Documenting Ecological Change in Time and Space:
The San Joaquin Valley of California

Patrick A. Kelly, Scott E. Phillips, and Daniel F. Williams

The collections and journal archives of the Museum of Vertebrate Zoology (MVZ) at the University of California, Berkeley, provide a unique historical database that can be used in conjunction with new technologies in genetics and spatial analysis to address serious challenges to the conservation of biological diversity. Through direct reference to the journal entries of Joseph Grinnell and other MVZ biologists of the early 1900s and quantitative analyses of land use changes, we document the tempo and scale of land conversion in the San Joaquin Valley of California during the 20th century. We discuss the impacts of landscape level habitat changes for populations of selected mammalian species, most notably the endemic San Joaquin kangaroo rat (*Dipodomys nitratoides*). Of the three described subspecies of *D. nitratoides*, two (Tipton, *D. n. nitratoides*; Fresno, *D. n. exilis*) are listed as endangered under the California and U.S. endangered species acts, and the third (short-nosed, *D. n. brevinasus*) is a California species of special concern. Despite intensive field surveys begun in 1992, we have been unable to locate a population of Fresno kangaroo rats. This is particularly troubling because analysis of cytochrome-b DNA sequences, which were developed from museum specimen tissue samples, has shown that the Fresno kangaroo rat is unique and strongly differentiated from the other two subspecies. As the population of California continues to grow, the assault on biological diversity will continue. Analyses of the unique historical data provided by the MVZ and other natural history museums using the tools of modern molecular genetics and spatial analysis are essential to addressing these threats and halting or reversing the decline of biological diversity.

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Since its establishment, the Museum of Vertebrate Zoology (MVZ) at the University of California, Berkeley, has provided remarkable intellectual leadership in the ecology and evolution of terrestrial vertebrates, with emphasis on western North America. When Annie Alexander sponsored and established the MVZ in 1908, she was in pursuit of excellence in research and scholarship, and chose Joseph Grinnell to lead the museum towards that goal, largely because of their deeply shared

interest in field biology and mutual commitment to the study of natural history (Stein, 1997, 2001). Under the direction of Grinnell, work at the MVZ was exclusively in the realm of field biology. He set the example for museum scientists with extensive field research throughout California (Grinnell, 1911, 1927, 1928a,b, 1937; Grinnell and Linsdale, 1936; Grinnell and Miller, 1944; Grinnell and Storer, 1924; Grinnell and Wythe, 1927; Grinnell et al., 1930, 1937).

Today, MVZ scientists continue to work in various ecosystems throughout the western United States, Central and South America, and elsewhere. When they are not in the field, MVZ scientists are conducting genetic and other analyses in the laboratory to support their field studies. They continue to address problems that were of interest to Grinnell and other early MVZ scientists. Had Grinnell lived longer, he would have more vigorously pursued his keen interest in pocket gophers (Grinnell, 1927). His goal was achieved 50 years later when two other MVZ scientists, James Patton and Margaret Smith, published their ca 20-year study of the evolutionary dynamics of pocket gophers in California (Patton and Smith, 1990). One of Grinnell's major achievements is that the MVZ became one of the premier institutions for the study of vertebrate zoology. Few other institutions have amassed such a body of scholarship and knowledge about the natural world or have worked as assiduously to promote field research as has the MVZ.

An appreciation for and desire to conserve the natural world has been a central theme in the MVZ's long record of research and service, even if that appreciation was not always explicitly expressed in terms that we might use today. The discipline we call conservation biology is the modern philosophical incarnation of a particular ecological worldview, one that evolved from economic zoology and more recently, from disciplines such as wildlife management, population ecology, behavioral ecology, and other fields (Hall, 1939a,b; Grinnell, 1940; Linsdale, 1942). MVZ scientists have played a large role in conservation biology throughout the museum's history. To understand this role, we provide a retrospective using extensive references to the work and writings of Joseph Grinnell and other principal figures in the early days of the museum.

Almost immediately upon his appointment as the first Director of the MVZ in 1908, Joseph Grinnell took a deep personal interest in Yosemite National Park (Runte, 1990). Grinnell and other MVZ scientists conducted the key surveys that documented the vertebrate fauna of Yosemite (Grinnell and Storer, 1924). From this foundation of intensive field research, Grinnell played a critical role in the evolution of the management policies not only for Yosemite, but also for the National Park Service (Runte, 1990). He wrote thousands of letters and memos to park officials (Runte, 1990, p. 127). This dedication was not out of a sense of duty to assist in public administration. Rather, through his unfading commitment to science, Grinnell gently urged, prodded, and guided park officials towards more scientific management policies, directed primarily towards the conservation of native species (Runte, 1990, p. 129). Through his commitment to public education, he also fostered

and encouraged public support for science-based management principles and practices in the parks (Runte, 1990, p. 111-112). Today, Yosemite is one of the crown jewels of the U.S. National Park System and is appreciated annually by millions of visitors from all over the world.

