WATER RELATIONS OF OBLIGATE RIPARIAN PLANTS AS A FUNCTION OF STREAMFLOW DIVERSION ON THE BISHOP CREEK WATERSHED[1]

Stanley D. Smith, Janet L. Nachlinger, A. Bruce Wellington, and Carl A. Fox[2]

Abstract: We investigated the water relations of obligate riparian plants on paired diverted and undiverted reaches on Bishop Creek, Eastern Sierra Nevada. Riparian plants on diverted reaches had reduced stomatal conductance and water potential compared to plants on undiverted reaches in a dry year, but not in a high runoff year. Juvenile plants on diverted reaches had reduced stomatal conductance and lower midday water potentials relative to surrounding mature trees, a trend that was not observed on undiverted reaches. Plants on diverted reaches possessed significantly smaller, thicker leaves and a reduced total leaf area relative to trees on streamside reaches. Reduced community leaf area and effective stomatal control of water loss may allow riparian corridors on diverted reaches to retain their canopies in low runoff years. However, a long term consequence of partial streamflow diversion may be selective mortality of juvenile plants because of the elimination of floods and high flows.

Riparian plant communities in the semi-arid western U.S. occur in transition zones between aquatic andupland ecosystems, and are characterized by vegetation types that are adapted to, and tolerant of, relatively high soil moisture content (Swift 1984). Riparian plants have been thought to depend largely on flowing water rather than on groundwater, which separates them functionally from phreatophytes.

Riparian woodlands represent one of the most heavily modified vegetation types in the western U.S., having been reduced in area by more than 80% since presettlement times (Swift 1984). In California, riparian ecosystems are under considerable pressure as a result of increased needs for water and power. These ecosystems may also be highly dependent on streamflow because of the semiarid climate and predictable summer dry season which is characteristic of the region.

The primary objective of the present study was to analyze the water relations of riparian vegetation along Bishop Creek on the eastern slope of the Sierra Nevada Mountains, where a series of streamflow diversions have been in existence since the early 1900's. We wished to determine if streamflow diversions influence plant water relations, patterns of water use, and differential mortality of individuals at key life stages. We have examined daily and seasonal patterns of plant water potential, stomatal conductance and transpirational water loss of adults and juveniles of the dominant riparian species to determine how these patterns may be affected by streamflow diversion.

Materials and Methods

Study Sites and Species

Physiological observations of riparian vegetation on the east slope of the Sierra Nevada were conducted on Bishop Creek, Inyo County, California. Bishop Creek has a well defined series of streamflow diversions, including three catchment lakes, two primary intakes, and five power stations (Fig. 1). Two primary sites of differing elevation were selected for study (Fig. 1). One site, called the Four Jeffrey Site, was located below the Intake 2 South Fork diversion near the U.S. Forest Service Four Jeffrey campground (37° 15' N, 118° 36' W, 2465m). A second site, called the Plant Six Site, was located along the lowermost stretches of Bishop Creek at Southern California Edison Plant Six (37° 21' N, 118° 28' W, 1400 m). Zonal (upland) vegetation adjacent to the two sites was dominated by sagebrush (*Artemisia tridentata*) at Four Jeffrey and a mixed community of Mojave Desert shrubs at Plant Six. Each site was selected so as to include riparian vegetation growing in a streamside environment and in a reduced or diverted streamflow environment. At Four Jeffrey, this entailed comparing a streamside reach with a dry channel located about 100m from the creek that had a riparian corridor. At Plant Six, paired sites we re-selected above (diverted) and below (undiverted) the power station.

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[2] Assistant Professor Department of Biological Sciences, University of Nevada- Las Vegas, Las Vegas, Nev.; Staff Ecologist and Executive Director, respectively and Biological Sciences Center, Desert Research Institute, Reno, Nev.; and Research Fellow Ecosystem Dynamics Research Group, Research School of Biological Sciences, Australian National University, Canberra, Australia.

