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An assessment of the endangerment status of the Santa Cruz kangaroo rat

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AN ASSESSMENT OF THE ENDANGERMENT STATUS
OF THE SANTA CRUZ KANGAROO RAT

A Thesis

Presented to

The Faculty of the Department of Environmental Studies

San Jose State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

By

Caitlin Bean

May 2003

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ABSTRACT

AN ASSESSMENT OF THE ENDANGERMENT STATUS OF THE SANTA CRUZ KANGAROO RAT

By Caitlin Bean

In order to assess the endangerment status of the Santa Cruz kangaroo rat (*Dipodomys venustus venustus*) I investigated four of the major correlates of extinction: historic isolation, genetic diversity, range collapse, and demographics. Specifically, this study: 1) clarifies taxonomic relationships between *D. venustus* conspecifics, 2) examines genetic variability within the remaining *D. v. venustus* population, 3) assesses the contraction of the historic range of the taxon, and 4) documents population dynamics to evaluate population viability. Based on evolutionary autonomy, reduced gene diversity, an extremely reduced range, and the potential instability of the current demographic trends, I suggest that this species be listed as endangered pursuant to both the State and Federal Endangered Species Acts.

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CHAPTER 1. INTRODUCTION

Santa Cruz kangaroo rat (*Dipodomys venustus venustus*) is a dark colored, five-toed heteromyid that occurs in the central coast of California. Most historical records of this taxon are from “silverleaf manzanita chaparral,” a vegetation community that occurs in the Zayante sand hills ecosystem in the Santa Cruz Mountains. Historic extent of this ecosystem has been severely reduced by urbanization and sand mining. Due to concerns about the endangerment status of this subspecies, the California Department of Fish and Game (CDFG) identified *D. v. venustus* on a draft list of “Species of Special Concern.” However, due to a lack of in-depth studies, the status of the Santa Cruz kangaroo rat has been unknown. The purpose of this study was thus to determine whether or not the taxon is at risk of extinction. Specifically, I was interested in whether or not it merits protection pursuant to either the Federal (FESA) or California Endangered Species Act (CESA). Each aspect of this study targets one of the major correlates of extinction: historic isolation, genetic variability, range collapse, and demographics.

The molecular systematics analysis (Chapter 2) reveals information about the taxonomic relationships between *D. v. venustus* and its conspecifics, elucidating degrees of historical isolation among these taxa as compared to other species in the genus. Genetic isolation is an important indicator that the taxon is evolutionarily unique; this is one factor for determining if listing is warranted pursuant to FESA. Using genetic methods I was also able to estimate heterogeneity within *D. v. venustus*, a critical measure of how successfully the subspecies will tolerate a stochastic or changing

environment. The genetic data suggest that the subspecies may have undergone a bottleneck in recent evolutionary history, rendering it less genetically diverse than any of its conspecifics.

In order to assess range contraction, I conduct an analysis of the current and historic distribution of *D. v. venustus* (Chapter 3). It was important to evaluate the accuracy of original range estimates given that some of the specimens that have defined the historic range of *D. v. venustus* may have been misidentified due to morphological similarity among *D. venustus* subspecies. I find that the historic range is likely less extensive than previously thought. In addition, assessing the current distribution is critical for an evaluation of extinction risk. I document *D. v. venustus* on only one of the four sites where the subspecies has been observed since the 1960's.

Finally, to effectively assess the risk of extinction, it is important to estimate how well the remaining populations are surviving and reproducing. To accomplish this I carry out an abridged demographic assessment (Chapter 4) based on two years of data. This assessment indicates that the remaining population of *D. v. venustus* increased during the two-year study period, yielding high annual population growth (λ) values. However, this high growth rate may indicate an unstable population. Similar variability in a negative direction may drive the population below its survival threshold, potentially leading to extirpation. The fact that demographic parameters other than adult survival were remarkably comparable to values obtained for the endangered congener *D. stephensi* indicates that *D. v. venustus* may be susceptible to the same environmental stochasticity that has been documented for *D. stephensi*. Additional years of data collection are

required to capture temporal variability, which is critical to understanding the long-term viability of the sampled *D. v. venustus* population.

Each of the above studies resulted in new information regarding the subspecies, adding to our understanding of its endangerment risk. Based on my results, I recommend that *D. v. venustus* be listed as endangered pursuant to both CESA and FESA. I hope to use the data from these studies to form the basis of a listing petition that will be submitted to both the United States Fish and Wildlife Service and CDFG.

CHAPTER 2. AN EVALUATION OF THE ENDANGERMENT STATUS OF THE SANTA CRUZ KANGAROO RAT (*Dipodomys venustus venustus*) USING MOLECULAR SYSTEMATICS

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ABSTRACT

Due to habitat loss and other anthropogenic factors, the Santa Cruz kangaroo rat (*Dipodomys venustus venustus*) may be on the brink of extinction. In order to evaluate this question more fully I employ molecular systematic methods to assess gene diversity and historic isolation, two correlates of extinction. Specifically, I provide an estimate of genetic heterogeneity of *D. v. venustus* as compared with its conspecifics and I investigate whether or not the population sampled is a “distinct population segment,” a term used to define units of biodiversity that can be protected pursuant to the Federal Endangered Species Act (FESA). My results indicate that the *D. v. venustus* population sampled suffers from severely reduced gene diversity and that the *D. v. venustus* population sampled is a “distinct population segment.” These findings support the argument that this taxon should be protected by either the California Endangered Species Act (CESA) or FESA.

INTRODUCTION

Santa Cruz kangaroo rat (*D. v. venustus*) persistence is threatened due to habitat loss, habitat fragmentation, fire suppression, predation, stochastic environmental change, and recreational uses (Williams 1986, see Chapter 3). This raises the question of whether

or not this taxon should be protected pursuant to either CESA or FESA. FESA defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." In the original legislation, the term "species" was only meant to apply to species or subspecies of fish or wildlife or plants "in common spatial arrangements that interbreed when mature (Federal Register 1996)." However, when FESA was amended in 1978, the definition of the term "species" was expanded to include "any *distinct population segment* of any species of vertebrate fish or wildlife which interbreeds when mature" (emphasis added). The legislation failed to define this new term however, and there has been much debate in the scientific community over its meaning (Crandall et al. 2000, DeWeerd 2002). In this paper I investigate the question of whether or not the Santa Cruz kangaroo rat population known from Felton, in the Santa Cruz Mountains, is a "distinct population segment." In addition, using the same methods, I evaluate haplotype, gene, and nucleotide diversity in *D. v. venustus* and compare these metrics to those of closely related taxa to assess potential genetic uniformity.

Conservation scientists have been using the term "evolutionary significant units" (ESU's) interchangeably with the term "distinct population segment" (DPS) (DeWeerd 2002). The concept of ESU's was introduced by Ryder (1986) specifically to guide setting of priorities in captive breeding programs. Recognizing the inevitable uncertainty associated with defining potentially significant populations, Ryder (1986) suggested that different types of data be used to identify an ESU, including natural history information, morphometrics, range and distribution data, and genetics. While the development of

these two concepts (ESU and DSP) followed separate paths, today they ultimately determine the unit of biodiversity protected pursuant to FESA (Clark 2002).

Moritz (1994) proposed that ESU's be defined as having reciprocally monophyletic mtDNA alleles (i.e., all individuals in the ESU should have a common ancestor not shared by any individuals outside of the group) and significant divergence of allele frequency at nuclear loci, advancing the notion that historical population structure rather than current adaptation is the most critical aspect of a taxon to protect through conservation efforts. However, he subsequently updated his proposal (Moritz 2002) and now emphasizes the value of conserving both molecular and adaptive diversity. Moritz (2002) separates genetic diversity into two types: that arising from adaptive variation and that derived from long-term historical isolation. The former is illustrated through phenotypic variation and the latter through molecular phylogeography (Moritz 2002). Both types of diversity should be protected through conservation planning.