When Joseph Grinnell passed away prematurely in 1939, his legacy was measured by more than the prodigious numbers of study skins, journal pages, and publications he produced during his 21-year tenure as director; his commitment to conservation had become woven into the fabric of the MVZ. Over the past century, MVZ scientists and students have continued to follow Grinnell's philosophy through their profound commitment to preserving as well as understanding the natural world. This commitment is needed more today than ever before.

> It is probable that "Californians Incorporated," a commercial agency whose efforts are expended vigorously toward securing congestion of human population in the San Francisco Bay region, is right now the greatest single enemy of wild animal life in west-central California. The slogan "where life is better" is a curious perversion: it has sinister portents for even man himself.
>
> Joseph Grinnell (1928a; p. 204 in Grinnell, 1943)

When Joseph Grinnell wrote these prophetic words, California had a human population of less than 6,000,000. By 2000, more than 33,000,000 persons called California home. This more than five-fold increase in population has resulted in very serious consequences for biological diversity throughout California. Further losses in biological diversity, sometimes referred to as natural capital (UNEP-WCMC, 2000), are inevitable. The State of California is expected to have a population of about 46,000,000 people by 2020 (California Department of Finance, 2001). The impacts of this high rate of population growth are being felt throughout California but they have been most profound in four of the State's ten bioregions: South Coast, Central Coast, Bay Delta, and San Joaquin Valley (California Biodiversity Council, 1991). In this analysis, we report on landscape change in the San Joaquin Valley over the past century and describe the consequences of these changes for biological diversity in this region. MVZ scientists have worked in the San Joaquin Valley since 1911. Their collections and journal archives provide a unique historical database that can be explored using new technologies in genetics and spatial analysis to address significant challenges to the conservation of biological diversity in the San Joaquin Valley. We report on an initial exploration of this body of work and make recommendations for future study.

THE SAN JOAQUIN VALLEY: A CENTURY OF CHANGE

March, 1911, saw the arrival of the first MVZ expedition in the San Joaquin Valley (Grinnell, 1911). Joseph Grinnell, Harry Swarth and other MVZ biologists spent much of March, April, and May, 1911, collecting at various localities throughout the San Joaquin Valley and the Carrizo Plain. This was followed by much more work by Grinnell, Swarth, Joseph Dixon, Ward Russell, Seth Benson and many others in 1912 and subsequent years. The extensive journal notes from these MVZ expeditions not only describe the fauna of the region but also paint a detailed and graphic picture of a changing landscape:

> The surrounding country is flat and mostly farmed (wheat and orchards); unless it has been graded the surface shows the queer hummocky condition know locally as hog-wallow land *[vernal pool ecosystem]* of clayey, "hard pan".
>
> Joseph Grinnell, Lane Bridge, 10 mi. N Fresno, Fresno Co., 6 April 1911.

> Proceeding to Goshen this afternoon, the country is observed from the train. Practically every rod from Berenda *[Madera Co.]* to Selma *[Fresno Co.]* is under close cultivation in grain, alfalfa, raisins, and orchards.
>
> Joseph Grinnell, Goshen, Fresno Co., 23 April 1911.

> To the north and northwest the county is pretty closely farmed, up to the Tule River; but a belt through Tipton and to the south and east, is largely grazing land yet tho there are pumps being put in and it is only a matter of a few years until every rod of ground in under cultivation.
>
> Joseph Grinnell, Tipton, Tulare Co., 24 April 1911

> Left Berkeley at 8:00 A.M., catching the 8:53 train at Oakland, which reached Bakersfield at 8 P.M. I had thus a good chance to see the whole length of the San Joaquin Valley, on the east side. It appears to be nearly all under cultivation, or else used as pasturage, and open tracts are evidently changing rapidly, being divided into smaller holdings and more intensively cultivated.
>
> Harry Swarth, traveling from Oakland to Bakersfield by train, 5 May 1911.

> Left Bakersfield on the 8:15 A.M. train (which pulled out at 9:30) reaching McKittrick at 11:30. The stretch of country between the two places is not cultivated as I expected to see it. Outside of Bakersfield were long stretches of brush land, and then miles of bottom land, with ditches and sloughs, pretty well grown up with cotton woods and willows. Around Buttonwillow there was a good deal of alfalfa and other hay fields, but from there to McKittrick it was all brush land, much of it quite sandy.
>
> Harry Swarth, traveling from Bakersfield to McKittick (western Kern Co.) by train, 17 May 1911.

