorphological change. However, increasing fish habitat complexity from 1991 (when the gorge was a dry channel) to 1997 was due more to riparian vegetation than microhabitat or geomorphological change.

Pulse flow effects also can be seen in vegetation data. Cross-channel transect data (Table 4) for willow cottonwood and other woody plant species show that riparian vegetation growth at the test sites was better under flow management than at reference sites. The greatest increases in riparian vegetation occurred in 1994 (one year after the first pulse flow) and 1997.

The response of riparian plants to disturbances such as pulse flows in the initial recovery stage (1994 in the gorge) is typically rapid (Gecy and Wilson 1990) and is followed by less-dramatic but steady seasonal growth (McBride and Strahan 1984). In 1995 and 1996 riparian growth in the Owens River Gorge was less dramatic than in 1994 and 1997. In 1997 riparian vegetation again increased dramatically as additional landforms became vegetated with higher pulse flows. In comparison with reference sites, riparian vegetation at test sites increased each year as a consequence of pulse flows (Figure 2). Photo points also indicate an annual increase in biomass of riparian vegetation.

The effect of flow management on riparian vegetation by landform can be seen in Table 5. Streambank landforms at test sites exhibited the greatest diversity in riparian plant communities reflecting early to mid-seral stages and succession. The dominant vegetation type on streambank landforms at the test sites was 58% boulder and herbaceous boulder bar. Vegetation types on streambank landforms at the reference sites were in the late seral stages and had reached final plant succession. The dominant riparian vegetation type on reference site streambanks was willow/mesic meadow.

Vegetation types on floodplain landforms at test sites were 76% herbaceous sandbar, willow/wet meadow, and mesic meadow, respectively (Table 5). Reference site floodplains supported 73% marsh-type vegetation. While it appears that floodplains at test sites were developing diverse riparian communities, it is too early to determine whether the late seral stage will consist of mostly mesic meadow like reference sites or retain a mix of willow/wet meadow and mesic meadow.

Terrace landforms (the highest elevation landform) at test sites were more than 56% rabbit and sage brush (xeric

Table 4 lists number of woody species (cottonwood, willow, birch, rose) by life stage measured in 1994 and 1997 at reference and test sites in the Owens River Gorge. Probability values of the Wilcoxin Signed Rank test are given.

Vegetation	Reference sites 1 through 6			Test sites 8 through 24		
Life stage	1994	1997	P-value	1994	1997	P-value
Sprout	174	116	0.020	60	308	0.000
Young	243	284	0.105	152	733	0.000
Mature	163	192	0.382	108	622	0.000
Decadent	51	55	0.877	3	53	0.000
Dead	32	23	0.095	0	24	0.000

plant types), while reference site terraces were 73% willow/mesic meadow (Table 5). However, it is important to note that more than 27% of terraces at test sites supported riparian grasses and shrub willow vegetation. This is particularly important since pulse flows had not been of sufficient magnitude to inundate large areas of terrace landforms. Nevertheless, riparian vegetation was established on these highest elevation landforms, indicating that groundwater associated with base flows influenced riparian vegetation on terraces. Terraces at the reference sites also were not subject to pulse flows but were mostly vegetated with willow and mesic meadow, thus it is reasonable to expect that terraces at the test sites will at least mimic reference sites in time.

Willows quickly out-competed tules *(Scirpus* spp. and *Typha* spp.) as vegetated landforms developed. Tules on slightly submerged landforms initially slowed pulse flows and caused significant deposition of sediments, but as landform elevation exceeded adjacent water surface elevation, willows established and rapidly grew to out-compete tules. Young willow and cottonwood represented the age class at one year after a pulse flow. Growth of willows and cottonwoods was rapid in the gorge and compared favorably with, but slightly lower than growth rates at reference sites (Table 6).

By the third year of growth, willows in the gorge produced viable seeds, adding to the reproductive potential of the whole ecosystem. Cottonwoods generally require four years to reach maturity.

