

Natural Range of Variation Assessment for Non-Meadow Riparian Zones in the Sierra Nevada

Sarah C. Sawyer, Assistant Regional Ecologist,
USDA Forest Service, Pacific Southwest Region

May 2013

Table of Contents

Introduction:	2
<i>Physical setting</i>	2
<i>Ecological Setting</i>	3
<i>Cultural/socioeconomic setting</i>	5
Methods:	6
Natural Range of Variation:	6
1. Function	6
<i>1.1. Flow Regimes</i>	6
<i>1.2 Fire Regimes</i>	8
<i>1.3 Grazing</i>	10
2. Structure	10
<i>2.1 Extent of Riparian Habitat</i>	10
<i>2.2. Canopy Characteristics</i>	11
<i>2.3 Stand Structure</i>	11
3. Composition	12
<i>3.1 Native Species Composition</i>	12
<i>3.2 Non-Native Species Composition</i>	12
Projected Future Trends:	13
Acknowledgements	14
Literature Cited:	15
Tables and Figures	21

Introduction:

Physical setting

Riparian zones occur throughout the Sierra Nevada bioregion, which serves as the headwaters for 24 major watersheds (Kattelmann 1996; Kondolf et al. 1996). Riparian zones can be defined as the three-dimensional zones of direct interaction between terrestrial and aquatic ecosystems (Gregory et al. 1991) that provide critical physical exchanges of material and energy (Collins et al. 2006). Due mainly to the type of data available, this chapter largely focuses on vegetated riparian zones adjacent to streams and rivers within the assessment area. Meadow habitats are covered in the Meadow chapter. Riparian areas generally differ from adjacent upland areas in topography, vegetation, geomorphology, microclimate, productivity, and disturbance regime (Table 1; Dwire & Kauffman 2003), and on the lower East side of the Sierra Nevada, riparian areas have been compared to oases within the surrounding upland habitat (East South Subregion; Kattelmann & Embury 1996). Riparian areas are often found at the lowest point in the landscape, where slopes may be less steep (Dwire & Kauffman 2003). They generally have cooler microclimates with higher relative humidity and lower wind speeds compared to adjacent upland areas (Dwire & Kauffman 2003; Rambo & North 2008). Currently, the amount of land in the assessment area classified as riparian forest habitat type is 58 km², with an additional 119 km² of riparian scrub (Kattelmann & Embury 1996).

Riparian ecosystems are shaped by both biotic factors and hydrogeomorphic processes; riparian communities tend to arrange themselves in response to climatic, geomorphic, and hydrologic gradients (Harris 1989). Significant drivers include: moisture, salinity, topography (especially elevation), channel morphology, substrate, flood patterns, sediment systems, streamflow-groundwater relationships, disturbance, and succession (Kattelmann & Embury 1996; Goodwin et al. 1997; Busch & Smith 1995; Dwire & Kauffman 2003; Potter 2005). In general, as slope increases, as substrate coarsens, and/or as flooding frequency increases, riparian communities tend to simplify (Harris 1989; Harris 1999). Areas with steeper slopes and gradients generally also have narrower riparian zones (Kattelmann & Embury 1996). Fluvial conditions are often the dominant force driving riparian stand composition in the Sierra Nevada, with fire playing a significant, though less prominent, role (Lewis 1996; Russell & McBride 2001; Stromberg & Patten 1996). Within the Sierra and Cascade mountains, species richness tends to peak at an intermediate distance from the channel edge, where water is still available from a shallow water table, but the surface is less frequently disturbed by flooding (Gregory et al. 1991; Patten 1998). Floodplains (ie areas that are flood prone) tend to have greater species diversity than non-flooding streambanks (Potter 2005).

Substrate parent material varies across the assessment area, shaping riparian communities. Broadly, parent material is mostly granitic within the southern Sierra Nevada and more volcanic in the Northern and Eastern Sierra Nevada and southern Cascades, but includes scattered metamorphic rock, particularly in the foothills, central Sierra Nevada and along the Sierra Nevada crest, and glacial till at higher elevations (Harris et al. 1987; Potter 2005). Substrate traits influences the riparian community supported at a given site, and soils in riparian areas are highly variable in structure, particle size, and other features (NRC 2002). Particular dominant vegetation is often associated with specific substrates or locations within the channel profile. For example, willows (*Salix* spp.) are often associated with sand and cobble substrates and alders (*Alnus* spp.) are often found immediately adjacent to channels (Harris 1989; Potter 2005). Significant associations between geomorphic valley type & riparian community

composition exist (Harris 1988). Table 2 (reproduced from Harris 1988) summarizes valley type vegetation relationships from the east side of the Sierra Nevada (East South Subregion).

Depth to water table is also a key determinant of vegetation patterns within riparian areas (Loheide & Gorelick 2007; Elmore et al. 2003; NRC 2002), with obligate wetland plants (e.g. *Salix laevigata*) giving way to facultative wetland plants (e.g. *Populus fremontii*) which in turn give way to upland species (e.g. some *Pinus* spp., *Caocedrus decurrens*, *Abies concolor*) in the outer floodplain as depth to groundwater increases (Stromberg et al. 1996; Harris 1989). Lowering water table levels by as little as one meter can induce water stress in riparian trees, particularly in the western U.S., thereby altering community patterns (NRC 2002).

Ecological Setting

Riparian zones represent a keystone community type, playing a more significant ecological role than their proportional area in the landscape would suggest (Gregory et al. 1991; Malanson 1993; NRC 2002). Kattelmann and Embury (1996) reported that the amount of riparian habitat within the assessment area is between only 0.1% and 1% of the total area. Yet riparian ecosystems in the assessment area, as elsewhere, provide many important ecological services, including: streambank stabilization, sediment retention, water quality improvement, hydraulic process moderation, nutrient exchange, and wildlife species habitat and food web provisioning (Patten 1998; NRC 2002). Key hydrologic functions provided by riparian vegetation include: improving water quality by trapping and filtering sediment, nutrients, and pollutants; reducing flood damage and enhancing ground-water recharge by slowing water velocity and increasing river surface area; and maintaining an elevated water table by preventing channelization (Patten 1998). Riparian communities contain more plant and animal species than any other California community type (Schoenherr 1992) and about one fifth of terrestrial vertebrate species in the Sierra Nevada depend on riparian habitat (Kattelmann & Embury 1996). Riparian zones also play an important role as ecological corridors (Naiman & Decamps 1997) and recreational sites (NRC 2002). Riparian forests are highly productive and, in general, the basal area, biomass, and complexity of riparian forests are as great as or greater than those of adjacent upland forests (Naiman et al. 1998; Pettit & Naiman 2007; Dwire & Kauffman 2003; Keeton et al. 2007).

Riparian zones in California are likely refuges for Arcto-Tertiary vegetation community elements, which were mostly replaced elsewhere by drought resistant vegetation known as Madro-Tertiary Geoflora during California's transition to a Mediterranean-type climate (Holstein 1984). Kattelmann & Embury (1996) describe some of the ecological characteristics generally shared by riparian zone plants: broad-leaved; winter-deciduous; fast-growing; short-lived; requiring high soil-moisture; tolerant of flooding and low oxygen root environments; and able to produce sprouts, suckers, and new root systems. Riparian tree species can generally be divided into two main categories: pioneer species and secondary successional species (Vaghti & Greco 2007; Strahan 1984). Pioneers, which include some species of *Salix*, *Populus*, and often release their water/wind born seeds in late spring, when flooding creates moist, available substrate (Vaghti & Greco 2007). They rely on spring flooding to create habitat and on low summer flows to promote seedling survival (Vaghti & Greco 2007). They are fast growing and produce debris like leaf litter that aids in soil development. Later seral species, like those of *Alnus*, *Acer*, *Fraxinus*, *Platanus*, and *Quercus* then grow up through the accumulated litter in areas where less frequent flooding occurs (Vaghti & Greco 2007; Strahan 1984).

Disturbance is particularly important to riparian ecosystems as many riparian plants are disturbance adapted (Kobziar & McBride 2006; Naiman & Decamps 1997; Naiman et al. 1998; Potter 2005; Vaghti & Greco 2007). Plant distribution and composition depends on both fluvial disturbance (e.g. debris flow, floods, scouring) and nonfluvial disturbance from adjacent upland ecosystems (e.g. fire, wind, disease, avalanche, herbivory, pests, etc.; Gregory et al. 1991; Naiman et al. 1998; Potter 2005). Riparian forests are heterogeneous in space and time (Naiman et al. 1998), and due to the high frequency of fluvial disturbances in the Sierra Nevada, riparian vegetation in the assessment area is especially patchy (Kobziar & McBride 2006). Under natural flow regimes in the Sierra Nevada, variation in flood frequency, magnitude, and duration- creates a diversity of age and structural conditions within riparian communities. These processes often result in high levels of patchiness through both space and time, with average riparian plant associations existing in patches smaller than 0.1 hectares (0.25 acres; Kattelmann & Embury 1996; Kobziar & McBride 2006; Potter 2005). Diversity in soil properties, topography, and other forms of disturbance add to this structural complexity (Gregory et al. 1991; Naiman et al. 1998).