The MVZ journal archives again and again reveal the commitment to detail exhibited by Grinnell and his field teams. They not only surveyed the landscape and collected examples of the fauna, but they also reported on numerous conversations and interviews with local residents, especially 'old-timers.' Grinnell's journal entries in particular are peppered with references to local observations on the presence, or, more usually, absence of kit foxes (*Vulpes macrotis*), "chipmunks" (antelope ground squirrels, *Ammospermophilus nelsoni*), kangaroo rats (*Dipodomys* spp.), bighorn sheep (*Ovis canadensis*), grizzly bears (*Ursus arctos*) and other mammals that were declining in numbers or losing significant amounts of habitat to land conversion by the early 1900s:

> One man interviewed said there were "Kangaroo rats" in his place six years ago when he first plowed but that he had seen none since. Several have told us that 20 years or more ago "rattlesnakes and kangaroo rats" abounded in certain places in the vicinity of Fresno. Evidently the mammal and reptile fauna of the region have been as profoundly modified by human settlement as the birds.
>
> Joseph Grinnell, Clovis, Fresno Co., 11 April 1911

> It would seem that this chipmunk *[antelope ground squirrel]* is retreating in range from the east side of the Tulare Valley, as the country settles up (either cultivated or pastured closely) and as the ground squirrel (C. beecheyi) comes in. We are repeatedly told that the latter has only recently come into this belt, and that it is becoming more numerous all the while.
>
> Joseph Grinnell, Earlimart, Tulare Co., 1 May 1911

> Mr. J.S. Douglas is the superintendent of the ranch here. He has been in the country since the 70's, and is absolutely trustworthy. He tells me as follows: He personally knows of sheep *[bighorn sheep]* in the Sespe Country, where the last one was killed in 1900. On the San Emigdio ranch, there were many sheep in the steep hills in the 70's and early 80's. Many were shot. In 1888 there were fully 150 sheep in 3 flocks.
>
> Joseph Grinnell, San Emigdio Ranch (Wind Wolves Preserve today), Kern Co., 22 April 1912

The landscape that Grinnell and Swarth described on the east side of the San Joaquin Valley differed significantly from that of the west side. The great water projects—the Central Valley Project and the State Water Project—had not yet been undertaken and much of the west side was still open rangeland characterized by a mix of grassland, alkali sink scrub, and salt bush scrub (Kahrl, 1978; Reisner, 1987; Thelander, 1994; USFWS, 1998; Hundley, 2001). Between 1915 and 1923, Joseph Dixon spent a considerable amount of time in the San Joaquin Valley, much of it on the "plains" on the west side of the valley. There, he documented the detrimental effects of human activity on native fauna such as pronghorn antelope (*Antilocapra americana*) and the kit fox:

> Serious inroads have been made into the population of kit foxes in the San Joaquin Valley, comprising the subspecies mutica. Large numbers of the animals have been caught there for fur in recent years. For instance, in 1919 Arthur Oliver caught 100 foxes in one week on an area 20 miles long and 2 miles wide, on the plains on the west side of the San Joaquin Valley, in Fresno County. (See fig. 162.) On December 3, 1920, 37 steel traps set in that region caught 5 kit foxes in one night.
>
> Grinnell, Dixon, and Linsdale (1937 p. 418).

Far more significant inroads than those provided by fur trappers, however, were in store for kit foxes. The MVZ photography archive provides an understanding of agricultural development in this region between 1920 and 1937 (Figure 1a, from Grinnell, Dixon, and Linsdale, 1937, p. 419). For this study, on June 3, 2001 one of us (PAK) took a photograph from about the same location and approximately of the same scene as Dixon's 1920 image (Figure 1b). The location of the 2001 photograph (latitude 36.67738 N, longitude 120.62191 W, Datum WGS 84) is 25.1 km southwest (bearing 216º) of Firebaugh, Fresno Co. It is about 5 km from the base of the foothills and, in contrast to 1920, is now completely cultivated.

Today, most of the west side plains of the San Joaquin Valley are cultivated to the base of foothills.

With the progressive construction of water storage and delivery projects over the past century — notably the massive Central Valley and State Water projects (1935 to 1970) — great tracts of formerly uncultivated or rarely cultivated land were converted to intensive agricultural use (Kahrl, 1978; Reisner, 1987; Thelander, 1994; Hundley, 2001). The natural landscape became increasingly fragmented as grasslands, wetlands, shrublands, woodlands, and forests were converted for cultivation (Figures 2a-d). The fragmented mosaic of natural and cultivated land described by Grinnell and Swarth in 1911 and 1912 gave way over time to the vast cultivated landscape evident today (USFWS, 1998).