California is home to 23 endemic species/subspecies of kangaroo rats (*Dipodomys* spp.), five of which are listed pursuant to FESA (Goldingay et al. 1997). An additional five species/subspecies are considered "Species of Special Concern" by the California Department of Fish and Game (CDFG). The primary threat to these species is habitat loss due to large-scale urban and agricultural development.

At least some species in this genus can play a "keystone" role in the ecosystems within which they occur (Brown and Heske 1990, Goldingay et al. 1997, Brock 2001) and it has been suggested that in California they are indicators of ecosystems or plant communities "at risk" (Goldingay et al. 1997). For these reasons, the conservation of

these species should be elevated in priority (Goldingay et al. 1997, see Chapters 3 and 4).

It is critical to understand the taxonomic and genetic relationships between related *Dipodomys* before an assessment regarding endangerment status can be considered complete. Specifically, phylogenetic relationships within existing *Dipodomys* subgroups (Grinnell 1922) should be investigated to assess degrees of historic isolation. Areas of sympatry among congeners should be investigated to clarify their relationships. In addition, haplotype, gene, and nucleotide diversity of kangaroo rats with limited distribution should be investigated to evaluate the risk of population bottlenecks.

An assessment of endangerment of *Dipodomys* species in the agilis-group (Stock 1974) has been confounded due to a lack of clarity regarding their taxonomic relationships (Stock 1974, Best 1996). Specifically, relationships among members of the agilis-group of the central California coastal ranges has generated some confusion. Because of an overall high level of morphological similarity, particularly at localities on the border of each range, three taxa within the region regarded as the species *Dipodomys venustus* (Santa Cruz kangaroo rat), with three subspecies, *D. v. venustus*, *D. v. sanctiluciae*, and *D. v. elephantinus* (Williams et al. 1993, Patton 1993), are difficult to identify and therefore distribution and endangerment status of each are difficult to determine.

D. v. venustus

D. v. venustus at one time occurred as far north as Belmont in San Mateo County (Figure 2-1) (Grinnell 1922). Grinnell (1922) collected *D. v. venustus* specimens for his comprehensive taxonomic analysis from the nearby Jasper Ridge Biological Preserve,

owned and operated by Stanford University. Additionally, Grinnell references specimens collected in Saratoga, south of the Reserve. Due to extensive land use change, fragmentation, and fire suppression throughout the Bay Area it is unlikely that *D. v. venustus* survives anywhere in this portion of the historic range (see Chapter 3).

The southern-most collections of this subspecies are from Fremont Peak in San Benito County. Although land use change in this area is not as extensive as it is in the Bay Area, Price et al. (1995) demonstrate that fire suppression has negative impacts on Stephen's kangaroo rat (*D. stephensi*), and it is likely that fire suppression has had a negative effect on persistence of this *D. venustus* in this portion of the range.

D. v. venustus specimens housed at the Museum of Vertebrate Zoology at the University of California at Berkeley (MVZ) were collected mostly during the 1930's and 1940's. The majority of these specimens were collected from the Zayante sand hills ecosystem in Santa Cruz County. Many of the locations where the subspecies was historically documented have been irrevocably altered and no longer provide suitable habitat (Table 2-1).

Currently, the Santa Cruz kangaroo rat is known to persist at only one site, referred to as the Save-the-Redwoods League (SRL) parcel (see Chapter 3). This site is located in the sand hills ecosystem near Felton in Santa Cruz County. The sand hills ecosystem is at great risk due to impacts from sand mining as well as other anthropogenic impacts described above. For these reasons, *D. v. venustus* is likely vulnerable to extinction.

D. v. venustus is not currently legally protected although it is identified by CDFG as a “Species-of -Special–Concern” in an unpublished draft update to this list. This designation applies to animals that are not listed under FESA or CESA, but which nonetheless 1) are declining at a rate that could result in listing, or 2) historically occurred at low numbers and known threats to their persistence currently exist. Concerns identified for this subspecies include loss of habitat, fragmentation, urban edge effects, and reduced opportunities for recolonization (CDFG 1996).

D. v. sanctiluciae

D. v. sanctiluciae is known primarily from the Santa Lucia Mountains (Figure 2-1), the coast range that defines the Big Sur coast. This subspecies has been collected from as far north as the Hasting Natural History Reservation in Carmel Valley, Monterey County, and as far south as the vicinity of Santa Margarita in San Luis Obispo County. Known to occur in chamise chaparral at fairly low densities (Heske et al. 1997), the limited changes in land use patterns in this region make it unlikely that the subspecies is declining. Similar to *D. v. venustus*, however, it is possible that fire suppression has impacted this subspecies. A substantial portion of the range of this taxon occurs on protected lands (public landowners include Department of Defense, United States Forest Service, and University of California), but this does not diminish concerns about fire suppression on these lands. *D. v. sanctiluciae* is not provided any type of legal or administrative protection.

D. v. elephantinus

Dipodomys v. elephantinus is distributed on the western flank of the Gabilan Range of San Benito and eastern Monterey counties, based on known localities from museum collections (Figure 2-1). There has been no recent survey of its range, however, and it is likely that this taxon is largely limited to the Pinnacles National Monument region. Grinnell (1922) regarded *D. v. elephantinus* as a species distinct from *D. venustus*, a conclusion followed by most recent authors who have compiled taxonomic lists (e.g., Hall 1981, Patton 1993, Williams et al. 1993). Grinnell (1922), however, thought that intergradation might occur between *D. elephantinus* and *D. venustus* along the northern edge of the Gabilan Range, and Hawbecker (1940) suggested that some specimens from Santa Cruz County were actual integrades between these two taxa.

Stock (1974) suggested that the two were conspecific, based on a shared set of chromosomal characteristics. Best et al. (1996) confirmed this view by documenting both close morphometric similarity and a complete lack of uniquely fixed alleles at any of 33 allozyme loci examined between them. As a consequence, the most recent compilation of the taxonomy of heteromyid rodents (Patton in press) places *D. v. elephantinus* as a subspecies of *D. venustus*.

Best (1986) regarded *D. v. elephantinus* as rare and CDFG currently lists it as a State “Species of Special Concern,” both views based on its small geographic range. However, CDFG is considering removing this species from the “Species of Special Concern” list, presumably due to a lack of data regarding threats (B. Bolster, pers. comm.).

Historic Isolation

Each of the *Dipodomys* populations sampled for this study are separated from each other by long distances and barriers to movement (Figure 2-2). The Hastings Reserve and Pinnacles National Monument (where *D. v. sanctiluciae* and *D. v. elephantinus* were trapped, respectively) are separated by the Salinas River and are ca. 35.5 km apart. The SRL parcel (*D. v. venustus*) and the Hastings Reserve are ca. 92 km apart and are separated by urbanized areas, the Salinas River, the Pajaro River, and Elkhorn Slough. Pinnacles National Monument is ca. 99 km from the SRL parcel and includes all of the above listed barriers to movement. Therefore, it seems unlikely that gene flow occurs among these populations and likely has not for a substantial period of time. In fact, the Santa Cruz Mountains population of *D. v. venustus* is considered disjunct from other historically known populations of this subspecies (Williams et al. 1993).

