

## Chapter 7

## *Effects of Geomorphic Processes and Hydrologic Regimes on Riparian Vegetation*

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The degradation of riparian areas results in changes in the composition, pattern, and areal extent of riparian vegetation (Stromberg 2001). In the central Great Basin, as in other semiarid regions, riparian ecosystems exhibit widespread degradation. Restoration and management of these riparian areas require an understanding of (1) the causes of disturbance and (2) the relationships among riparian vegetation and geomorphic and hydrologic processes (Goodwin et al. 1997). Although the degradation of riparian areas often has been attributed largely to anthropogenic disturbance, in arid and semiarid regions both past and present climate strongly influence geomorphic and fluvial processes and, thus, riparian vegetation. In upland watersheds of the central Great Basin, climate-driven changes in hillslope and fluvial processes that occurred during the mid- to late Holocene are still affecting the composition and pattern of riparian vegetation over a broad range of scales. Of major significance was a period of extended drought that occurred between 2500 and 2000 YBP. Consequences of the drought include the erosion and depletion of hillslope sediment reservoirs, and the subsequent aggradation of valley bottoms and expansion of side-valley alluvial fans (Miller et al. 2001; chapter 3). The depletion of hillslope sediments has resulted in streams that are currently sediment limited and, thus, have a natural tendency to incise. The expansion of side-valley alluvial fans has resulted in stepped valley profiles that often are related to abrupt changes in the morphology, hydrology, and vegetation of associated valley segments and stream reaches. The rate, magnitude, and pattern of stream incision differ among watersheds and depend

largely on basin sensitivity to disturbance as governed by factors such as geology, basin relief and morphometry, and valley width and gradient as well as by the influence of side-valley alluvial fans (chapter 4).

In many cases, anthropogenic disturbances such as roads in the valley bottoms, overgrazing by livestock, and recreational activities have accelerated the degradation of stream and riparian ecosystems and altered riparian vegetation (Belsky et al. 1999; Martin and Chambers 2001a; Martin and Chambers 2002). Incision and other types of channel change occur during high stream flows and can result from natural disturbances that increase runoff, such as wildfire in the uplands (Germanoski and Miller 1995) and rain on snow (Germanoski et al. 2001). However, incision also can result from anthropogenic disturbances that concentrate stream flows and increase erosional power, such as roads in the valley bottoms (Lahde 2003). Consequences of stream incision include altered channel pattern and form (Miller et al. 2001; chapter 3), changes in surface water and groundwater interactions (chapter 5), lowered water table depths and, ultimately, changes in vegetation composition, pattern, and extent (Wright and Chambers 2002; chapter 5). Anthropogenic disturbances cause changes in stream channels and riparian ecosystems that are in addition to stream incision, including compacted soils and decreased infiltration, altered biogeochemical cycles, and changes in plant physiological, population, and community processes (Belsky et al. 1999; Martin and Chambers 2001a, 2002).

Riparian meadow complexes often occur in incision-dominated watersheds and are susceptible to stream incision (see chapter 5). They also are highly valued for ecosystem services such as forage for native herbivores and livestock and recreational activities and, thus, are frequently overutilized. Because of ongoing degradation in these ecosystems, they are one of the highest priorities for management and restoration.

In this chapter, the relationships among riparian vegetation and geomorphic and hydrologic processes in central Great Basin watersheds are evaluated over a range of scales. These relationships are examined through a series of case studies that have been conducted by the Great Basin Ecosystem Management Project. First, the effects of differences in the geologic and hydrologic characteristics of the watersheds (i.e., basin sensitivity to disturbance) on the composition and pattern of streamside vegetation are investigated. Second, the influence of side-valley alluvial fans on riparian vegetation composition and pattern within riparian corridors is evaluated. Third, relationships among water table regimes, riparian soils, and riparian vegetation composition and dynamics are examined at the scale of the

valley segment or stream reach with an emphasis on meadow complexes. The effects of anthropogenic disturbance on meadow complexes also are evaluated at the valley segment or stream-reach scale with a focus on livestock grazing. The chapter concludes with a discussion of the implications for management and restoration.

### Composition and Pattern of Streamside Vegetation

Differences in geologic and hydrologic characteristics often exist among watersheds in semiarid regions, and these differences influence the composition and pattern of riparian vegetation at multiple scales (Harris 1988; Bendix 1999; Wasklewicz 2001). In the central Great Basin, watersheds with varying geologic and hydrologic characteristics, including basin relief and morphometry, have been characterized according to basin sensitivity to natural and anthropogenic disturbance (chapter 4).

#### *Influence of Geologic and Hydrologic Characteristics of Watersheds*

In this section, the combined influences of watershed characteristics and ongoing stream incision on riparian vegetation are evaluated. Specifically, relationships among the hydrogeomorphic characteristics of the stream channels and the composition and pattern of riparian vegetation are examined for watersheds with different sensitivities to disturbance.

#### WATERSHED CHARACTERISTICS

This research focused on gaged watersheds representing both flood-dominated (Group 1) and incision-dominated basins (Groups 2 and 4) (see chapter 4) (table 7.1). Group 1 basins are underlain by Tertiary volcanic rock and are characterized by high-relief basins with moderate to high stream power. These are narrow, bedrock-controlled systems with minimal sediment storage. During large floods, significant cutting results in multiple, discontinuous terraces. Group 2 basins are underlain primarily by Tertiary volcanic rocks and have large, high-relief basins and relatively high stream power. The streams have eroded completely through existing side-valley alluvial fans; they have high incision values and relatively smooth longitudinal profiles. These basins appear to be reaching an equilibrium state because their channel morphologies are currently somewhat stable. Group 3 basins are dominated by side-valley alluvial fans and are described in the following section. Group 4 basins are underlain by intrusive igneous

and sedimentary rocks and tend to have lower relief and stream power than other basin types. Group 4 basins are pseudostable. They have stream channels that typically exhibit minimal downcutting but have the potential for rapid and catastrophic incision on small or local scales.

#### METHODS

Valley segments were selected that had relatively uniform characteristics in terms of geology, valley morphometry, stream channels, and vegetation, were located at the base of upland watersheds, and were moderately to highly incised. Each of the valley segments was coincident with a stream gaging station and ranged from 1.5 to 3.0 kilometers in length. Sampling was conducted along five to seven cross-sectional valley transects. The analysis focused on channel parameters because in other semiarid systems, changing channel morphologies and their associated fluvial landforms have greater influence on riparian vegetation distributions than flood hydraulics (Wasklewicz 2001). Sampling methods followed protocols detailed in Davis (2000). Transects were surveyed with a total station. The geomorphic variables measured included valley width, channel slope, number of inset terraces, terrace height above the channel bed, bankfull channel depth, bankfull width/depth ratio, depth of the incised channel, width of the incised channel, channel bed particle size ( $D_{50}$ ), and percentage of bank particles less than 2 millimeters in size. Channel bed particle size ( $D_{50}$ ) was determined along a 30-meter stretch of stream using methods modified from Wolman (1954). Bank particle size was obtained by sieving four bulked samples that were collected from the right and left channel banks 5 meters upstream and downstream of the transects.

Vegetation was sampled along the same transects as the geomorphic variables. Nested frequency of herbaceous vegetation was determined for each stream terrace on both the left and right banks from three 0.1-square-meter quadrats placed 2.0 meters apart (Castelli et al. 2000). Stem density of woody vegetation was recorded at the same locations from three 1.0-square-meter quadrats. Relative stem density was recorded for clonal species (*Salix* spp., *Rosa woodsii*) using the following scheme: 1 = 1–10; 2 = 11–25; 3 = 26–50; 4 = 51–100; 5 = 101–150; 6 = 151 or greater). Actual stem density was recorded for nonclonal species (*Artemisia*, *Chrysothamnus*, tree species). Tree densities were determined for both banks within 2-meter-wide belts at the center of each transect.

Two-way indicator species analysis (TWINSPAN, Hill 1979; McCune and Medford 1999) was used to classify vegetation samples into vegetation

TABLE 7.1.  
Locations and characteristics of the study watersheds

Drainage	Latitude/Longitude of Gaging Station	Reference Elevation (m)	Basin Geology	Basin Area (km <sup>2</sup> )	Mean Annual Discharge (m <sup>3</sup> s)	Mean Peak Discharge (m <sup>3</sup> s)
Group 1 Flood Dominated South Twin River	38°53'15"N 117°14'40"E	1,950	Volcanic: welded tuff, andesite	52.5	0.199 ± 0.022	1.762 ± 0.416
Pine Creek	38°47'40"N 116°51'13"E	2,300	Volcanic: rhyolite, andesite	32.0	0.164 ± 0.021	1.919 ± 0.465
Mosquito Creek	38°48'22"N 116°40'43"E	2,195	Volcanic: welded tuff	39.6	0.070 ± 0.013	0.644 ± 0.178
Group 2 Deeply Incised Upper Reese River	38°51'00"N 117°28'00"E	2,165	Volcanic: andesite, basalt	139.1	0.353 ± 0.051	4.321 ± 1.026
Lower Kingston Creek	39°12'45"N 117°06'45"E	1,975	Sedimentary: shale, limestone	61.4	0.270 ± 0.029	1.523 ± 0.414
Currant Creek	38°50'50"N 115°22'00"E	2,040	Volcanic/ sedimentary	33.9	0.096 ± 0.018	2.076 ± 1.057
Group 4 Pseudostable Illipah Creek	39°19'07"N 115°23'39"E	2,085	Sedimentary	82.7	0.093 ± 0.033	1.755 ± 1.140

Stream flow data from U.S. Geological Survey gaging stations (<http://water.usgs.gov/nwis/sw>)

types. The analyses used proxy frequency data based on presence/absence of herbaceous and shrubby species within the three subsamples at each well location (D. Weixelman, personal communication). Species that occurred in one subsample were assigned a value of 1, those that occurred in two subsamples were given a value of 2, and species that were present in all three subsamples were given a value of 3. Canonical correspondence analysis (CCA) was used to evaluate relationships among the vegetation types and the geomorphic variables (ter Braak 1986). *Artemisia tridentata* vegetation types were eliminated from the CCA as these types consistently occurred on the highest-elevation terraces (valley floor), and their occurrence within a valley segment was largely unrelated to channel attributes.