Effects on Native Mammals

The scale of land conversion in the San Joaquin Valley over the past 100 to 150 years is staggering (Figure 3, Table 1). We estimate that there has been a loss of more than 27,000 km^2 of natural communities in the San Joaquin Valley. About 65% of grasslands, 64% of San Joaquin Valley shrublands, 88% of water and wetlands, and 95% of riparian forest and oak woodland have been converted, mainly to agricultural use (Table 1). The resulting losses in biological diversity are almost incalculable. If we were to assume conservatively that valley grasslands had an average annual small mammal biomass of 0.300 kg/ha (i.e., low density and low diversity situation of 5-10 kangaroo rats or 15-20 'mice' per hectare), the loss of grasslands represented in Table 1 would translate to an annual loss of 507.42 metric tonnes of small mammals. When we consider the interrelated population dynamics of small mammals and the many predatory species that largely depend on them (e.g, carnivores, raptors, owls, snakes), this loss in biodiversity is compounded significantly.

Mammals that have larger area requirements (e.g., tule elk, *Cervus elaphus;* pronghorn, and kit foxes) were quickly impacted by the settlement and development of the San Joaquin Valley. Perhaps less evident were effects on species with seemingly smaller area requirements. Work by MVZ and other researchers, however, indicates that these species also appear to be very susceptible to habitat fragmentation and degradation. We have already noted Grinnell's 1911 observations that kangaroo rats and antelope ground squirrels appeared to be declining in the face of land settlement. Extensive field research throughout the San Joaquin Valley since 1992 by biologists with the California State University, Stanislaus, Endangered Species Recovery Program (ESRP) confirmed Grinnell's fears that kangaroo rats are susceptible to habitat fragmentation (USFWS, 1998; Uptain et al., 1998). A review of the MVZ collections and journal archives helps reveal the extent of the impact to kangaroo rat populations from land conversion.

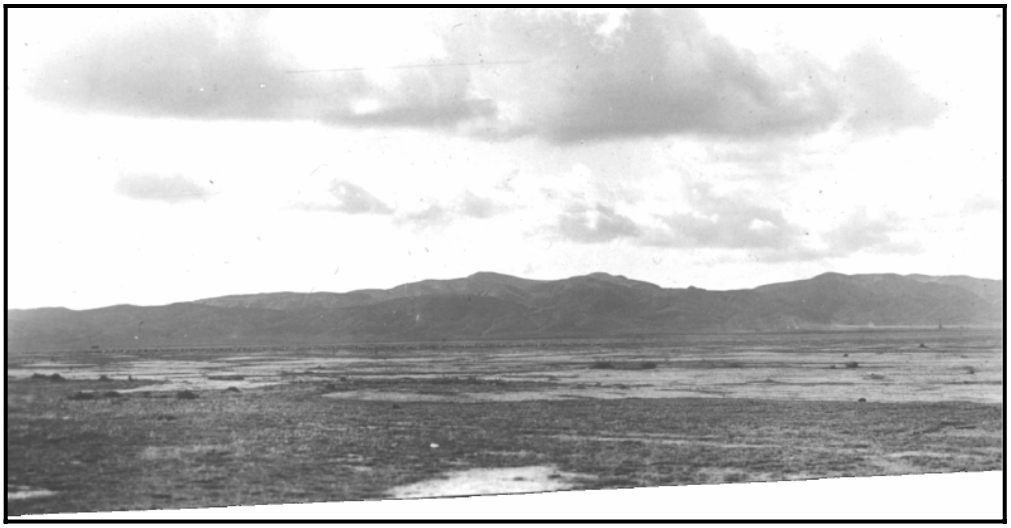

Figure 1a. Habitat of the San Joaquin kit fox in western Fresno Co. on 3 December 1920. (Adapted from a photograph by Joseph Dixon, Museum of Vertebrate Zoology Archives; no. 3426).

Figure 1b. Photograph taken on 3 June 2001 from approximately the same location as Joseph Dixon's 1920 photograph. (CSU Stanislaus, Endangered Species Recovery Program).