Riparian forests may be dominated by the same tree species as the surrounding uplands (e.g. in conifer dominated areas) or deciduous trees and shrubs like cottonwoods (*Populus* spp.), alders, willows, or quaking aspen (*Populus tremuloides*; Dwire & Kauffman 2003; Potter 2005). Riparian zones within low- and mid-elevation forests of the Sierra Nevada are often dominated by non-coniferous deciduous trees (Russell & McBride 2001; Potter 2005). Cottonwoods (*Populus fremontii* and *P. trichocarpa*), red willow (*Salix laevigata*), and white alder (*Alnus rhombifolia*) are often considered keystone species in mid- and low-elevation riparian communities (west side Sierra Nevada) and willows, in shrub form, become more dominant in higher elevation areas (Patten 1998; Potter 2005). Willows are often confined to low topographic positions along streams where frequent flooding provides a favorable moisture balance (Klikoff 1965), but species and life forms of willow vary greatly by elevation (Potter 2005). Common riparian willow shrub species in the subalpine mixed conifer forests of the assessment area include *Salix eastwoodiae*, *S. orestera*, *S. planifolia*, and *S. boothii* (Weixelman et al. 1999). In the eastside mixed conifer zone (~6,500 – 8,000 ft.), common riparian willow species are *S. boothii*, *S. lemmoni*, and *S. geyeriana*. Quaking aspen also occurs in this area (Weixelman et al. 1999). Quaking aspen is widely distributed in riparian areas throughout the upper montane elevations of the assessment region, but is more scattered on the Westside, particularly in the south (Potter 2005; see Aspen chapter). In the eastside yellow pine forests (5,500 – 6,500 ft.), aspen is common, black cottonwood (*Populus trichocarpa*) becomes common as well, and willow species dominance shifts to sandbar willow (*S. exigua*) and yellow willow (*S. lutea*) (Weixelman et al. 1999). Alder species (*Alnus rhombifolia* and *A. incana*) are often found immediately adjacent to active channel (Patten 1998; Potter 2005). *Alnus incana* occurs mainly from the Stanislaus National Forest northward (Central South Subregion northward), with sparser occurrences towards the south (Potter 2005). For a list of riparian vegetation dominance types in the eastern and western Sierra Nevada, see Table 3, reproduced from Harris 1989. For a more fine-scale description of vegetation alliances on the west slope of the Southern/Central Sierra Nevada, see Potter (2005). For a description of Eastern Sierra Nevada riparian species, see Weixelman et al. 1999. For details on the Great Valley riparian community types, see Vaghti & Greco (2007).

Cultural/socioeconomic setting

Prior to Euro-American settlement, Native Americans used riparian areas extensively for food and other resources (Kattelmann & Embury 1996). Native American management of riparian vegetation included burning, pruning, tending, transplanting, and weeding (Vaghti & Greco 2007; Anderson 1993). Native Americans often preferentially burned riparian areas to clear hunting and transportation routes; increase production of food, medicine, and fiber; improve forage and habitat mosaics for wildlife; produce desirable new growth of plants like willows for basketry; and minimize catastrophic wild fires (Vaghti & Greco 2007; Anderson 1993). The Owens Valley Paiute also used ditches to divert water and encourage the growth of several grass and sedge species as food sources (East South Subregion; Anderson 2005).

Following the discovery of gold in 1848, riparian areas were quickly modified on a vast scale due to damming, diversion, dewatering, excavation, and pollution of waterways (Kattelmann & Embury 1996). In places like the Owens Valley (East South Subregion), total cultivated and irrigated pastureland increased continuously from settlement (in this case 1861) until the early 1900s (~1920), with direct effects (conversion of riparian land to pasture) and indirect effects (increased water diversion to meet increasing demand) on riparian systems (Elmore et al. 2003). Today, Sierra Nevada runoff provides almost 65% of water for agricultural and other human uses in California (Timmer 2003). In addition to water provisioning, however, assessment area watersheds are asked to provide for food production, power production, flood control, aesthetic values, and recreation (Kattelmann 1996; Vaghti & Greco 2007). Riparian ecosystems support the most diverse bird communities in the Western United States (Vaghti & Greco 2007), making them particularly popular recreation destinations as well as biodiversity refugia. While some drainages, particularly remote and high elevation reaches, have escaped human impact, water development and altered land-use has been so extensive in California, that many current riparian conditions have no historic analog (Kattelmann 1996).

Management plans in National Forests, and other land management systems in the assessment area, often exclude any sort of disturbance-based management in riparian zones. Mechanical thinning, as well as prescribed burning and managed wildfire, are prohibited in the riparian corridor due to concern for both water quality and sensitive riparian ecosystems (Kobziar & McBride 2006). These policies may create both positive and negative impacts, including reduced fire-related erosion and stream warming, but also greater fire risk and evapotranspirative water demand. One study showed that prescribed fire had no short-term negative effects in riparian areas of a northern Sierra Nevada stream (Beche et al. 2005), and scientists are beginning to recommend considering fuel treatment in riparian areas as part of landscape restoration strategies (Van der Water & North 2011), taking into account characteristics of riparian systems that influence the natural fire regime (Table 4). Human values associated with riparian systems have led to diverse impacts, including both massive water diversion and near prohibition of vegetation management. On the other hand, these same values, coupled with a changing climate, have recently led to broad riparian restoration efforts and a new respect for riparian system significance. Thus riparian systems today may exhibit diverse relationships to the natural range of variation (NRV) of various traits and conditions, with significant management implications into the future.

Methods:

While very few data are available on the natural range of variation (NRV) of riparian systems within the assessment area, we compile existing data here and, where possible, draw conclusions about the NRV of key ecosystem characteristics. We then compare the NRV to current conditions where feasible.

Natural Range of Variation:

In 1992, the National Research Council reported “[r]iparian and aquatic ecosystems are currently being altered, impacted, or destroyed at a greater rate than any time in history” (Kauffman et al. 1997). Thus, it is more important than ever to understand natural range of variation (NRV) of ecological and physical characteristics of these communities. However, despite their ecological importance, very little is known about historic conditions of riparian zones. This section represents a compilation of the information from current peer-reviewed literature about historic or natural ranges of variation within riparian communities of the assessment area.

1. Function

1.1. Flow Regimes

Flow regimes, including timing and quantity of average, maximum, and minimum flow, represent an important determinant of riparian communities (Poff et al. 1997). The heterogeneity, or variation in extremes, of flow discharge is an especially powerful ecosystem driver in riparian systems (Vaghti & Greco 2007).

1.1.1. Low Flows

NRV: Reconstructions of Sacramento River flow (fed from the North, Central, and Central South Subregions) derived from tree ring analyses back to A.D. 869 indicate that periods of high or low flows lasting more than fifty years were common in parts of the long-term flow history (Meko et al. 2001). Extended periods of drought may have been more common before A.D. 1400 than after (Meko et al. 2001). Tree-ring and relict stump records from the Sierra Nevada corroborate that the era including the Medieval Warm Period (~ 900 – 1350 A.D.) exhibited the largest droughts of the last thousand years (Brunelle & Anderson 2003), including two severe droughts ending about 840 and 600 years before present (ybp). These droughts of the last millennium, however, are likely relatively minor compared to those from the early middle Holocene (8,000 – 5,000 ybp; Brunelle & Anderson 2003) and the later middle Holocene (Benson et al. 2002). Drought conditions dominated the Truckee River – Pyramid Lake system (Central & East North Subregions) during the latter part of the middle Holocene (6,500 – 3,800 ybp), when Lake Tahoe (~ 32% of Truckee flow) did not overflow into the Truckee River (Benson et al. 2002). Sediment cores from Owens Lake (East South Subregion, south of Lone Pine) and Walker Lake (just east of northern East South Subregion) also suggest desiccation from 6480 to 3930 ybp, and around 5030 ybp respectively (Benson et al. 2002). Records from cored sediments of Pyramid Lake show that over the last 2,740 years, drought durations ranged from 20 to 100 years, with intervals between droughts ranging from 80 to 230 years (Benson et al. 2002; Table 5).

Comparison to Current: During the current period, droughts in the Sierra Nevada have lasted less than a decade (Benson et al. 2002). The drought record suggests that over the last 2,740 years, droughts often lasted several decades, and that multicentennial droughts occurred prior to 3,430 ybp (Benson et al. 2002). Thus, current *natural* flow regimes may fall at the low end of the natural range of variation for droughts, with larger and more prolonged droughts expected under more typical conditions within NRV (Table 6). In many regions of the assessment area, natural flow regimes have been so compromised by water development (e.g. diversion, exportation, inter-basin transfers), that we must also consider altered flow regimes when comparing current conditions to NRV (Elmore et al. 2003). Only three Sierra Nevada rivers greater than 100 miles long (Clavey, Middle Fork Cosumnes, and South Fork Merced) are free flowing (CA DWR 1998; USFS 2001), and in some areas diversions have had dramatic effects. For example, water diversion from the Truckee River led to a decrease in depth of Pyramid Lake in the 1960s greater than the estimated effects of one of the most severe droughts of the previous 2,000 years (Benson et al. 2002). Thus, an examination of pre-development flow patterns may also offer insight into flow NRV.

1.1.2. Water development: New Low Flows

NRV: At Rush Creek (north-western portion of East South Subregion), Stromberg and Patten (1990) established tree-ring chronologies of black cottonwood (*P. trichocarpa*) and Jeffrey pine (*Pinus jeffreyi*) trees as well as hydrologic chronologies of stream flow from 1910 (pre-1941 diversion) to 1986. They report that pre-diversion stream flow at Rush Creek produced about 62,000 acre-feet/year (af/yr), an annual equivalent of constant flow of 84 ft³/second, ranging from 30,000 to 120,000 af/yr over the 31 year period (Table 5; Stromberg & Patten 1990). In addition to inter-annual variation, pre-diversion flows varied significantly by season, with high spring flows (~4,000 – ~23,000 acre-feet/month) and low winter flows (< 2,000 acre-feet/month). Rush Creek is the largest tributary to Mono Lake. Pre-diversions, Rush Creek was a typical stream for the East Side of the Sierra Nevada, in that it was a snowmelt dominated perennial stream that had the highest flows in spring and the lowest in fall/winter, with headwaters at high elevations around 13,000 feet. It had wide annual variation in annual streamflow and peak flows based on precipitation (Stromberg & Patten 1990).