#### RELATIONSHIPS AMONG GEOMORPHIC CHARACTERISTICS AND VEGETATION TYPES

Various studies have found riparian plant species and communities to be related to landform type and position, substrate characteristics, water availability, and tolerance to flooding (see reviews in Hupp and Osterkamp 1996; Hughes 1997; Bendix and Hupp 2000). In this study, the vegetation types identified included *Carex nebrascensis* meadow, mesic meadow, *Salix* spp./mesic meadow, *Salix* spp./mesic forb, *Betula occidentalis*/mesic meadow, *Artemisia tridentata tridentata*/*Leymus cinereus*, and *Artemisia tridentata tridentata*/*Poa secunda*. These types correspond roughly to the ecological types described by Weixelman et al. (1996) in a regional analysis of central Nevada riparian areas (appendix 7.1). Two additional types also were identified: dense *R. woodsii* and *Prunus virginiana*/*R. woodsii*. Eight geomorphic variables were significantly related to the vegetation types on one or both axes in the CCA (fig. 7.1). The eigenvalues for axis 1 and axis 2 were 0.350 and 0.289, respectively, and the correlation of vegetation type with the combined environmental variables was about 80 percent for both axes. The correlation coefficients from the CCA indicated that channel particle  $D_{50}$ , terrace height, width/depth ratio, channel slope, bank particle size (percentage less than 2 millimeters), incised channel depth, number of terraces, and bankfull depth were related to vegetation type on one or both axes ( $R^2 = 0.58$  to  $0.15$ ;  $P < 0.05$  to  $P < 0.01$ ).

These results are consistent with those from other arid and semiarid areas and indicate that the vegetation types are closely related to the hydrologic and geomorphic characteristics of the study watersheds. At local scales, water availability, as indicated by surface elevation above the water surface or stream channel, is often the primary control on riparian species

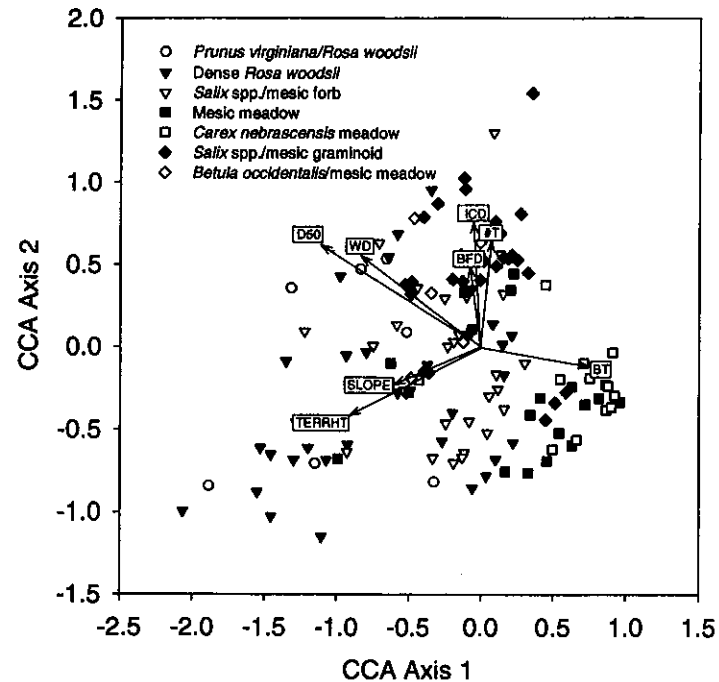


FIGURE 7.1. Relationships among stream geomorphic characteristics and vegetation types for the study watersheds as indicated by Canonical Correspondence Analyses (CCA). Arrows indicate the direction and approximate magnitude of effects for environmental variables in the model.

SLOPE = channel slope; TERRHT = terrace height; BFD = bankfull channel depth; WD = bankfull width/depth ratio; ICD = incised channel depth;  $D_{50}$  = channel particle size ( $D_{50}$ ); BT = percentage bank particle size less than 2 millimeters; and #T = number of terraces.

distributions (Furness and Breen 1980; Hughes 1990; Hupp and Osterkamp 1996; Stromberg et al. 1996; Merritt and Cooper 2000; Wasklewicz 2001). Terrace height was more closely related to vegetation type than any other variable in the study watersheds. Because terrace height is correlated with a suite of environmental variables that are influenced by the hydrologic regime, including shear stress, sediment deposition and erosion, soil water, and soil oxygen concentration, it is often correlated with the distributions of riparian species (Auble et al. 1994; Merritt and Cooper 2000). Channel and bank particle size also were highly correlated with vegetation type in the study watersheds. Similarly, for the San Pedro River in Arizona, depth to groundwater and its spatial correlate, geomorphic surface or terrace elevation, had the greatest influence on species composition, followed by soil texture and moisture-holding capacity (Stromberg et al. 1996).

At larger scales, species occurrence and community composition is affected not only by the hydrologic regime and water availability, but also by fluvial geomorphic processes and landforms (Harris 1988; Bendix 1999; Wasklewicz 2001). Thus, a larger set of stream channel attributes is necessary to define the physical setting of vegetation types that occur in watersheds or valley segments with varying geomorphic characteristics. For the study watersheds, channel variables that were significantly associated with vegetation types, including those that influence water availability (table 7.2), can be used to characterize the geomorphic setting of the vegetation types. Although some of the vegetation types are broadly distributed among the watersheds, others occur in only one or two watersheds, reflecting more narrowly defined geomorphic settings.

The *C. nebrascensis* meadow type occurs only on the lowest stream terraces ( $0.38 \text{ meters} \pm 0.06$ ) and is composed of obligate and facultative wetland species (USDA NRCS 2002) such as *C. nebrascensis*, *Deschampsia cespitosa*, and *Juncus balticus* (table 7.2; appendix 7.1). It is typically associated with low-gradient streams with small channel particle sizes, fine-textured banks, and low width/depth ratios (table 7.2). The other grass- and sedge-dominated type, mesic meadow, occurs on slightly higher terraces ( $0.87 \pm 0.16$  meter) and is characterized by facultative wetland species such as *Poa pratensis*, *Elymus trachycaulus*, *J. balticus*, and *Aster occidentalis* (table 7.2; appendix 7.1). Channel characteristics for the mesic meadow vegetation type are moderate stream gradients and, like the *C. nebrascensis* vegetation type, relatively small channel and bank particle sizes and low width/depth ratios (table 7.2). Riparian wet meadow communities of sedges and rushes (*C. nebrascensis*, *J. balticus*) have two to six times the root density and biomass of grasses like *P. pratensis* and *D. cespitosa* (Manning et al. 1989; Dunaway et al. 1994). Consequently, sedges and rushes provide greater resistance to erosion (Dunaway et al. 1994) and compression (Kleinfelder et al. 1992) and are more effective at stabilizing stream channels than are riparian grasses. However, because riparian obligate sedges and rushes require relatively high water tables, they can rapidly decrease in abundance following stream incision.

The *Salix* spp./mesic meadow type occurs on terraces that average  $0.49 \pm 0.05$  meter in height, while the *Salix* spp./mesic forb type is found on terraces  $0.73 \pm 0.11$  meters high (table 7.2; appendix 7.1). In the study systems, the latter type consistently has a significant *R. woodsii ultramontana* component and frequently has a minor component of *Populus tremuloides*, *P. angustifolia*, or *P. balsamifera trichocarpa*. Relative to the other types,

TABLE 7.2.  
Geomorphic characteristics of the dominant vegetation types within the study watersheds