MATERIALS AND METHODS

Data Collection

Specimens of the agilis-group from central California were captured using Sherman live traps (model XLK, H.B. Sherman Traps, Inc.) between May and September 2001. A small section of the right ear of each kangaroo rat trapped was biopsied and preserved in 95% reagent-grade ethanol for subsequent genetic analysis. Ear tissue samples were collected from 5 *D. v. sanctiluciae* at Hastings Natural History Reservation, 8 *D. v. elephantinus* at Pinnacles National Monument near Hollister in San Benito County, and 22 *D. v. venustus* at the SRL property (Figure 2-2). In addition, tissue

samples of 11 *D. agilis perplexus* from 6 locations in Kern, Ventura, and Los Angeles Counties, 3 *D. simulans* from one locality in Riverside County, 24 *D. panamintinus* from 6 locations in Kern County and one location in Inyo County, and 9 *D. heermanni* (5 *D. h. swarthi* and 4 *D. h. goldmani*) from 2 locations in San Luis Obispo County, and one location each in Santa Barbara, Monterey and San Benito Counties, were analyzed. The addition of these samples provides both a phylogenetic and genetic diversity context with which the pattern of variation within and among the three taxa of concern here can be evaluated.

Genetic analysis

I examined haplotypic diversity of the mitochondrial cytochrome-*b* gene, a protein-coding gene in the oxygen transport system of the mitochondria. The characteristics of mtDNA (high mutation rate, no recombination, and female inheritance) make it ideal for analysis of population structure, population history, and the relationships among taxa being compared (Hillis et al. 1996)

DNA was extracted with Chelex (Walsh et al. 1991), and the initial 800 bases of the cytochrome-*b* gene was amplified with the polymerase chain reaction (Saiki et al. 1988), with primers MVZ05 and MVZ16 for double-stranded amplifications, following reaction conditions described in Smith and Patton (1993), and confirmed with a 2% agarose gel. Sequences were obtained on an Applied Biosystems (Foster City, California) model 377 automated sequencer using the d Rhodamine cycle sequencing kit. A final sequence of 720 base pairs (bp) was obtained using MVZ05 as the sequencing primer (Smith and Patton 1993). Sequences were edited using Sequence Navigator Software (Applied

Biosystems, Inc. 1994). Standard measurements of molecular diversity (gene diversity, nucleotide diversity, and number of pairwise differences between all unique haplotypes) were obtained using the Arlequin 2.01 program (Schneider et al. 2000). Genetic distances were calculated using the Kimura 2-parameter model of nucleotide substitution (Kimura 1980) assuming minimal evolution, and a neighbor-joining tree with 1,000 bootstrap replicates was constructed using PAUP*4.0 b10 (Swofford, 2000). Maximum parsimony analyses, with all sites weighted equally, were run in PAUP*4.0 b10. A 50% majority rule consensus tree from 1,000 bootstrap replicates summarized parsimony results.

RESULTS

Within-Population Molecular Diversity

Dipodomys v. venustus has lower haplotypic diversity than either *D. v. sanctiluciae* or *D. v. elephantinus* (Table 2-2). *D. v. venustus* has only 4 unique haplotypes among the 22 sampled individuals, whereas all sampled individuals of the other two taxa *each* had unique haplotypes. *D. v. venustus* has only half the gene diversity (i.e., the number of unique haplotypes relative to their proportional representation within the sample examined) of the other two taxa and 1/3 to 1/2 the nucleotide diversity (i.e., the number of site substitutions relative to the total coalescent depth of their genealogical relationships) of the other two taxa. Last, the number of pairwise differences (i.e., the genealogical distinctness of the average pair of haplotypes) among the four unique haplotypes of *D. v. venustus* are only 1/3 to ca. 1/2 those measured for either of the other two taxa.

Phylogenetic Analyses

Both the parsimony and neighbor-joining analyses result in the same general topology of haplotypes (Figure 2-3), with agilis-group taxa forming a strongly monophyletic lineage relative to two species of “broad-faced” (Grinnell 1922) kangaroo rats (*D. heermanni* and *D. panamintinus*). Support for the node connecting all agilis-group taxa is high, 92% (bootstrap). There are two lineages within the agilis-group, one including the triad of central coast taxa (*D. v. elephantinus*, *D. v. sanctiluciae*, and *D. v. venustus*) and the other including the more southern pair of taxa (*D. agilis* and *D. simulans*). Each of these clades is supported with a bootstrap of 100% and they are strongly divergent (average Kimura 2 parameter distance is 10.6%), suggesting that the two clades last shared a common ancestor long ago. Within the triad of central coast species, haplotypes of each of these taxa are reciprocally monophyletic, with *D. v. venustus* and *D. v. sanctiluciae* indicated as sisters relative to *D. v. elephantinus*, although the level of support for their common node is limited (79% bootstrap) and haplotypes of *D. v. elephantinus* are similarly grouped with relatively low support (81% bootstrap). The level of sequence divergence within and among the taxa of the central coast clade is appreciably less than that measured for haplotypes within and among population samples of any of the other species examined (1.4-1.6% Kimura 2-parameter distance for nodes connecting the three taxa of the central coast clade versus those of the sister-species *D. agilis* and *D. simulans* [2.7%] and *D. heermanni* and *D. panamintinus* [6.2%]).

DISCUSSION

Within population molecular diversity

The single, extant population of *D. v. venustus* has less genetic diversity (as measured by mtDNA haplotypes) than do single population samples of either *D. v. santaluciae* or *D. v. elephantinus*. This difference is more marked given the substantially larger sample size (22) relative to those of the others (5 and 8, respectively). The low haplotype diversity observed in the *D. v. venustus* population sampled may indicate small population size, population instability, and/or a limited degree of gene flow between adjacent populations (Avice 2000). Therefore, these data support the finding that *D. v. venustus* may be at risk of endangerment.

Both low nucleotide diversity and limited number of pairwise differences in this population also suggests that it has experienced a demographic bottleneck. This bottleneck, however, probably is not due to recent perturbations, since the same kinds of anthropogenic causes implicated in the limited range of *D. v. venustus* have also presumably been impacting *D. v. elephantinus* and *D. v. sanctiluciae*, yet the latter exhibits higher degrees of diversity in all measures. This may be of concern since low genetic diversity can in turn limit the ability for the population to respond to environmental change, be it global climate change or new pathogens, leading to the potential for extinction (Lande 1988). However, this analysis examines diversity only within single populations of *D. v. venustus*, *D. v. elephantinus*, and *D. v. santaluciae*, and therefore, it may provide an incomplete picture of haplotype diversity. Additionally, Matocq and Villablanca (2001) warned that correlating low genetic diversity with a

historic population crash should be tempered since “pre-bottleneck” diversity is unknown.

It is interesting, however, that an apparent relationship exists between each of these diversity measures and the relative range size (and thus presumptive number of extant populations and overall population sizes) of each of these three taxa, with *D. v. sanctiluciae* having the largest diversity measures followed by *D. elephantinus* and *D. v. venustus*.

Phylogenetic analyses

Results from this study serve to resolve some of the confusion about the taxonomic relationships among several *Dipodomys* in the agilis-group. The significance of these findings relative to the triad of central coast species is two-fold. First, the monophyletic central coast clade supports earlier suggestions that *D. v. elephantinus* and *D. v. venustus* are closely related. *D. v. elephantinus* is only marginally more differentiated from *D. v. venustus* in mtDNA than are *D. v. sanctiluciae* and *D. v. venustus*. In addition, the three form a clade that is markedly different from other members of the agilis-group. The low level of sequence divergence among them suggests relatively recent divergence in relation to that between the other species pairs analyzed here. These data thus fully support the conclusion of Best et al. (1996) that all three taxa are best considered geographic representatives of the same species, *Dipodomys venustus*.

