Developing Ecological Site and State-and-Transition Models for Grazed Riparian Pastures at Tejon Ranch, California[1]

Felix P. Ratcliff,[2] James Bartolome,[2] Michele Hammond,[2] Sheri Spiegal,[2] and Michael White[3]

Abstract

Ecological site descriptions and associated state-and-transition models are useful tools for understanding the variable effects of management and environment on range resources. Models for woody riparian sites have yet to be fully developed. At Tejon Ranch, in the southern San Joaquin Valley of California, we are using ecological site theory to investigate the role of two managed ungulate populations, cattle and feral pigs, on riparian woodland communities. Responses in plant species composition, woody plant recruitment, and vegetation structure will be measured by comparing cattle and feral pig management treatments among and between areas with similar abiotic conditions (ecological sites). Results from the second year of this project highlight the spatial variability of riparian woodland vegetation communities as well as temporally and spatially variable abundances of cattle and feral pigs. Development of riparian ecological site descriptions and state-and-transition models provide both a generalizable framework for evaluating management alternatives in riparian areas, and also specific direction for managing cattle and feral pigs.

Key words: cattle, ecological site descriptions feral pigs, riparian area management, state-and-transition models

Introduction

Ecological site concepts and state-and-transition models have been widely developed to model spatial and temporal vegetation dynamics in arid rangelands. An 'Ecological Site' as defined by the Natural Resources Conservation Service is "a distinctive kind of land with specific physical characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation, and in its ability to respond to management actions and natural disturbances" (Bestelmeyer and Brown 2010, Caudle and others 2013). Describing ecological sites allows land managers to prioritize management and conservation objectives and fine-tune management practices in heterogeneous landscapes by classifying the management area into discreet units with different potential vegetation dynamics and different responses to management actions (Bestelmeyer and Brown 2010).

State-and-transition models are typically organized as box and arrow diagrams showing what the potential vegetation states are for a given ecological site and what conditions cause transitions between states. States may be quantitatively or qualitatively described, but essentially represent a plant community within a range of variation which is of ecological or management interest (Westoby and others 1989). Dynamic soil properties such as erosion and sedimentation may also be used to distinguish between states (Duniway and others 2010). Most often these models are

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[2] University of California Berkeley, 137 Mulford Hall, MC 3114, Berkeley, CA 94720. (felixratcliff@berkeley.edu).

[3] Tejon Ranch Conservancy, 1037 Bear Trap Rd., Lebec, CA 93243.

used to display transitions due to temporal drivers on a given area such as: changes due to management, fire, or precipitation; however they can also be used to catalog spatial transitions occurring within an ecological site as a result of past conditions (Bestelmeyer and others 2011, Petersen and others 2009).

Development of ecological sites and state-and-transition models in the United States has been almost entirely limited to upland sites and has largely ignored riparian areas (Stringham and others 2001). Riparian systems along creeks in California's semi-arid San Joaquin Valley have the underlying spatial and temporal variability in environmental factors which make them good candidates for non-linear plant community succession.

In addition to the physical factors responsible for spatial variability in upland systems (differences in soils, climate, and landscape position) spatial variation in riparian areas is also largely driven by differences in fluvial processes and hydrologic cycles between sites (Caudle and others 2013, Repp 2011, Stringham and Repp 2010). Processes governing temporal variation within riparian ecological sites differ somewhat from those in uplands as well. In addition to climatic and management drivers associated with inter-annual variation in uplands, intra and inter-annual fluvial processes and changes in soil hydrology may drive temporal variation in vegetation composition (Stringham and others 2001, Stringham and Repp 2010).

Some management practices that have limited effects on species composition in California's upland rangelands may have amplified effects in riparian areas. Livestock grazing is thought to be responsible for little of the inter-annual variation seen in California's upland grasslands (Jackson and Bartolome 2002), but even in lightly-stocked pastures grazing may have large effects on riparian vegetation as cattle tend to prefer these areas to surrounding uplands (George and others 2011). The effects of livestock grazing, however, are likely contingent on physical attributes of the system and characteristics of the plant species present (Kauffman and Krueger 1984).