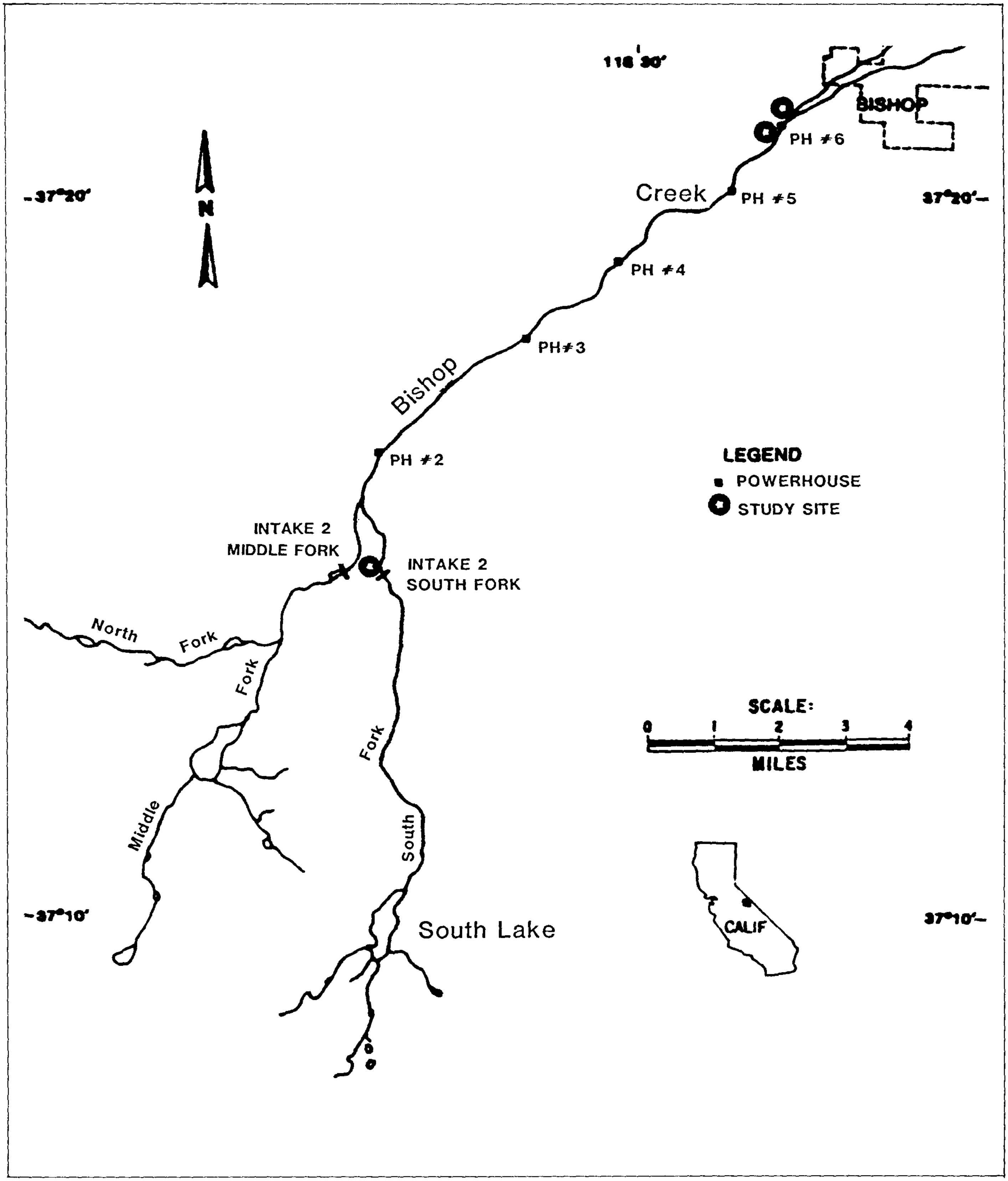

Figure 1— The Bishop Creek Watershed, showing the South, Middle and North Forks (left to right, top) merging into a single channel. A primary pair of intakes (Intake 2) divert water to a series of hydroelectric generating station (Plant 2 - Plant 6). The primary study sites were Four Jeffrey, located below Intake 2 (top), and Plant Six (bottom).

Three dominant riparian plant species were selected for measurement on Bishop Creek: water birch (*Betula occidentalis* Hook.); black cottonwood (*Populus trichocarpa* T. & G.); and Fremont cottonwood (*Populus fremontii S.* Wats. ssp. *fremontii*). All three taxa are obligate riparian plants in the region. *Populus trichocarpa* only occurred at higher elevations on Bishop Creek, including the Four Jeffrey site, whereas *P. fremontii* only occurred at lower elevations, including the Plant Six site. Observations were also made on willows (*Salix* spp.).