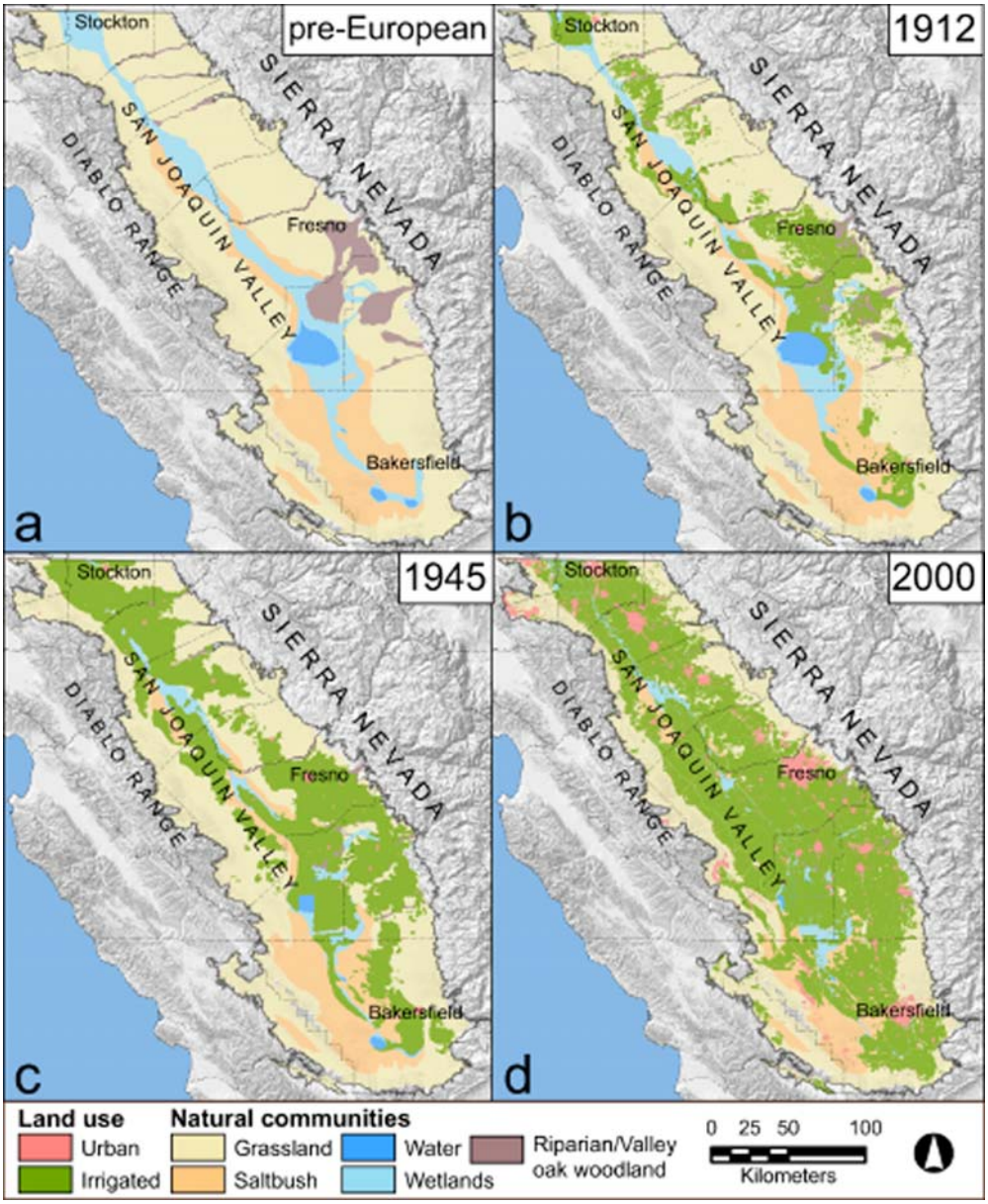

Figure 2. Agricultural land conversion in the area of the Great Valley Region of California (UCSB, 1996) south of latitude 38°N, pre-European settlement to 2000.

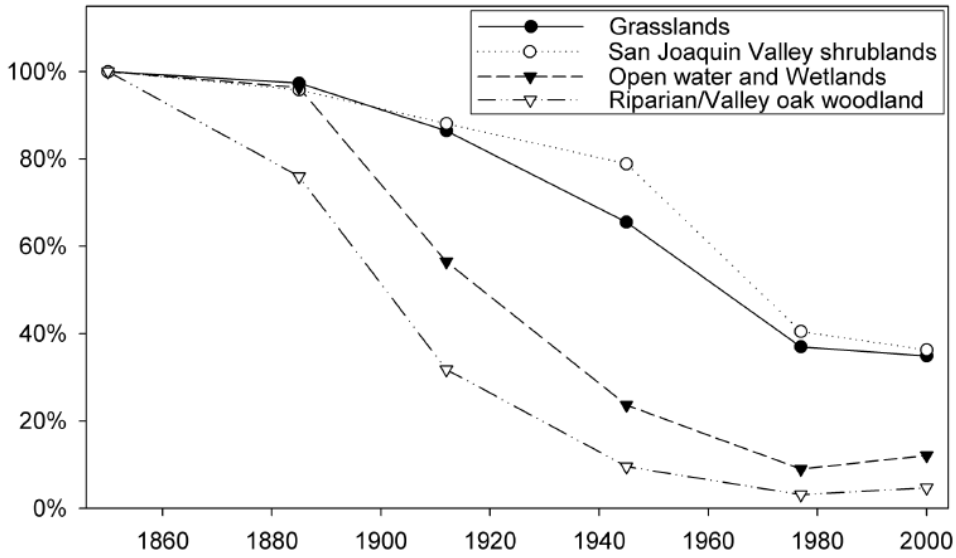

Figure 3. Percent change in natural community cover in the area of the Great Valley Region of California (UCSB, 1996) south of latitude 38°N, pre-European settlement to 2000.