Tejon Ranch, located in Southern California, contains 97 124 ha (240 000 ac) of conserved lands which are jointly managed by the Tejon Ranch Company, Tejon Ranch Conservancy (Conservancy), and two grazing lessees. Riparian area management was highlighted in the 2013 Ranch-Wide Management Plan, and the Conservancy's riparian goals and objectives primarily revolve around managing vegetation structure to benefit a suite of nesting birds, but also include increasing native plant species cover and elimination of non-native species such as tamarisk (*Tamarix ramosissima*). Cattle grazing is the most widespread management action affecting riparian areas on the ranch, but recently concern has grown around a large population of feral pigs which appear to disproportionately favor riparian areas. In 2013, this study was initiated to investigate whether an ecological site and state-and-transition approach could identify baseline characteristics in riparian vegetation and demonstrate the effect of cattle and feral pig management on riparian resources.

Methods

Project location

The Tejon Ranch is located in southern California, encompassing areas of the San Joaquin Valley, Sierra Nevada, Mojave Desert, Tehachapi Mountains, and South Coast Ranges. The study takes place in the San Joaquin Valley portion of the Tejon

Ranch and is limited to major streams with well-developed woody riparian vegetation.

Five creek segments were selected for study within the area of interest: Chanac Creek, El Paso Creek, Lower Tejon Creek, Tunis Creek, and Upper Tejon Creek. Within each of these creek segments, three study plots were selected randomly within areas with woody vegetation for a total of 15 study plots.

Vegetation sampling

Vegetation sampling occurred at each of the plots in late May and early June of 2013 and 2014. A "greenline" transect followed the foot of the creek bank and sampled vegetation growing near the water's edge. This sampling method was adapted from the greenline sampling technique developed by Alma Winward (2000). Winward defines the greenline as "The first perennial vegetation that forms a lineal grouping of community types on or near the water's edge. Most often it occurs at or slightly below the bankfull stage" (Winward 2000). We decided to move the greenline from the top of bank to the toe of the bank for the following reasons:

- The herbaceous vegetation at the top of bank was typically composed of the same annual grass species that dominate the adjacent uplands. In order to sample the herbaceous species composition most influenced by the stream we needed to sample in the wetter soils found at the toe of the bank.
- The first perennial species to form a continuous or semi-continuous line of vegetation was either a shrub (typically *Baccharis salicifolia*) or tree (typically *Salix* sp. or *Populus fremontii*). These woody plants were recorded in the sampling transects regardless of whether they were performed at the toe of the bank or the top of bank.

At each plot, greenline vegetation composition was measured along 50 m of the creek in three different strata: herbaceous, shrub, tree. To measure herbaceous vegetation, a line-point transect was performed whereby a point was extended every half-meter along the transect tape and the first hit within the first one-meter above the ground was recorded. A line-intercept transect was used to record shrub and tree composition along the greenline and perpendicular transects. This method records the lineal distance occupied by each species overhanging the transect tape within each canopy. Any plant overhanging the tape between one and three meters of height was recorded in the "shrub" category, and any plant overhanging the tape above three meters in height was recorded as a "tree". It is important to note that the canopy categories were distinguished only by height. For example, the vining California grape (*Vitis californica*) could occur in the herbaceous, shrub, or tree category even though it is not technically an herb, shrub or tree.

Cattle and feral pig monitoring

In July 2013, a Moultrie M-880 camera trap was deployed at each study location to monitor feral pig and cattle activity at each study location, and to develop estimates of their activity on each plot. The camera traps were deployed within 25 m of the plot center. They were positioned to maximize detections of pigs, cattle, and other wildlife. Cameras were typically put along game trails or along creeks in areas with wide fields of view and few obstructions or branches which could trigger the camera in the wind.

The cameras were set to record a 30 second video each time they were triggered by movement, with a 15 second time lapse between videos. Videos were chosen instead of still photographs because we wanted to more accurately assess the number of feral pigs, which often occur as large groups of unidentifiable individuals. Videos also enable the collection of behavioral data.