Since each of these taxa is reciprocally monophyletic they meet the unique lineage requirement of Moritz’s (1994) original definition of an ESU. No pair of the geographic units of *D. venustus* is exchanging genes currently, and none are likely to

have been in genetic contact in recent history. As mentioned above, each of these taxa is threatened by altered fire regimes and may be historically isolated due to barriers to migration. Therefore, each may meet criteria for protection pursuant to FESA as “distinct population segments” (Federal Register 1996).

CONCLUSION

Dipodomys v. venustus meets the genetic criteria for being a “distinct population segment,” faces threats from potential genetic uniformity, and has experienced substantial habitat loss; therefore, this subspecies should be protected as endangered pursuant to either CESA or FESA. The molecular data combined with the distribution data and recent reduction in range all point to a potentially dire situation for this subspecies.

Additional work is needed to fine-tune our understanding of the degree of endangerment of *D. v. venustus*. Specifically, ongoing comprehensive searches for extant populations of *D. v. venustus* are needed to assess any additional genetic diversity that may remain in this taxon. Additional genetic and morphometric studies could determine whether any of the specimens housed in the MVZ have been misidentified, further refining the historic and current distribution maps of all sympatric congeners and elucidating their degree of endangerment. In addition to resolving questions regarding species range boundaries, this would also provide an opportunity to assess whether or not hybridization was occurring where outlier populations occurred in the past. However, given the information currently available it appears that the subspecies is in a potentially precarious situation and our attention will be necessary to assure that it does not become extinct.

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LIST OF FIGURES

Figure 2-1: Generalized historic range of *D. venustus* and each of its three subspecies in the central coast of California, based on Grinnell (1922) and specimens preserved in the mammal collection at the Museum of Vertebrate Zoology at the University of California at Berkeley.

Figure 2-2: Field sites for genetic study.

Figure 2-3: Phylogenetic hypothesis of relationships among haplotypes of the mitochondrial cytochrome b gene for species of kangaroo rats, genus *Dipodomys*, from California: The agilis-group taxa *D. elephantinus*, *D. v. venustus*, *D. v. sanctiluciae*, *D. agilis* (6 populations, 11 individuals, 9 unique haplotypes), and *D. simulans* (1 population, 3 individuals, 2 unique haplotypes), and the “broad-faced” taxa *D. heermanni* (4 populations, 9 individuals, 9 unique haplotypes) and *D. panamintinus* (7 populations, 25 individuals, 24 unique haplotypes).

Figure 2.1

Figure 2.2

Figure 2-3.

TABLES

Year	County	Locality	Source	Habitat Still Available?
1904	San Mateo	Belmont	Grinnell	No
1941, 1907	Santa Clara	Stanford University, Jasper Ridge	MVZ, CAS	No
1922, 1892	Santa Clara	Mt Hamilton Rd. "toward summit"	MVZ, CAS	Specimen misidentified?
1930	Santa Cruz	Doyle (Rodeo) Gulch, 9 mi. NE Santa Cruz	MVZ	Unlikely due to fire suppression and fragmentation. Small patch of maritime chaparral occurs on private property.
1931, 1935, 1941, 1960	Santa Cruz	Head of Doyle (Rodeo) Gulch	MVZ, CAS	See above
1931	Santa Cruz	1 mi. NE Bonny Doon	MVZ	Trapped in 2001; not found
1937	Santa Cruz	1mi. NNE Bonny Doon	MVZ	See above
1938	Santa Clara	2 mi. SW Saratoga	MVZ	No
1942	Santa Cruz	Berglund Ranch, 2 mi. NW Corralitos	MVZ, Rudd	No
1940	San Benito	Fremont Peak Rd. 7 mi. S San Juan	MVZ	Specimen misidentified?
1940	Santa Cruz	Bean Creek Rd., 1.8 mi. E Mt. Hermon	MVZ, Rudd	No
1940, 1961, 1995	Santa Cruz	Zayante Rd., 2.1 mi, E Ben Lomond (@Quail Hollow)	MVZ/CAS, Rudd	Trapped in 1995 by Biosearch Wildlife Surveys; not found
1984	Santa Cruz	Old Olympia Quarry, Zayante Road	Roest	Trapped in 2001; not found
1940, 1941	Santa Cruz	Graham Hill Rd., 1.1 mi. From Felton Station	MVZ/CAS	Yes. This is the SRL parcel
1937, 1939	Santa Cruz	J. Enos Ranch, 1 mi. NW Corralitos	MVZ	No
1936	Santa Cruz	Bear Creek Rd., 2 mi. NE Boulder Creek	MVZ	No
1940	Santa Cruz	Mt Hermon Rd, 1.3 mi. E Mt Hermon	MVZ	No
1958	San Benito	4.25 mi S and 4.75 mi. E San Juan Batista (Fremont Peak)	MVZ	Specimen misidentified?
1933	San Mateo	Redwood City	CAS	No
1948	Santa Cruz	1 mi from the summit of Hecker Pass	Rudd	Specimen misidentified?
1947	Santa Cruz	1.7 mi. SSE Loam Prieta	SJSU	Specimen misidentified?
1984, 1996	Santa Cruz	Kaiser Quarry, Lockwood Lane	Roest, Laabs	No, mined.
1990	Santa Cruz	Grey Whale State Park	Axtell	Trapped in 2001; not found

Table 2-1. All known historic locations of *D. v. venustus*. MVZ=Museum of Vertebrate Zoology at Univ. of Calif. At Berkeley, CAS= Calif. Academy of Sciences, SJSU = San Jose State University

Character	<i>D. v. venustus</i>	<i>D. v. sanctiluciae</i>	<i>D. v. elephantinus</i>
N _{individuals}	22	5	8
N _{haplotypes}	4	5	8
Gene diversity	0.558±0.101	1.000	1.000
Nucleotide diversity	0.0018±0.00133	0.0044±0.0032	0.0029±0.0020
Number of pairwise differences	1.3247±0.8565	3.2000±1.9794	2.0714±1.2916

Table 2-2. Haplotype, gene, and nucleotide diversity, and the number of pair wise differences, in sampled populations of *D. v. venustus*, *D. v. sanctiluciae*, and *D. v. elephantinus*

CHAPTER 3. THE HISTORIC AND CURRENT DISTRIBUTION OF THE SANTA CRUZ KANGAROO RAT (*Dipodomys venustus venustus*) IN THE CENTRAL COAST OF CALIFORNIA

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ABSTRACT

Often the most compelling evidence for a species extinction risk is the loss (or contraction) of its historic range. Anecdotal and unpublished evidence suggests that habitat for the Santa Cruz kangaroo rat (*Dipodomys venustus venustus*) has diminished at an alarming rate. Due to concerns regarding range collapse of this taxon, I evaluate both the historic and current range of *D. v. venustus*. Through careful evaluation of all known records of the subspecies, I find that the historic range, may be more restricted than previously thought due to the potential of misidentified specimens. To assess the current distribution and range collapse, I live-trapped the four sites where the subspecies has been documented most recently and confirm its presence on only one site. These findings strongly support the recommendation that *D. v. venustus* be listed as endangered pursuant to both the Federal (FESA) and the California Endangered Species Act (CESA).

INTRODUCTION

The Santa Cruz kangaroo rat (*D. v. venustus*), a five-toed, narrow-face, dark-colored rodent in the family Heteromyidae, is known primarily from the Santa Cruz Mountains in the central coast of California (Best 1992). Perhaps reflecting regional fire suppression and other local impacts such as sand quarrying operations, predation by feral

cats (*Felis catus*), loss of habitat due to development, and dirt biking, records indicated that this subspecies was represented by only a few small and spatially disjunct populations and consequently is thought to be at risk (Axtell 1990, Williams 1986).