Vegetation Type	Terrace Height (m)	Channel Particle D <sub>50</sub>	Bank Particles < 2 mm (%)	Slope (%)	Channel Width/depth Ratio	Bankfull Depth (m)	Number of Terraces	Incised Channel Depth (m)
<i>Artemisia tridentata tridentata/Leymus cinereus</i> or <i>Poa secunda</i>	1.85 ± 0.19	39.2 ± 4.4	60.5 ± 5.6	0.035 ± 0.006	6.12 ± 0.57	0.59 ± 0.09	1.80 ± 0.13	1.92 ± 0.22
<i>Prunus virginiana/Rosa woodsii</i>	1.77 ± 0.40	59.7 ± 5.3	26.4 ± 6.4	0.054 ± 0.014	9.26 ± 1.48	0.50 ± 0.09	1.50 ± 0.22	1.38 ± 0.37
Dense <i>Rosa woodsii</i>	1.56 ± 0.18	48.9 ± 3.4	50.7 ± 5.7	0.041 ± 0.007	7.87 ± 0.63	0.49 ± 0.27	1.77 ± 0.17	1.95 ± 0.25
<i>Betula occidentalis/mesic meadow</i>	1.04 ± 0.40	65.4 ± 3.0	35.0 ± 11.4	0.048 ± 0.008	7.38 ± 1.54	0.84 ± 0.29	1.75 ± 0.16	1.63 ± 0.31
Mesic meadow	0.87 ± 0.16	25.5 ± 6.4	60.9 ± 7.5	0.034 ± 0.008	4.90 ± 0.63	0.52 ± 0.03	1.92 ± 0.15	1.57 ± 0.14
<i>Salix</i> spp./mesic forb	0.73 ± 0.11	55.3 ± 3.1	52.8 ± 6.3	0.047 ± 0.006	6.60 ± 0.48	0.53 ± 0.04	1.63 ± 0.15	1.45 ± 0.15
<i>Salix</i> spp./mesic meadow	0.49 ± 0.05	51.7 ± 5.5	60.8 ± 7.7	0.034 ± 0.009	8.02 ± 0.82	0.53 ± 0.04	2.00 ± 0.30	2.48 ± 0.47
<i>Carex nebrascensis</i> meadow	0.38 ± 0.06	15.3 ± 5.0	77.6 ± 6.0	0.018 ± 0.006	4.48 ± 0.41	0.50 ± 0.02	1.78 ± 0.15	1.50 ± 0.19

the *Salix* vegetation types are associated with moderate to high stream gradients, large channel particle sizes and fairly fine bank textures (table 7.2). *Salix* spp. are densely rooted and are highly effective at stabilizing the lower terraces of stream channels (Thorne 1990). Both *Salix* spp. and *Populus* spp. depend largely on flood events for regeneration. However, *Salix* spp. are typically less drought tolerant but more flood tolerant than *Populus* spp. (Van Splunder et al. 1996; Amlin and Rood 2002) and generally occur at lower terrace elevations and closer to the stream than *Populus* spp. (Busch et al. 1992; Amlin and Rood 2002). In the study watersheds, *Salix* occurs primarily on lower terraces (table 7.2), while *P. tremuloides*, *P. angustifolia*, and *P. balsamifera* occur on all terraces but are most abundant on intermediate terraces. As might be expected for either incising or flood-dominated systems, increasingly older individuals of the *Populus* species occur on progressively higher terraces within the study systems (J. Chambers and D. Henderson, unpublished data) and elsewhere (Scott et al. 1996).

The *B. occidentalis*/mesic meadow, dense *R. woodsii*, and *Prunus virginiana*/*R. woodsii* types are located on progressively higher terraces (1.04 ± 0.40, 1.56 ± 0.18, and 1.77 ± 0.40 meters, respectively) (table 7.2; appendix 7.1). These types are associated with steep stream gradients and large channel particle sizes (table 7.2). The *Betula* and *Prunus* types also have coarse bank textures. The dense *Rosa* type is widespread among the watersheds and tends to have intermediate channel characteristics. *Rosa woodsii* is categorized as a disturbance-adapted species (Manning and Padgett 1992; Weixelman et al. 1996) that is abundant in flood-dominated or grazed systems.

*Artemisia tridentata* vegetation types (*A. tridentata tridentata*/*L. cinereus*, and *A. tridentata tridentata*/*Poa secunda*) are often the dominant vegetation types on the valley floors and, thus, occur on the highest stream terraces within the riparian corridor (table 7.2; appendix 7.1). Exceptions are in highly confined or flood-dominated systems where riparian shrub and tree species tend to dominate. The *Artemisia* types occur on deep soils with higher available moisture than adjacent hillslopes (Weixelman et al. 1996). Herbaceous species composition of these types is controlled largely by depth to the water table (Wright and Chambers 2002).

#### ASSOCIATIONS AMONG VEGETATION TYPES AND BASIN GROUPS

Like other semiarid ecosystems, watersheds with different geomorphic characteristics and sensitivities to disturbance are characterized by unique vegetation associations (Harris 1988). Flood-dominated systems with vol-

canic lithologies (Group 1), including South Twin River, Pine Creek, and Mosquito Creek, are dominated largely by flood-tolerant species. The *Salix* spp./mesic forb type (with *R. woodsii ultramontana* or *Populus* spp.) and dense *Rosa* types occur on low to intermediate terraces, while *Artemisia* vegetation types are found on upper terraces. Geomorphic characteristics of these systems, and predictive variables for the streamside vegetation types, are high stream gradients, large channel particle sizes, intermediate stream width/depth ratios and incised channel depths (table 7.3).

Incised basins with volcanic lithologies (Group 2), including Upper Reese River, Lower Kingston Canyon, and Currant Creek, have significantly incised channels with trenched side-valley alluvial fans (see chapter 4). Common elements in these systems include lower terraces dominated by *Salix* spp./mesic meadow or *Salix* spp./mesic forb vegetation types, intermediate terraces characterized by *R. woodsii ultramontana* associated vegetation types and upper terraces with *Artemisia* vegetation types. Lower Kingston Creek also supports two other woody vegetation types on intermediate terraces, *B. occidentalis*/mesic meadow and *Prunus virginiana*/*R. woodsii*. These watersheds have relatively low to intermediate gradients, high numbers of terraces, and high, incised channel depths (table 7.3). Upper Reese River is characterized by the lowest gradient reaches and the finest-textured banks. These characteristics favor graminoid understories in central Great Basin *Salix* spp. vegetation types (Weixelman et al. 1996). In contrast, higher stream gradients, poorly defined lower terraces, and coarser-textured bank soils, like those found in Lower Kingston Canyon and Currant Creeks, favor forb understories.

Incision-dominated basins with crystalline and sedimentary lithologies (Group 4), like Illipah Creek, typically exhibit minor to moderate stream incision. Valley segments with deep alluvium and elevated water tables have the potential for catastrophic incision due to processes associated with groundwater sapping (Germanoski et al. 2001; chapters 4 and 5). Where incised, these streams often have lower and intermediate terraces dominated by the *C. nebrascensis* and mesic meadow types, respectively. Upper terraces are again characterized by *Artemisia* vegetation types. In general, the stream channels exhibit well-defined terraces, low stream gradients, small channel substrates, fine-textured banks and low width/depth ratios (table 7.3).

*Influence of Side-Valley Alluvial Fans*

Alluvial fans that prograde from tributary valleys into the axial drainage can have major influences on stream processes, hydrologic regimes and, thus,

TABLE 7.3. Geomorphic characteristics and dominant vegetation types of the study watersheds

Drainage	Dominant Vegetation Types (%)	Channel Slope (m/m)	Number of Terraces	Channel Particle D <sub>90</sub> (mm)	Bank Particles > 2 mm (%)	Bankfull Width/Depth Ratio	Bankfull Channel Depth (m)	Incised Channel Depth (m)	Incised Channel Width (m)	Valley Width (m)
Group 1 Flood Dominated South Twin River	Mesic meadow(31) <i>Artemisia</i> (23) <i>Salix</i> spp./mesic forb (15)									
	Dense <i>Rosa</i> (15) Dense <i>Rosa</i> (39)	0.054 ± 0.01	1.8 ± 0.3	53.7 ± 3.9	65.6 ± 3.9	6.93 ± 0.87	0.57 ± 0.06	1.65 ± 0.13	11.42 ± 1.9	23.4 ± 3.6
Pine Creek	<i>Salix</i> spp./mesic forb (17) <i>Salix</i> spp./mesic forb (54) Dense <i>Rosa</i> (21) <i>Artemisia</i> (21)	0.076 ± 0.016	1.2 ± 0.4	59.8 ± 3.0	59.7 ± 9.8	9.00 ± 1.66	0.47 ± 0.08	1.36 ± 0.18	8.58 ± 2.02	46.2 ± 4.9
Mosquito Creek		0.046 ± 0.012	1.4 ± 0.2	49.5 ± 7.2	41.3 ± 10.1	5.70 ± 0.41	0.44 ± 0.04	0.80 ± 0.04	4.82 ± 0.60	46.1 ± 4.6
Group 2 Deeply Incised Upper Reese River	<i>Salix</i> spp./mesic med (50) Dense <i>Rosa</i> (21) <i>Artemisia</i> (18) <i>Betula/Comus</i> (32)	0.014 ± 0.002	2.3 ± 0.3	50.8 ± 5.2	25.1 ± 4.8	8.87 ± 0.92	0.53 ± 0.03	3.13 ± 0.66	19.90 ± 4.69	108.1 ± 28.5
Lower Kingston Creek	<i>Salix</i> spp./mesic forb (16) <i>Prunus/Rosa</i> (16) <i>Artemisia</i> (16) <i>Artemisia</i> (50) Dense <i>Rosa</i> (31) <i>Salix</i> spp./mesic forb (14)	0.048 ± 0.009	1.7 ± 0.2	67.5 ± 3.9	78.1 ± 3.8	5.93 ± 1.38	1.01 ± 0.31	1.81 ± 0.37	11.03 ± 2.41	54.2 ± 2.9
Currant Creek		0.03 ± 0.005	1.8 ± 0.4	36.9 ± 3.5	58.4 ± 5.6	6.82 ± 0.99	0.44 ± 0.05	2.02 ± 0.13	12.6 ± 2.42	No data
Group 4 Pseudostable Illipah Creek	<i>Artemisia</i> (50) Mesic meadow (31) <i>C. nebrascensis</i> med (29)	0.012 ± 0.002	1.9 ± 0.1	8.3 ± 2.3	15.4 ± 3.7	4.01 ± 0.38	0.47 ± 0.02	1.49 ± 0.22	8.44 ± 1.25	No data

For complete vegetation type names and dominant species see appendix 7.1

riparian vegetation patterns (e.g., Grant and Swanson 1995; Swanson et al. 1998). Side-valley alluvial fans are dominant features of many upland watersheds in the central Great Basin. The fans reached their maximum extent during the drought that occurred approximately 2500 and 2000 YBP when many of the fans extended across the valley floors (Miller et al. 2001; chapter 3). The fans have resulted in stepped valley profiles and are often associated with major changes in the morphology and hydrology of associated valley segments. Because side-valley alluvial fans influence both geomorphic characteristics and water availability, they affect the types and patterns of riparian vegetation above (upstream), at, and below (downstream) fan deposits.