Comparison to Current: Post-diversion flows in Rush Creek were lower, averaging 19 ft³/second annually, and more consistent throughout the year (< 5,000 acre-feet/month), indicating reduced seasonality of the flow regime. Post-diversion flow also exhibited shifted seasonality, with peak flow occurring in July rather than May/June, due to release after reservoir filling (Stromberg & Patten 1990). In addition to lower average flow, and both lower and shifted seasonality in flow, patterns of inter-annual variation differed greatly in post- diversion flows (Table 6). Inter-annual variation was much more significant post-diversion, ranging from 0 to 180,000 af/yr (Stromberg & Patten 1990).

Generally, water development in California has reduced flow seasonality and shifted flow peak timing of lower to mid elevation rivers, reducing spring flood pulses and augmenting summer flow (Vaghti & Greco 2007). The resulting lack of episodic disturbance and increased summer water levels have led to decreased recruitment of pioneer species like *Populus* throughout the western United States (Vaghti & Greco 2007). In the Sierra Nevada this is likely true for *Populus fremontii* at lower elevations (Potter pers comm). Decreased recruitment is compounded by decreased growth and survival, due to lower overall water flow averages. Annual variation in cottonwood growth at Rush Creek was largely explained by volume of stream flow, suggesting

that post-diversion flow regime, which averaged 50% lower than pre-diversion, likely resulted in reduced tree growth (73% of normal for *P. trichocarpa*; < 50% for *Pinus jeffreyi*) in the riparian area (Stromberg & Patten 1990). Reduced cottonwood (*P. fremontii* and *P. trichocarpa*) tree/seedling abundance, tree growth, leaf size, and survival resulting from river damming have been observed along numerous rivers within and near the assessment area (NRC 2002).

1.1.3. High Flows

High maximum flows and flooding are important structuring events for riparian systems. Debris flows represent one of the major shaping forces associated with flooding.

NRV: Radiocarbon dates suggest that the recurrence rate for debris flows at any given site within the assessment area may have ranged from once every 5,000 years around the start of the Holocene (~18,000 - 11,000 ybp) to once every 400 and 500 years more recently (Table 5; DeGraff 1994). Geologic investigations in the Owens Valley (East South Subregion) indicate that debris flows occurred in the steep alluvial systems on a recurrence interval of several hundred years, often in association with fires (Wagner et al. 2012). Thus the NRV of the recurrence of debris flows in the assessment area likely ranges from several hundred to several thousand years

Comparison to Current: Historic logging and hydraulic mining in the Sierra Nevada foothills discharged large debris flows, causing increased downstream flooding (Vaghti & Greco 2007). Additional causes of debris flow in the assessment area include intense rainfall, rain-on-snow events, and seasonal melting of heavy snowpacks (DeGraff 1994). Over the last century, climate change has caused discernible shifts in these factors in the montane areas of Western United States, including: more winter precipitation falling as rain instead of snow, leading to earlier peak runoff and with larger late-winter flows (Barnett et al. 2008; Stewart et al. 2005; Moser 2009); increased variability of streamflow (Pagano & Garen 2005) increased frequency of catastrophic floods due to rain-on-snow events (Herbst & Cooper 2010); and increased melting of alpine glacier cover (31-78% in the Sierra Nevada; Basagic & Fountain 2011). These shifts suggest that debris flow recurrence may currently be outside of the NRV, with more frequent events than historically occurred (Table 6), and may move further outside of the NRV in the future.

1.2 Fire Regimes

In addition to watercourse characteristics, fire also plays an important role in shaping riparian communities (Russell & McBride 2001). In some forested riparian areas, pre-fire suppression fire return intervals were likely lower than adjacent uplands, while in others, fire frequency appears to have been comparable in riparian and upland areas (Dwire & Kauffman 2003). Similarly, some riparian areas show lower fire severity than upland sites while others do not (Dwire & Kauffman 2003). Evidence of the true fire regime may be more limited in the riparian zone than adjacent upland forest, due to the lower abundance of gymnosperms necessary for dendrochronological analysis of historical fire patterns (Kobziar & McBride 2006), and variability in fire scarring may complicate estimation of fire frequency (Potter 1998). However, some studies have attempted to examine NRV of fire frequency and severity in riparian systems of the Sierra Nevada and are discussed here.

NRV: Van de Water and North (2010) measured dendrochronological fire records across riparian and upland coniferous forests at 36 sites in the northern Sierra Nevada (Central and North

Subregions) for the time period between 1387 and 2009. They found that the mean fire return interval (FRI) for riparian forests and upland forests were very similar, 16.6 years and 16.9 respectively (Table 5). Riparian FRI ranged from 8.4 – 42.3 years, while upland FRI ranged from 6.1 – 58.0 years. Only 9 of 36 sites exhibited significant differences in FRI between riparian and upland areas (Van de Water & North 2010). At three of these nine sites, FRI was actually shorter in riparian than upland sites, indicating that riparian habitat may occasionally act as a conduit for fire movement in some locations (Van de Water & North 2010; Dwire and Kauffman 2003; Pettit & Naiman 2007). At six sites FRI was shorter for upland than riparian sites, indicating the potential for riparian areas to also act as a buffer against fire in other areas (Van de Water & North 2010; Skinner & Chang 1996; Taylor & Skinner 2003).

Size of stream and riparian area were key determinants of fire regime. FRI was found to be shorter for riparian zones which bordered narrower, more incised streams, with FRI being shortest for streams with a width to depth ratio less than 6.2 (Table 4). Larger, extended, less steep riparian zones, on the other hand, sometimes acted as natural fire breaks (Kobziar & McBride, 2006; Van de Water & North 2010). FRIs in this study were also shorter for: sites with a higher proportion of fire-tolerant pines; lower elevation sites; and those sites east of the Sierra crest (Van de Water & North 2010). Similar reconstructions in the Klamath Mountains suggest that FRIs in riparian areas are more variable than in neighboring uplands, and that they are generally longer in riparian zones adjacent to perennial streams than those bordering intermittent streams (Skinner 2003). Intermittent stream riparian zones appear to have burned with frequencies similar to surrounding uplands (Skinner 2003). In more arid ecosystems of the assessment area, riparian zones are more likely to act as conduits for fire, and may bring more frequent fire to those areas in comparison to areas with no riparian reaches (Pettit & Naiman 2007). This phenomenon has been observed in the Owens Valley in the East South Subregion, especially where non-native black locusts in riparian areas have carried fire rapidly and repeatedly through the sagebrush zone (Finch 2012). See Table 4 for a summary of environmental variables associated with riparian areas and their relationship to fire frequency.

Comparison to current: Only 2 of Van de Water and North's (2010) 36 sites showed differences in pre- and post- 1850 FRI, suggesting no significant change in fire frequency in this area since Euro-American settlement (Table 6). However, broader studies of FRI across California suggest that, at a larger scale, riparian habitats within certain vegetation types and subregions likely exhibit FRI significantly different from pre-settlement regimes (Safford & Van de Water 2013). The most extreme departures from pre-settlement FRI have likely occurred in riparian zones at middle elevations, and within yellow pine/mixed pine conifer forests (Safford & Van de Water 2013). The aspen vegetation type also showed a >67% decrease in fire frequency compared to the pre-settlement period (Safford & Van de Water 2013), suggesting that aspen-dominated riparian systems may be particularly divergent from natural range of variation. Those riparian areas that may remain within pre-settlement FRI regimes include those at the northern and southern ends of the Sierra Nevada Foothills (generally within grassland & oak woodlands where contemporary fire frequencies remain high), within the Mojave/Southeastern Great Basin, and portions of the Modoc Plateau (generally dryland ecosystems with longer natural FRIs; Safford & Van de Water 2013). Additionally, larger, less steep riparian areas bordering larger streams may also remain within the pre-settlement FRI range due to their longer FRI (Table 6). It may be possible that in areas heavily impacted by human management, maintenance of conditions within the NRV does not indicate presence 'natural' conditions. The effects of fire suppression (increased FRI) and water diversion and channel incision (decreased FRI) may theoretically act as opposing forces maintaining NRV conditions.

1.3 Grazing

NRV and comparison to current: Domestic livestock grazing was ubiquitous across the Sierra Nevada prior to 1930, peaking between about 1890 and 1930, with almost all accessible (particularly low elevation) riparian areas impacted (Kattelmann & Embury 1996; Potter 2005). Cattle tend to congregate in riparian areas due to the abundance of food, water, shade, and cooler temperatures (Kattelmann 1996; NRC 2002; Potter 2005). Thus, ungrazed reference conditions may be difficult to find, particularly at more accessible sites. One study showed that more recent livestock impacts vary greatly across the region, and only 27% of riparian areas sampled indicated recent livestock use, generally concentrated at mid-elevations (Potter 2005). Whether these sites were historically impacted by grazing is more difficult to determine. Kattelmann & Embury (1996) note anecdotally that ungrazed reference sites have higher vegetation densities than grazed sites (Tables 5 & 6), though this may only be the case when compared to heavily and consistently impacted sites. In addition to affecting overall vegetation density, grazing also directly affects riparian plant species in idiosyncratic ways. Some willow species, such as Lemmon's willow (*Salix lemmoni*) and shining willow (*S. lasiandra* ssp. *lasiandra*) are heavily browsed, while other, less palatable species like Sierra willow (*S. orestera*) are rarely browsed (Potter 2005). Thus, grazing may have impacted relative species dominances and community composition in areas where heavily browsed species once dominated. Grazing was also largely responsible for accelerating erosion beginning in the late 1800s, leading to gullying, incision, and loss of riparian vegetation (Kattelmann 1996; Potter 1998; Kinney 1996). While severity of overgrazing has declined since 1930, riparian systems may remain simplified compared to pre-settlement conditions, and continued grazing pressure has prevented some degraded sites from recovering at all (Kattelmann 1996). Thus, domestic livestock grazing has likely effected the function (erosion, incision), structure (vegetation density), and composition (preferential grazing of certain species) of riparian communities. While lack of reference conditions makes a comparison of these effects to NRV very difficult, some conclusions can likely be drawn from sites that show no current human impacts (Potter 2005).