The Santa Cruz kangaroo rat generally occurs in association with a unique assemblage of northern maritime chaparral plant species that are distributed on inland marine sand deposits (Roest 1988). This plant community, referred to as “silverleaf manzanita mixed chaparral” (Marangio and Morgan 1987), is one of two plant communities endemic to Santa Cruz County that comprise the Zayante sand hills ecosystem (Federal Register 1997). These communities – silverleaf manzanita mixed chaparral and maritime coast range ponderosa pine– are considered local indicators of the Zayante soil series (Marangio and Morgan 1987).

Zayante Soils

The Zayante soil series is typified by soft, well-drained sand that provides an ideal substrate for digging burrows, a critical habitat component for *D. v. venustus* (Hawbecker 1940, Rudd 1948). These soils cover 3,237 ha (3% of Santa Cruz County; Lee 1994, Marangio and Morgan 1987). Known *D. v. venustus* habitat patches are generally restricted to this naturally fragmented sandy substrate. Other chaparral-vegetated heavy soils are not typically used by *D. v. venustus* (Rudd 1948). In an unpublished 1984 report, Gilchrist and Associates estimated that 40-50% of the original Zayante soils acreage in the County had been eliminated and that an additional 20-25% was threatened with various forms of land use change.

Zayante Sand Hills Ecosystem

The Zayante sand hills ecosystem has a high level of endemism, supporting at least 11 rare plant and 3 rare animal species (CNDDDB 2002). It is found within a very small portion of the County, from Scotts Valley and Zayante to Felton and Ben Lomond, in addition to several small, isolated areas in Bonny Doon (Gilchrist and Associates 1984) and Corralitos (Hawbecker 1940). Typical woody plant species include, silverleaf and brittleleaf manzanita (*Arctostaphylos silvicola* and *A. tomentosa*), chamise (*Adenostoma fasciculatum*), coyote bush (*Baccharis pilularis*), ponderosa pine (*Pinus ponderosa*), knobcone pine (*Pinus attenuata*), wild lilac (*Ceanothus cuneatus*), poison oak (*Toxicodendron diversiloba*), monkey flower (*Mimulus aurantiacus*), and yerba santa (*Eriodictyon californicum*). Common animals include coyote (*Canis latrans*), Merriam's chipmunk (*Tamias merriami*), Botta's pocket gopher (*Thomomys bottae*), pinyon mouse (*Peromyscus truei*), scrub jay (*Aphelocoma coerulescens*), California thrasher (*Toxostoma redivivum*), northern flicker (*Colaptes auratus*), brown towhee (*Pipilo fuscus*), dark eyed junco (*Junco hyemalis*), and wrentit (*Chamaea fasciata*).

Silverleaf Community

The Santa Cruz kangaroo rat has shown a close association with silverleaf manzanita chaparral (Roest 1988). The distribution of silverleaf manzanita mixed chaparral community, where most specimens of *D. v. venustus* have been collected, has always been very limited and fragmented. Lee (1994) estimated that of the 1,263 ha of silverleaf manzanita chaparral that historically existed in the county, roughly 169 ha had been altered by residential development, 142 ha had been removed for sand quarrying,

and 167 ha had been removed for development as landfills and commercial development.

In addition to the direct loss of habitat through various land uses, the suppression of fire in this plant community may have rendered some of the previously occupied sites unsuitable for *D. v. venustus*. Land use change has greatly diminished the historic distribution of this unique habitat, and available evidence suggests a severe decline in the distribution and abundance of the Santa Cruz kangaroo rat (Roest 1988, Williams 1986).

Historic Distribution

D. v. venustus historically ranged as far north along the San Francisco Bay Area peninsula as Belmont and the Jasper Ridge Biological Reserve operated by Stanford University (Grinnell 1922) (Figure 3-1). Grinnell (1922) described the range of this subspecies as, “Chiefly the Santa Cruz Mountain region, in other words the area south from San Francisco to Monterey Bay and lying west of the Santa Clara Valley and the south arm of San Francisco Bay; but the race also occurs, east of the Santa Clara Valley, on Mount Hamilton, and southeast to [the] northern end of the Gabilan Range.” Due to extensive land use change, fragmentation, and fire suppression throughout the peninsula and Santa Clara Valley, it is highly unlikely that *D. v. venustus* survives in this portion of the historic range.

Museum Records

The Museum of Vertebrate Zoology (MVZ) at the University of California, Berkeley, and the California Academy of Sciences (CAS) in San Francisco, both house collections of *D. v. venustus*, providing an excellent idea of the historic distribution for this subspecies. Most *D. v. venustus* specimens housed at the MVZ and CAS were

collected during the 1930's and 1940's; only two specimens were added to either collection after 1961. While most of the collections were made from areas characterized by sandy soils, it is important to note that some of the historic localities are from areas not underlain with Zayante soils.

Problems with Identification

The historic range of *D. v. venustus* may be more limited than previously thought. The difficulty that various scientists have had in distinguishing *D. v. venustus* from *D. v. elephantinus* raises questions about the true extent of the historic ranges of each; Williams et al. (1993) noted that samples of *D. v. venustus* from the Diablo Range are indistinguishable from *D. v. elephantinus*. Due to the difficulty in actually identifying these subspecies accurately based on morphological characters, some of the *D. v. venustus* study skins at MVZ may be misidentified. Roest (1984) compared measurements of *D. v. venustus* from San Juan Bautista (San Benito County) to *D. v. elephantinus* and postulated that this record had been misidentified. San Juan Bautista is well within the range of *D. v. elephantinus*, and the specimens examined had ear measurements within the range of *D. v. elephantinus*. Additionally, San Juan Bautista is much closer to the range of *D. v. elephantinus* than to *D. v. venustus*, casting doubt on the identification of specimens from Fremont Peak, south of San Juan Bautista. Roest (1984) asserted that measurements of *D. v. venustus* specimens from Loma Prieta were much more closely aligned with measurements of *D. heermanni* and suggested that these specimens were mislabeled.

Despite previous efforts to define the historic range of *D. v. venustus*, no accurate map overlaying soils and historic *D. v. venustus* localities is available. Price and Endo (1989) showed that soil maps might be useful for predicting and identifying habitat for sensitive species. They used soil maps to estimate the potential distribution of Stephen's kangaroo rat (*Dipodomys stephensi*) with 70% accuracy (Price and Endo 1989). This is a valuable approach to identifying inaccessible lands with potential habitat and/or lands that may have had suitable habitat but have since been altered.

Current Distribution

Many of the sites on which the subspecies was documented have been irrevocably altered. In addition, the Santa Cruz Mountains population of *D. v. venustus* is considered naturally disjunct from all other historically known populations of this subspecies (Williams et al. 1993). Roest (1988) conducted a field study to determine if indeed the subspecies was still present in several areas previously investigated. Of four sites trapped in 1984, only two were still occupied by *D. v. venustus*; these were the Save-the-Redwoods League (SRL) property adjacent to the north side of Henry Cowell State Park, and the Old Olympia Quarry, on Zayante Rd, owned by the San Lorenzo Water District.

Only three other studies, two of which are unpublished, have documented presence of the subspecies within Santa Cruz County since the 1984 study. These studies documented presence of the subspecies on three different sites, Wilder Ranch State Park (Axtell 1990), the Kaiser Quarry (owned by Hanson's Aggregates) adjacent to Mount Hermon (Biosearch Wildlife Surveys 1996), and the SRL parcel (Biosearch Wildlife Surveys 1996). In addition, Best et al. (1996, T. L. Best pers. comm. 2002) collected *D.*

v. venustus specimens from the SRL parcel in the early 1990's in order to conduct their allozyme study.