Watersheds with the most highly developed side-valley alluvial fans often are elongated in planform and are underlain by sedimentary and metasedimentary rocks. These basins exhibit incision-dominated responses (Group 3; see chapter 4), but reaches upstream of the fans often vary considerably with respect to erosional and depositional processes and in the degree of fan entrenchment. Watersheds with volcanic lithologies that exhibit incision-dominated responses (Group 2) also are elongated in planform and characterized by side-valley alluvial fans, but in contrast to Group 3 streams, more of the side-valley alluvial fans have been trenched. The influence of alluvial fans on the geomorphic characteristics and vegetation patterns of associated valley segments and stream reaches has been examined for watersheds in the central Great Basin representing Group 2 basins (Washington Creek, Cottonwood Creek, and San Juan Creek) and Group 3 basins (Big Creek and upper Kingston Creek) (Korfmacher 2001).

#### METHODS

Study methods are detailed in Korfmacher (2001). Fifty-five cross sections were located for twenty-one alluvial fans that represented three geomorphic positions (above, at, and below fans) and all likely vegetation types. Data on geomorphic parameters likely to influence vegetation patterns were collected for each transect including valley width, slope perpendicular to the channel, channel slope, number of terraces, bankfull width, depth, width/depth ratio, depth of entrenchment, and entrenchment ratio (entrenchment depth/bankfull depth). Vegetation in the study watersheds was classified and mapped from low-altitude, high-resolution multispectral videoimagery using methods described in Neale (1997). Vegetation sampling was conducted from the classified imagery using a GIS (geographic information system) (Korfmacher 2001). A 20 × 24-meter sampling grid was

centered on each cross section with the sides parallel to the stream channel. Percent cover class was determined from eight 3-meter-wide zones, four on each side of the stream (0–3, 3–6, 6–9, and 9–12 meters). A split-plot ANOVA model was used to evaluate differences in the geomorphic variables and percentage cover of each vegetation class for fan position and distance from the stream (SAS Institute 2000).

#### INFLUENCE OF SIDE-VALLEY ALLUVIAL FANS ON GEOMORPHIC CHARACTERISTICS

As expected, alluvial fans influence the geomorphic characteristics of the study watersheds. Three geomorphic variables exhibited significant differences for above, at, and below fan positions—valley width, slope perpendicular to the channel, and bankfull channel width (Korfmacher 2001). Valley width was greatest above fans, intermediate below fans, and least at fans. Also, slope perpendicular to the channel was three times steeper at fans than above or below fans, and bankfull depth was greater at fans.

#### INFLUENCE OF SIDE-VALLEY ALLUVIAL FANS ON VEGETATION CHARACTERISTICS

The vegetation types show distinct differences with respect to both fan position and distance from the stream (fig. 7.2; Korfmacher 2001). At the fans, *Salix* spp. or *P. tremuloides* are the major streamside components, while below the fans *Salix* spp. and *B. occidentalis* are the dominant streamside components (fig. 7.3). Woody riparian types (*Salix* spp., *P. tremuloides*, *B. occidentalis*) at and below fans are most abundant at 0–3 meters from the stream (greater than 80 percent in many cases), and rapidly decrease in abundance with increasing distance from the stream. Upland vegetation types are also most abundant at and below the fans but increase in abundance with increasing distance from the stream. For upland vegetation types at and above fans, vegetation cover increases from less than 20 percent cover at 0–3 meters to greater than 50 percent at 9–12 meters. Above-fan locations have significantly higher percentages of *C. nebrascensis* and mesic meadow vegetation types than either at-fan or below-fan locations (fig. 7.3). Woody riparian types, *P. tremuloides*, *Salix* spp., and *B. occidentalis*, also are abundant in above-fan locations. In comparison to at-fan and below-fan positions, woody riparian types above fans generally exhibit significantly smaller declines in abundance with distance from the stream. In above-fan positions, the woody riparian types have greater than 35 percent cover at 9–12 meters from the stream.

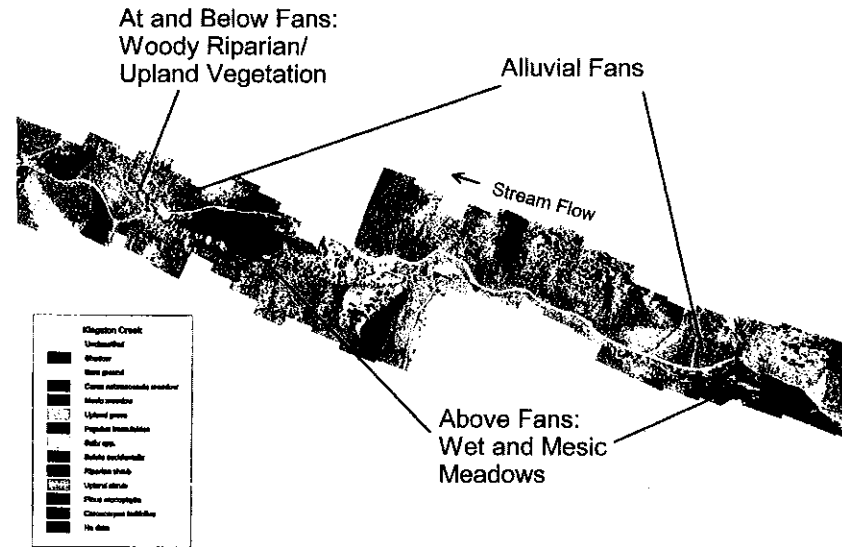


FIGURE 7.2. Vegetation types in relation to alluvial fan position as determined from low-altitude, high-resolution, multispectral videoimagery for a fan-dominated basin (Group 3; Upper Kingston Canyon). Vegetation was classified and mapped using methods described in Neale (1997).

The *C. nebrascensis*, mesic meadow and woody riparian vegetation types all require relatively high water availability. *Carex nebrascensis* and the dominant willow species, *Salix exigua*, and *S. lutea*, are wetland obligate species, *B. occidentalis* is a facultative wetland species, and *P. tremuloides* is a facultative species. The abundance of the *C. nebrascensis*, mesic meadow, and woody riparian vegetation types at all distances from the stream indicates that above-fan locations generally have higher water tables and wider riparian zones than at-fan or below-fan locations.

The prevalence of riparian meadow or woody vegetation types in above-fan locations appears to vary with stream type. The *C. nebrascensis* meadow type is best developed in Group 3 basins with sedimentary and metasedimentary lithologies (Group 3), while woody riparian types, especially *P. tremuloides*, are most abundant in basins with volcanic lithologies (Group 2). The differences in vegetation types may be explained largely by less fan incision and higher water table depths above fans in Group 3 basins, although varying groundwater hydrology due to different lithology also may play a role. Both *B. occidentalis* and *P. tremuloides* occur on higher stream terraces than *C. nebrascensis* (table 7.2), and *P. tremuloides* is capable of

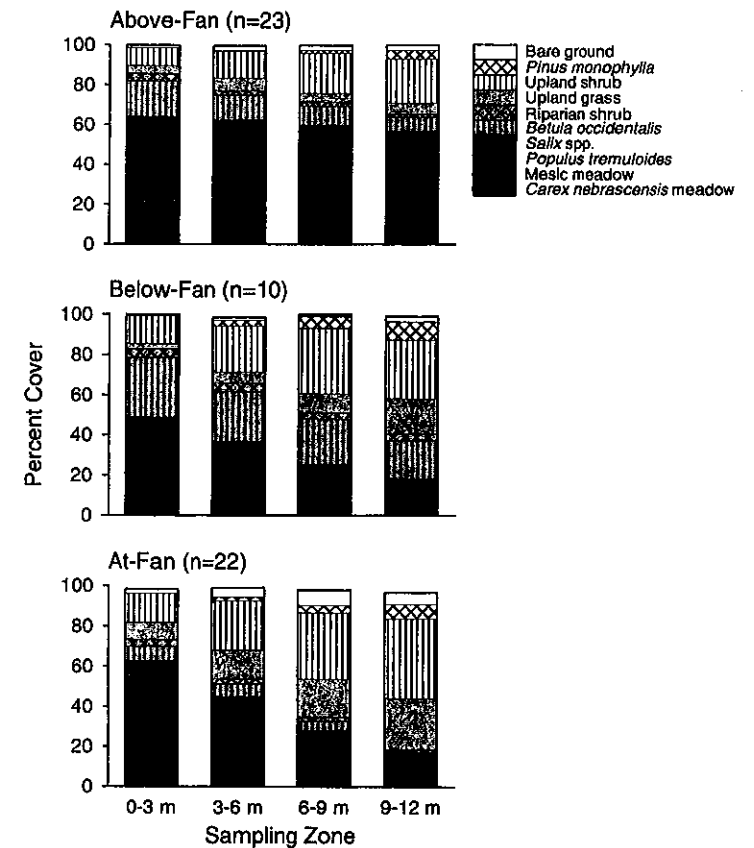


FIGURE 7.3. Mean percentage areal cover by category for different alluvial fan positions and distances from the stream. The cover categories were obtained from classified and mapped low-altitude, high-resolution videoimagery using a GIS (geographic information system).

root sprouting. These traits should favor the persistence of the latter species following stream incision and decreases in water tables.