For each species at the two paired study sites on Bishop Creek (Fig. 1), three adult individuals and three juveniles were chosen for measurement. Adults were at least 3m in height, whereas juveniles were either saplings or vegetative suckers less than lm tall. When present, first year seedlings were also monitored.

Measurements were made approximately monthly at Bishop Creek, from July to September 1985 and from May to September 1986.

Plant Water Relations and Morphology

Diurnal patterns of stomatal conductance, transpiration, and the microclimate of selected leaves were determined for the sample plants at a paired site on a given day. Measurements were made at 60 to 90 minute intervals with a Lambda Instruments LI-1600 steady state porometer (LI-COR, Lincoln, Neb.) Abaxial leaf surfaces were measured on two leaves of each plant and comparative readings of adaxial and abaxial leaf surfaces were made periodically. Incident photon flux density was measured for individual leaves with a Lambda Instruments LI-190S quantum sensor. Plant water potentials (xylem potentials) were obtained for two to three leaves or shoots from each tagged individual both before dawn and at midday (1200 to 1300 h) with a portable pressure chamber apparatus (Soil Moisture Equip. Corp., Santa Barbara, Calif.).

In September 1986, twenty shoots (ca. 25 cm in length) were randomly harvested from each adult at the two sites on Bishop Creek. Shoots were stored in sealed bags on ice. Leaves on each shoot were counted, shoot lengths were measured, and total leaf area per shoot was measured with a Lambda Instruments LI-3000 leaf area meter. Dry weight of leaves and stems was determined after oven drying plant material at 80°C for 48h.

Results and Discussion

Mean monthly streamflows during the growing seasons of 1985 and 1986 for key reaches of Bishop Creek are given in Table 1. On the upper Bishop Creek watershed, streamflows above the diversion intakes were 0.6 to 1.3 m^3/sec (20-40 cubic feet per second) in 1985 and 1.1 to 3.0 m^3/sec (30-100 cfs) in 1986.

Table 1 - Mean monthly streamflow (in m^3 sec) for the Bishop Creek watershed during the 1985 and 1986 growing seasons. Sites are shown in Fig. 1. All flows above Intakes and below Plant Six are undiverted.

		Streamflow					
Date	Site	Apr	May	Jun	Jul	Aug	Sep
1985	Above Intakes*	1.12	1.33	0.63	0.77	0.97	0.87
	Four Jeffrey	0.08	0.30	0.10	0.10	0.07	0.11
	Above Plant Six	0.12	0.30	0.03	0.03	0.003	0.006
	Below Plant Six	4.16	4.68	4.29	3.81	3.32	2.92
1986	Above Intakes*	1.30	1.60	2.61	3.01	2.03	1.13
	Four Jeffrey8	0.11	1.06	1.69	2.20	1.28	0.08
	Above Plant Six	0.03	2.40	6.26	5.18	2.23	0.08
	Below Plant Six	9.06	9.23	9.13	9.06	9.06	8.13

*Mean value for Middle and South Forks of Bishop Creek.

The Four Jeffrey Site, located below the South Fork diversion, exhibited a streamflow of less than 0.1 m^3/sec throughout most of 1985 but about 1-2 m^3/sec in 1986. The dry creek at Four Jeffrey had no observable flows during any of our measurement periods, but based on the presence of a well-developed riparian corridor we can assume it had maintained perennial flow in the past.

Water that is diverted from Bishop Creek and pumped through power plants 2-6 (see Fig. 1) re-enters Bishop Creek below Plant Six. At the Plant Six undiverted reach (below the power station), streamflows averaged 3.9 m^3/sec (120 cfs) in 1985 and 9 m^3/sec (280 cfs) in 1986. In contrast, streamflows in the diverted reach above Plant Six averaged 0.08 m^3/sec (2.5 cfs) in 1985 and 2.7 m^3/sec (100 cfs) in 1986. High flows at the diverted site did not cease until early September in 1986. A comparison of these flows with past records for the whole watershed indicates that 1985 was a low flow year and 1986 was a high flow year.