Table 1. Estimated area changes (km^2) by major land cover category in the area of the Great Valley Region of California (UCSB, 1996) south of latitude 38°N, pre-European settlement to 2000.

Land Cover Category	Pre-European	2000	Change	%
Developed or degraded	0	27,636	27,636	
Grasslands	25,989	9,075	-16,914	-65.1
San Joaquin Valley shrublands	6,151	2,231	-3,920	-63.7
Open water and Wetlands	5,205	630	-4,575	-87.9
Riparian/Valley oak woodland	2,335	109	-2,225	-95.3

Between 1911 and 1960, MVZ expeditions collected San Joaquin kangaroo rats (*Dipodomys nitratoides*) at 40 localities throughout the San Joaquin Valley (Figure 4). We estimate that *D. nitratoides* is currently extant at probably no more than 18 of these locations, 16 of which are in the band of largely uncultivated rangeland that remains around the margins of the San Joaquin Valley (including the Carrizo Plain National Monument in San Luis Obispo Co.). The remaining two locations are in Tulare County, in the vicinity of the Pixley National Wildlife Refuge and the California Department of Fish and Game's Allensworth Ecological Reserve. These two public land holdings are still occupied by *D. nitratoides*, at least on some land parcels, but most of the valley floor locations trapped by Grinnell and other MVZ researchers have given way to cultivation. Where uncultivated lands remain on the valley floor, they are usually privately owned and closed to trapping surveys.

There are some small populations of *D. nitratoides* at other locations, especially in the southern San Joaquin Valley, that are not represented in the MVZ collections. San Joaquin kangaroo rats however, appear to have largely disappeared from the valley floor, even from most of the larger parcels that remain uncultivated. Populations seem to be in a continuing decline, probably due to the combined effects of habitat conversion, fragmentation, degradation, and other factors (Chesemore and Rhodehamel, 1992; Williams and Kilburn, 1992; Williams and Germano, 1993; Goldingay et al., 1997; USFWS, 1998; Uptain et al., 1998; Kelly 2000). Populations in the more or less continuous band of grassland around the valley periphery are doing better but, even there, San Joaquin kangaroo rats are difficult to find.

THE TOOLS OF CONSERVATION ECOLOGY

Joseph Grinnell was a visionary scientist and conservationist. At the very outset of his MVZ career, he recognized that the true value of the museum would not be gained from the simple accumulation of vertebrate specimens.

> It is quite probable that the facts of distribution, life history, and economic status may finally prove to be of more far-reaching value, than whatever information is obtainable exclusively from the specimens themselves.
>
> At this point I wish to emphasize what I believe will ultimately prove to be the greatest value of our museum. This value will not, however, be realized until the lapse of many years, possibly a century, assuming that our material is safely preserved. And this is that the student of the future will have access to the original record of faunal conditions in California and the west wherever we now work. He will know the proportional constituency of our faunae by species, the relative numbers of each species and the extent of the ranges of species as they exist to-day.

> Perhaps the most impressive fact brought home to the student of geographical distribution, as he carries on his studies, is the profound change that is constantly going on in the faunal make-up of our country. Right now are probably beginning changes to be wrought in the next few years vastly more conspicuous than those that have occurred in ten times that length of time preceding. The effects of deforestation, of tree-planting on the prairies, of the irrigation and cultivation of the deserts, all mean the rapid shifting of faunal boundaries, the extension of ranges of some animals, restriction in the ranges of others, and, with no doubt whatever, the complete extermination of many others, as in a few cases already on record.
>
> Joseph Grinnell (1910)

The tools that Grinnell employed in his work were his scientific intellect, exceptional observational skills, the thousands of scientific specimens he and his colleagues so painstakingly collected, and, above all else, the detailed journal notes that he accumulated during his surveys of the western United States. A century later, the MVZ has powerful tools that were unavailable to Grinnell. The rapid development of new techniques in genetics, spatial analysis, and landscape ecology that have been pioneered or rapidly adopted by MVZ scientists have provided fresh insights into not only evolutionary questions, but also our most pressing conservation concerns.