### Dynamics of Riparian Meadow Complexes

In upland watersheds of the Great Basin, meadow complexes often occur in incision-dominated basins—such as basins dominated by side-valley alluvial fans—and are highly susceptible to stream incision. In basins that are dominated by side-valley alluvial fans (Group 3), meadow complexes are located primarily upstream of side-valley alluvial fans (Miller et al.



2001; see chapters 4 and 5). In these basins, incision often starts at the fans as channel gradients and fluid shear stress are at maximum values where axial channels traverse the fans. Once the fans are breached, the wave of incision migrates upstream through the meadow complex in the form of knickpoints or knick zones. In basins with pseudostable channels (Group 4), localized incision occurs as a result of upstream migration of knickpoints and often is facilitated by groundwater sapping (see chapters 4 and 5). Rapid incision of meadow complexes can occur due to short-term forcings such as high runoff associated with snowmelt and rainfall (see chapters 4 and 5). Riparian meadow complexes occur in areas with elevated groundwater and typically exhibit strong hydrologic gradients related largely to topographic position. Stream incision usually results in progressive lowering of water tables and the degradation of meadow complexes. Because meadow complexes are highly valued for both landscape diversity and ecosystem services, they have been the subject of several Great Basin Ecosystem Management Project studies (Chambers et al. 1999; Castelli et al. 2000; Chambers and Linnerooth 2001; Martin and Chambers 2001a,b, 2002; Wright and Chambers 2002; Wehking 2002). Meadows at low to intermediate elevations (2,000 to 2,350 meters) have received the most attention. The common vegetation types along the hydrologic gradient within these meadow complexes are, from wettest to driest, *C. nebrascensis* meadow, mesic meadow, dry meadow, and *Artemisia tridentata tridentata* / *L. cinereus* (see appendix 7.1 for representative species within each type).

### Hydrologic Regimes

Montane meadow complexes often exhibit high spatial and temporal variability in groundwater regimes (Allen-Diaz 1991; Castelli et al. 2000; chapter 5). In floodplain aquifers, subsurface hydrology is a consequence of flood frequency and duration, flow exchange between the stream channel and the floodplain (hyporheic flow), permeability and heterogeneity of the alluvial substrates, subsurface flows from upland slopes and the contribution from regional aquifers (Bencala 1993; Stanford and Ward 1993; Huggenberger et al. 1998). Large differences in the depth to water table can occur over small distances due to differences in the sources and directions of subsurface flows and in the hydraulic conductivity of the substrate. Also, in montane meadows like those in the central Great Basin, the hydrologic cycle is heavily influenced by snowpack, and summers are typically char-

acterized by drought. Consequently, there can be significant fluctuations in water-table levels both during growing seasons and among years.

### Soil Characteristics

The effects of groundwater regimes are often predictable for wetland soils (Mitsch and Gosselink 1993) and are fairly consistent for meadows in the central Great Basin. A comparison of soil physical and chemical characteristics was made for meadow sites that were (1) dominated by *C. nebrascensis* and had consistently high water tables (0–20 centimeters measured over three years in mid-August), (2) codominated by *C. nebrascensis* and mesic graminoid vegetation and had intermediate water tables (–30 to –50 centimeters), and (3) dominated by mesic graminoid vegetation with relatively low water tables (–60 to –80 centimeters) (Chambers et al. 1999). Soil types for the high- to low-water-table sites were, respectively, typic cryaquolls, cumulic cryaquolls, and aquic cryoborolls (soils that have mean annual temperatures lower than 8°C at 50 cm, that are continuously or periodically saturated, and that have loamy surface horizons with >2.5 percent organic carbon). Differences in soil morphology associated with increasing wetness parallel those for other hydrosequences (Johnston et al. 1995; Castelli et al. 2000). They include increasing thickness of O and A horizons, disappearance of B<sub>w</sub> horizons, and decreasing depth to redoximorphic features. Differences in physical and chemical properties of soils along the hydrologic gradient are due to moisture, parent material, and the interactions between these two variables. Sites with higher water tables have higher organic matter, total nitrogen, cation exchange capacity, and extractable potassium, but lower pH. Parent materials influence both physical and chemical properties of soils. Watersheds with chert, quartzite, and limestone have higher silt and clay, neutral pH, and high levels of extractable phosphorus. In contrast, watersheds characterized by acidic volcanic tuffs, rhyolites, and breccia have coarser-textured soils, low pH, and extractable phosphorus. Because parent material can influence substrate characteristics, it affects soil and water chemistry (see chapter 6) and nutrients available to plants.

Because groundwater regimes influence soil water and oxygen availability, they also affect chemical reactions and biotic processes in riparian meadow complexes. The relationships between vegetation types, groundwater depths, soil redox potentials, and soil temperature were examined for two riparian meadow complexes in the central Great Basin (Castelli et al. 2000). Groundwater depth, redox potential, and soil temperature were all

strongly related to elevation and vegetation type, but there were significant differences in these relationships between sites and over the growing season (fig. 7.4). Precipitation during the study year (1998) was about 30 percent higher than the long-term average, with more spring and summer moisture. Consequently, seasonal declines were probably less than in an average or dry year for both water tables (see Big Creek data in chapter 5) and redox potentials. As for other higher-elevation hydrosequences, temperature regimes varied inversely with soil moisture regimes (Klickoff 1965). Redox values ranged from a low of about -300 millivolts at 30 centimeters for the wettest and most reducing sites (*C. nebrascensis* meadow) to a high of about +500 millivolts for the driest sites (*A. tridentata* tridentata/*L. cinereus* type). These values are typical of hydrosequences in the Sierra Nevada (Svejcar et al. 1992) and elsewhere (Johnston et al. 1995).

#### Ecophysiological Responses

The groundwater regimes of these meadow complexes influence plant rooting activity, physiological responses, and productivity (Martin and Chambers 2001a,b, 2002). Seasonal and yearly differences in water table depth over a three-year period largely determined the rooting activity (number of roots per square centimeter) and depth of mesic meadow vegetation in central Great Basin meadow complexes (fig. 7.5) (Martin and Chambers 2002). Depth to water table ranged from about 0 to 40 centimeters after peak runoff in early June to about 50 to 100 centimeters in August. Little rooting activity occurred within or at the surface of the water table, and rooting activity increased as water table elevation declined during the growing season. Similarly, for a *C. nebrascensis*-dominated site in the Sierra Nevada, minimal rooting activity was observed within the water table (Svejcar and Trent 1995).

Plant and soil water relations, photosynthesis, and biomass also are related to spatial and temporal differences in water tables. For *C. nebrascensis*, *J. balticus*, and *D. cespitosa* in a Sierra Nevada meadow, photosynthesis rates were 12.5 percent higher at streamside locations than 20 meters from the stream, where water tables were 40 centimeters deeper (Svejcar and Riegel 1998). In the central Great Basin, standing-crop biomass was influenced by grazing and restoration treatments, but the underlying controls were depth to water table and soil water content of the surface 50 centimeters. When the data were examined across sites and treatments, biomass was lowest in 1996, a low water table year, and highest in 1998, a high water table year (Martin and Chambers 2001a).

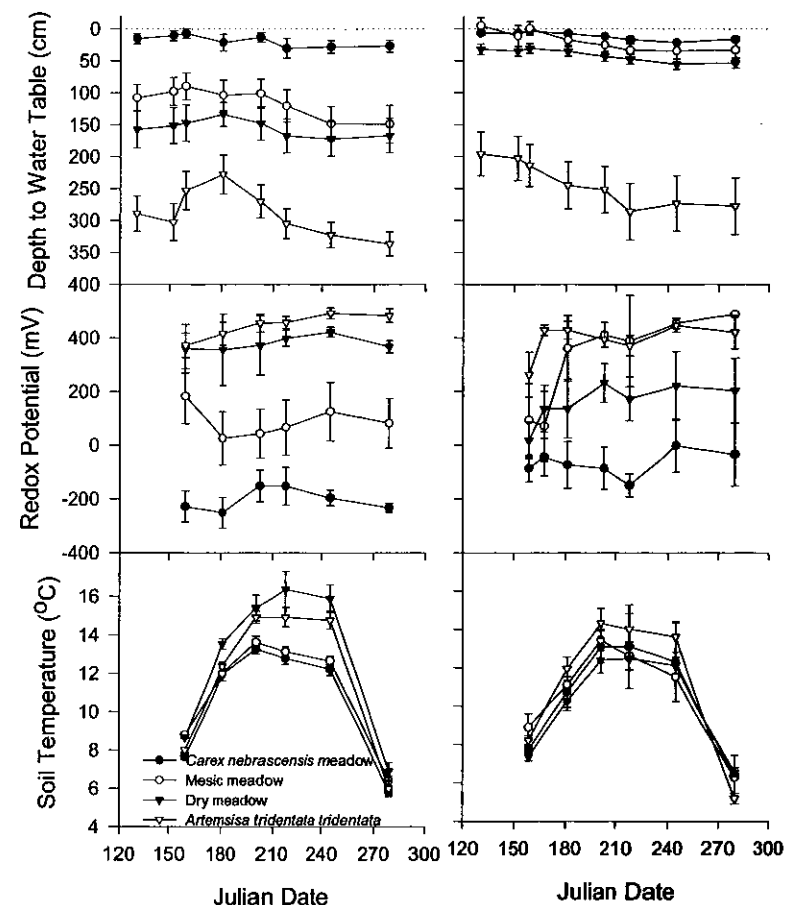


FIGURE 7.4. Depth to water table, redox potential, and soil temperature during the 1998 growing season for common vegetation types in two central Great Basin meadow complexes (modified from Castelli et al. 2000).