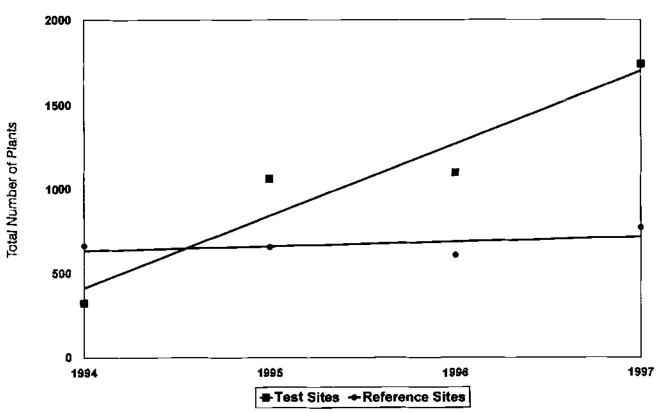

Figure 2 illustrates results of trend analysis of riparian plant (willow, cottonwood, birch, rose) numbers at Owens River Gorge reference sites 1–6 (r^2=0.56) and test sites 8–24 (r^2=0.95).

The combination of increasing pulse and base flows, the establishment and rapid growth of riparian vegetation on all landforms, and increasing microhabitat features (pools, runs, depth, and wetted width) has resulted in extremely complex habitat throughout the gorge. Small-diameter, woody limbs of willows in the water column; overhanging vegetation; deeper pools; and undercut banks all provided excellent cover for fish, and brown trout have responded to greater habitat complexity with increasing population and biomass.

Fish response

The river below the Upper Gorge power plant was stocked with approximately 30,000 brown trout in 1994. Some rainbow trout (*Oncorhynchus mykiss*), Owens sucker (*Catostomus fumelventris*), speckled dace, and Owens tui chub occur in the gorge, but the dominant fish species is brown trout.

Snorkel surveys performed in 1995, 1996, and 1997 correlated well with electrofishing (r values of 0.74 to 0.85, $P < 0.05$). Brown trout numbers have increased each year since stocking (Figure 3), which indicates that, so far, spawning and recruitment is not limiting, and annual mortality is low. A healthy fishery in good condition has quickly developed in response to restoration efforts.

Electrofishing data from three sites were used to estimate annual brown trout populations (Van Deventer and Platts 1989). The brown trout population in the gorge increased by approximately 40% from an estimated population of 1,815 trout/mile in 1996 to almost 3,000 trout/mile in 1997. Creel survey results indicated catch rates increased from 0 fish/hr in 1991 to between 5.8 and 7.1 fish/hr (with a maximum catch rate of 15.7 fish/hr) in 1996.

Brown trout were able to spawn and maintain healthy size structure (Figure 3), which indicates that fish habitat criteria for different life stages were met. Limiting conditions (spawning, rearing, food competition, predation, etc.) are hypothesized to be eased as a function of habitat response to each incremental increase in pulse and base flows. As flows increased, more spawning, rearing, and escapement habitat was created; riverine-riparian habitat complexity increased; and the food base expanded proportionally. Brown trout distribution throughout the gorge (Figure 5) followed changes in habitat complexity. Riparian habitat, channel configuration, and microhabitat conditions became increasingly complex from upstream to downstream. Brown trout distribution followed this trend, exhibiting increasing numbers of trout that used the increasingly complex and diverse downstream habitat.

A river ecosystem restored from a dysfunctional to functional state may or may not produce a large number of big fish. Every stream has a unique carrying capacity with natural limitations inherent in its functional state that dictate fish numbers and size. Depending on the restoration goal, fishery success can be measured in many ways. Success may be a blue-ribbon trout fishery, a self-sustaining population with adequate recruitment, growth and age distribution, and low mortality rates, or a healthy population with high endemic species biodiversity. However, fishery success may not be the functional endpoint of restoration. Kauffman et al. (1997) state that because an entire suite of organisms, physical features, and processes comprise an ecosystem, a species-only or single-process approach to restoration will likely fail.

Restoration endpoint

Restoration of the Owens River Gorge is an ongoing process, but managers must begin focusing on how to identify the endpoint and final flow regime necessary to sustain the gorge ecosystem. Common endpoints used in assessing the recovery of river systems are divided into either biotic or abiotic resources.