2. Structure

2.1 Extent of Riparian Habitat

NRV: In 1848, the Sacramento River had an estimated 800,000 acres (~324,000 hectares) of riparian forests, extending up to one mile in "jungle-like conditions" on each side of the river (Table 5; Spotts 1988). The San Joaquin River system, on the other hand, carries less sediment than the Sacramento system, producing less prominent natural levee land forms, and consequently historically supporting narrower bands of riparian forest bounded by large marshes (Vaghti & Greco 2007). The first aerial photos of the Truckee River (Central & East North Subregions), taken in 1938 after some Euro-American caused decline in riparian vegetation had likely already occurred, indicate extensive riparian woodlands, ranging from 300 to 600 meters in width, and exhibiting about 50% canopy closure (Table 5; Rood et al. 2003). By the 1970s, these riparian woodlands had been reduced to sparsely scattered relict trees due to diversion and dewatering (Rood et al. 2003). However, new instream flow regulations to protect the endangered cui-ui fish (*Chasmistes cujus*) led to some recovery of cottonwood and willow along the river in the 1980s (Rood et al. 2003).

Comparison to Current: Most available accounts indicate a massive decline in riparian vegetation since European colonization. As of 1988 only about 12,000 acres (~5,000 hectares), or less than 2%, of the Sacramento River's riparian forest is estimated to remain (Table 6; Spotts

1988). Statewide estimates suggest between 5 and 10% of original riparian habitat remains in California (NRC 2002). Riparian vegetation currently makes up less than 1% of the assessment area (Kattelmann & Embury 1996). Late 19th century timber harvest had disproportionate impacts on riparian forests both because rivers and drainages were frequently used to transport harvested logs and because gold-mining activities were focused within streams and required wood (Kattelmann & Embury 1996). Additionally, many historic riparian sites are now under water, as wide valleys with large swaths of riparian habitat offered ideal reservoir locations (Kattelmann & Embury 1996). In some areas, shoreline of artificial reservoirs and waterways may have actually created new riparian habitat where none previously exists (e.g. Lake Isabella, South Subregion), but these areas are often unstable as water levels change due to either climate or human control (USFWS 2002). In other areas, where water flow has been completely or nearly eliminated due to water development (e.g. Rush Creek in the Mono Basin), riparian vegetation has nearly disappeared (Kattelmann & Embury 1996; Stine et al. 1984). The changes described above may be more applicable to larger, lower elevation, more accessible rivers, where more data is available. Some researchers suggest that smaller streams and higher elevation rivers may look much more similar to historic conditions (Potter pers. comm.). While studies suggest that a forested riparian width (including riparian and/or upland species) equal to at least two to three tree heights is necessary to maintain the characteristic microclimate of forested riparian zones (Kondolf et al. 1996; Collins et al. 2006), the riparian plant associations along streams are less than 100 meters long and 10 meters wide (Potter 2005). Estimates of minimum and maximum riparian habitat widths to maintain other key functions are examined by Collins et al. (2006; Table 7), but will depend on specific location characteristics.

2.2. Canopy Characteristics

NRV: While no data are available on pre-European settlement canopy characteristics in riparian areas, Erman et al. (1977) surveyed canopy density of 13 unlogged first and second order streams in the northern Sierra Nevada. The authors observed canopy density ranging from 50 to 100% along the Truckee River, with a mean of 75% (Table 5; Erman et al. 1977; Kattelmann & Embury 1996). These studies were conducted after commencement of fire-suppression practices, so should be interpreted cautiously.

Comparison to current: Current vegetation monitoring by the US Forest Service should provide data for comparison of current canopy cover to NRV.

2.3 Stand Structure

NRV and Comparison to Current: Van de Water and North (2011) reconstructed historic forest structure within the Almanor Ranger District of the Lassen National Forest (North Subregion), the Onion Creek Experimental Forest, and the Lake Tahoe Basin (Central Subregion) to determine whether current stand structure and fuel loads differ from historic conditions. Reconstruction was set at the year of the last fire at each site, which ranged from 1848 to 1990, with 64% of reconstruction periods occurring before 1940 (Van de Water & North 2010, 2011). The authors found that at their sites, reconstructed historic structural conditions at riparian sites included lower basal area, stand density, snag volume, and fuel loads than current riparian forests (Tables 5 & 6; Van de Water & North 2011). Additionally, reconstructed historic riparian forests at the study sites were not significantly different than reconstructed upland forests, while current riparian forests have much greater stand density than current upland forests (Van de Water & North 2011). Denser riparian forests, likely resulting from fire suppression, may further reduce water yields in many basins of the western slope of the Sierra Nevada due to

increased water demand to balance evapotranspiration (Kattelmann 1996). Once again, these results should be interpreted cautiously, as reconstructed time periods sometimes post-dated many years of fire-suppression practices and they represent the conclusions of only one study.

3. Composition

3.1 Native Species Composition

NRV: While fossil data indicate that the dominant species found in modern lowland riparian habitats have been associated for 20 million years (Robichaux 1980), few records exist to refine our understanding of pre-European species composition in riparian forests for the assessment area. However, qualitative historical accounts by early explorers may offer some insight into characteristics of particular riparian zones within and surrounding the bioregion. Visitors to the Sacramento Valley in the mid-1800s described riparian forests dominated by *Quercus lobata*, *Platanus racemosa*, and *Populus fremontii*, also noting presence of *Alnus rhombifolia*, *Fraxinus latifolia*, and *Salix* spp. (Vaghti & Greco 2007). Historical accounts from the 1840s – 1860s describe the Owens Valley as having very little tree cover, except near Lone Pine (South Owens Valley, East South Subregion), or as having no timber aside from a few cottonwoods or willows directly adjacent to the river (Table 5; Brothers 1984). These accounts note herbaceous perennials as the dominant vegetation cover (Brothers 1984). Ridgeway (1877) describes riparian vegetation of the lower Truckee River (Central Subregion) as dense and extensive, with large groves of cottonwoods and shrubby understory of buffalo-berry (*Shepherdia* spp.) and willow amongst others (Table 5; Klebenow & Oakleaf 1984). Ridgeway notes that in 1867 the Truckee River banks were “fringed with dense thickets of rather tall willows, growing about fifteen feet high” (Ridgeway 1877). Bird surveys along the lower Truckee River in 1868 found 107 bird species, including 21 obligate riparian species (Rood et al. 2003). In 1894, John Muir wrote of California’s lowland riparian systems: “close along the water’s edge there was a fine jungle of tropical luxuriance, composed of wild-rose and bramble bushes and a great variety of climbing vines, wreathing and interlacing the branches and trunks of willows and alders, and swinging across from summit to summit in heavy festoons” (Vaghti & Greco 2007). In the early 1900s, prior to water development in the Mono Lake watershed, the lower reaches of Rush, Walker, Parker, and Lee Vining Creeks (East South Subregion) were characterized by groves of aspen, black cottonwood, willow, Jeffrey pine, and likely mountain alder (Table 5; Stine et al. 1984).

Comparison to Current: In 1984, Stine et al. wrote that most of the vegetation characterizing the Mono Lake watershed in the early 1900s “has now been lost” (Stine et al. 1984). Resurveying of the lower Truckee River in 1981 revealed that only 1 of the 21 obligate riparian bird species had not shown strong declines in population since 1868 (Rood et al. 2003). As of the mid 1990s, about one quarter of wildlife species that depend on riparian habitat were considered at risk of extinction (Graber 1996; Kattelmann & Embury 1996), and half of the 32 amphibian species and almost half of the 40 fish species/subspecies found in the Sierra Nevada were endangered, threatened, or of special concern (Jennings & Hayes 1994; Moyle et al. 1996). Additionally, 85% of Sierra Nevada watersheds are characterized by poor to fair aquatic biotic communities (Moyle & Randall 1996). These data suggest that wildlife species diversity and threat levels are likely outside of the NRV (Table 6).

3.2 Non-Native Species Composition

NRV: Despite the lack of data on community composition of historic riparian communities, we can infer by knowledge of introduction dates, that these communities did not include the common non-indigenous plant species now present (Tables 5 & 6).

Comparison to Current: Riparian zones within the assessment area are among those most heavily affected by non-native species invasions (Schwartz et al. 1996). Salt cedars (*Tamarix chinesis*, *T. ramosissima*, *T. parviflora*) have notably invaded the southern and eastern portions of the Sierra Nevada, and are better adapted to survive water stress and drought conditions than genera like *Populus* and *Salix* (Smith et al. 1991; Shafrroth et al. 2000; Alstad et al. 2008). Salt Cedar invasion may also increase flammability of riparian systems, interacting with the increase in fire risk through fire suppression to create highly volatile conditions (Alstad et al. 2008). *Ailanthus altissima* (tree of heaven), introduced into the US in 1784 from Asia, has impacted mainly the foothill regions of the Sierra Nevada, below elevations of 1,000 meters (3,280 ft.; Schwartz et al. 1996). Russian olive (*Elaeagnus angustifolia*), introduced during the Euro-colonial period, is known to decrease site suitability for cottonwood species, thus further impacting riparian zone composition (Schwartz et al. 1996). Other non-native species that readily colonize riparian ecosystems of the Sierra Nevada include giant reed (*Arundo donax*), perennial pepperweed (*Lepidium latifolium*), Himalayan blackberry (*Rubus armeniacus*), and purple loosestrife (*Lythrum salicaria*) (D' Antonio et al. 2004; NRC 2002). Decline in depth to water table, due to water development and diversion, is thought to facilitate species invasion in the more arid regions of the assessment area. In the Owens Valley, decline in the water table has led to a competitive advantage of exotic annual plants during drought years (Elmore et al. 2003). In some areas, particularly on the westside, studies found few if any of these invasive species (Potter 2005). For a more complete discussion of the impacts of nonindigenous plants in the Sierra Nevada, see Schwartz et al. (1996). Introduced fauna have also altered riparian and aquatic community composition. Introduction of non-native fish species for recreation over the last century has had a major impact on native aquatic wildlife (Knapp 1996) with cascading consequences for both aquatic and terrestrial food webs (Finlay & Vredenburg 2007; Epanchin et al. 2010).