#### Indicators of Groundwater Status

Because species composition of plants is closely related to particular water table regimes, it can serve as an indicator of groundwater status in riparian ecosystems. In arid and semiarid riparian areas, few data are available on the hydrologic requirements of individual species or communities of riparian plants (but see Stromberg et al. 1996). Most of the data that do exist are for riparian trees, especially *Populus* spp. (e.g., Amlin and Rood 2002). Data for the streamside vegetation types described above allow for examination of the relative water requirements of riparian species that occur both in meadows and adjacent to streams in Great Basin watersheds. Along effluent or hydrologically losing streams that typify semiarid areas, the

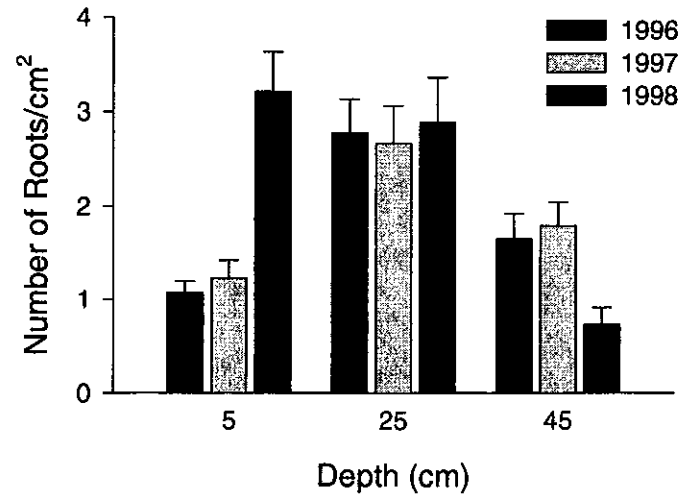


FIGURE 7.5. Rooting activity (number of roots per square centimeter) at three depths for mesic meadow vegetation in the central Great Basin. Data are from Corral Canyon;  $n = 4$ . Measurements were taken in August and include relatively dry years (1996, 1997) and a relatively wet year (1998) (modified from Martin and Chambers 2002).

elevation of the riparian water table usually is similar in elevation to the adjacent river or stream stage, and declines in river stage result in corresponding declines in water table elevation (Busch et al. 1992; Stromberg and Patten 1996). In the central Great Basin, total stream flow is highly variable among and within years, but peak flows are runoff dependent and consistently occur in the late spring (May–early June), after which flows decline rapidly. In these low flow systems, water depth in the thalweg (a line connecting the deepest part of the channel) at base flow is seldom greater than 10 centimeters. Thus, height above the channel may slightly underestimate depth to groundwater, but it appears to be a reasonable proxy measurement during most of the year.

The dominant species of the different streamside vegetation types exhibit individualistic but overlapping responses in terms of height above the channel bed and relative water requirements (fig. 7.6). Graminoid and forb species classified as obligate or facultative wetland species, *C. nebrascensis*, *D. cespitosa*, and *Epilobium ciliatum*, do not occur at terrace heights greater than 1 meter, and the graminoids have low occurrence rates on terraces higher than 0.25 meter. Obligate wetland shrubs, *S. exigua* and *S.*

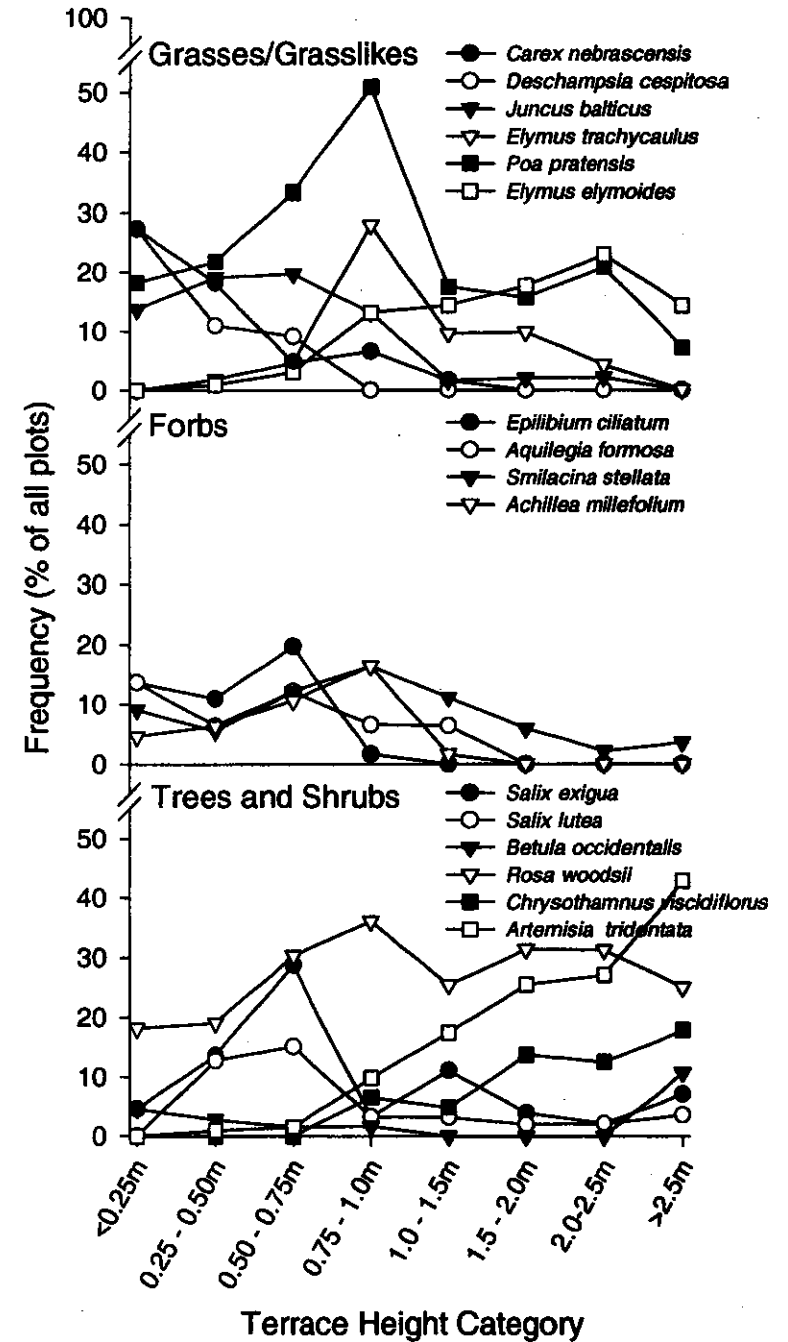


FIGURE 7.6. The frequency of the dominant species by terrace height category for the gaged drainage basins listed in table 7.1.

*lutea*, have high occurrence rates on terraces 0.25 to 1.0 meter high but are uncommon on terraces higher than 1.0 meter. Facultative wetland species, such as the widespread *Poa pratensis pratensis* and disturbance-adapted *R. woodsii ultramontana*, occur on all terraces, but their rates of occurrence are highest on intermediate terraces. *Juncus balticus*, *Aquilegia formosa*, and *Achillia millefolium* occur primarily on terraces less than 1.5 meters high, while *Elymus trachycaulus* and *Smilacina stellata* occur on terraces less than 2.5 meters high. Species that are not wetland associated, such as *Elymus elymoides*, *Artemisia tridentata tridentata*, and *Chrysothamnus viscidiflorus*, occur primarily on the highest terraces. Earlier studies indicate that wetland obligate species decline rapidly when terrace heights, a surrogate for groundwater depths, exceed about 0.30 meter (Stromberg et al. 1996; Castelli et al. 2000). *Carex nebrascensis*, a dominant, wetland obligate, consistently occurs at high water tables (0.30 meter in meadows; 0.38 meter on stream terraces) and appears to be a dependable indicator of average depth to water table. In contrast, large temporal and spatial variability in water table depths for species associated with higher stream terraces suggest that these species indicate only broad ranges in water table depths.