In summary, *D. v. venustus* has been documented at four different sites in Santa Cruz County since the 1960's (Figure 3-2). Of the four sites, two are currently in public ownership (Wilder Ranch State Park, San Lorenzo Water District). The site owned by Hanson's Aggregates (Kaiser Quarry) has since been mined, and the SRL parcel is in the process of being annexed to Henry Cowell State Park. Finally, the MVZ houses specimens that were collected from the Bonny Doon Ecoreserve parcel in 1931 and 1937. Adjacent landowners made anecdotal observations of kangaroo rats up to the 1950's. However, a more thorough investigation of current *D. v. venustus* distribution is warranted.

The objectives of this study are to evaluate the historic range of the subspecies based on museum records and Zayante soils distribution and to provide an estimate of current *D. v. venustus* distribution based on field data. Since habitat loss has been identified as a leading cause of endangerment for many species protected by FESA it is critical to develop an understanding of the degree of range collapse that this taxon has experienced. FESA states that the Secretary of the Interior shall determine if a species is threatened or endangered based on a number of factors, the primary factor being "the present or threatened destruction, modification, or curtailment of its habitat or range." The goal of this analysis is to assess the need for legal protection of the subspecies.

MATERIALS AND METHODS

Historic Distribution

In order to evaluate historic *D. v. venustus* distribution, I compiled all recorded observations and trapping studies. This effort included summarizing observations made in relevant literature including several unpublished theses, reports submitted to the County for permitting purposes, and reports prepared for submittal with museum specimens. In addition, in November 2002, I visited MVZ to review the existing museum specimens and field notes with MVZ staff. I was able to retrieve all CAS records of *D. v. venustus* from their web site.

Current Distribution

To assess the current distribution of *D. v. venustus*, I conducted trapping studies at the four sites where this subspecies has been recorded recently. I focused my efforts specifically in the Santa Cruz Mountains rather than trying to assess the presence of taxon at other historic areas, like Mt. Hamilton or the Stanford campus. At each site, small mammals were captured using Sherman live traps (model XLK, H. B. Sherman Traps, Inc.) between May and September 2001; some additional trapping occurred on several of the sites (described below). Traps were baited with dried millet seed and were set for four consecutive nights during each trap session. During cold weather a paper towel was placed in the trap to provide bedding material. Traps were opened and baited between 1800 h and 2000 h and checked the following morning between 0600 h and 0800 h. One hundred traps were set during each trap session. Traps were placed as line

transects and set in pairs with approximately 10 m spacing between stations. All small mammals trapped were identified to species and released immediately at the point of capture.

Study Sites

The climate in the Santa Cruz Mountains is characterized as Mediterranean (Thomas 1961). It is generally cool and maritime with an average annual rainfall of ca. 74 cm in the lower elevations near Santa Cruz. Although most rainfall occurs in the winter, the rainless summer and fall are tempered by fog and proximity to the ocean. Occurrence of *Dipodomys* in this climate is somewhat unusual when compared to the hot and dry desert climate in which most other members of this genus occur (Rudd 1948).

Four sites were sampled in this study. These included SRL parcel on Graham Hill Rd; the Old Olympia Quarry owned by the San Lorenzo Water District located on Zayante Road; Wilder Ranch State Park adjacent to Smith Grade Road in Bonny Doon; and the Bonny Doon Ecoreserve on Martin Road. These sites were selected because the subspecies has been documented on them more recently than anywhere else in the County (Figure 3-2). In addition, three of the sites are owned by public agencies and the SRL property is in the process of being transferred to a public agency, facilitating access. Each of these sites is separated from others by relatively large stands of mixed evergreen forest.

The SRL parcel represents one of the largest undisturbed parcels of sand-related habitats (124 ha) remaining in Santa Cruz County (Figure 3-3). The site is bordered on the south by Henry Cowell Redwoods State Park, on the east by Graham Hill Road, on

the west by the Southern Pacific Railroad Tracks and on the north by Roaring Camp Railroad. The site supports a variety of habitats including northern maritime chaparral, silver-leaf manzanita chaparral with a scattered ponderosa pine/ knobcone pine canopy, sand parkland, mixed evergreen forest, and redwood forest. The silverleaf manzanita habitat patch covers approximately 54 ha.

The majority of the site supports a mosaic of plant associations adapted to sandy soils. Patches of scrub with variable density occur throughout the site. However, variability in the vegetation cover on site has not been measured. Elevations on the site range from 97 m to 219 m.

In an earlier study Biosearch Wildlife Survey (1996), reported capturing 24 individual kangaroo rats were trapped during 2,800 trap nights. In addition, Roest (1984) captured three kangaroo rats in 737 trap nights, and Best (1996) captured 11 animals on this site. For the present study, the SRL site was trapped monthly from April to September 2001 (2,400 trap nights) and from May to September 2002 (2,000 trap nights). Two transects on the site were marked with permanent markers and a temporary transect was established in a third location in May 2001 to assess distribution of the subspecies throughout the site (Figure 3-3). All *D. v. venustus* captured were marked with numbered ear tags and standard morphometric measurements were taken.

The Old Olympia Quarry, located off of Zayante Road (ca 2.4 km east of Graham Hill Road) in Santa Cruz County, is currently owned by the San Lorenzo Valley Water District (Figure 3-4). The 25 ha sand mine has been inactive since 1962 (Roest 1984) and frequently is used by dirt bikers. Some native vegetation is recolonizing the mined

area but no sand hills chaparral habitat remains within the mine footprint. Successful trapping of *D. v. venustus* on the site occurred in 1984 (Roest 1984) on the slopes surrounding the mine pit where, historically, sand hills habitat was distributed (B. Davilla, pers. comm., A. Haynes pers. comm.). Seven kangaroo rats were caught during 737 trap nights between February and May 1984. For this study, the Old Olympia Quarry site was trapped from 7 – 10 August 2001.

Wilder Ranch State Park is a 2,959 ha State Park located adjacent to the coast, north of the town of Santa Cruz. A small patch of silver-leaf manzanita chaparral (22 ha) is located along Laguna Creek in the mountain community of Bonny Doon (Figure 3-5). Plant species that occur on the Zayante sand on site include silver leaf manzanita, wild lilac, yerba santa, cryptantha (*Cryptantha hispidissima*), and small sun cup (*Oenothera micrantha*). Knobcone pine are scattered throughout the sandy habitat patch. The site is occupied by the federally protected Ben Lomond spineflower (*Chorizanthe robusta* var. *hartwegii*). Elevations of the silverleaf chaparral patch range from 243 to 305 m. Axtell (1990) sampled this site yielding 15 *D. v. venustus* in 888 trap nights. For this study, trapping was conducted on Wilder Ranch State Park from 15 – 18 September 1999 and 15 – 19 May 2001.

The Bonny Doon Ecological Reserve is a 208 ha site owned by the California Department of Fish and Game (Figure 3-6). The Department acquired the site in order to assure that the unique natural resources present would be protected in perpetuity. Vegetation at this site includes a pine parkland component and silverleaf manzanita chaparral (DeWald 1997). The silverleaf manzanita chaparral community at Bonny Doon

Ecological Reserve covers ca. 26 ha but it is separated into several patches. The patch that I sampled is 12 ha. Specimens were collected from this site in 1931 and 1937 and deposited at the MVZ, and cat belonging to a neighbor of the Ecological Reserve is reported to have brought home kangaroo rats until the late 1950's (Davilla 1980). This site also was trapped to determine presence of kangaroo rats for three nights in September 1992 with negative findings (D. Laabs, pers. comm). For the present study, trapping was conducted on the Bonny Doon Ecological Reserve between 12 – 15 June 2001.