Genetics

This application of new technology is exemplified by the work of James Patton (in litt.), who, on the basis of cytochrome-b DNA sequences, has shown that the Fresno kangaroo rat (*D. n. exilis*) is unique and strongly differentiated from the other two subspecies of the San Joaquin kangaroo rat, the Tipton and short-nosed kangaroo rats (*D. n. nitratoides* and *D. n. brevinasus*, respectively). This finding is noteworthy because both the Fresno and Tipton subspecies are listed as endangered by the State and Federal governments. Despite intensive surveys and trapping efforts conducted throughout its former range, not a single Fresno kangaroo rat has been captured since 1992. One individual was captured on the California Department of Fish and Game's Alkali Sink Ecological Reserve (Fresno Co.) on two occasions in Nov. 1992 by one of us (DFW, ESRP data), but Patton's analyses of *D. n. exilis* had to be completed using tissue biopsies taken from study skins in collections at the MVZ and California State University, Fresno. On the basis of this new genetic information, if extant populations of the Fresno kangaroo rat can be located, they are likely to be given the highest priority for conservation by government agencies.

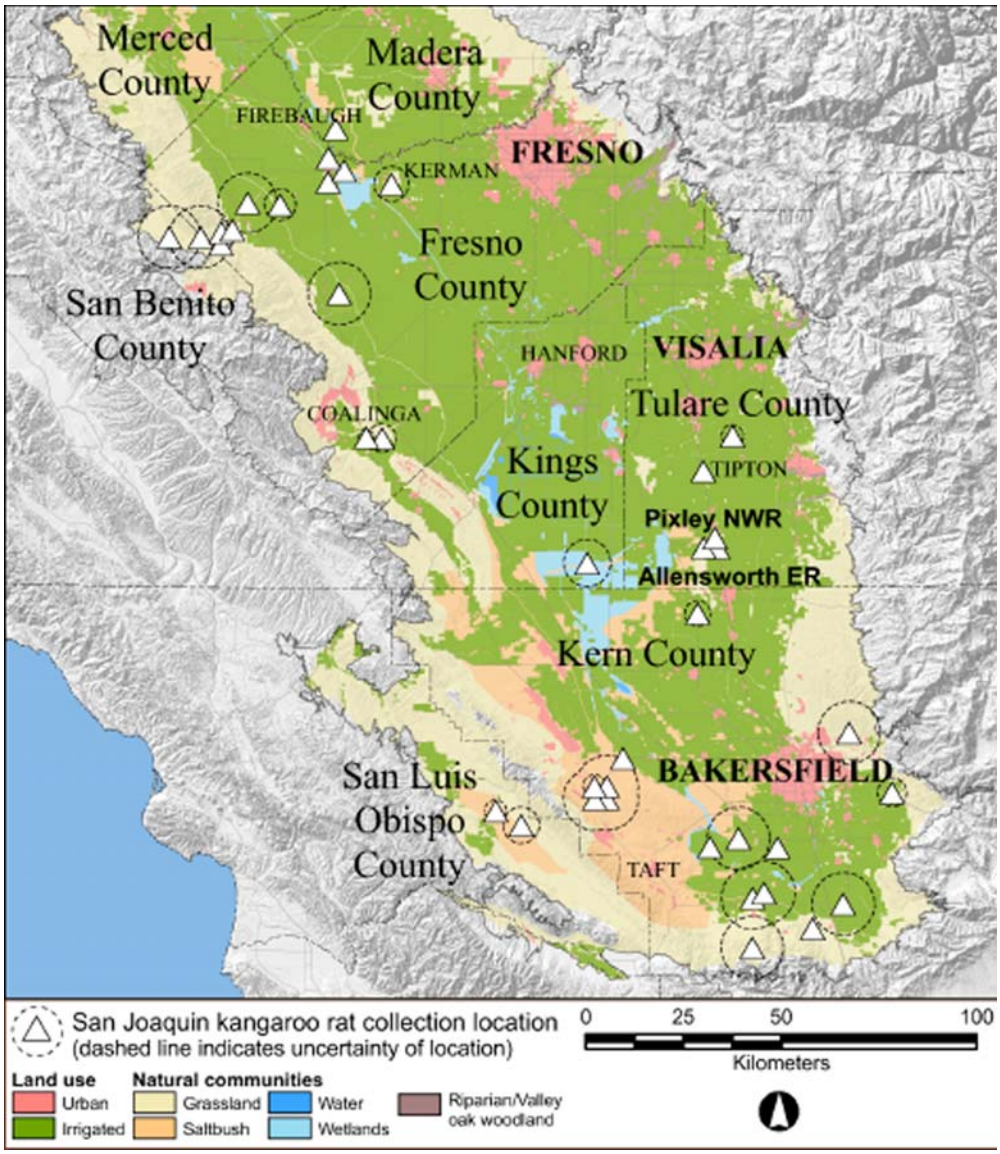

Figure 4. MVZ collection localities for San Joaquin kangaroo rats, 1911 to 1960. (Data provided by the Museum of Vertebrate Zoology, University of California, Berkeley.)

