The Effects of Indigenous Prescribed Fire on Herpetofauna and Small Mammals in Two Central Valley California Riparian Ecosystems

Don L. Hankins
California State University, Chico

Abstract

The role of fire in riparian ecosystems of California's Central Valley is poorly documented. However, it is known that Native Americans have used fire in these ecosystems for millennia to manage riparian resources. The effects of such indigenous management practices on wildlife are important to understand when considering the restoration of fire as a process in riparian ecosystems. The objectives of this research were to work with California Indian cultural practitioners to implement and study the effects of culturally appropriate prescribed fire on herpetofauna and small mammals utilizing riparian ecosystems in central California, and to determine the utility to contemporary resource management and conservation practices. The results suggest that fall burning had a significant effect on trap captures and the number of species captured, resulting in greater abundance and diversity in burned areas. Thus, fall burning may be a useful tool in managing and conserving herpetofauna and small mammal biodiversity.

Introduction

Lyon and Smith (2000) suggested that the knowledge of Native American (or respective indigenous groups) about fire regimes and practices may assist in achieving wildlife management objectives today. With exception to studies of fire effects on game species, field observations, and ethnographic literature, few studies have empirically analyzed the effects of Native American fire regimes and practices on wildlife, although several studies investigate the effects of prescribed fires in general (see Ford et al. 1999; Moseley et al. 2003; Bury 2004). Several examples exist from abroad (e.g., Australia), which offer insight into indigenous fire management and the effects on wildlife (see Russell-Smith et al. 1997; Fraser et al.

2003; Murphy and Bowman 2007). Distinguishing the effects of anthropogenic fires from natural fires on the landscape is an emerging area of research (Natcher et al. 2007), and the implications of these fires on wildlife are of interest (Larsen et al. 2007). Understanding the effects of Native American fire-management practices on wildlife may inform contemporary management practices in order to achieve conservation objectives.

Ethnohistoric Context

California Indians have utilized fire in landscape-scale management for millennia; Schurr and Sherry (2004) identified that the region has been populated for approximately 15,000 to 20,000+ years. The annual extent of burning in pre-contact times was quite extensive, and has been estimated between 4.5 and 12 percent of the state (excluding the desert regions) (Stephens et al. 2008). Virtually every terrestrial ecosystem type, including riparian areas (where many of the villages were located) experienced some level of indigenous fire management. Martin and Sapsis (1992) have suggested that the implementation of these practices over long time periods has likely led to selection for species tolerant of such disturbance regimes (Russell et al. 1999), and were effective in maintaining biodiversity. In support of this concept, Agee (1999) and Besctha et al. (2004) suggest restoration of these fire regimes as a "coarse filter" approach to conserve biological resources.

Many studies have discussed the role of indigenous burning in grasslands, chaparral, mixed conifer forests, and oak woodlands (for example, see Anderson 1999, 2005; Keeley 2002; Mensing 2006). However, few literature examples exist pertaining to California Indian fire practices in riparian ecosystems. Some historic accounts are described in Belcher (1853), Driver (1939), Sutter (1939), and Anderson (2005). Traditional use of fire within riparian ecosystems, and at a landscape scale, has been greatly impacted since European colonization, due to such factors as indigenous population decline, the loss of land tenure, and fire suppression policies. Among surviving California Indian traditional cultural practitioners, knowledge of such fire practices persists and continue to be passed via oral tradition through the generations. Despite the limitations of being unable to implement this knowledge at a landscape scale, there remains considerable awareness of fire use and fire effects on riparian ecosystems. Based on input from traditional cultural practitioners and historic records mentioned above, burning in the riparian forest for general management was typically, but not always, done during the beginning of the wet season (i.e., October–January), but may vary with local conditions. A variety of reasons for burning riparian areas existed historically (Bean & Lawton 1973; Lewis 1973; Anderson 1999). A basic reason for burning is to clean up the landscape (i.e., remove dead biomass and create space for new growth). Additional reasons including clearing corridors for travel or access to resources, management of plans (such as valley oaks for acorns or willows for basketry), game management, and the protection of resources.

Conservation and Management Issues

Contemporary land managers often seek cost-effective management that yields the best results for the resources and ensures long-term conservation objectives. Where appropriate, fire can be useful to fulfill these objectives (Kirby et al. 1988). In recent years, several papers have addressed the role of fire in riparian ecosystems (see Bisson et al. 2003; Dwire and Kauffman 2003; Petit and Naiman 2007); however, none have specifically addressed fire in California's Central Valley riparian ecosystems through applied research. Wills (2006) discusses the role of fire in California's Central Valley, but there is still much need for research on the specific effects and histories of fire within these and other riparian ecosystems. In general, the available literature focuses on the effects of high-intensity (heat-generated) and high-severity (magnitude-of-destruction) fires on riparian vegetation (Busch 1995; Gom and Rood 1999; Ellis 2001), or they are in relationship to larger wildland fires (Everett et al. 2003; Kobziar and McBride 2006) rather than prescribed burns, which typically have objectives for low to moderate intensity and severity.