Prior to analysis, camera trap data were seasonally adjusted per plot. The seasonal adjustment corrected for missing data due to camera malfunction by estimating the number of cattle and pig detections in the missing period. We assumed these were proportional to the detection rate of the remainder of the season. For example, if a camera malfunctioned for 1 week out of the 12-week winter season, we assumed the missing week contained 1/11 the number of detections of pigs and cattle as seen over the remainder of that season.

Statistical methods

Hierarchical cluster analysis of plot-level plant species composition can be used as a quantitative method of defining states and transitions for state-and-transition models (Spiegal and others 2014). A state can be defined as a grouping of plots with similar vegetation characteristics and close linkage distances between plots (close distances between plots in the cluster dendrogram). A temporal transition, then, is when a plot moves in cluster space between years (when the vegetation on a given plot changes from that characteristic of one cluster to another) (Spiegal and others 2014). Spatial transitions would then occur when different vegetation clusters occur in different areas within the same ecological site.

A cluster analysis was performed on the greenline vegetation data to investigate patterns of riparian plant community structure within the 15 study plots over 2 years. For this analysis the 30 unique plot*year combinations were clustered based on absolute cover of all live plant hits. Data were square-root transformed so that dominant species did not overly-influence the cluster assignments (McCune and Grace 2002). Similarly, all species occurring on less than 2 plot*years were removed from the analysis so that very rare species did not disproportionately influence the analysis. Species were entered for each canopy class separately. For example, the tree *Salix laevigata* occurring in both the shrub and tree canopies would be included twice: SALA_S and SALA_T. This allowed us to determine when differences between clusters were due to vegetation structure as well as composition. The cluster analysis was performed using Bray-Curtis distance which calculates similarity based on species found to be present on plots, not based on mutual absences (Zuur and others 2007).

Following Dufrene and Legrendre (1997), the cluster dendrogram was pruned to the number of groups which contained the most significant indicator species. Indicator species analysis also describes which species best characterize a cluster-based on the presence and abundance of species within and between groups (Dufrene and Legrendre 1997). Cluster analysis and indicator species analysis were performed in PC-ORD (McCune and Mefford 2011).

Results

The cluster analysis and subsequent dendrogram pruning using indicator species analysis revealed that four clusters was the optimal number to describe the variation seen among the 30 plot*years. These clusters are composed of anywhere from 4 to 12 plot*years, and include plots from one to three stream segments (table 1).

Table 1—Cluster assignments among the 30 plot*years

Cluster Number	Plots included	Total plot*years in cluster	Stream segments included
1	CH1*2013, CH1*2014, CH3*2013, CH3*2014, EP1*2013, EP1*2014, EP2*2013, EP2*2014, EP3*2013, EP3*2014, UT1*2013, UT1*2014	12	Chanac Creek, El Paso Creek, Upper Tejon
2	UT2*2013, UT2*2014, UT3*2013, UT3*2014	4	Upper Tejon Creek
3	CH2*2013, CH2*2014, LT1*2013, LT1*2014, LT2*2013, LT2*2014, LT3*2013, LT3*2014	8	Chanac Creek, Lower Tejon Creek
4	TU1*2013, TU1*2014, TU2*2013, TU2*2014, TU3*2013, TU3*2014	6	Tunis Creek