Milner (1994) describes structural and functional endpoints for biotic resources and habitat and water quality endpoints for abiotic resources. *Structural endpoints* cover community assemblages with such attributes as density, number of species, species diversity, etc., and typically involve comparison with the predisturbance condition or a reference community. *Functional endpoints* refer to the functioning of the community (for example, species equilibrium) and may be evaluated independently of a reference community. An ecosystem, however, is generally regarded as a synergistic unit that comprises both biotic and abiotic resources, thus it is impossible to consider a community in isolation from the environment in which it exists.

Table 5 shows riparian vegetation types and percent of total vegetated area measured on landforms at test and reference sites in 1997 in the Owens River Gorge.

Vegetation type	Description	Landforms in Test Sites 8–24				Landforms in reference sites 1–6			
		Stream-bank	Flood-plain	Terrrace	Island	Stream-bank	Flood-plain	Terrace	Island
Streambar									
Silt-muck bar	Dominant substate silt-muck	0	0	0	0	0	0	0	0
Herbaceous siltbar	>30% vegetation cover	0	0	0	0	0	0	0	0
Sandbar	Dominant substrate sand	0.3	3.5	0	0	0	0	0	0
herbaceous sandbar	>30% vegetation cover	8.5	35.6	8	56	0	0	0	0
Gravelbar	Dominant substrate gravel (<2")	1.1	0	0.5	0	0	0	0	0
Herbaceous gravelbar	>30% vegetation cover	1.5	0	0	0	0	0	0	0
Cobblebar	Dominant substrate cobble (2"–12")	0.7	0	0.2	0	0	0	0	0
Herbacous cobblebar	>30% vegetation cover	1.5	0	0.4	0	1.5	0	0	0
Boulderbar	Dominant substrate boulder (>12")	31.8	0	1.7	14	5	0	0	0
Herbaceous boulderbar	>30% vegetation cover	26.1	9.1	5.2	14	16.2	0	0	0
Eroded bank	Eroding streambank	0	0	0	0	0	0	0	0
Herbaceous									
Marsh	Bullrush, cattail, reed grass	0	2.9	0	0	0	72.7	0	0
Wet meadow	Sedges	0.3	3.1	0	0	0.5	5	1.6	100
Mesic meadow	Riparian grasses	1.3	18.9	13.7	0	4.2	6.1	0.6	0
Riparian shrub									
Willow/wet meadow	Willow with sedges	0.2	21.6	0	0	0.4	3.8	0	0
Tree willow/wet meadow	Willow with ruoarua grasses/forbes	0	0	0	0	0	0	0	0
Tamarisk/wet meadow	Tamarisk with sedges	0	0	0	0	0	0	0	0
Willow/mesic meadow	Shrub willow with riparian grasses/forbs	9.8	5.1	13.7	6	45.9	8.7	73.6	0
Tree willow/mesic meadow	Trunky willow	0	0	0	0	0	0	0	0
Tamarisk/mesic meadow	Tamarisk with other non-willow shrubs	0.2	0	0	0	14.1	3.5	7.4	0
Rose	Rose with other (non-willow) shrubs	0.2	0	0	0	14.1	3.5	7.4	0
Upland shrub									
Rabbit brush/sage	Terrestrial brush/sage	16.6	0	56.5	0	12.3	0	16.7	0
Riparian tree									
Cottonwood/mesic meadow		0	0	0	0	0	0	0	0

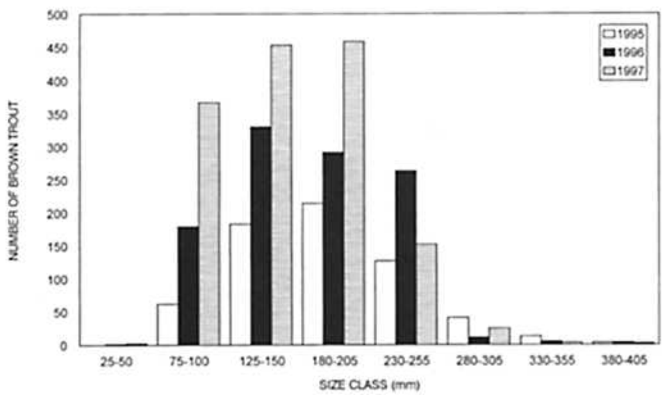

Figure 3 shows length-frequency distribution of brown trout from 1995 to 1997 snorkel surveys in even numbered test sites in the Owens River Gorge.