Globally, riparian ecosystems are of particular management and conservation concern due to habitat conversion and incompatible uses (Mitsch and Gosselink 1993). In California, up to ninety-nine percent of the riparian habitat of the Central Valley (Sacramento and San Joaquin valleys) has been lost, primarily as a result of agricultural conversion, urban development, and flood protection (Faber and Holland 1996). Riparian systems are of importance due to the various ecosystem services they provide including habitat for fish and wildlife, cycling nutrients, slowing the velocity of flood waters. Moreover, their high primary productivity makes them valuable in carbon sequestration (Zedler and Kercher 2005). Riparian ecosystems in the Central Valley provide habitat for a significant number of rare, threatened, or endangered species. In light of conservation and management activities where rare species exist, the effects of fires on wildlife and their habitat are an important area of interest

(Renken 2006; Lyet et al. 2009). Yearly, wildfires affect the remnant patches of riparian forest in the Central Valley, which in turn causes the temporal loss of habitat for some wildlife species. Prescribed fire within these areas is often avoided as a habitat management tool, due to the regulatory concerns for negative impacts to rare species, which stems from an uncertainty of fire effects.

It is known that fire generally results in few injuries or mortalities among wildlife present during any given fire event (Lyon et al. 2000). Many organisms that have evolved in association with periodic fire have life histories or behavioral mechanisms including aestivation during fire season, burrowing, and fleeing (Whelan 1995; Lyon et al. 2000; Arno and Allison-Bunnell 2002; Pilliod et al. 2003) to ensure survival during a fire event. Often, the indirect effects of fire are of larger concern to wildlife (Walter 1977). For instance, an individual may survive a fire, but the loss of cover may make it more susceptible to predation. Similarly, the loss of browse or a decrease in prey abundance as food resources can be detrimental to entire populations. These effects can be linked back to the behavior and spatio-temporal patterns of a fire.

Whelan (1995) provided an overview of fire effects and their influences on wildlife; these include intensity, rate of spread, complexity, season, and extent of fire behavior. These factors may contribute to both direct and indirect effects on wildlife, and may be key to assessing impacts to a given taxon. The season of burn can be important in individual survivorship for many taxa. For instance, ground-nesting species (e.g., California spotted towhee [*Pipilo maculates*] and deer mice [*Peromyscus maniculatus*]) may be vulnerable to fire if the fire occurs during nesting. As Lyon et al. (2000) stated, adults and juveniles are more likely to survive a fire, but nestlings are particularly at risk of mortality due to their limited mobility. Cavitt (2000) reported that fire-induced mortalities of reptiles were avoided by burning when reptiles were in their winter hibernacula, but injuries or mortality could occur when reptiles were active. Western fence lizards (*Sceloporous occidentalis*) have been observed to survive fires under the cover of surface litter, rocks, and burrows (see Kahn 1960). Renken (2006) synthesized that fires had no effect on abundance, diversity, or number of species of amphibians or reptiles. Lillywhite and North (1974) noted that a temporal population increase in Western fence lizards may occur following a fire. Conversely, Sullivan and Boateng (1996) documented a short-term decrease in deer mice abundance following summer burn treatments. However, Vreeland and Tietje

(2002) found that low- to moderate-intensity burns in the fall resulted in no detectable impact on mammal, avian, or herpetofauna abundances. Larsen et al. (2007) observed greater species richness among small mammals at burned sites.

The extent and complexity of a fire can be particularly important for a variety of reasons, including increased predation risks in large burn areas, competition for food resources, and loss of food items for food specialists. Additionally, some wildlife may be unable to move to or between suitable patches of habitat. The effects of a disturbance may be difficult to detect, depending upon the scale at which a given disturbance event occurs—particularly if the disturbed area is smaller than the home range of the wildlife being monitored (Cramer and Willig 2005). The rate of vegetation recovery is somewhat related to the extent and complexity of fire in that the more rapidly the plant community recovers from fire, temporal impacts of habitat loss will be minimized. In some cases, the effects may be linked to available plant cover, food resources, and vegetation structure (e.g., the presence of a duff layer or woody debris). Knowledge of what effects may occur and time needed until the community recovers to pre-burn functions may assist land managers in fulfilling multiple conservation objectives (e.g., how to use fire to promote native vegetation diversity while maintaining the existing diversity of animals).

The purpose of this study was to investigate the effects of indigenous (i.e., California Indian) prescribed fires (early wet season) on herpetofauna and small mammals within riparian ecosystems of the Central Valley. Traditional cultural practitioners representing fourteen tribes from throughout California cooperated to test the hypothesis that late fall (early wet season) burns do not result in significant differences in trap captures and species diversity of herpetofauna and small mammals.

Methods

Field treatments involving ladder-fuel (fuels that can cause the spread of fire from the ground to canopy) removal followed by burning were conducted at two 2.43-hectare study sites: the Cache Creek Nature Preserve (Cache Creek), located near Woodland, Yolo County; and the Natural Resource Conservation Service's Plant Material Center (Mokelumne), located along the Mokelumne River in Lockeford, San Joaquin County (see Figure 1). Each study site was divided equally into contiguous unburned control and treatment (fuel reduction followed by an early wet season burn) areas. Both study sites have