When looking at all three canopies together (table 1), there are strong spatial patterns to the cluster assignments. The Tunis Creek plots all form one exclusive cluster (cluster 4), and the indicator species analysis suggests that this cluster is distinguished from others by the occurrence of *Salix laevigata* in the herbaceous, shrub, and tree canopies; and by the high cover of *Hordeum murinum*, *Nasturtium officionale*, *Polypogon monspeliensis*, and *Rumex* sp. in the herbaceous canopy (table 2). The plots along Lower Tejon Creek cluster together as well (cluster 3), and one plot (Chanac 2) is included in the cluster too. This cluster is distinguished by *Salix goodingii* in the shrub and tree canopies, high cover of *Populous fremontii* in the shrub and tree canopies, high cover of *Baccharis salicifolia* in the shrub canopy, and high cover of *Xanthium strumarium*, *Apium graveolens*, and *Cynodon dactylon* in the herbaceous canopy. The plots along El Paso Creek cluster together and are joined in the cluster by plots from Chanac and Upper Tejon Creeks (cluster 1). This cluster is distinguished by having high cover of *Vitis californica* in all canopies and high cover of *Carduus pycnocephalus* in the herbaceous canopy. Finally, one cluster contains two dry plots on Upper Tejon Creek which are characterized by upland vegetation along the greenline (cluster 2). Significant indicator species for these plots are: *Bromus diandrus*, *Bromus rubens*, and *Brassica nigra*.

Table 2. Significant indicator species for each cluster

Cluster	Species	Canopy layer	Indicator value[a]	p-value[b]
1	*Carduus pycnocephalus*	Herbaceous	50	0.0186
	Vitis californica	Herbaceous	83.3	0.0002
	Vitis californica	Shrub	100	0.0002
	Vitis californica	Tree	100	0.0002
2	*Bromus diandrus*	Herbaceous	45.5	0.001
	Brassica nigra	Herbaceous	50	0.0126
	Bromus rubens	Herbaceous	100	0.0004
3	*Apium graveolens*	Herbaceous	46.5	0.0166
	Cynodon dactylon	Herbaceous	37.5	0.0476
	Xanthium strumarium	Herbaceous	37.5	0.0452
	Baccharis salicifolia	Shrub	44.8	0.0034
	Populus fremontii	Shrub	47	0.0196
	Salix goodingii	Shrub	62.5	0.0026
	Populus fremontii	Tree	47.4	0.008
	Salix goodingii	Tree	75	0.0008
4	*Hordeum murinum*	Herbaceous	47.2	0.0226
	Nasturtium officionale	Herbaceous	54.6	0.0082
	Polypogon monspeliensis	Herbaceous	77.4	0.0002
	Rumex sp.	Herbaceous	52.8	0.0086
	Salix laevigata	Herbaceous	50	0.0086
	Salix laevigata	Shrub	49	0.0002
	Salix laevigata	Tree	43.2	0.0002

[a] Indicator value is a measure of how well each species characterizes the cluster it is in. It is maximized (with a value of 100) when a species is only found in one cluster, and when it is found to occur in all plots within that cluster (Dufrene and Legrande 1997).
[b]The p-value tests the null hypothesis that the indicator value is actually 0 (McCune and Grace 2002).

There were no transitions observed between years for any of the 15 plots. For each of the plot*years, the plot*year with the closest linkage distance (distance in the cluster dendrogram) was the same plot in the alternate year, indicating that vegetation composition was very stable between years. This compositional stability between years also held when the tree layer was removed and the analysis was performed on the shrub and herbaceous canopies together. In this analysis, the closest plot*years in cluster space were always the same plot in an alternate year (with the exception of two plots in Lower Tejon Creek), and no transitions between clusters were observed between years. When both tree and shrub layers were removed from the analysis, the plots comprising each cluster changed significantly, and one transition was observed. In this subset of the analysis, Tunis Creek Plot #3 (TU3) transitioned from a cluster containing only Tunis Creek plots to one with a variety of other creeks. The indicator species analysis suggests that this transition is driven by a decrease in cover of *Hordeum murinum*, *Nasturtium officionale*, and *Rumex* sp.; and a subsequent increase in *Bromus diandrus*.

Abundances of pigs and cows

More than 27,000 videos were reviewed from the 15 plots between late July 2013 and the first week of June 2014. Of these, 9,540 videos contained cattle and 4,173 videos contained pigs. An index of activity was built for each species. The index is simply the sum of the seasonally adjusted number of individuals of each species observed in all the videos reviewed. This activity index was then separated by season and plot to show seasonal as well as spatial heterogeneity in cattle and pig activity (figs. 1 and 2).