For both streamside and meadow vegetation in the central Great Basin, the variability in water table depth increases with increasing depth to water table (fig. 7.3; Castelli et al. 2000). Similar relationships between water table depth and variability have been observed in other semiarid riparian ecosystems (Stromberg et al. 1996) and elsewhere in the central Great Basin (see chapter 5). Integrated environmental variables (range in water table depth, number of days the water table was less than 30 and 70 centimeters, number of degree-days of anaerobiosis during the growing season) that incorporate the variability in water table depths over the growing season have closer relationships to the *C. nebrascensis* and mesic meadow vegetation types than water table alone (Castelli et al. 2000). Other studies have identified elevation above the stream channel and hydrologic variables as those most closely related to plant distributions (Allen-Diaz 1991; Stromberg et al. 1996). In central Great Basin meadows, integrated environmental variables were more sensitive to the spatial and temporal differences in water tables than individual species or vegetation types. They would be expected to respond more rapidly to changes in local hydrology than plant species and are probably more reliable indicators of both current water-table status and potential vegetation following stream incision.

### Effects of Livestock Grazing

Montane riparian meadows in the central Great Basin have been extensively used for livestock grazing since the late 1800s. The effects of livestock grazing on riparian vegetation in the western United States are controversial and are reviewed in Kauffman and Krueger (1984), Clary and Webster (1989), Skovlin (1984), Fleischner (1994), Ohmart (1996), Belsky et al. (1999), and elsewhere. In general, livestock grazing influences riparian vegetation by (1) removing plant biomass, which allows soil temperatures to rise and results in increased evaporation, (2) damaging plants by rubbing, trampling, grazing or browsing them, (3) altering nutrient dynamics by depositing nitrogen in excreta from animals and removing foliage, and (4) compacting soil, which increases runoff and decreases water availability to plants. These effects can cause changes in plant physiology, population dynamics, and community attributes such as cover, biomass, composition, and structure. Relatively few studies exist on the effects of livestock grazing on montane meadows, and methodologies often differ, making it difficult to draw overarching conclusions about grazing effects.

### BIOMASS REMOVAL

In general, moderate to heavy clipping or grazing of montane meadows can significantly decrease plant growth (Clary and Kinney 2002) and alter species composition (Green and Kauffman 1995). Native sedges (*Carex* species) and bunch grasses (e.g., *D. cespitosa*) often decline in abundance, while the widely naturalized *P. pratensis* and exotic species increase under heavy grazing (Kauffman et al. 1983; Schultz and Leininger 1990; Green and Kauffman 1995; Martin and Chambers 2001a). Species richness is often higher in grazed than not grazed plots, primarily due to the presence of nonnative grasses (e.g., *Bromus mollis*, *Phleum pratense*) (Green and Kauffman 1995) and low-growing forbs (e.g., *Aster occidentalis*, *Stellaria longipes*, *Taraxacum officinale*) (Martin and Chambers 2001a).

### NITROGEN DEPOSITION

Nitrogen is deposited in the excreta of grazing animals and has the potential to enrich meadow soils. In Idaho, for example, autumn application of manure and urea at levels similar to those produced by cows in high-elevation sedge meadows increased standing crop biomass in the following year by almost 10 percent (Clary 1995). To assess the effects of nitrogen addition on Great Basin meadows, a slow-release nitrogen fertilizer, sulfur-

coated urea (36-0-0), was applied to three mesic meadow sites at a rate of 100 kilograms per hectare in autumn 1995, 1996, and 1997, and the ecophysiological responses and community dynamics were quantified (Martin and Chambers 2001a, 2002). The type of fertilizer and application rate used in the study increases above-ground production and disease resistance in both *C. nebrascensis* and *Poa pratensis* in agricultural settings (Davis and Dernoeden 1991; Thompson and Clark 1993; Reece et al. 1994). In general, addition of nitrogen to Great Basin mesic meadows decreased rooting activity (number of roots per square centimeters) and resulted in less-negative water potentials for both *C. nebrascensis* and *P. pratensis* (Martin and Chambers 2002). Photosynthetic rates were higher than for nontreated plots early in the growing season but lower later in the season. The effects of added nitrogen on both water relations and photosynthesis could be attributed to accelerated plant phenology and earlier senescence in the nitrogen-enhanced plots. Nitrogen addition in combination with clipping to a stubble height of 5 centimeters increased biomass during all three years of the study (Martin and Chambers 2001a). The nitrogen application level used in this study probably exceeded the level of nitrogen addition due to livestock grazing in these types of meadows. Much of the nitrogen deposited by grazing animals may be lost due to volatilization and leaching (Woodmansee 1978), and vegetation removal by grazing animals may result in an export of nitrogen from grazed systems (Berendse et al. 1992). However, the results of this study indicated that relatively high levels of nitrogen addition can decrease rooting activity in mesic meadows. In meadow systems subject to high annual as well as seasonal variability, this may have long-term negative effects on species responses and community productivity.

#### SOIL COMPACTION

The hoof action of grazing animals can decrease soil macropore space resulting in soil compaction. Soil compaction decreases water infiltration and leads to reduced root growth and overall lower primary productivity (Laycock and Conrad 1967; Bohn and Buckhouse 1985). In the central Great Basin, mesic and dry meadows frequently have layers of compacted soil at depths of 15 to 30 centimeters, and soil compaction has been used as an indicator of ecological condition in these systems (Weixelman et al. 1996, 1997). The effects of a one-time aeration treatment on plant ecophysiological responses and community dynamics were evaluated for three central Great Basin mesic meadows with compacted soils (Martin and

Chambers 2001a, 2002). The treatment consisted of using a 2-centimeter-diameter drill to create 30-centimeter-deep holes that were uniformly spaced 20 centimeters apart. In general, aeration increased rooting depth and activity (number of roots per square centimeters) where there was no confounding effect of water table. Also, both predawn and midday water potentials of *C. nebrascensis* and predawn water potentials of *P. pratensis* were less negative in aerated plots. The one-time aeration treatment had no effect on total standing crop biomass, but repeated treatments may have greater effects.

#### Interacting Effects of Hydrologic Regimes and Livestock Grazing

The outcomes of species interactions in riparian meadows are often attributed largely to anthropogenic disturbances like livestock disturbance. Based on research in the central Great Basin, it was hypothesized that water table is the primary variable influencing species responses and interactions within *C. nebrascensis* and mesic meadows in the central Great Basin but that the direct and indirect effects of livestock grazing can modify those responses and interactions. This hypothesis was examined for two widespread riparian species (*C. nebrascensis* and *P. pratensis*) that co-occur but are most abundant at different water table depths (Martin and Chambers 2001b). *Carex nebrascensis* is a sedge that has loosely arranged and widely spread tillers, while *P. pratensis* is a grass that has closely spaced and compact tillers (termed "guerilla" and "phalanx" plant architecture, respectively, by Lovett Doust 1981). Individuals of both species were grown at mid- and low water tables with or without neighbors and were either clipped or not clipped at the end of the first growing season. Water table depths measured during the growing season (May through August) varied among years. For the meadow with the most continuous record, water table depths were -32 centimeters in year 1 and -7 centimeters in year 2 for the mid-water table plots, and -69 centimeters in year 1 and -31 centimeters in year 2 for the low-water table plots. Water table depth had no effect on tillering or biomass of *C. nebrascensis*, indicating that the species is adapted to the range of water table depths examined. In contrast, growth and tillering of *P. pratensis*, a facultative upland species, was severely restricted at shallower water table depths. Clipping had little effect, possibly because clipping closer than the 10-centimeter stubble height used in the study is required to reduce tiller number and shoot mass of these species (Ratliff and Westfall 1987; Thompson and Clark 1993). *Poa pratensis* responds

more rapidly than *C. nebrascensis* to disturbances that remove neighbors and create open patches. Neighborhood removal resulted in a three- to ten-fold increase in tillering for *C. nebrascensis*, but a 6- to 100-fold increase in tillering for *P. pratensis*. Comparisons of single- and mixed-species plots showed that given water table conditions favorable to both species, *P. pratensis* limited tiller production of *C. nebrascensis*.

The distribution and relative abundance of *C. nebrascensis* and *P. pratensis* are undoubtedly influenced by both the timing and duration of soil saturation and soil water availability during the growing season. Disturbances resulting from livestock grazing or other land uses that increase space and resources within the plant community allow both species to expand locally. The interactions between the two species do not seem to be related to plant architecture and can be attributed to generally greater growth rates and increased competitive ability for *P. pratensis* at lower water table depths. Livestock grazing may alter the relative competitive ability of the two species in favor of *P. pratensis*. Research on riparian meadows in the central Great Basin and elsewhere indicates that *P. pratensis* generally increases in cover in response to both grazing and clipping but decreases in cover or does not change in the absence of grazing (Kauffman et al. 1983; Schultz and Leininger 1990; Green and Kauffman 1995; Martin and Chambers 2001a). In contrast, *C. nebrascensis* shoot growth and cover increases in response to release from grazing and either remains unchanged or decreases under grazing (Ratliff and Westfall 1987; Martin and Chambers 2001a).

#### *Hydrologic Variability and Study Designs*

The high spatial and temporal variability of the water table and its importance to riparian meadow species and vegetation communities indicates that studies designed to evaluate the structure or function of these systems need to consider the water table regime (Martin and Chambers 2001a). The variability in the water table regime is often sufficient to obscure treatment effects and may explain, in part, a lack of consistent responses in both grazing and restoration studies (Clary 1995). In most cases, water table should be treated either as a main factor or as a covariate when evaluating treatment effects on plant response variables. Depending on the study design, a high number of blocks or relatively large blocks with multiple, randomly located treated plots should be used to adequately account for the high spatial variability in water tables. Finally, sampling should be conducted over relatively long time periods (three to five years) to account for the annual and seasonal variability in these systems.