Projected Future Trends:

Today, riparian zones are at greater risk of fragmentation, non-native species invasion, and high severity fire, than historically. An analysis of aerial photographs of about 1/5 of the Sierra Nevada Watersheds showed that 121 of 130 watersheds have clear gaps in the riparian corridor – largely from road/railroad crossings, timber harvest, private lot clearing, livestock grazing, and dam/diversion dewatering (Kondolf et al. 1996). Riparian zones are also among those areas of the Sierra Nevada most impacted by non-native invasive species (Schwartz et al 1996), and altered riparian systems may be especially vulnerable (Parks et al. 2005) to the 300-400 non-native plant species that have entered the assessment region (Millar & Woolfenden 1999). Van de Water and North (2011) found that current riparian forests are likely more fire prone than reconstructed historic riparian forests, including greater duff and total fuel loads, predicted surface and crown flame lengths, probability of torching, and predicted post-fire tree mortality (Table 6).

Anticipated impacts of climate change to riparian ecosystems in the Sierra Nevada include more frequent and severe flash flooding events, earlier peak flows, greater streambed incision, increased evapotranspiration rates, contraction of riparian communities, increased invasions by non-native species, increased stream temperatures, and lower groundwater recharge (Southern Sierra Partnership 2010). Projected future conditions will thus likely exacerbate the current trends of increased fragmentation, invasion, and fire risk, as well as decreased average and minimum streamflows. Projected future conditions are expected to

more closely resemble the early Holocene insolation maximum and the Medieval Warm Period, which exhibited greater droughts and temperatures, lower flows, and greater fire frequencies than current conditions (Brunelle & Anderson 2003; Beaty & Taylor 2009). For example, climate warming is projected to reduce mean annual flow, initiate earlier peak runoff timing, and increase the duration of low flow conditions in Sierra Nevada watersheds (Null et al. 2010). In general, watersheds in the northern Sierra Nevada are the most vulnerable to decreased mean annual flow, southern-central watersheds are most susceptible to runoff timing changes, and the central portion of the range is most affected by longer periods with low flow conditions. Null et al. (2010) suggest the American and Mokelumne Rivers are most vulnerable to all three metrics, and the Kern River is the most resilient, due in part to the high-elevation topography of the watershed.

In addition to low flow declines, high flow increases and pulse events are likely to become more significant in the future. Increases in extreme hydrologic events across the western U.S. are predicted to be especially pronounced in the mountains of the California coast range and the Sierra Nevada (Kim 2005). Such events could facilitate unprecedented debris flow and landslide events within the region as evidenced by recent case studies (e.g., DeGraff et al. 2011, Huggel et al. 2012).

Finally, as the human population of California continues to grow, so too will demand for water, leading to greater diversion and de-watering within the Sierra Nevada riparian systems (Elmore et al. 2003). The synergistic impacts of declining water table depth, due to human demand, and increased climate variability, due to climate change, are likely to facilitate further invasion by non-native species (Elmore et al. 2003). More studies on natural range of variation in these traits will offer potential direction for management decision-making for riparian ecosystem sustainability.

Acknowledgements

Special thanks to Mehrey Vaghti and Ann Chrisney for their time and assistance in improving this draft. Thanks also to Marc Meyer, Hugh Safford, and Shana Gross for insightful comments and suggestions. Thanks to the R5 Ecology Program for their guidance and facilitation.

Literature Cited:

Alstad, K. P., S. C. Hart, J. L. Horton, and T. E. Kolb. 2008. Application of tree-ring isotopic analyses to reconstruct historical water use of riparian trees. *Ecological Applications* **18**:421-437.

Anderson, K. 1993. Native Californians as ancient and contemporary cultivators. Pages 151 – 174. In: T.C. Blackburn and K. Anderson (eds), *Before the wilderness: environmental management by native Californians*. Ballena Press, Menlo Park.

Anderson, M. K. 2005. *Tending the wild*. University of California Press, Berkeley.

Barnett, T. P., D. W. Pierce, H. G. Hidalgo, C. Bonfils, B. D. Santer, T. Das, G. Bala, A. W. Wood, T. Nozawa, A. A. Mirin, D. R. Cayan, and M. D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. *Science* **319**:1080-1083.

Beatty, R. M. and A. H. Taylor. 2009. A 14 000 year sedimentary charcoal record of fire from the northern Sierra Nevada, Lake Tahoe Basin, California, USA. *Holocene* **19**: 347-358.

Basagic, H.J. and Fountain, A.G. 2011. Quantifying 20th Century Glacier Change in the Sierra Nevada, California. *Artic, Antarctic, and Alpine Research* **43**: 317-330.

Benson, L., M. Kashgarian, R. Rye, S. Lund, F. Paillet, J. Smoot, C. Kester, S. Mensing, D. Meko, and S. Lindstrom. 2002. Holocene multidecadal and multicentennial droughts affecting Northern California and Nevada. *Quaternary Science Reviews* **21**: 659 – 682.

Brothers, T.S. 1984. Historical Vegetation Change in the Owens River Riparian Woodland. In: Warner R.E. and K.M. Hendrix, (eds) 1984. *California Riparian Systems: Ecology, Conservation, and Productive Management*. Berkeley: University of California Press

Brunelle, A. and R. S. Anderson. 2003. Sedimentary charcoal as an indicator of late-Holocene drought in the Sierra Nevada, California, and its relevance to the future. *Holocene* **13**:21-28.

Busch, D. E. and S. D. Smith. 1995. Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern US. *Ecological Monographs* **65**:347-370.

California Department of Water Resources (CA DWR) 1998. California Water Plan Update Bulletin 160-98. Department of Water Resources, Sacramento CA.

Collins, J.N., M. Sutula, E.D. Stein, M. Odaya, E. Zhang, K. Larned. 2006. Comparison of Methods to Map California Riparian Areas. Final Report Prepared for the California Riparian Habitat Joint Venture. 85 pp.

DeGraff, J.V. 1994. The geomorphology of some debris flows in the southern Sierra Nevada, California. *Geomorphology* **10**: 231 – 252.

DeGraff, J., D. Wagner, A. Gallegos, M. DeRose, C. Shannon, and T. Ellsworth, 2011. The remarkable occurrence of large rainfall-induced debris flows at two different locations on July 12, 2008, Southern Sierra Nevada, CA, USA. *Landslides* **8**:343-353.

D'Antonio, C.; Berlow, E.L.; Haubensak, K.L. 2004. Invasive exotic plant species in Sierra Nevada ecosystems. In: Murphy, D.D.; Stine, P.A., eds. *Proceedings of the Sierra Nevada Science Symposium; 2002 October 7-10, Kings Beach, CA*. General Technical Report PSW-GTR-193. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 175-184.

Dwire, K. A. and J. B. Kauffman. 2003. Fire and riparian ecosystems in landscapes of the western USA. *Forest Ecology and Management* **178**:61-74.

Elmore, A.J., J.F. Mustard, and S.J. Manning. 2003. Regional patterns of plant community response to changes in water: Owens Valley, California. *Ecological Applications* **13**: 443 – 460.

Epanchin, P.N., R.A. Knapp, and S.P. Lawler. 2010. Non-native trout impact an alpine-nesting bird by altering aquatic-insect subsidies. *Ecology*. **91**: 2406-2415.

Erman, D. C., J. D. Newbold, and K. B. Roby. 1977. Evaluation of streamside bufferstrips for protecting aquatic organisms. Contribution 165. Davis: University of California, Water Resources Center.

Finch, D. M., editor. 2012. Climate change in grasslands, shrublands, and deserts of the interior American west: A review and needs assessment. US Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Finlay J.C. and V.T. Vredenburg. 2007. Introduced trout sever trophic connections in watersheds: Consequences for a declining amphibian. *Ecology*. **88**: 2187-2198.

Goodwin, C. N., C. P. Hawkins, and J. L. Kershner. 1997. Riparian restoration in the western United States: Overview and perspective. *Restoration Ecology* **5**:4-14.

Graber, D.M. 1996. Status of terrestrial vertebrates. Pages 709 – 734 in Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An Ecosystem Perspective of Riparian Zones. *BioScience* **41**:540-551.

Harris, R. R. 1988. Associations between stream valley geomorphology and riparian vegetation as a basis for landscape analysis in the eastern Sierra Nevada, California, USA. *Environmental Management* **12**:219-228.

Harris, R. R. 1989. Riparian Communities of the Sierra Nevada and their Environmental Relationships. Pages p. 393-398. In: Abell, Dana L., Technical Coordinator. 1989. Proceedings of the California Riparian Systems Conference: protection, management, and restoration for the 1990s; 1988 September 22-24; Davis, CA. Gen. Tech. Rep. PSW-GTR-110. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

Harris, R. R. 1999. Defining reference conditions for restoration of riparian plant communities: Examples from California, USA. *Environmental Management* **24**:55-63.

Harris, R. R., C. A. Fox, and R. Risser. 1987. Impacts of hydroelectric development on riparian vegetation in the Sierra Nevada region, California, USA. *Environmental Management* **11**:519-527.

Herbst, D. B. and S. D. Cooper. 2010. Before and after the deluge: rain-on-snow flooding effects on aquatic invertebrate communities of small streams in the Sierra Nevada, California. *Journal of the North American Benthological Society* **29**:1354-1366.

Holstein.G. 1984. California Riparian forests: deciduous islands in an evergreen sea. In: Warner R.E. and K.M. Hendrix, (eds) 1984. California Riparian Systems: Ecology, Conservation, and Productive Management. Berkeley: University of California Press

Huggel, C., J.J. Clague, and O. Korup. 2012. Is climate change responsible for changing landslide activity in high mountains? *Earth Surface Processes and Landforms* **37**: 77-91.