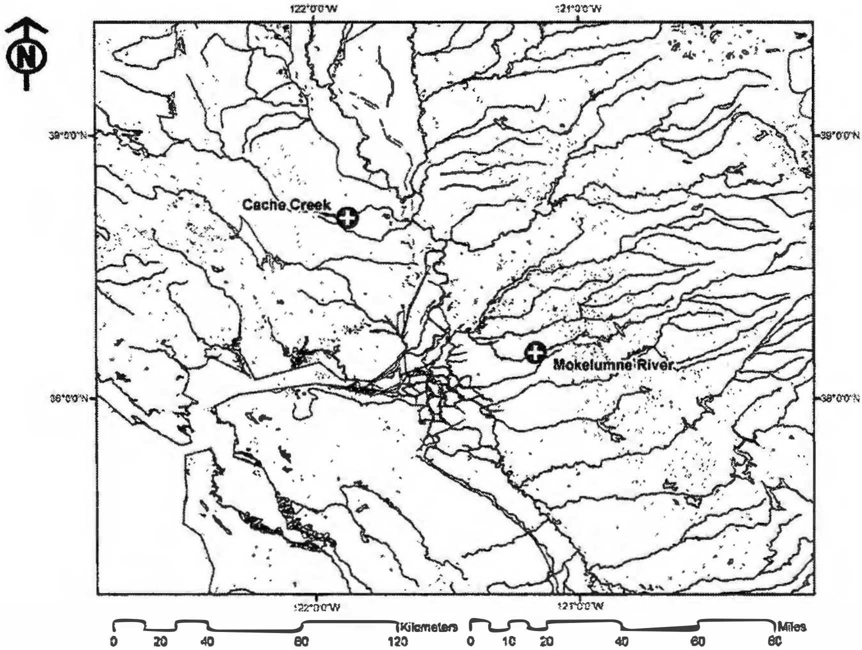

Figure 1.—Map of study site locations. Components of this map were obtained from the California Spatial Information Library data sets.

representative native and nonnative vegetation. Vegetation at each study site has been classified as Valley Foothill Riparian (Grenfell 1988) dominated by a willow/cottonwood (*Salix* spp./*Populus fremontii*) or willow/box elder (*Acer negundo*) canopy with an understory of grasses, herbs, and forbs including Santa Barbara sedge (*Carex barbarae*), creeping wild-rye (*Leymus triticoides*), stinging nettle (*Urtica californica*), and mugwort (*Artemesia douglasiana*). Some of the nonnative species found within the study sites include arundo (*Arundo donax*), salt cedar (*Tamarix chinensis*), perennial pepperweed (*Lepidium densiflorum*), ripgut brome (*Bromus diandrus*), and Himalaya blackberry (*Rubus discolor*). Common herpetofauna and small mammals expected or known to occur within the riparian corridor at both study sites include gopher snake (*Pituophis melanoleucus*), sharp-tailed snake (*Contina tenuis*), western fence lizard (*Sceloporus occidentalis*), western skink (*Eumeces skiltonianus*), southern alligator lizard (*Elgaria multicarinata*), bullfrog (*Rana catesbeiana*)—introduced species, Pacific chorus frog (*Psuedacarus regilla*), deer mice (*Peromyscus maniculatus*), and California vole (*Microtus californicus*).

Between late August and mid-November 2002 (prior to any burn treatments), ladder fuels within the treatment areas were reduced via pruning, coppicing, and other methods to create a cleared understory, representative of pre-contact structure described in oral accounts and journal entries (Belcher 1853; Driver 1939; Sutter 1939), and conducive of a desired low-intensity burn. Prescribed burns were implemented at the onset of the rainy season, which among the participating traditional cultural practitioners was recognized as a traditional time for conducting landscape maintenance burns within the riparian forests.

California Indians historically used a variety of tools to aid in the ignition and spread of fires, one being the slow match (Anderson 2005, 136). The slow match is a bundle of vegetation bound together and ignited to burn very slowly. Typically an individual or group of people would traverse an area, igniting spots of vegetation they desired to burn. Many modern incendiary devices can be used in a similar fashion. For this study, fires were set by drip torch, with multiple ignitions being set at random distances while traversing the burn plot as a means to mimic a probable ignition pattern used by pre-contact California Indians. All burns were implemented by traditional cultural practitioners in coordination with local volunteer fire departments and air-quality management districts. Fires were contained between a combination of roads, water bodies, fuel breaks, or points of ignition.

Burn-day conditions at each site are summarized in Table 1. The exception of the 20 November 2002 burn, the air temperature, wind, and relative humidity were recorded on a Kestrel® 3000 handheld weather meter. The 20 November 2002 weather data was obtained via an onsite weather station. Precipitation data was obtained from the National Oceanic and Atmospheric Administration (2002a, 2002b), and the University of California Integrated Pest Management weather data Web site (UC IPM 2005). Under these weather conditions, the fires burned slowly and were of low to moderate intensity and low to moderate severity, with high spatial complexity. At Cache Creek, approximately one-half of the treatment area was burned, leaving a mosaic of small burned and unburned patches. High fuel moisture at the Mokelumne site limited the spread of fire across the entire treatment area, so burning was concentrated in roughly rectangular areas of approximately 200 m^2 around each sampling location.

Table 1. Summary of fire weather conditions. With the exception of precipitation, the remaining data were taken at the time of ignition. This precipitation represents the first few rains of the season, which for traditional cultural practitioners would provide sufficient moisture to dry fuels, such that fire intensity would decrease.