Seasonal trends in maximum (predawn) and minimum (midday) water potentials are shown for *Betula occidentalis* at Four Jeffrey (Fig. 2), and *Populus fremontii* at Plant Six (Fig. 3).

Minimum water potentials were obtained around midday (1200-1300 h), based on representative diurnal curves of plant water potential (data not shown). A comparison of these data sets suggest the following trends: (1) both predawn and midday water potentials tended to be lower in the low flow year than in the high flow year; (2) minimum water potentials tended to be lower on diverted than on undiverted reaches, a pattern which was not observed for predawn water potentials; and (3) there were no consistent differences in water potentials between adult and juvenile plants of the same species.

Although no predawn water potentials that could be interpreted as stressful were observed in either year, minimum water potentials reached -1.2 MPa or lower in several species.

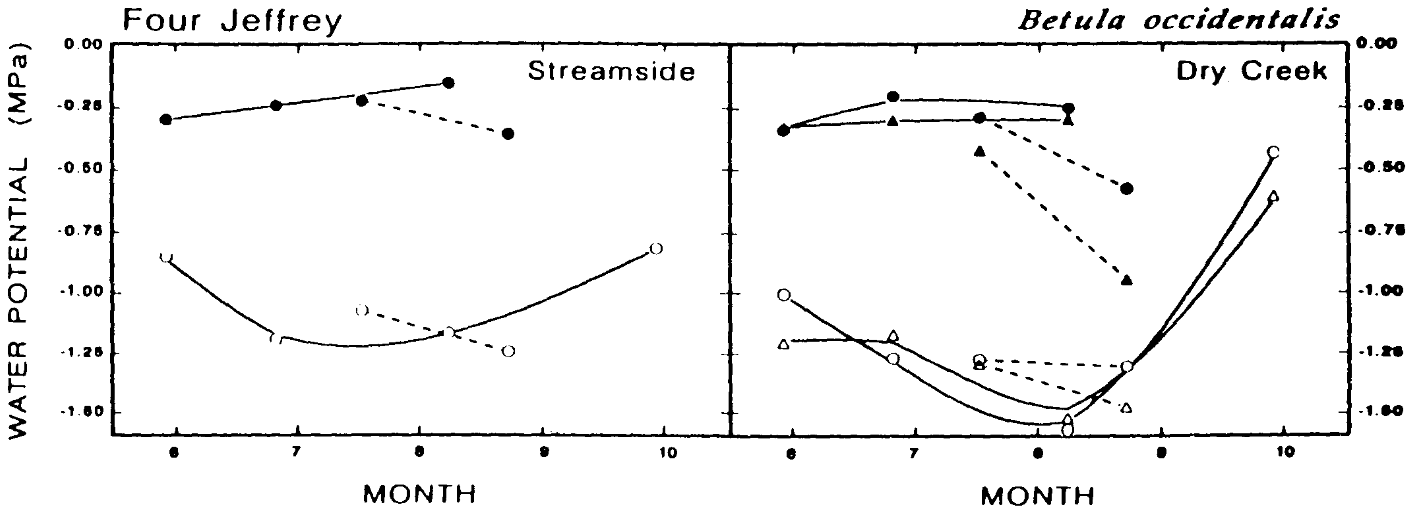

Figure 2— Seasonal patterns in plant water potential (xylem potential) for *Betula occidentalis* at the Four Jeffrey site. Data are for the growth seasons of a high flow year (solid lines) and a low flow year (dashed lines) for both adult (circles) and juveniles (triangles) plants. Water potentials were obtained at predawn (solid symbols) and at midday (open symbols).