Seasonal cattle activity declined in the riparian plots from summer 2013 to spring 2014, likely reflecting cattle preference for these areas in the summer and fall when they offer thermal cover, green forage, and water. This decline may also reflect operational decisions by grazing lessees to remove cattle in response to the severe 2013-2014 drought. In contrast, feral pig activity was relatively stable over the course of the year (fig. 1). Spatial variation in pig and cattle activity was high when looking across the entire sampling period. Even plots within the same pasture (such as CH1, CH2, and CH3) had cattle and pig activity that varied by more than a factor of 2 (fig. 2).

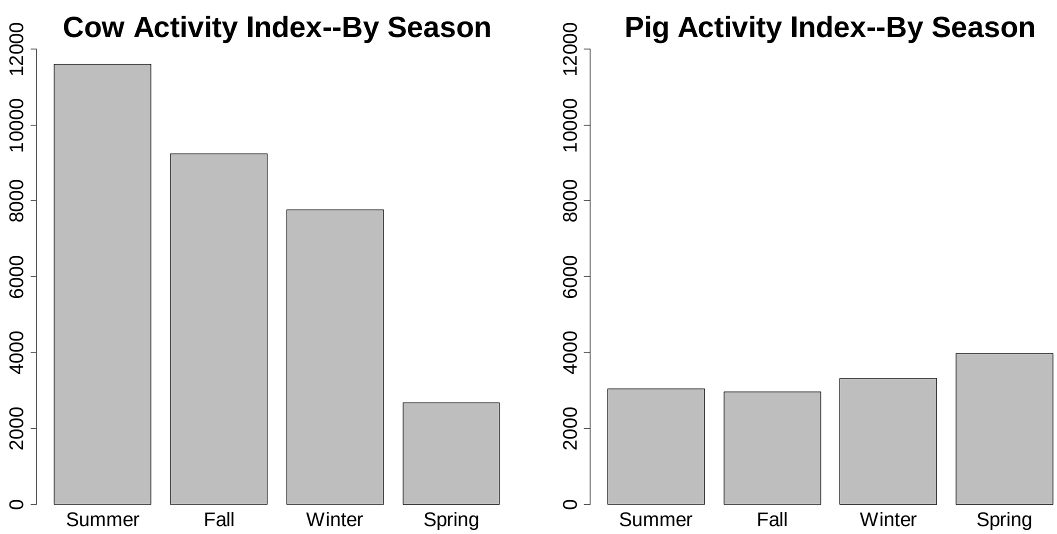

Figure 1—Cattle and pig activity among the 15 plots by season, starting in summer 2013 and continuing through spring 2014.

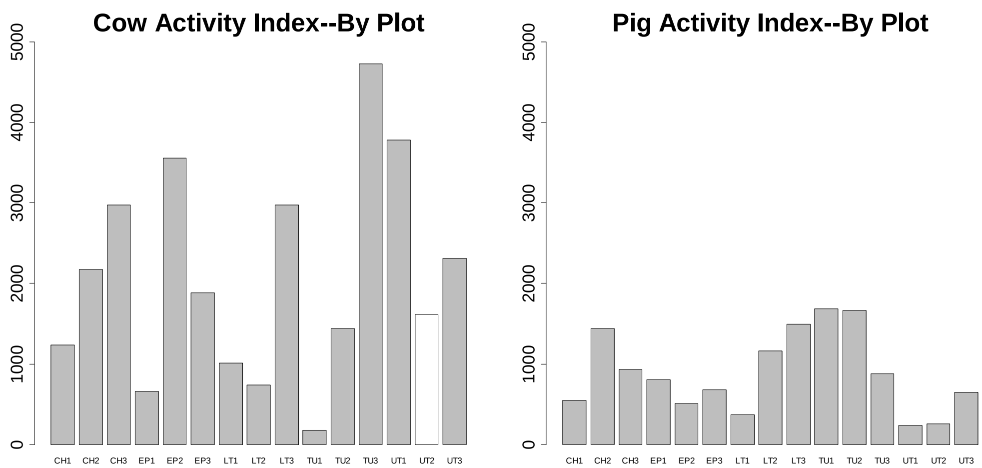

Figure 2—Cattle and pig activity by plot.