	Cache Creek	Mokelumne
Burn Date(s)	20 and 27 November 2002	8 December 2002
Cumulative Precipitation for Rainy Season	5.27 cm	6.3 cm
Temperature	17.2-23.8 C	14.4 C
Wind Direction and Speed	North 1.6 $km{\cdot}h^{-1}$	North 4 $km{\cdot}h^{-1}$
Relative Humidity	30%	57%

Surveys focusing on herpetofauna and small mammals were conducted through the use of drift-fence arrays with associated funnel traps. Funnel traps are a common method employed in herpetofauna sampling (Crosswhite et al. 1999; Enge 2001; Creer 2005; Shine et al. 2005; Fitch 2006), and are effective in capturing other organisms, including small mammals and invertebrates. Corn and Bury (1990) noted that multiple sampling techniques are necessary if attempting to document all herpetofauna within an area. Enge (2001) noted that use of funnel traps is effective in sampling most herpetofauna. Ryan et al. (2002) found that drift fence arrays were effective in documenting the greater richness and number of individuals across habitat types sampled. Funnel traps were constructed of 3-mm hardware mesh attached to a wood frame measuring 30.5 cm wide by 45.7 cm long by 29.2 cm high. Each trap was fitted with two funnels, also constructed of 3-mm hardware mesh, which opened to alternate sides of the drift fence. Four drift-fence arrays were located in both the control and treatment areas at the Cache Creek study site, and three drift-fence arrays were located in both the control and treatment areas at the Mokelumne study site. Altogether, the two study sites contained a total of fourteen arrays with twenty-eight associated traps. The drift-fence arrays were arranged linearly in representative vegetation types in both the control and treatment areas. Each drift-fence array was constructed of staked Masonite panels 4.5 m long and 35.5 cm tall. The lower edge of each panel was buried at least 5 cm below the soil surface, and soil was compacted along the buried edge. Funnel traps were placed at each end of the array, with two funnels per trap opening on each side of the drift fence. In an effort to minimize trap mortalities, each trap contained a terracotta water dish with a non-cellulose sponge, approximately two tablespoons of rolled oats, and a wad of cotton batting for insulation purposes. Traps were set in the afternoon and checked the following morning, in an effort to capture both diurnal and nocturnal animals.

Pre-burn trapping was conducted for 158 trap nights, from October through November 2002, to document and assess the diversity of species present at the study site prior to burning, and also to determine which species might be active at the time of the burn. Post-burn trappings were conducted for 230 trap nights between March and September 2003. Trapping was simultaneously conducted at control and treatment plots at each study site. All trapping activities were conducted under the authority of a California Department of Fish and Game scientific collecting permit (permit number SC-006324) issued to the author. The species and numbers of individuals present in each trap were recorded. Individuals were not marked, thus no effort to identify recapture was made. Cursory observations of species and their activities were recorded during and immediately following the prescribed burns, with efforts made to locate any injured or deceased animals.

Data were analyzed in JMP 7.0.2 © using a one-way analysis of variance and means comparison using Student's t test at alpha = 0.05 confidence interval to compare both the number of trap captures in the control and treatment areas. Statistical trials were performed to analyze the parameters of trap captures within the control and treatment areas within and between each site and also pre- and post-burn trapping efforts in order to determine if site location contributed any bias in data analysis. Contingency analysis of species captures by trap by site was also completed in order to understand the variability in species diversity. Further assessment of species diversity and habitat similarity were made using the Shannon-Wiener and Morisita's Measure respectively (Krebs 1989).

Results

A total of eighty-four animals were captured over the course of 395 cumulative trap nights, during which time nine trap malfunctions were noted. Vertebrates captured included nineteen western fence lizards (*Sceloporous occidentalis*), thirty-eight deer mice (*Peromyscus* *maniculatus*), twenty California voles (*Microtus californicus*), two southern alligator lizards (*Elgaria multicarinata*), two western harvest mice (*Reithrodontomys megalotis*), and two ornate shrews (*Sorex ornatus*). More than twice the numbers of captures were made in the burn areas at each study site. A total of thirty-six captures were made in the burn area and seventeen in the control area at the Cache Creek site; and twenty-two were made in the burn area and nine within the control area at the Mokelumne site (see Table 3).

Overall, the number of trap captures differs significantly between control and burn areas (F=10.2213, df=1,377, P=0.0015), with more captures occurring in the burn areas. However, site-by-site comparisons reveal differing results in response to both pre- and post-burn trap data (see Table 2). The significant difference between the control and treatment areas at each study site suggests that the prescribed fire had increased the abundance or species composition of herpetofauna and small mammals at both study sites.

Table 2. ANOVA summary. Asterisk represents statistical significance at α=0.05.

Site	Pre-Burn Trapping	Post-Burn Trapping	Pre-Post Comparison
Cache Creek	F=5.6001, df=1, 84 P=0.0203*	F=4.0892, df=1, 124, P=0.0453*	F=7.714, df=1, 210, P=0.0059*
Mokelumne	F=2.2281, df=1, 56, P=0.1411	F=5.0782, df=1, 107, P=0.0264*	F=8.8935, df=1, 165, P=0.0033*

Table 3 summarizes capture data by species at each site. Comparisons of the trap capture data at each control and treatment site indicates that the highest species diversity, as calculated by the Shannon-Wiener method occurred at the Mokelumne treatment site, while the lowest occurred at the Mokelumne control site. At the Cache Creek site, the highest species diversity occurred at the control site (see Table 3). Habitat similarity comparisons based on Morisita's Measure of Similarity suggest that the most habitat similarity is found at the Cache Creek site, whereas the Mokelumne site is most dissimilar (see Table 4).