RESULTS

Historic Distribution

I summarized of all the historic localities of *D. v. venustus* (Table 3-1) and superimposed these points on a map of the distribution of the Zayante soils, with areas of uncertain subspecies identification noted (Figure 3-1). Fifteen of the historic records of *D. v. venustus* occur in areas underlain with Zayante soils and nine are located on other soil types. This map includes the full range of the subspecies, as contrasted with Roest (1988), which shows only localities south of Saratoga, and omits points south of Corralitos.

Some records or specimens were difficult to verify. Some of the *D. v. venustus* specimens at MVZ were juveniles, making accurate identification based on morphometrics difficult. Two specimens from the Diablo Range (i.e., Mount Hamilton) were much smaller than the other *D. v. venustus* specimens; because these were roadkills, their skulls were not available for analysis, but it is not out of the question that the latter specimens are misidentified. Roest (1984) noted that *D. v. venustus* records from Loma

Prieta were similar to *D. heermanni goldmani*. The CAS has one record of *D. heermanni goldmani* from San Jose, Santa Clara County (CAS MAM 19215 collected in 1892) and one from Redwood City, San Mateo County (CAS MAM 7208 collected in 1932). This lends some credence to Roest's (1984) idea that the Loma Prieta locality of *D. v. venustus* may be a misidentification. MVZ collections of *D. h. goldmani* do not include any specimens north of Salinas.

Finally, there are two records of *D. v. elephantinus* in close proximity to a record for *D. v. venustus* in the Fremont Peak area (Figure 3-1). One of the *D. v. elephantinus* records is within 630 m of the *D. v. venustus* record. Additional work will be necessary to determine if any of these specimens have been mislabeled. If they are confirmed to be *D. v. elephantinus*, the historic range map for *D. v. venustus* would be more limited than previously thought.

Current Distribution

No kangaroo rats were captured at the Old Olympia Quarry, Wilder Ranch, and Bonny Doon Ecological Reserve. Of the most recently documented locations of *D. v. venustus* in Santa Cruz County, the SRL site supports the only population known today. Small mammal species diversity was variable on each site (Table 3-2).

A total of 73 individual kangaroo rats were trapped on the SRL site over the course of two years. Sixty-nine individuals were captured on the two permanent transects during a total of 4,200 trap nights. Four individuals were captured on the temporary transect in 200 trap nights. Nineteen animals were first captured as juveniles. Sign of *D.*

v. venustus was observed throughout silver-leaf manzanita chaparral habitat on the property.

DISCUSSION

Habitat loss and habitat fragmentation have been identified as leading causes of the loss of biodiversity and species endangerment (Primack 1993). Reflecting this trend, the range of *D. v. venustus* has been severely reduced by land use change, fragmentation, and likely by fire suppression. This species evidently has not persisted at 3 of the 4 sites where it has been documented in the past two decades. Demographic parameters from the extant population were strong (estimated $\lambda = 1.29$) in the years this study was conducted (see Chapter 4); therefore, negative findings at other sites are not likely due to poorer-than-average climatic conditions in the region.

Urbanization has accounted for much of the loss of the historic range of this subspecies. The entire San Francisco Bay Area portion of the historic range for *D. v. venustus* can be considered irrevocably altered. The historical locations within areas underlain with Zayante soils in Santa Cruz County have also been impacted by urbanization, fragmentation, and edge effects such as predation by feral and domestic cats. A large portion of the once intact sandhills ecosystem has been directly destroyed by sand mining operations.

Relatively low small mammal diversity on the Olympia Quarry site was not surprising, given the destruction of the silverleaf chaparral community by the historic mine at that site and the adjacent active mine. The quarry was closed in 1962 after clearing and mining ca. 25 ha of habitat. It is likely that the *D. v. venustus* population

documented in 1984 on the old Olympia quarry site was dependent on an extensive patch of intact silverleaf manzanita chaparral on the adjacent parcel that was cleared by Kaiser mining operations in 1986.

Less obvious, is why this subspecies may be extirpated from the Wilder Ranch site, where it had been observed as recently as 1990. There have been no major changes in land use at this site other than fire suppression. If a higher burn frequency allowed the subspecies to persist on this site, then the loss of the subspecies on this site may indicate niche requirements that only occur under a regular fire regime (Price et al. 1995).

In support of this explanation, Price and Waser (1984) found that *D. agilis* was consistently more abundant in burned than in unburned sites. Price et al. (1995) reported that population growth of *D. agilis* on burned sites was twice as rapid as on control sites. In addition, population size of *D. agilis* declined steadily at unburned sites. Their results suggest that in coastal sage scrub communities *D. agilis* is actually maintained by periodic fires that create ephemeral patches of open habitat (Price and Waser 1984). The long-term benefit of fire to kangaroo rats is likely to occur through an increase in bare ground with a minimal effect on forbs (Price et al. 1995). As a member of the *agilis*-group (Grinnell 1922), it is possible that *D. v. venustus* has similar habitat requirements.

In addition, it is likely that *D. v. venustus* is vulnerable to extirpation once a patch of suitable habitat is reduced below a certain threshold area. The causes of this type of threat could be direct, as in the land clearing that occurred adjacent to the old Olympia Quarry, or they could be indirect such as the loss of suitable habitat through fire suppression. Price and Endo (1989) estimated that a minimum reserve size of 100 ha

would be necessary for Stephen's kangaroo rat to persist. However, more research would be necessary to estimate the threshold for a minimum patch size for the Santa Cruz kangaroo rat.

In a long-term study the Hastings Natural History Reservation in Carmel Valley Heske et al. (1997) found that *D. v. sanctiluciae* presence was strongly associated with the interior of large patches of chaparral. Based on this, they suggest this taxon is more sensitive to area and isolation effects caused by fragmentation than are other small mammals trapped in this habitat type.

The apparent extirpation of *D. v. venustus* from the Wilder Ranch site highlights the potential significance of demographic stochasticity to the fate of this subspecies. It is likely that at one time, *D. v. venustus* populations functioned as a metapopulation, with patches of occupied habitat "interconnected" by some level of long-distance dispersal sufficient for "re-inoculation" in the event of local extirpation. The combination of patch size reduction and limitations to dispersal connections that this taxon has suffered increases the likelihood of extirpation by demographic stochasticity and eliminates the possibility of recolonization. Therefore, it is critical that the one known population of *D. v. venustus* be managed carefully to prevent chance extirpation.

The lack of small mammal diversity and abundance at the Bonny Doon Ecoreserve likely reflects historic land uses, edge effects from nearby subdivisions (e.g., cat predation), and low burn frequency. It is unknown how much habitat clearing occurred when agricultural operations occurred in the area, but the patch of silverleaf manzanita chaparral that remains is quite limited.

If the above arguments concerning interior habitat apply to *D. v. venustus*, then the population at SRL may be persisting due to the size of the intact habitat patch. Also, unlike the other sites, open areas of bare ground are more abundant on this site. These would appear to be the only features distinguishing this site from other sites where this subspecies was historically documented. Land use at the SRL site likely has been more intense than at the Wilder Ranch site, therefore, the size of the patch and the habitat quality differentiates these two sites.

The size of the historic population at the SRL site is not known. It is possible that the population observed today may be on a downward trajectory as was likely the case on Wilder Ranch in 1990. Threats to the species at the SRL site include recreational uses, edge effects from urbanization, and fire suppression. Even though the site has not burned since 1943 (based on a review of historic aerial photos) there are portions of the site where the silverleaf manzanita chaparral habitat is open and high densities of burrows were observed. This is a qualitative observation and additional research will be necessary to determine habitat affinities of this subspecies. This type of information is critical to developing future recovery goals and management plans for *D. v. venustus*.