#### **Management and Restoration Implications**

Results of the research conducted on upland watersheds in the central Great Basin have implications for the restoration and management of both streamside vegetation and riparian meadow complexes. Differences in basin geology and morphometry have significant effects on watershed sensitivity to both natural and anthropogenic disturbances (Swanson et al. 1998; chapter 4). In the central Great Basin, the composition and pattern of riparian vegetation is determined by the hydrogeomorphic characteristics of individual watersheds and is closely related to basin sensitivity to disturbance as indicated by past stream incision. Side-valley alluvial fans influence the geomorphic and hydrologic characteristics and vegetation patterns of riparian corridors even after stream incision. The overriding effects of the geomorphic characteristics of the watersheds on basin sensitivity to disturbance and riparian vegetation composition and pattern illustrate the importance of developing management and restoration schemes that address larger scales and incorporate hydrogeomorphic attributes.

Many of the management guidelines and restoration approaches that have been developed for riparian vegetation are based on a limited number of geomorphic and hydrologic variables, and focus primarily at stream reach scales (Goodwin et al. 1997). However, fluvial geomorphic processes and landforms at watershed-to-valley-segment scales strongly influence the occurrence and community composition of riparian plant species (Harris 1988; Bendix 1999; Wasklewicz 2001). The parameters used to categorize Great Basin watersheds according to sensitivity to disturbance, including geology and morphometry, valley width and gradient, substrate characteristics, channel gradient and uniformity, channel incision and erosion, and the relative influence of side-valley alluvial fans (chapter 4), also are the major determinants of vegetation types and associations. At valley-segment-to-stream-reach scales, water availability, as indicated by surface elevation above the water surface or stream channel and by soil texture and moisture-holding capacity, is the primary control on riparian species distributions (Hughes 1990; Stromberg et al. 1996; Wasklewicz 2001). In the central Great Basin, species occurrences and vegetation types are strongly correlated with elevation above the stream channel and with bank and channel particle sizes. Examining a broader range of scales and collecting integrated geomorphic, hydrologic, and vegetation data can improve understanding of the linkages among the abiotic and biotic components across a range of scales—from watershed to stream reach (Gregory et al. 1991).

Riparian meadow complexes are one of the highest-priority ecosystems for management and restoration in the central Great Basin because they often occur in incision-dominated watersheds and are susceptible to stream incision (chapter 5). Determining appropriate management and restoration scenarios for riparian meadow complexes begins with understanding the geomorphic and hydrologic controls on stream-incision processes. Meadow complexes in fan-dominated basins (Group 3) are located primarily upstream of side-valley alluvial fans (Miller et al. 2001; chapters 4 and 5). Incision in these basins often starts at the fans because maximum values of channel gradients and shear stress occur where axial channels traverse the fans. For fans that have been breached, waves of incision migrate upstream through the meadow complexes in the form of knickpoints. In basins with pseudostable channels (Group 4), localized incision occurs as a result of upstream migration of knickpoints and often is facilitated by groundwater sapping (chapters 4 and 5). In both types of basins, land-use activities that destabilize stream channels in or adjacent to meadows, including stream diversions, road crossings, and overgrazing by livestock, should be avoided. Restoration efforts should focus on meadow complexes with relatively stable stream channels. For fan-dominated basins, it may be possible to stabilize the axial channel at the point where it crosses the fans with grade-control structures or armoring.

Determining the site-restoration potential of degraded riparian meadow complexes requires an understanding of the relationships among hydrologic regimes, soil characteristics, and riparian vegetation. Riparian meadow complexes occur along hydrologic gradients, and soil physical and chemical properties, plant physiological processes, and plant population and community dynamics are strongly influenced by water table depths (Chambers et al. 1999; Castelli et al. 2000; Martin and Chambers 2001a,b, 2002; Wright and Chambers 2002; chapter 5). Water table depths within meadow complexes are highly variable in space and time, and the variability increases with increasing depth to the water table (Castelli et al. 2000; chapter 5). Species that require the shallowest water table depths, such as the *C. nebrascensis*, tolerate the least variability. In degraded areas, integrated environmental variables, such as the range in water table depth and the number of degree-days of anaerobiosis during the growing season, are more sensitive to the spatial and temporal differences in water tables than individual species or vegetation types and are accurate indicators of groundwater status and potential vegetation (Castelli et al. 2000). Riparian obligate species that require relatively high and stable water tables also are

fairly consistent indicators of groundwater status. In contrast, species associated with deeper water tables indicate only broad ranges in water table depths. To accurately understand the site-restoration potential, both water table depths and vegetation should be monitored over relatively long time periods (more than three years) (Martin and Chambers 2001a), and sample sizes should be large enough to account for the high spatial variability.

Overgrazing by livestock and other types of anthropogenic disturbance can alter physiological responses and competitive interactions of plant species and can exacerbate the effects of changes in groundwater levels. For example, overgrazing of riparian meadows by livestock often decreases the infiltration capacity of soils via soil compaction and alters plant physiological processes and population and community dynamics through vegetation removal and nitrogen deposition. Proactive management of livestock and other anthropogenic disturbances is essential for sound management and successful restoration of these ecosystems and, in incision-dominated basins, can potentially lessen the effects on ongoing stream incision.

The research described in this chapter indicates that understanding the underlying relationships among geomorphic processes, hydrologic regimes, and vegetation patterns and dynamics is required for managing and restoring riparian ecosystems. Assessing these relationships over a broader range of scales than has been done in the past—watershed to stream reach—is necessary for predicting vegetational responses to stream incision and other types of disturbance and for developing appropriate management guidelines and restoration techniques.

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## APPENDIX 7.1.

Representative species of common vegetation types discussed in this chapter.  
Vegetation types and representative species correspond with  
the ecological types described in Weixelman et al. (1996) for  
central Nevada.

Vegetation Type	Graminoids	Forbs	Shrubs and Trees
<i>Carex nebrascensis</i> meadow	<i>Carex nebrascensis</i> <i>Deschampsia cespitosa</i> <i>Juncus balticus</i>	<i>Geum macrophyllum</i> <i>Veronica americana</i>	
Mesic meadow	<i>Poa pratensis</i> <i>Elymus trachycaulus</i> <i>Juncus balticus</i> <i>Agrostis stolonifera</i>	<i>Aster occidentalis</i> <i>Iris missouriensis</i> <i>Stellaria longipes</i>	
Dry meadow	<i>Poa secunda</i> <i>Muhlenbergia richardsonis</i> <i>Leymus triticoides</i>	<i>Potentilla gracilis</i> <i>Achillia millefolium</i> <i>Penstemon rydbergii</i>	
<i>Salix</i> spp./mesic meadow	<i>Poa pratensis</i> <i>Juncus balticus</i>	<i>Smilacina stellata</i> <i>Viola sororia</i> <i>Trifolium wormskjoldii</i>	<i>Salix exigua</i> <i>Salix lutea</i> <i>Rosa woodsii</i>
<i>Salix</i> spp./mesic forb	<i>Leymus triticoides</i> <i>Elymus trachycaulus</i> <i>Carex praegracilis</i>	<i>Smilacina stellata</i> <i>Aquilegia formosa</i> <i>Aconitum columbianum</i>	<i>Salix exigua</i> <i>Salix lutea</i> <i>Salix lasiolepis</i> <i>Rosa woodsii</i>
<i>Betula occidentalis</i> /mesic meadow	<i>Poa pratensis</i> <i>Agrostis stolonifera</i> <i>Carex microptera</i> <i>Elymus trachycaulus</i>	<i>Smilacina stellata</i> <i>Aquilegia formosa</i> <i>Aconitum columbianum</i>	<i>Salix exigua</i> <i>Salix lutea</i> <i>Cornus sericea</i> <i>Rosa woodsii</i>
<i>Populus tremuloides</i> / <i>Symphoricarpos</i> spp.	<i>Elymus trachycaulus</i> <i>Poa pratensis</i> <i>Carex rossii</i>	<i>Aquilegia formosa</i> <i>Lupinus argenteus</i> <i>Astragalus lentiginosus</i>	<i>Populus tremuloides</i> <i>Symphoricarpos oreophilus</i> <i>Rosa woodsii</i>
<i>Populus</i> spp.	<i>Leymus triticoides</i> <i>Bromus carinatus</i> <i>Carex microptera</i>	<i>Smilacina stellata</i> <i>Aquilegia formosa</i> <i>Lupinus argenteus</i>	<i>Populus balsamifera</i> <i>Populus angustifolia</i>

<i>Artemisia tridentata</i> tridentata	<i>Leymus cinereus</i>	<i>Lupinus argenteus</i>	<i>Artemisia tridentata</i> tridentata <i>Chrysothamnus viscidiflorus</i>
<i>Leymus cinereus</i>	<i>Muhlenbergia richardsonis</i> <i>Poa secunda</i> <i>Leymus triticoides</i>	<i>Cryptantha flavoculata</i> <i>Astragalus lentiginosus</i>	
<i>Artemisia tridentata</i> tridentata	<i>Poa secunda</i> <i>Elymus</i>	<i>Lupinus argenteus</i>	<i>Artemisia tridentata</i> tridentata <i>Chrysothamnus viscidiflorus</i>
<i>Poa secunda</i>	<i>lanceolatus</i> <i>Leymus cinereus</i>	<i>Allium bisceptrum</i> <i>Cryptantha flavoculata</i>	

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