Table 3. Abundance and diversity data for captured species.

Species Name	Cache Creek Control	Cache Creek Burn	Mokelumne Control	Mokelumne Burn	Total Per Species	Relative % of Total
Sceloporous occidentalis	4	8	0	7	19	22.89
Peromyscus maniculatus	10	21	5	2	38	45.78
Microtus californicus	0	6	4	10	20	24.09
Reithrodontomys megalotus	0	0	0	2	2	2.41
Sorex ornatus	1	1	0	0	2	2.41
Elgaria multicarinata	2	0	0	0	2	2.41
Total Number of Individuals by Trap Site	17	36	9	21	83	100
Percent Total	20.48	43.37	10.84	25.30	100	*
Species Richness	4	4	2	3	6	*
Species Diversity (Shannon-Wiener)	1.071	1.047	0.687	1.167	*	*

Table 4. Pairwise comparison of values for the Morisita's Measure of similarity.

	Cache Creek Control	Cache Creek Burn	Mokelumne Control
Cache Creek Burn	1.0129		
Mokelumne Control	0.7976	0.9412	
Mokelumne Burn	0.3848	0.5762	0.6887

Discussion and Conclusions

These results reject the hypothesis that late-fall (wet season) burns do not result in significant differences in habitat utilization by herpetofauna and small mammals, as measured by the number of individuals and number of species captured in control and treatment areas. The increase in species abundance and diversity following the burns at both sites supports the idea that fire promotes biodiversity (e.g., Martin and Sapsis 1992). However, greater trap effort over a similar pre- and post-burn period may have yielded different results. Similarly, the temporal effects of habitat response over longer post-fire periods may demonstrate how long such effects lag beyond a given fire event. Deer mice and western fence lizards tend to excel in relatively open habitats. Improved food resources and availability may have contributed to the increase of these species. While previous studies (see Sullivan and Boateng 1996; Vreeland and Tietje 2002; Renken 2006) have demonstrated little or no effect of fires on small mammals and herpetofauna, these results suggest that fire does increase species abundance. The lack of difference between burned and unburned areas between and within each study site is likely a result two factors—the rate of vegetation recovery and the limited extent of the treatments. Since the burn treatments occurred during the beginning of the rainy season, many of the grasses and forbs present within the study sites had sufficiently recovered between the date of the burn and the commencement of trapping the following spring. In fact, many areas where traps were placed had substantial ground cover throughout the trapping period. Although this study did not mark animals, which would have aided in determining individual home ranges, the patchy nature of these burns are potentially problematic in determining effects, given the likelihood that many of the captured species' home ranges extend due to the proportion of the burn area, with respect to the represented species' home ranges (Cramer and Willig 2005). It is probable that the mosaic of burned and unburned vegetation may have provided an optimal arrangement of cover and forage for the individuals.

Kilpatrick et al. (2004) observed that one-time captures can contribute greatly to differences in species richness comparisons. The capture of two southern alligator lizards on one day appears to have skewed the diversity indices for the Cache Creek site. If these captures are removed from the data set, the resulting Shannon-Wiener species diversity index becomes 0.81, which would suggest that the burn areas at both study sites support higher species diversity than the control areas. The Morista's Measure of Similarity suggests that the control and burn areas at Cache Creek are most similar; surprisingly however, the control and burn areas at the Mokelumne are less similar than the comparison between the Cache Creek burn and Mokelumne control site. This is of interest, because in terms of trap captures, there is less diversity and abundance at the Mokelumne control site. Beyond the trap capture data, there are differences in plant species composition, structure, age class, and distribution between the control and treatment areas at each study site.

Cursory observations during and following each prescribed fire noted many unique findings for a variety of taxa. No mortalities or injuries were observed. During each fire, informal observations of at least three adult western fence lizards were noted in close proximity to the active fire front, burrowing and dusting themselves in the warm ash. One deer mouse was observed scurrying through an area soon after the fire had passed. The lack of locating injured or killed individuals during or following the fires suggests that the slow rate of spread and spatial complexity of the fire provide ample opportunity for individuals to escape. As Martin and Sapsis (1992) have reported, the combination of removed ladder fuels and the season of burn contribute to fire complexity, thus creating burned and unburned areas within the treatment area. In fact, the maximum area burned within the treatment area at either of the study sites was approximately 0.61 hectares (half of the treatment area), with patches of burned and unburned vegetation dispersed throughout the larger burn perimeter.

The observed behaviors of the western fence lizards, deer mouse, and non-reported animals (e.g., insects, avifauna, and larger mammals) both during and immediately following the prescribed burns suggest a neutral or beneficial relationship with fire. For instance, the observation of western fence lizards in the recently burned area could be linked to foraging opportunities, opportunistic bathing, or aid in thermoregulation. During the active fire, birds were observed foraging on fleeing insects. Several unidentified spiders were observed passing through the flame front unscathed. Within a week following the fire, as many as twelve deer were routinely observed in the treatment area at the Cache Creek site, rolling in the ash and foraging on fresh growth of Santa Barbara sedge and other perennial vegetation that were quick to respond to the burn.