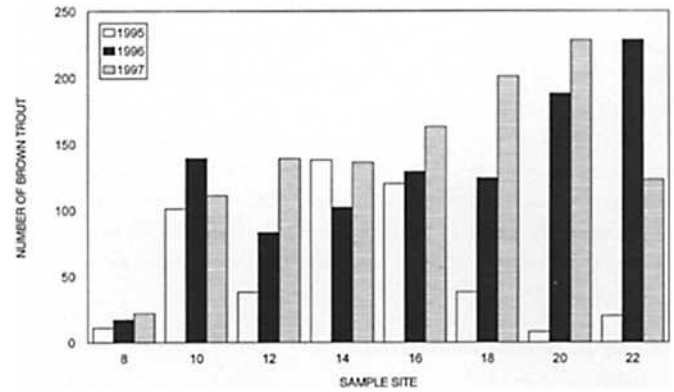

Figure 4 reports distribution of brown trout by sample site from 1995 to 1997 snorkel surveys in even-numbered test sites in the Owens River Gorge.

A critical question regarding restoration endpoint is whether the structural and functional endpoints of a recovered community can be maintained without constant management. Cairns (1990) argued that unless a self-sustaining community based on natural reproduction, succession, and adaptation is attained, system restoration has not been achieved.

Experience gained from the Owens River Gorge restoration effort shows there are several possible endpoints. The gorge ecosystem can be made functional at many different flow levels, depending on the degree to which vacant landforms are vegetated with pulse flows and maintained with base flows. At a given flow regime, riparian habitat, in-channel habitat, stream morphology, and brown trout populations will eventually reach an asymptote. Biotic and abiotic resources will tend toward steady conditions that fluctuate around predictable means; eventually the ecosystem will become a self-sustaining community based on natural reproduction, succession, and adaptation. This level of restoration may be different from historical conditions and may be far below the ecosystem's maximum potential. It is apparent that careful identification of goals, with measurable and achievable endpoints, must be the first step in restoration planning.

Conclusions

After five years of natural restoration, the Owens River Gorge ecosystem has made a rapid comeback to a functional ecosystem capable of sustaining a productive fishery and riparian biota. The river ecosystem has responded so well to incremental base and pulse flows that it has been possible to implement pulse flows twice as high as originally planned (Table 1). On the other hand, to provide adequate growing time for riparian vegetation and to secure landforms, base flows have not been increased as rapidly as originally planned (Table 1).

The key to ecosystem recovery and sustainable biota in the gorge is a multiple-flow regime that allows nature to build and maintain riparian habitat. Monitoring results in the Owens River Gorge validate the approach used: incrementally restoring a riverine-riparian structure for the river to "hold on to" at high flows. We are meeting our original restoration goal by retaining sediments that annually build streambanks and vegetation near the water's edge.

Table 6 illustrates average annual maximum and minimum growth of young age-class willow and cottonwood vegetation at reference and test sites in the Owens River Gorge, 1993–1997.

Year	Test sites 8–24		Reference sites 1–6	
	Minimum Growth (m)	Maximum Growth (m)	Minimum Growth (m)	Maximum Growth (m)
1993	0.7	1.5	0	1.6
1994	0.9	1.5	0.5	1.3
1995	0.6	1.8	0.5	1.4
1996	0.5	1.9	0.5	1.6
1997	0.5	1.8	0.7	1.5

Acknowledgment

We thank the Los Angeles Department of Water and Power for its generous support beyond just research funding. We especially thank George Brodt and Brian Tillemans for their helpful reviews and constructive ideas throughout the study.

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