Spatial Analysis

As with genetic analyses, there have been tremendous developments in recent years in computer and database technology. In particular, rapid growth in computer and satellite technologies has provided powerful tools for spatial analyses, notably geographic information systems (GIS) and global positioning systems (GPS). GIS technology allows a user to create databases that store and relate spatial and non-spatial information. Historical map and descriptive data can be combined with current information to assess spatial changes over time. GPS provides researchers with greater capacity to remotely collect and retrieve spatial information. Compact and inexpensive GPS receivers provide the ability to geo-reference collecting and other localities in the field, rather than after the fact. This can be very valuable for relating locations to external spatial data derived from GIS.

In this study, using GIS to associate historical and modern map sources, we have described a striking pattern of habitat loss across the San Joaquin Valley during the 20th century (Figure 2, Table 1). We quantified conversion of four major natural community types from pre-European settlement to 2000 (Table 1); the recent geo-referencing of MVZ museum specimen records (Wieczorek, 2001) allowed us to relate collection locations to external spatial data. The specimen records, along with associated journal entries, genetic and other data, are providing further insights into the dynamics of landscape change in the San Joaquin Valley (see Appendix 1).

THE CHALLENGE

As Joseph Grinnell predicted in 1910, the MVZ collections and journals are needed now more than ever. The persistent growth of the human population of California continues to erode the tremendous, and in many ways unique, biological diversity of the State.

Many of the species that Grinnell inquired about when interviewing local residents of the San Joaquin Valley in 1911 and 1912 are now extinct, rare, or are listed as sensitive, threatened, or endangered by State and Federal governments. Ecosystems throughout California are threatened by urbanization, resource extraction, recreation, and other anthropogenic activities.

The vernal pool ecosystems ("hog-wallow land") that Grinnell commented on in 1911 have been greatly reduced and will likely become further degraded in the coming years. For example, ground breaking for the University of California's 10th campus occurred on Oct. 25, 2002 near the city of Merced, immediately adjacent to the largest remaining expanse of vernal pools in the San Joaquin Valley.

Proposed housing, commercial, highway, and other infrastructure developments present a more routine and pervasive threat to biodiversity. Agency biologists are daily required to provide their professional judgment on the likely impacts of such developments on sensitive species and ecosystems, usually with

incomplete knowledge of the distribution, abundance, and natural history of the affected species, and nearly always with no phlyogeographic information for key taxa. It is regrettable that the Fresno kangaroo rat declined to near extinction, if not extinction itself, before a phylogeographic analysis demonstrated its uniqueness. We have no doubt that there are many other taxa with similarly interesting but largely unstudied evolutionary histories that are currently facing uncertain futures in California.

The pressures on the remaining natural land in California are intensifying, suggesting that the decline of ecosystems and their constituent flora and fauna will continue. MVZ scientists and students have at their disposal the tools needed to address these increasingly serious conservation challenges. In particular, they have many of the tools required to identify and to provide a better understanding of major phylogeographic boundaries throughout California.

The combination of the MVZ collections, journal library, genetic laboratories, and GIS technology greatly enhance the analytical power of ecologists, systematists, and conservation biologists. It is our fervent hope that the MVZ will continue its strong leadership role in addressing these conservation challenges in the years ahead.

ACKNOWLEDGEMENTS

The authors would like to extend their sincere gratitude to Jim Patton for his friendship, scholarship, advice, and support over many years of professional and personal interaction. If Joseph Grinnell were alive today, he would be very pleased to know that Jim has so closely followed in his footsteps.

> Our institution is a repository of facts; and no matter what may be said to the contrary by those who undervalue the efforts of the hoarder of facts, it must always be the mass of carefully ascertained facts upon which the valid generalization rests.
>
> Joseph Grinnell (1910)

Jim's accumulation of facts about the ecology and evolution of small mammals throughout the New World has been nothing short of astonishing. Those of us who have had the privilege to work with Jim over the years know that he has also contributed many "valid generalizations."

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APPENDIX 1

Within the boundaries of the Great Central Valley region of California (UCSB, 1996) south of latitude 38°N, we estimated the extent of historical vegetation types using wetland features from 1885 irrigation maps (Hall, 1886), GIS data derived from a map of potential vegetation of California (ESRP and USBR, 1999), and vegetation data derived from additional map sources (Holmes et al., 1919; Nelson et al., 1918; Nelson et al., 1921; Piemeisel et al., 1937). We scanned the source maps and used image-processing software to align the images to a common map coordinate system.

To normalize the classification differences between sources, we reclassified map features to four general habitat types: grasslands, shrub lands, riparian/Valley oak woodland, and open water/wetlands. We digitized the reclassified map information to quantify the area of each habitat type within our study area. Using scanned irrigation and land cover maps and GIS data, we estimated the extent of developed land in 1885, 1912, 1940, 1977, and 2000 (ESRP 2001; Hall, 1886; USBR 1949; USDA, 1912; USGS, 1990).