Burning at these sites occurred following the initial germination of many nonnative annuals that were largely reduced by the fires. However, many of the native riparian plants at both study sites are perennials, and thus began to resprout immediately following the fires. The combination of burning during the germination period and the presence of perennials (e.g., Santa Barbara sedge, creeping wild rye, and mugwort) that resprout contributed to a rapid recovery of structure and cover in the vicinity of the drift fence arrays. Thus, the presence of cover has likely contributed to the similarities of capture numbers and species between treatment and control areas. Had vegetation not recovered so quickly, the extent been greater (i.e., the whole study site burned), or the season of burn been different, the effect of burning may have been more significant.

The allowance of California Indians to manage riparian communities with traditional methods such as those described by this research have frequently met obstacles (i.e., by skeptical land managers and restrictive regulations) particularly in areas where rare species exist. It is somewhat ironic that many of these species have persisted in landscapes under similar management regimes for millennia prior to European settlement of the region; however, due to a lack of understanding of this process and the effects, the use of fire in riparian communities has been largely overlooked. Overall, these findings are supportive of the use of fire as a tool to aid in the conservation and management of Central Valley riparian ecosystems. The restoration of this type of fire to Central Valley riparian ecosystems could be effective in mitigating the impacts of wildfires by removing accumulated biomass and ensuring the maintenance of wildlife habitat. This study involved burning during the non-breeding season, and occurred at a limited spatial scale. Future research should focus on the effects of fires at various spatial and temporal scales within riparian ecosystems. Similarly, studies of other wildlife of fish species responses to fires of this type would contribute to a broader understanding of fire effects. Given the limited extent of remnant patches of Central Valley riparian forests, efforts to implement the restoration of indigenous fire management strategies should be made, particularly within habitats for rare species.

Acknowledgments

I would like to thank Karen Swaim for donating the funnel traps and reviewing the drift-fence array configuration. I am grateful for the assistance of Elizabeth Hankins, Joseph Montiel, Shannon Brawley, Michael McGirr, Kathryn Jackson, Jan Lowrey, Jacquelyn Ross, Kathy Wallace, Kimberly Stevenot, Curt Stevenot, Dr. Deborah Elliott-Fisk, Sally Barrett, Tish Espinoza, and the Willow Oak Fire Department for their assistance with burn implementation, trapping, and observations. Drs. Deborah Elliott-Fisk, Michael Barbour, Melissa Nelson, and an anonymous reviewer provided comments on an earlier version of this paper.

References

Agee, J. K. 1999. A coarse-filter strategy. *Forum* 14(1):15–19.

Anderson, M. K. 1999. The fire, pruning, and coppice management of temperate ecosystems for basketry material by California Indian tribes. *Human Ecology* 27:79–113.

———. 2005. Tending the Wild: Native American Knowledge and the Management of California's Natural Resources. University of California Press. Berkeley, California. 526 pp.

Arno, S. F. and S. Allison-Bunnell. 2002. *Flames in Our Forests: Disaster or Renewal?* Island Press. Washington, D.C. 227 pp.

Bean, L. J. and H. W. Lawton. 1973. *Some explanations for the rise of cultural complexity in native California with comments on proto-agriculture and agriculture.* Pages 27–54 In L. J. Bean, ed. Ballena Anthrop. Pap. 1. Ballena Press, Ramona, CA. [Reprinted in: Blackburn, T. C. and K. Anderson, eds. 1993. Before the Wilderness: Environmental Management by Native Californians. Menlo Park, CA: Ballena Press]. 476 pp.

Belcher, E. 1843. *Narrative of a voyage around the world, performed in H.M.S. "Sulpher," during the years 1836–1842.* Vol. 2. Henry Colburn. London, England.

Beschta, R. L., J. J. Rhodes, J. B. Kauffman, R. E. Gresswell, G. W. Minshall, J. R. Karr, D. A. Perry, F. R. Hauer, and C. A. Frissell. 2004. Postfire management on forested public lands of the western United States. *Conservation Biology* 18:957–967.

Bisson, P. A., B. E. Rieman, C. Luce, P. F. Hessburg, D. C. Lee, J. L. Kershner, G. H. Reeves, and R. E. Gresswell. 2003. Fire and aquatic ecosystems of the western USA: current knowledge and key questions. *Forest Ecology and Management* 178 (2003):213–229.

Bury, R. B. 2004. Wildfire, Fuel Reduction, and Herpetofaunas across Diverse Landscape Mosaics in Northwestern Forests. *Conservation Biology* 18(4):968–975.

Busch, D. E., 1995. Effects of fire on southwestern riparian plant community structure. *Southwest Naturalist* 40:259–267.

Cavitt, J. E. 2000. Fire and a Tall Prairie Reptile Community: Effects on Relative Abundance and Seasonal Activity. *Journal of Herpetology* 34(1):12–20.

Corn, P. S. and R. B. Bury. 1990. *Sampling methods for terrestrial amphibians and reptiles*. Gen. Tech. Rep. PNW-GTR-256. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 34 pp.

Cramer, M. J. and M. R. Willig. 2005. Habitat heterogeneity, species diversity and null models. *Oikos* 108:209–218.

Creer, D. A. 2005. Correlations between ontogenic change in color pattern and antipredator behavior in the racer, *Coluber constrictor*. *Ethology* 111:287–300.