Jennings, M.R., and M.P. Hayes. 1994. Amphibian and reptile species of special concern in California. Rancho Cordova: California Department of Fish and Game, Inland Fisheries Division.

Kattelmann, R. 1996. Hydrology and Water resources. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources. Pages 855 – 920.

Kattelmann, R. and M. Embury. 1996. Riparian areas and wetlands. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. III, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources.

Kauffman, J. B., R. L. Beschta, N. Otting, and D. Lytjen. 1997. An ecological perspective of riparian and stream restoration in the western United States. *Fisheries* **22**:12-24.

Keeton, W. S., C. E. Kraft, and D. R. Warren. 2007. Mature and old-growth riparian forests: Structure, dynamics, and effects on adirondack stream habitats. *Ecological Applications* **17**:852-868.

Kim, J. 2005. A projection of the effects of the climate change induced by increased CO₂ on extreme hydrologic events in the western US. *Climatic Change* **68**:153-168.

Kinney, W.C. 1996. Conditions of rangelands before 1905. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources.

Klebenow, D.A. and R.J. Oakleaf. 1984. Historical Avifaunal Changes in the Riparian Zone of the Truckee River, Nevada. In: Warner R.E. and K.M. Hendrix, (eds) 1984. California Riparian Systems: Ecology, Conservation, and Productive Management. Berkeley: University of California Press

Klikoff, L. G. 1965. "Microenvironmental influence on vegetational pattern near timberline in the central Sierra Nevada". *Ecological Monographs* **35**: 187–211

Knapp, R.A. 1996. Non-native trout in natural lakes of the Sierra Nevada: an analysis of their distribution and impacts on native aquatic biota. Sierra Nevada ecosystem Project: Final report to Congress. Volume III. Assessments, commissioned reports, and background information. Davis, CA: University of California, Centers for Water and Wildland Resources. 363–407.

Kobziar, L. N. and J. R. McBride. 2006. Wildfire burn patterns and riparian vegetation response along two northern Sierra Nevada streams. *Forest Ecology and Management* **222**:254-265.

Kondolf, G., R. Mathias, R. Kattelmann, M. Embury, and D. Erman. 1996. Status of Riparian Habitat. In: Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources.

Lewis, W. M. 1996. Defining the riparian zone: lessons from the regulation of wetlands. In: At the water's edge: the science of riparian forestry. Conference Proceedings June 19-20, 1995. Minnesota Extension Service.

Loheide, S.P. and S.M. Gorelick. 2007. Riparian hydroecology: a coupled model of the observed interactions between groundwater flow and meadow vegetation patterning. *Water Resources Research* **43**: W07414.

Malanson, G.P. 1993. Riparian landscapes. Cambridge University Press, Cambridge. 296 pp.

Meko, D. M., M. D. Therrell, C. H. Baisan, and M. K. Hughes. 2001. SACRAMENTO RIVER FLOW RECONSTRUCTED TO A.D. 869 FROM TREE RINGS1. JAWRA Journal of the American Water Resources Association **37**:1029-1039.

Millar, C. I. and W. B. Woolfenden. 1999. Sierra Nevada forests: Where did they come from? Where are they going? What does it mean? In: Transactions of the 64th North American Wildlife and Natural Resources Conference, 31 p.

Moser, S., G. Franco, S. Pittiglio, W. Chou, D. Cayan. 2009. The future is now: An update on climate change science impacts and response options for California. California Climate Change Center Report CEC-500-2008-071, May 2009. California Energy Commission, Sacramento, CA.

Moyle, P.B. and R.J. Randall. 1996. Biotic Integrity of Watersheds. In: Sierra Nevada Ecosystems Project: final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources, 1996.

Moyle, P.B., R.M. Yoshiyama, and R.A. Knapp. 1996. Status of Fish and Fisheries. In: Sierra Nevada Ecosystems Project: final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources, 1996.

Naiman, R. J. and H. Decamps. 1997. The Ecology of Interfaces: Riparian Zones. Annual Review of Ecology and Systematics **28**:621-658.

Naiman, R.J., K.L. Fetherston, S.J. McKay, and J. Chen. 1997. Riparian forests. In: Naiman R.J. and R.E. Bilby (eds). River ecology and management: lessons from the Pacific coastal ecoregion. New York: Springer, pp 289 – 323.

National Research Council (NRC). 2002. Riparian areas: Functions and strategies for management. Academy of Sciences, Washington DC.

Null, S.E., J.H. Viers, and J.F. Mount. 2010. Hydrologic response and watershed sensitivity to climate warming in California's Sierra Nevada. PLoS One 5(4):e9932.

Pagano, T. and D. Garen. 2005. A recent increase in western US streamflow variability and persistence. Journal of Hydrometeorology 6:173-179.

Parks, C. G., S. R. Radosevich, B. A. Endress, B. J. Naylor, D. Anzinger, L. J. Rew, B. D. Maxwell, and K. A. Dwire. 2005. Natural and land-use history of the Northwest mountain ecoregions (USA) in relation to patterns of plant invasions. Perspectives in Plant Ecology Evolution and Systematics **7**:137-158.

Patten, D. T. 1998. Riparian ecosystems of semi-arid North America: Diversity and human impacts. Wetlands **18**:498-512.

Pettit, N. E. and R. J. Naiman. 2007. Fire in the riparian zone: characteristics and ecological consequences. Pages 673-687. Ecosystems.

Potter, D.A. 1998. Forested communities of the upper montane in the Central and Southern Sierra Nevada. . Gen. Tech. Rep. PSW-GTR-169. Albany, CA: U.S. Department of Agriculture, Forest Service. Pacific Southwest Region. 326 p.

Potter, D.A. 2005. Riparian plant community classification: west slope, central and southern Sierra Nevada, California. Gen. Tech. Rep. R5-TP-022. Albany, CA: U.S. Department of Agriculture, Forest Service. Pacific Southwest Region. 630 p.

Rambo, T.R., and M.P. North. 2008. Spatial and Temporal Variability of Canopy Microclimate in a Sierra Nevada Riparian Forest. *Northwest Science* 82:259-268.

Ridgeway, R. 1877. *Ornithology*. Pages 303–669 in King C. (ed.) *Ornithology and Paleontology*. US Geological Explorations 40th Parallel, Vol. 4. Washington (DC): US Government Printing Office.

Robichaux, R. 1980. Geologic history of the riparian forests of California. Pages 21-34 In: A. Sands (ed.), *Riparian forests in California: their ecology and conservation*. Institute of Ecology Publication No. 15, University of California, Davis.

Rood, S. B., C. R. Gourley, E. M. Ammon, L. G. Heki, J. R. Klotz, M. L. Morrison, D. A. N. Mosley, G. G. Scoppettone, S. Swanson, and P. L. Wagner. 2003. Flows for Floodplain Forests: A Successful Riparian Restoration. *BioScience* 53:647-656.

Russell, W. H. and J. R. McBride. 2001. The relative importance of fire and watercourse proximity in determining stand composition in mixed conifer riparian forests. *Forest Ecology and Management* 150:259-265.

Schoenherr, A. A. 1992. *A natural history of California*. Berkeley and Los Angeles: University of California Press.

Schwartz, M.W., D.J. Porter, J.M. Randall, and K.E. Lyons. 1996. Impacts of Nonindigenous plants. Pages 1203 –1226 in *Sierra Nevada Ecosystem Project: Final report to Congress*, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources.

Shafroth, P. B., J. C. Stromberg, and D. T. Patten. 2000. Woody riparian vegetation response to different alluvial water table regimes. *Western North American Naturalist* 60:66-76.

Skinner, C. N., and C. Chang. 1996. Fire regimes, past and present. Pages, 1,04 1 - 1,070 in *Sierra Nevada Ecosystem Project: Final report to Congress*. Vol. II, Assessments and scientific basis for management options. Rept. No. 36. Univ. California, Ctrs. for Water and Wildland Resources, Davis.

Skinner, C.N. 2003. A tree-ring based fire history of riparian reserves in the Klamath Mountains. In: Faber, Phyllis M., Editor. 2003. *California Riparian Systems: Processes and Floodplains Management, Ecology, and Restoration*. Riparian habitat and floodplains conference Proceedings. March 12-15, 2001, Sacramento, CA. Riparian Habitat Joint Venture, Sacramento, CA. 116-119

Smith, S. D., A. B. Wellington, J. L. Nachlinger, and C. A. Fox. 1991. Functional Responses of Riparian Vegetation to Streamflow Diversion in the Eastern Sierra Nevada. *Ecological Applications* 1:89-97.

Southern Sierra Partnership. 2010. Framework for cooperative conservation and climate adaptation for the southern Sierra Nevada and Tehachapi Mountains, California, USA. Report prepared by The Nature Conservancy, Audubon Society, Sequoia Riverlands Trust, and Sierra Business Council. October, 2010. 275 p.

Spotts, R. 1988. Perspective on Sacramento River riparian habitats – impacts, threats, remedies, opportunities, and consensus. In: USDA Forest Service General Technical Report PSW – 110: Proceedings of the California Riparian Systems Conference. Sept 22-24, 1988. Davis CA. Protection, Management, and Restoration for the 1990s..

Stewart, I.T., D. R. Cayan, and M. D. Dettinger. 2005. Changes toward earlier streamflow timing across western North America. *Journal of Climate* 18: 1136-1155.

Stine, S., D. Gaines, and P. Vorster. 1984. Destruction of Riparian Systems Due to Water Development in the Mono Lake Watershed. In: Warner R.E. and K.M. Hendrix, (eds) 1984. California Riparian Systems: Ecology, Conservation, and Productive Management. Berkeley: University of California Press

Strahan, J. 1984. Regeneration of riparian forests of the Central Valley. Pages 58 – 67 in: R.E. Warner & K.M. Hendrix (eds.), California riparian systems: ecology, conservation, and productive management. University of California Press, Berkeley.