Discussion

The cluster analysis showed that there is strong spatial grouping of vegetation states on the landscape; however, this is expressed differently among the stream segments. Sometimes a cluster is exclusive to a stream segment (for example cluster 4 on Tunis Creek). This might indicate that the creek segment constitutes a unique ecological site and that the physical differences which distinguish this site are responsible for the observed variation in vegetation. Other times clusters occur alongside other clusters on multiple stream segments (for example clusters 1, 2, and 3 on Chanac, El Paso, and Upper Tejon Creeks). This means either that different ecological sites are present within a single stream segment, or that there are different states found in the same ecological site across space. An important future step for this project will be defining the ecological sites so that we can better understand the drivers governing spatial variation.

When looking at the indicator species associated with transitions, it is evident that differing cover of widespread species (not just presence/absence) often plays a big role in differentiating between clusters. For example, *Bromus diandrus* and *Salix laevigata* are found on many sites, yet they are indicative of clusters 2 and 4 respectively. Therefore it is feasible that these represent alternate states within an ecological site and transitions could occur over time within a plot if the abundances of these species were to change. Furthermore, if cattle and pigs affect woody plant recruitment or survival then it is possible for them to drive transitions on a plot.

The high degree of stability between years on all plots indicates that when considering all vegetation canopies together, transitions are unlikely to occur on any given year and may take many years to transpire. This is largely due to the perennial nature of the species in the shrub and tree canopies. One strategy for observing transitions in such a system is to observe study plots over many years. A second strategy will be available to us after we define ecological sites among all the plots. If there are multiple states occurring on different plots within an ecological site, then we can infer that these represent alternate states and that there may be transitions between them. These ‘spatial transitions’ could result from different historical factors causing different transitions over time on each plot and could provide useful information about the range of potential vegetation states within an ecological site. Short-term studies could show what potential effects of management are by looking at the effects of temporal drivers including cattle and feral pig activity, annual variation in precipitation, fluvial disturbances such as floods and sediment deposition on woody plant recruitment, vegetation composition, and changes in fluvial geomorphology.

The camera trapping results show that cattle activity is greatly influenced by season; spending much more time in riparian areas in the summer and fall when these areas provide shade, water, and green forage. Pig activity increased over the course of a one-year period despite high hunting pressure from Tejon Ranch operations which took more than 1000 pigs between September 2013 and July 2014 (roughly the same window as the camera trapping). The spatial variability of cattle activity within a single pasture shows that pasture-scale grazing intensity along riparian corridors is difficult to control in large pastures; even in pastures with low grazing pressure. The pasture containing all three Chanac Creek plots is 4016 ha (9926 ac) and had cattle activity which varied by a factor of two within the three plots. While this heterogeneity in grazing intensity might have desirable outcomes such as increased vegetation heterogeneity (Fuhlendorf and Engle 2001), it poses challenges for management seeking to achieve uniform control or striving to avoid patches of intensive use. Some desired management outcomes may therefore be better achieved by limiting timing of riparian grazing rather than attempting to control intensity through stocking rates in large pastures.

The vegetation cluster analysis showed that there is significant variation in vegetation composition between the 15 study plots. Future work to define ecological sites will help determine when this variation is due to underlying physical factors at each plot and when it is due to historical transitions that brought about the states observed today. The stability of vegetation clusters between years points to the need to look at factors which could precipitate transitions over time, rather than expecting to see transitions on an inter-annual basis. These investigations will focus on the effects of temporal drivers including cattle and feral pig activity, annual variation in precipitation, and fluvial disturbances such as floods and sediment deposition on woody plant recruitment, vegetation composition, and changes in fluvial geomorphology. Finally, we plan on building cattle and pig exclosures to better understand the role of cattle and pig activity in these systems.

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