Crosswhite, D. L., S. F. Fox, and R. E. Thill. 1999. Comparisons of Methods for Monitoring Reptiles and Amphibians in Upland Forests of the Ouachita Mountains. *Proceedings of the Oklahoma Academy of Sciences* 79:45–50.

Driver, H. E. 1939. Culture Element Distributions: X. Northwest California. *University of California Anthropological Records* 1(6):297–435.

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

Ellis, L. M. 2001. Short-term response of woody plants to fire in a Rio Grande riparian forest, Central New Mexico, USA. *Biological Conservation* 97:159–170.

Enge, K. M. 2001. The Pitfalls of Pitfall Traps. *Journal of Herpetology* 35(3):467–478.

Everett, R., R. Schellhaas, P. Ohlson, D. Spurbeck, and D. Keenum. 2003. Continuity in fire disturbance between riparian and adjacent sideslope Douglas-fir forests. *Forest Ecology and Management* 175:31–47.

Faber, P. M. and R. F. Holland. 1996. *Common Riparian Plants of California: A Field Guide for the Layman*. Pickleweed Press. Mill Valley, California. 140 pp.

Fitch, H. S. 2006. Ecological Succession on a Natural Area in Northeastern Kansas From 1948–2006. *Herpetological Conservation and Biology* 1(1):1–5.

Ford, W. M., M. A. Menzel, D. W. McGill, J. Laerm, and T. S. McCay. 1999. Effects of a community restoration fire on small mammals and herpetofauna in the southern Appalachians. *Forest Ecology and Management* 114:233–243.

Fraser, F., V. Lawson, S. Morrison, P. Christopherson, S. McGreggor, and M. Rawlinson. 2003. Fire management experiment for declining Partridge Pigeon, Kakadu National Park. *Ecological Management and Restoration* 4(2):94–102.

Gom. L. A. and S. B. Rood. 1999. Fire Induces Clonal Sprouting of Riparian Cottonwoods. *Canadian Journal of Botany* 77:1604–1616.

Grenfell, W. E. 1988. Valley Foothill Riparian. Pages 86–87 In Mayer, K. E. and W. F. Laudenslayer, eds. *A Guide to Wildlife Habitats of California*. California Department of Forestry and Fire Protection. Sacramento, California.

Kahn, W. C. 1960. Observations on the Effects of a Burn on a Population of Sceloporous occidentalis. *Ecology* 41(2):358–359.

Keeley, J. 2002. Native American impacts on fire regimes of the California coastal ranges. *Journal of Biogeography* 29:303–320.

Kilpatrick, E. S., D. B Kubacz, D. C. Guynn Jr., J. D. Lanham, and T. A. Waldrop. 2004. The Effects of Prescribed Burning and Thinning on Herpetofauna and Small Mammals in the Upper Piedmont of South Carolina: Preliminary Results of the National Fire and Fire Surrogate Study. Pages 18–22 In Connor, Kristina F., ed. 2004. *Proceedings of the 12th biennial southern silvicultural research conference*. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 pp.

Kirby, R. E., S. J. Lewis, and T. N. Sexson. 1988. *Fire in North American wetland ecosystems and fire-wildlife relations: an annotated bibliography*. U.S. Fish and Wildlife Service. Washington, D.C., U.S.A. Fish and Wildlife Biological Report 88(1).

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.

Krebs, C. J. 1989. *Ecological Methodology*. Harper and Row. New York, New York.

Larsen, K. W., I. T. Adams, and D. L. Haughland. 2007. Small mammal communities in a pyrogenic habitat mosaic. *International Journal of Wildland Fire* 16:728–740.

Lewis, H. T. 1973. *Patterns of Indian burning in California: Ecology and ethnohistory.* Pages 55–116 In L. J. Bean, ed. Ballena Anthrop. Pap. 1. Ballena Press, Ramona, CA [Reprinted in: Blackburn, T. C.; Anderson, K., eds. 1993. Before the wilderness: Environmental management by Native Californians. Menlo Park, CA: Ballena Press]. 476 pp.

Lillywhite, H. B. and F. North. 1974. Perching Behavior of Sceloporous occidentalis in Recently Burned Chaparral. *Copeia* 1: 256–257.

Lyet, A. M. Cheylan, R. Prodon, and A. Besnard. 2009. Prescribed fire and conservation of a threatened mountain grassland specialist: a capture–recapture study on the Orsini's viper in the French Alps. *Animal Conservation* 12:238–248.

Lyon, L. J. and J. K. Smith. 2000. *Management and Research Implications*. Pages 59–62 In Smith, J. K. ed. 2000. *Wildland fire in ecosystems: effects of fire on fauna*. Gen. Tech. Rep. RMRS-GTR-42 vol. 1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 pp.

Lyon, L. J., E. S. Telfer, and D. S. Schreiner. 2000. *Direct Effects of Fire and Animal Responses*. Pages 17–23 In Smith, J. K. ed. 2000. *Wildland fire in ecosystems: effects of fire on fauna*. Gen. Tech. Rep. RMRS-GTR-42-vol. 1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 83 pp.

Martin, R. E. and D. B. Sapsis. 1992. Fires as Agents of Biodiversity: Pyrodiversity Promotes Biodiversity. Published in *Proceedings of the Symposium on Biodiversity of Northwestern California*, October 28–30, 1991. Santa Rosa, California.