Stromberg, J. C. and D. T. Patten. 1990. Riparian vegetation instream flow requirements: a case-study from a diverted stream in the Eastern Sierra Nevada, California, USA. *Environmental Management* **14**:185-194.

Stromberg, J. C. and D. T. Patten. 1996. Instream flow and cottonwood growth in the eastern Sierra Nevada of California, USA. *Regulated Rivers: Research & Management* **12**:1-12.

Stromberg, J.C., R. Tiller, and B. Richter. 1996. Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona. *Ecological Applications* **6**: 113 – 131.

Taylor, A.H., Skinner, C.N. 2003. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains. *Ecological Applications* **13**: 704–719. Timmer, K.L. 2003. Troubled Water of the Sierra. Sierra Nevada Alliance. Lake Tahoe, CA.

U.S. Fish and Wildlife Service (USFWS). 2002. Southwester Willow Flycatcher Recovery Plan. Appendix I. Albuquerque, New Mexico.

USDA Forest Service (USFS). 2001. Sierra Nevada Framework Environmental Impact Statement. Volume 2. Sierra Nevada Framework Project, Sacramento, CA.

Vaghti, M.G. and S.E. Greco. 2007. Riparian vegetation of the Great Valley. Pages 425 – 455. In: M.G. Barbour, T. Keeler-Wolf, and A.A. Schoenherr (eds), *Terrestrial Vegetation of California*. University of California Press, Berkeley, CA.

Van de Water, K. and M. North. 2010. Fire history of coniferous riparian forests in the Sierra Nevada. *Forest Ecology and Management* **260**:384-395.

Van de Water, K. and M. North. 2011. Stand structure, fuel loads, and fire behavior in riparian and upland forests, Sierra Nevada Mountains, USA; a comparison of current and reconstructed conditions. *Forest Ecology and Management* **262**:215-228.

Weixelman, D.A., D.C. Zamudio, and K.A. Zamudio. 1999. Eastern Sierra Nevada riparian field guide. R4-ECOL-99-01. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 262 p.

Woolfenden, W. B. 1996. Quaternary vegetation history. In: Sierra Nevada Ecosystem Project: final report to congress, Vol. II, Assessments and scientific basis for management options, pp. 47–69. University of California, Centers for Water and Wildland Resources, Davis, CA.

Tables and Figures

Table 1. Relative comparisons between riparian and upland ecosystems in the Sierra Nevada (reproduced from Dwire & Kauffman 2003).

Feature/Process	Riparian	Upland
Topographic Position	Canyon bottom (e.g., stream terraces, floodplains)	All slope positions except floodplains and stream terraces
Vegetation	Dominated by species requiring high soil moisture (e.g., <i>Alnus</i> , <i>Fraxinus</i> , <i>Populus</i> , <i>Salix</i> , <i>Carex</i> , <i>Scirpus</i> spp.)	Dominated by species with low to moderate soil moisture demand
Geomorphology	High rates of erosion, debris flow, and sediment transport	Low rates of fluvial processes
Microclimate	Mesic to hydric	Xeric to mesic
Water Table	Shallow	Deep
Productivity	High	Low
Disturbance Regime	High frequency of flooding Low frequency of fire ¹	High frequency of fire Infrequent flooding
Species diversity	High	Low

¹ Does not include narrow riparian ecosystems.

Table 2. Valley type physical conditions and vegetation characteristics (reproduced from Harris 1988). Study area located between 37° and 38° north latitude on eastern slope of Sierra Nevada, including McGee, Birch, Bishop, Rush, Mill, and Lee Vining Creeks.

Valley Type	Elevation (m)	Mean riparian zone width (m)	Mean species richness	Associated vegetation types*	Vegetation type association		
					Substrate	Cross section type	Diversion status
U-Shaped bedrock	> 2500**	7.4	8.0***	PICO/MDW SALX/GLST	Sand, cobble gravel	Incised Braided	Undiverted Undiverted
U-shaped till	2000 – 2500	27.0	13.0	SALX/COST POTM/SALX	Cobble NS	One-sided One- or –two-sided	NS Undiverted
V-shaped till	NS	21.0	9.0	BEOC/SALX	NS	NS	NS
Alluvial fan	< 2000	27.0	9.0	CHNA/ARTR POTR/ROWO	Gravel Gravel	Braided NS	Diverted Diverted
All				POTM/POTR	boulder	NS	NS

22

* Vegetation type codes - PICO/MDW: *Pinus contorta*-meadow; SALX/GLST: *Salix* spp-*Glyceria striata*; SALX/COST: *Salix* spp – *Cornus stonifera*; POTM/SALX: *Populus tremuloides* – *Salix* spp; BEOC/SALX: *Betula occidentalis* - - *Salix* spp; CHNA/ARTR: *Chrysothamnus nauseosus* – *Artemisia tridentata*; POTR/ROWO: *Populus trichocarpa* – *Rosa woodsii*; POTM/POTR: *Populus tremuloides* – *Populus trichocarpa*

** significant associations: $p < 0.05$, NS indicates no significant association

*** mean number of species per plot

Table 3. Riparian Vegetation Dominance Types (reproduced from Harris 1989; see Potter 2005 for more fine scale vegetation alliance descriptions for the west slope of the Southern/Central SN and Vaghti & Greco 2007 for description of Great Valley riparian communities).

Dominance Type Label	Dominant Tree/Shrub	Indicator Shrub/Herb
Western Sierra Nevada		
<i>Pinus contorta</i> var <i>murrayana</i>	<i>Pinus contorta</i> var <i>murrayana</i>	<i>Spirea densiflora</i> , <i>Carex fracta</i> , <i>Deschampsia elongata</i>
<i>Abies magnifica</i>	<i>Abies magnifica</i> , <i>Salix lasiolepis</i>	<i>Salix drummondiana</i> , <i>Cornus stolinifera</i> , <i>Senecio triangularis</i> , <i>Athyrium filix-femina</i>
<i>Alnus incapa</i> spp <i>tenuifolia</i>	<i>Alnus incapa</i> spp <i>tenuifolia</i>	<i>Rhododendron occidentale</i> , <i>Glyceria striata</i>
<i>Populus trichocarpa</i>	<i>Populus trichocarpa</i>	<i>Rhododendron occidentale</i>
<i>Abies concolor</i>	<i>Abies concolor</i> , <i>Corpus stolinifera</i> , <i>Salix lasiolepis</i>	<i>Rhododendron occidentale</i> , <i>Ribes nevedense</i> , <i>Rubus parviflorus</i> , <i>Boykinia major</i> , <i>Athyrium filix-femina</i>
<i>Alnus rhombifolia</i>	<i>Alnus rhombifolia</i>	Many shrubs & herbs. See Taylor & Davilla (1985).
<i>Fraxinus latifolia</i>	<i>Fraxinus latifolia</i> , <i>Alnus rhombifolia</i>	Many shrubs & herbs. See Taylor & Davilla (1985).
Eastern Sierra Nevada		
<i>Pinus contorta</i> var <i>murrayana</i> - meadow	<i>Pinus contorta</i> var <i>murrayana</i> , <i>Salix</i> spp.	<i>Alium validum</i> , <i>Carex</i> spp
<i>Salix</i> - <i>Glyceria</i>	<i>Salix</i> spp.	<i>Salix geyeriana</i>
<i>Populus tremuloides</i>	<i>Populus tremuloides</i> , <i>Salix</i> spp.	<i>Elymus triticoides</i> ,
<i>Salix</i> - <i>Cornus</i>	<i>Salix</i> spp., <i>Corpus stolinifera</i>	<i>Equisetum</i> , <i>Deschampsia caespitosa</i> ,
<i>Betula</i> - <i>Salix</i>	<i>Betula occidentalis</i> , <i>Salix</i> spp	<i>Carex lanuginosa</i>
<i>Populus tremuloides</i> - <i>Populus trichocarpa</i>	<i>Populus tremuloides</i> , <i>Populus trichocarpa</i>	<i>Salix lasiolepis</i> , <i>Corpus stolinifera</i> , <i>Carex lanuginose</i> ,
<i>Populus</i> - <i>Rosa</i>	<i>Populus trichocarpa</i> , <i>Rosa woodsii</i>	<i>Salix exigua</i> , <i>Artemisia tridentata</i>
<i>Chrysothamnus</i> - <i>Artemisia</i>	<i>Chrysothamnus nauseosus</i> , <i>Artemisia tridentata</i>	<i>Salix exigua</i> , <i>Betula occidentalis</i> , <i>Phragmites australis</i>

Table 4: Environmental variables associated with riparian areas and their relationship to fire frequency.

Variable	Frequency of Fire	Citation
Stream Size*	Decreases	(Pettit and Naiman 2007)
Soil Moisture*	Decreases	(Pettit and Naiman 2007)
Fuel Moisture*	Decreases	(Pettit and Naiman 2007)
Riparian area surrounded by Pine forest	Increases	(Van de Water and North 2010)
East Side Forests^	Increases	(Van de Water and North 2010)
Drought*	Increases	(Pettit and Naiman 2007)
Northern CA+	Decreases	(Van de Water and Safford 2011)

*Indicates increasing in size. ^Compared to West Side forests. +Compared to Southern CA

Table 5. Natural/Historic Condition Description from specific riparian sites where Studies have been conducted.