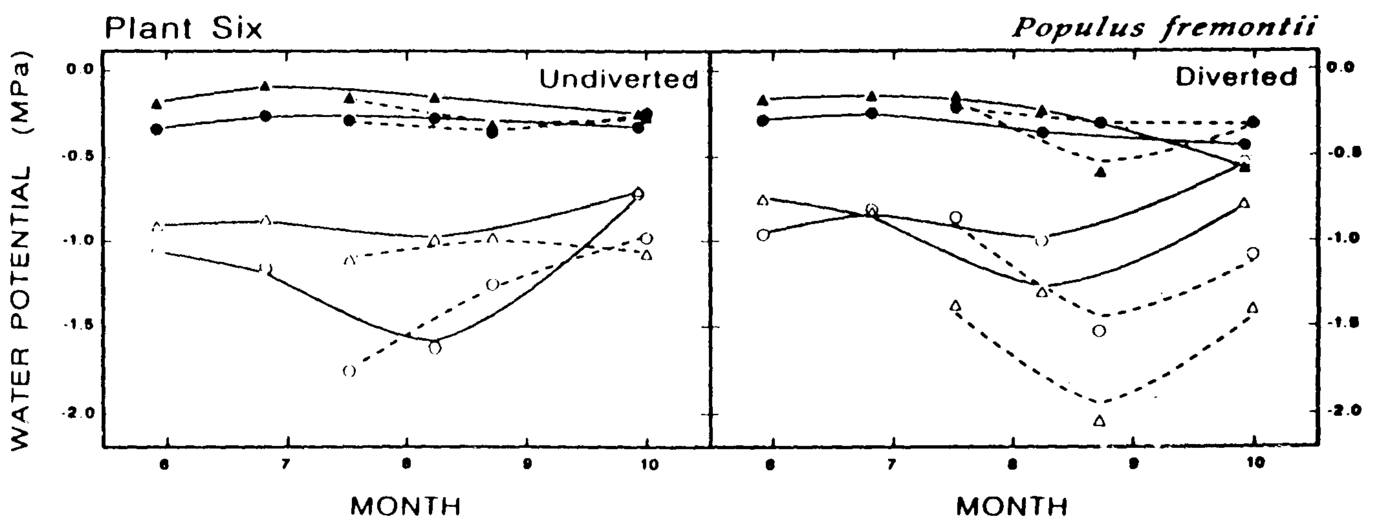

Figure 3— Seasonal patterns in plant water potential (xylem potential) for *Populus fremontii* at the Plant Six site. Legends are as in Fig. 2.

This was particularly the case on diverted reaches in the low flow year. Woodhouse (1983) observed *P. trichocarpa* and *Salix laevigata* to reach photosynthetic compensation at about -1.2 MPa, while Schulte and coworkers (1987) found *P. trichocarpa* to exhibit bulk leaf turgor loss at about -1.4 MPa. *Betula occidentalis* and *P. fremontii* both reached minimum water potentials below -1.5 MPa in late summer, but only on diverted reaches (Figs. 2 and 3). Several juveniles of *P. fremontii* reached water potentials below -2.0 MPa on the diverted reach at Plant Six in August of the low flow year. Such levels of water stress would certainly be anticipated to adversely affect carbon balance of these young plants, and may result in selective mortality in the regenerating population.

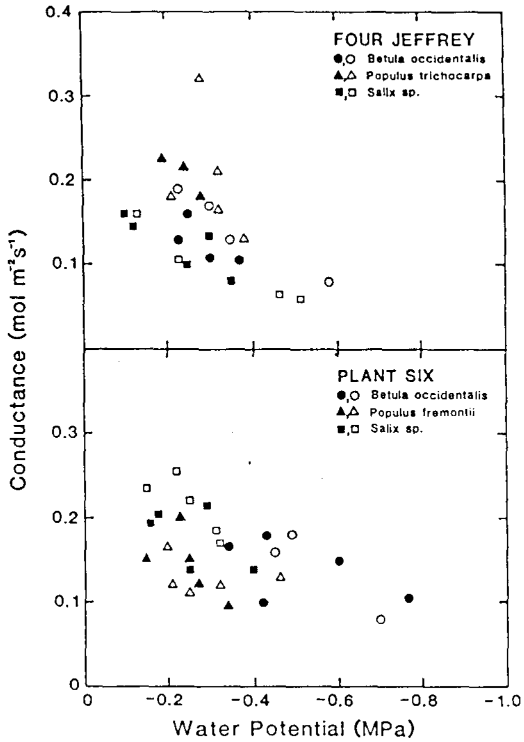

Figure 4– Diurnal patterns in stomatal conductance of *Betula occidentalis* (top) and *Populus trichocarpa* (bottom) at the Four Jeffrey site in August of the low flow year. Closed and open symbols designate undiverted and diverted reaches, respectively, for adult (circles) and juvenile (triangles) plants.