Mensing, S. 2006. The History of Oak Woodlands in California, Part II: The Native American and Historic Period. *The California Geographer* 46:1–31.

Mitsch, W. J. and J. G. Gosselink. 1993. *Wetlands*. Second Edition. Van Nostrand Reinhold. New York, New York. 736 pp.

Moseley, K. R., S. B. Castleberry, and S. H. Schweitzer. 2003. Effects of Prescribed Fire on Herpetofauna in Bottomland Hardwood Forests. *Southeastern Naturalist* 2(4):475–486.

Murphy, B. P. and D. M. J. S. Bowman. 2007. The interdependence of fire, grass, kangaroos and Australian Aborigines: a case study from central Arnhem Land, northern Australia. *Journal of Biogeography* 34:237–250.

Natcher, D. C., M. Calef, O. Huntington, S. Trainor, H. P. Huntington, L. DeWilde, S. Rupp, and F. S. Chapin III. 2007. Factors Contributing to the Cultural and Spatial Variability of Landscape Burning by Native Peoples of Interior Alaska. *Ecology and Society* 12(1):7.

National Oceanic and Atmospheric Administration. 2002a. *Local Climatological Data Annual Summary with Comparative Data: Sacramento, California (SAC)*. Washington, D.C.

———. 2002b. *Local Climatological Data Annual Summary with Comparative Data: Stockton, California (SCK)*. Washington, D.C.

Petit, N. E. and R. J. Naiman. 2007. Fire in the Riparian Zone: Characteristics and Ecological Consequences. *Ecosystems* 10:673–687.

Pilliod, D. S. R. B. Bury, E. J. Hyde, C. A. Pearl, and P. S. Corn. 2003. Fire and amphibians in North America. *Forest Ecology and Management* 178:163–181.

Renken, R. B. 2006. Does fire affect amphibians and reptiles in eastern U.S. oak forests? In Dickenson, M. B. *ed*. 2006. *Fire in eastern oak forests: delivering science to land managers, proceedings of a conference; 2005 November 15–17; Columbus, OH*. Gen. Tech.

Rep. NRS-P-1, Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station: 158–166.
Russell, K. R., D. H. Van Lear, and D. C. Guynn, Jr. 1999. Prescribed fire effects on herpetofauna: review and management implications. *Wildlife Society Bulletin* 27(2):374–384.
Russell-Smith, J., D. Lucas, M. Gapindi, B. Gunbunuka, N. Kapirigi, G. Namingum, K. Lucas, P. Giuliani and G. Chaloupka. 1997. Aboriginal resource utilization and fire management practice in western Arnhem Land, monsoonal Northern Australia: notes for prehistory, lessons for the future. *Human Ecology* 25:159–195.
Ryan, T. J., T. Philippi, Y. A. Leiden, M. E. Dorcas, T. B. Wigley, and J. Whitfield Gibbons. 2002. Monitoring herpetofauna in a managed forest landscape: effects of habitat types and census techniques. *Forest Ecology and Management* 167:83–90.
Schurr, T. G. and S. T. Sherry. 2008. Mitochondrial DNA and Y chromosome Diversity and the Peopling of the Americas: Evolutionary and Demographic Evidence. *American Journal of Human Biology* 16:420–439.
Shine, R., T. Landkilde, M. Wall, and R. T. Mason. 2005. The fitness correlates of scalation asymmetry in garter snakes *Thamnophis sirtalis parietalis*. *Functional Ecology* 19:306–314.
Sullivan, T. P. and J. O. Boateng. 1996. Comparison of small-mammal community responses to broadcast burning and herbicide application in cutover forest habitats. *Canadian Journal of Forest Research* 26:462–473.
Sutter, J. A. 1939. *New Helvetia diary: a record of the events kept by John A. Sutter and his clerks at New Helvetia, California, from September 1845 to May 25, 1848*. Grabhorn Press. San Francisco, California.
University of California Integrated Pest Management. 2005. http://www.ipm.ucdavis.edu/calludt.cgi/PCDATAREPORT
Vreeland, J. K. and W. D. Tietje. 2002. Numerical response of small vertebrates to prescribed fire in a California oak woodland. In R. B. Standiford et al. tech. editor. *Proceedings of the Fifth Symposium on Oak Woodlands: Oaks in California's Challenging Landscape*. Gen. Tech. Rep. PSW-GTR-184, Albany, CA: Pacific Southwest Research Station, Forest Service, USDA: 269–279.
Walter, H. 1977. Effects of Fire on Wildlife Communities. In Mooney, H.A. and C.E. Conrad technical coordinators. *Proceedings of the Symposium on the Environmental Consequences of Fire and Fuel Management in Mediterranean Ecosystems*. U.S. Department of Agriculture. Washington, D.C. 183–192.

Whelan, R. J. 1995. *The Ecology of Fire*. Cambridge University Press. Cambridge, United Kingdom. 346 pp.
Wills, R. 2006. Central Valley Bioregion. Pages 295–320 in Sugihara, N. G., J. W. van Wagtendonk, K. E. Shaffer, J. Fites-Kaufman, and A. E. Thode. 2006. *Fire in California's Ecosystems*. University of California Press. Berkeley, CA. 596 pp.
Zedler, J. and S. Kercher. 2005. Wetland Resources: Status, Trends, Ecosystem Services, and Restorability. *Annual Review of Environmental Resources* 30:39–74.