Source	Location	Variable	Reference Time Period	Natural/Historic Condition Description	Current Comparison
Spotts in PSW GTR 110 1988	Sacramento River	Area of Riparian forest	1848	Estimated 800,000 acres of riparian forest, extending up to 1 mile in some places on each side of the river	In 1988 only ~ 12,000 acres remain (< 2%)
Kattelmann & Embury, 1996 in SNEP	Sierra Nevada	Amount of Riparian habitat	Pre- European Settlement	More area than exists today (many areas that are currently under water).	"because broad valleys w/ wide riparian areas were often optimum reservoir sites, much of former best riparian habitat in SN is now under water"
Rood et al. 2003 (Lang et al. 1990)	Truckee River	Width of Riparian Forest	1938 ("after some decline had likely already occurred")	300-600 meters	1970s -"dwindled to sparsely scattered relict trees"
		Canopy Closure		50%	
Kattelmann & Embury, 1996	13 unlogged streams in SN	Canopy density	1975 – current unlogged	Range: 50% -100% ; mean: 75%	
Stromberg & Patten 1990	Rush Creek, Eastern SN	Volume of Stream flow: average, and inter-annual variation	1910-1941 (pre-diversion of Rush Creek)	Stream flow average: 62,000 af/yr, (equivalent to constant 84 cfs), annual range: 30,000 – 120,000 af/yr	average flow reduced (19 cfs), interannual variation increased (range: 0 – 180,000 af/yr)
		Tree growth effects of stream flow	1910-1941 (pre-diversion of Rush Creek)	stream flow explained 66% of annual variation in black cottonwood growth	below normal growth of black cottonwood (avg 73% of normal) and Jeffery pine (<50% of normal)
		Stream flow seasonal variation	1910-1941 (pre-diversion of Rush Creek)	High spring flows (~4,000 – ~23,000 acre-feet/month), Low winter flows (< 2,000 acre-feet/month)	Post diversion flows lower & consist through year (<5,000 acre-feet/month)

Source	Location	Variable	Reference Time Period	Natural/Historic Condition Description	Current Comparison
Benson et al. 2002	Truckee River – Pyramid Lake system	Drought duration	Last 2,740 years	20 – 100 years	Current: less than a decade
		Drought duration	Prior to 3430 ybp	Multiple 100s of years	
		Drought recurrence	Last 2,740 years	80 – 230 years	Current: less than a decade
DeGraff 1994	Sierra Nevada	Debris flow recurrence rate	Over Holocene	Once every 400 (recently) – 5,000 years (early Holocene)	Increase in rain-on-snow events suggests increased rate of debris flows
Van de Water & North 2010	36 sites- Lassen, LTBMU, Onion Creek	Fire Return Interval (FRI)	1387-2009 (first fire event: 1526)	Riparian FRI range: 8.4 – 42.3 years; mean: 16.6; no significant diff before and after 1850 Shorter FRI: East side sites, riparian zones bordering narrower, more incised streams	Upland FRI range: 6.1 – 58.0 years; mean: 16.9;
Van de Water & North 2011	36 paired sites in Lassen, LTBMU, & Onion Creek Experimental Forest	Basal area	Reconstruction period: year of last fire for each site - range 1848-1990 (65% before 1940)	28 m ² /ha	87 m ² /ha
		Stand density		208 stems/ha	635 stems/ha
		Snag volume		2 m ³ /ha / 3 Mg/ha	37 m ² /ha / 69 Mg/ha
		Duff / total fuel loads		28 Mg/ha	93 Mg/ha
		Canopy bulk density		0.04 kg/m ³	0.12 kg/m ³
		Surface / crown flame lengths		0.4 m / 0.4 m	0.6 m / 0.9 m
		Probability of torching / mortality		0.03 / 17% BA	0.45 / 31% BA
		Torching / crowning indices		176 km/hr / 62 km/hr	20 km/hr / 28 km/hr
		Total area	Early decades of 1900s	320 ha (800 ac.) of marsh, wet meadow, and riparian woodland covered the depressions and lined the banks of the creeks	most that veg lost now
Stine, Gaines, & Vorster 1984; in Warner & Hendrix (eds) 1984	Lower Rush, Parker, Walker, & Lee Vining Creeks; & Grant & Waugh Lake depressions	Vegetation description		Dense groves of aspen, black cottonwood, willow, Jeffrey pine, and probably mountain alder, interspersed with meadows and cattail marshes	

Source	Location	Variable	Reference Time Period	Natural/Historic Condition Description	Current Comparison
Source	Location	Variable	Reference Time Period	Natural/Historic Condition Description	Current Comparison
Brothers 1984 in Warner & Hendrix (eds)	Owens valley	Tree cover	1840s-1860s	"very little tree cover except near Lone Pine"; "no timber except few cottonwoods/willows right along river" mostly dominated by herbaceous perennials	
Klebenow & Oakleaf 1984, in Warner & Hendrix (eds)	Lower Truckee River	General description: veg cover	1840s-1860s	"Along the bank of the river and surrounding the sloughs connected with the stream, were exceedingly dense willow-jungles, the sloughs themselves being filled with rushes, flags, and other aquatic plants; but most of the valley consisted of meadowlands, interspersed with velvety swards of 'salt-grass' and acres of beautiful sun-flowers (<i>Helianthus giganteus</i>), studded with fine large cottonwood trees (<i>Populus monilifera</i> (sic) and <i>P. trichocarpa</i>), which were here and there grouped into delightful groves, sometimes unencumbered, but generally with a shrubby undergrowth, amongst which the 'buffalo-berry' (<i>Shepherdia argentea</i>) was conspicuous"	"this description no longer fits; today only thin, discontinuous ribbon of cottonwoods remains"
Kattelmann & Embury, 1996	Sierra Nevada	Vegetation density	Current – anecdotal	"anecdotally, ungrazed reference sites tend to have much denser vegetation"	Grazing nearly ubiquitous before 1930
Schwartz et al. 1996 & D'Antonio et al. 2004	Sierra Nevada	Presence of invasive species	As compared to current only	By definition, no invasive species present	Salt cedars, tree of heaven, Russian olive, giant reed, pepperweed, Himalayan blackberry, purple loosestrife, etc.
Kondolf et al. 1996	Sierra Nevada	Connectivity of riparian corridor	As compared to current only	High connectivity	93% of watersheds studies showed gaps in riparian corridor

Table 6. Current State of Riparian Zone Ecological Variables with regards to Natural Range of Variation (NRV)

Ecosystem attribute	Indicator group	Indicator	Variable	In NRV	Confidence	Notes	Pages in Text
Hydrology		drought	drought recurrence frequency and duration	No	High	current droughts last less than decade, droughts over last 2740 years often lasted several decades; droughts prior to 4330 ybp often lasts multiple 100s of years	6
		ground water	depth to water table	No	High	damming and diversion create novel systems	7
		stream flow	total water volume	No	High	damming and diversion create novel systems	7
		stream flow	flow seasonal variation	No	High	post diversion flows lower and more consistent throughout year than pre diversion (1910)	7
Function		fire	fire return interval	Depends	Med	Depends on: riparian characteristics, Subregion & surrounding veg type. Van de Water & North 2010 show no sig. difference in FRI pre- & post- 1850; Safford & Van de Water (2013) show significant departures from pre-settlement FRI for various veg types	8-9
			predicted surface & crown flame lengths (m)	No	Low	3/2X and 2X greater than reconstruction period respectively	13
		fire risk	probability of torching	No	Low	current 15X reconstruction period	13
			predicted post-fire mortality (BA)	No	Low	current almost 2X reconstruction period	13
Disturbance			torchning & crowning indices (km/hr)	No	Low	current <1/9 and <1/2 of reconstruction values respectively	13
		grazing	resulting vegetation density	No	Low	anecdotally, ungrazed reference sites have denser vegetation'	9
		debris flow	recurrence frequency, and duration	No	Low	increased rain on snow events likely indicates increased debris flow frequency over last century	7
Composition	Species (spp) diversity	wildlife spp diversity	species richness & endangerment	No	High	introduced fauna have altered riparian and aquatic community composition; 85% of SN watersheds characterized by poor to fair aquatic biotic communities	11-12
		introduced spp diversity	species richness	No	High		12

Ecosystem attribute	Indicator group	Indicator	Variable	In NRV	Confidence	Notes	Pages in Text
Structure 29	Area	riparian habitat area	total area	No	High	<2% of 1848 riparian forest area on the Sacramento River	10
		width of riparian forest	distance from stream bank to edge of riparian habitat	No	Low	1938 reference of 300- 600 meters along the Truckee River	10
	Physiognomy	plant density	historical anecdotal accounts	No	Low	dense groves' of early 1900s 'mostly lost' by 1984; 'dense jungles' of 1840s-1860s only 'thin, discontinues ribbon' by 1984	10
		canopy cover	percent closure	?	?	1938: 50% closure along Truckee River	10
		canopy density	canopy density	?	?	unlogged reference; range: 50 - 100%, mean: 75%	10
		canopy bulk density	kg/m3	No	Low	current >3X reconstruction period (1848 - 1990)	11
		snag occurrence	snag volume (m3/ha)	No	Low	current >10X reconstruction period (1848 - 1990)	11
	Connectivity	canopy gap attributes	gap presence/absence	No	High	93% of watersheds show gaps in riparian corridor due to anthropogenic factors	13
	Productivity	tree basal area	basal area (m2/ha)	No	Low	current >3X reconstruction period (1848 - 1990)	11
		stand density	density of trees (stems/ha)	No	Low	current >3X reconstruction period (1848 - 1990)	11
	Soil	litter/duff depth	duff load (mg/ha)	No	Low	current >3X reconstruction period (1848 - 1990)	13

Table 7. Riparian Functional Width Requirements. Reproduced from Collins et al. (2006)

Riparian Function	Average recommended or observed minimum riparian width (rounded to nearest 5m)	Average recommended or observed maximum riparian width (rounded to nearest 5m)
Sediment Entrapment	10	75
Contaminant Filtration or Chemical Transformation	10	115
Large Woody Debris Input to Water Body	40	80
Leaf Litter Input to Water Body	5	25
Flood Hazard Reduction	15	65
Aquatic Wildlife Support	20	60
Bank or Shoreline Stabilization	15	25
Riparian Wildlife Support	40	160
Water Body Cooling	20	40
Riparian Microclimate Control	70	130
Multiple Functions	30	120