Similar seasonal and diurnal courses in stomatal conductance within a given species were found on diverted and undiverted reaches during much of the growth season. Variations occurred only during times of dry weather and low flow, as shown for *B. occidenialis* and *P. trichocarpa* in August of the low flow year (Fig. 4).

Mature plants on the diverted reach showed much lower conductance than did plants from the undiverted reach through a majority of the day, but particularly after about 1000 h. Furthermore, juvenile plants showed even greater reductions in conductance on the diverted reach. Similar reductions were not observed at the Plant Six site, possibly because small flows were maintained on the diverted reach even during the driest months of the year (Table 1). However, we monitored several first-year seedlings of *P. fremontii* on the diverted reach and found stomatal conductances in these plants during the midday period to be only 10-20% of that observed in older juveniles and mature plants.

Comparative plant morphologies of *B. occidentalis, P. fremontii,* and *P. trichocarpa* on paired diverted vs undiverted reaches are given in Table 2 for plant samples harvested at the end of the growth season in the high flow year. Plants on diverted reaches produced significantly smaller leaves at reduced leaf area, and had higher specific leaf weights relative to plants on undiverted reaches. Similar trends were observed in adult and juvenile plants of each species. In some cases the morphological differences between paired sites were substantial.

Table 2—Comparative morphology of riparian plants on paired undiverted and diverted reaches at two sites on Bishop Creek. Harvests were taken late in the growth cycle of a high flow year. (*) Indicates a significant difference (t-test; p=0.05) between paired undiverted-diverted sites for each parameter. Total leaf area was not recorded for juveniles.

			Individual leaf area (cm^2)		Leaf area/branch length ($cm^2 \cdot cm^{-1}$)		Specific leaf weight ($mg \cdot cm^{-2}$)	
			Undiverted	Diverted	Undiverted	Diverted	Undiverted	Diverted
Betula occidentalis	Four Jeffrey	Adults	9.93	4.68*	5.17	3.22*	4.61	6.44*
		Juveniles	9.66	4.70*			4.61	6.08*
	Plant Six	Adults	8.50	6.78*	4.35	3.51*	6.56	9.35*
Populus trichocarpa	Four Jeffrey	Adults	25.28	20.97*	15.20	11.84*	6.08	9.60*
		Juveniles	16.63	14.69			6.24	11.77*
Populus fremontii	Plant Six	Adults	19.58	6.39*	8.67	2.85*	10.86	8.64*
		Juveniles	15.24	9.94*			11.65	10.51

In summary, we conclude that streamflow diversions may remove water normally available to shallow-rooted juvenile plants, while deep-rooted mature trees remain largely unaffected. Thus, it is doubtful that partial diversion of streamflows will result in substantial mortality of the riparian corridor over the short term. However, its more long term consequence could be the elimination of floods and high flows which stimulate regeneration and full canopy development of the riparian corridor.

For example, *B. occidentalis* exhibited a mean 52% reduction in leaf size on the diverted reach at Four Jeffrey, and *P. fremontii* exhibited three-fold higher total leaf area per unit stem length on the undiverted reach at Plant Six (Table 2).

Conclusions

A majority of our observations on mature trees showed few substantial differences in the water relations of riparian vegetation on diverted and undiverted corridors. One reason for this is an apparent morphological adaptation of the vegetation on diverted reaches to reduced flow regimes. As a result of a reduced community leaf area, these corridors should exhibit lower transpirational water loss under similar microclimatic conditions. Thus, effective stomatal control of water loss in concert with reduced community leaf area may allow the canopy to be retained during drought periods or in years of very low flow. Of primary importance in the physiological ecology of whole populations is the regeneration phase. Several studies have shown a shift in the age structure of riparian populations as a result of an inhibition of seedling establishment (Johnson et al. 1976; Boles and Dick-Peddie 1983). On Bishop Creek the absence of normal spring flooding due to control of streamflows may result in more xeric conditions for tree seedlings later in the summer and thus reduced seedling establishment. Our findings of increased stress in juvenile plants along diverted reaches suggests that lower, more controlled flow regimes may be detrimental to the regeneration process in these corridors. Indeed, we observed several cohorts of seedlings which did not survive the low flow year. Not surprisingly, many of these corridors with a history of streamflow diversion have been invaded by facultative riparian shrubs such as *Artemisia tridentata* and *Rosa woodsii.*

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