Questions remain about the validity of the identification of some of the specimens from more remote collection sites of *D. v. venustus*. In particular, the San Juan Bautista/Fremont Peak, Mount Hamilton, and Loma Prieta records cause concern because they are disjunct and not on Zayante soils. There is a potential that the animals collected at these locations were misidentified. This question could only be resolved with further study. Because I was unable to obtain access to trap in these remote locations, I could

not confirm whether kangaroo rats still occur in these areas. However, even if these specimens were identified accurately, and the subspecies still happens to survive in these locations, its range is exceedingly limited, and it is clearly at risk.

By overlaying the Zayante soils distribution map with the historic location data of *D. v. venustus* I observed several large patches of sandhills habitat that may not have been surveyed for the subspecies (Figure 3-1). One outcrop of sandy soil is located on Weston Road in Santa Cruz County. This site is in private ownership, and it is inaccessible. While it is possible that the subspecies may occur in this habitat patch, surveys conducted by Rudd (1948) throughout Santa Cruz County were so comprehensive that it seems unlikely that he would not have been aware of the Weston Road habitat patch. His report does not describe locations where he failed to capture Santa Cruz kangaroo rat. Another site occurs in a remote location in Bonny Doon on private property.

CONCLUSION

Due to the extreme range collapse that this subspecies has experienced, and ongoing concerns about appropriate habitat management, protection of *D. v. venustus* pursuant to FESA is warranted. The Fish and Wildlife Service (USFWS) developed a priority system designed to direct its efforts for listing toward species in greatest need of protection. The magnitude of threat is the most important consideration, followed by the immediacy of the threat and the distinctiveness of the species. This study indicates that the degree of threat to this unique kangaroo rat easily meets the USFWS criteria for listing priority.

ACKNOWLEDGEMENTS

I wish to thank the following organizations for allowing access onto their property: Save the Redwoods League, California Department of Fish and Game, California Department of Parks and Recreation, and the San Lorenzo Valley Water District. This work would not have been possible without the generosity of the Museum of Vertebrate Zoology at University of California at Berkeley for allowing access to their collection. David Laabs contributed significantly to this study by providing technical advice and field support and Jim Keller provided invaluable assistance in map production. Last, this paper benefited greatly from the review of my graduate advisor, Dr. Rachel O'Malley, and my committee members, Dr. Jim Patton, Dr. Douglas Kelt, and Dr. Patrick Kelly.

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Figure 3-1: Generalized historic range of *D. v. venustus* based on Grinnell (1922) and specimens preserved in the mammal collection of the Museum of Vertebrate Zoology, University of California at Berkeley contrasted with probable historic range and distribution of most recent records.

Figure 3-2: Four study sites for *D. v. venustus* current distribution assessment.

Figure 3-3: Save-the-Redwoods League parcel with silverleaf manzanita chaparral habitat patch shown.

Figure 3-4: The old Olympia Quarry parcel with silverleaf manzanita chaparral habitat patch shown.

Figure 3-5: Wilder Ranch State Park with silverleaf manzanita chaparral habitat patch shown.

Figure 3-6: Bonny Doon Ecological Reserve with patches of silverleaf manzanita chaparral habitat shown.

Figure 3.2

Aerial by AirPhoto USA
Imagery date: June, 2000

0 290 580 870 1,160
Feet

Legend

- Parcel Boundary
- Silver Leaf Manzanita Chaparral

Figure 3.3

Aerial by AirPhoto USA
Imagery date: June, 2000

0 290 580 870 1,160
Feet

Legend

Parcel Boundary

Silver Leaf Manzanita Chaparral

Figure 3.4

Aerial by AirPhoto USA
Imagery date: June, 2000

0 290 580 870 1,160
Feet

Legend

- Parcel Boundary
- Silver Leaf Manzanita Chaparral

Figure 3.5

TABLES

Year	County	Locality	Source	Habitat Still Available?
1904	Santa Mateo	Belmont	Grinnell	No
1941, 1907	Santa Clara	Stanford University, Jasper Ridge	MVZ, CAS	No
1922, 1892	Santa Clara	Mt Hamilton Rd. "toward summit"	MVZ, CAS	Specimen misidentified?
1930	Santa Cruz	Doyle (Rodeo) Gulch, 9 mi. NE Santa Cruz	MVZ	Unlikely due to fire suppression and fragmentation. Small patch of maritime chaparral occurs on private property.
1931, 1935, 1941, 1960	Santa Cruz	Head of Doyle (Rodeo) Gulch	MVZ, CAS	See above
1931	Santa Cruz	1 mi. NE Bonny Doon	MVZ	Trapped in 2001; not found
1937	Santa Cruz	1 mi. NNE Bonny Doon	MVZ	See above
1938	Santa Clara	2 mi. SW Saratoga	MVZ	No
1942	Santa Cruz	Berglund Ranch, 2 mi. NW Corralitos	MVZ, Rudd	No
1940	San Benito	Fremont Peak Rd. 7 mi. S San Juan	MVZ	Specimen misidentified?
1940	Santa Cruz	Bean Creek Rd., 1.8 mi. E Mt. Hermon	MVZ, Rudd	No
1940, 1961, 1995	Santa Cruz	Zayante Rd., 2.1 mi, E Ben Lomond (@Quail Hollow)	MVZ/CAS, Rudd	Trapped in 1995 by Biosearch Wildlife Surveys; not found
1984	Santa Cruz	Old Olympia Quarry, Zayante Road	Roest	Trapped in 2001; not found
1940, 1941	Santa Cruz	Graham Hill Rd., 1.1 mi. From Felton Station	MVZ/CAS	Yes. This is the SRL parcel
1937, 1939	Santa Cruz	J. Enos Ranch, 1 mi. NW Corralitos	MVZ	No
1936	Santa Cruz	Bear Creek Rd., 2 mi. NE Boulder Creek	MVZ	No
1940	Santa Cruz	Mt Hermon Rd, 1.3 mi. E Mt Hermon	MVZ	No
1958	San Benito	4.25 mi S and 4.75 mi. E San Juan Batista (Fremont Peak)	MVZ	Specimen misidentified?
1933	San Mateo	Redwood City	CAS	No
1948	Santa Cruz	1 mi from the summit of Hecker Pass	Rudd	Specimen misidentified?
1947	Santa Cruz	1.7 mi. SSE Loam Prieta	SJSU	Specimen misidentified?
1984, 1996	Santa Cruz	Kaiser Quarry, Lockwood Lane	Roest, Laabs	No, mined.
1990	Santa Cruz	Grey Whale State Park	Axtell	Trapped in 2001; not found

Table 3- 1. All known historic locations of *D. v. venustus*. MVZ=Museum of Vertebrate Zoology at the Univ. of Calif., Berkeley. CAS = Calif. Academy of Sciences. SJSU = San Jose State University

Species	Olympia	Wilder	Bonny Doon	SRL
California mice (<i>Peromyscus californicus</i>)	Present	Present	Present	Present
Pinyon mice (<i>Peromyscus truei</i>)	Present	Present	Present	Present
California pocket mice (<i>Chaetodipus californicus</i>).	Present	Present	—	Present
Deer mice (<i>Peromyscus maniculatus</i>)	—	Present	—	—
Dusky-footed woodrat (<i>Neotoma fuscipes</i>),	—	Present	—	Present
Merriam's chipmunk (<i>Eutamias merriemi</i>)	—	Present	—	Present
California meadow vole (<i>Microtus californicus</i>)	—	—	—	Present

Table 3-2. Small mammal species diversity at each of the four study sites.

CHAPTER 4. PRELIMINARY DEMOGRAPHICS OF THE SANTA CRUZ KANGAROO RAT (*Dipodomys venustus venustus*)

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ABSTRACT

To effectively evaluate the risk of extirpation of the only known population of the Santa Cruz kangaroo rat (*Dipodomys venustus venustus*), I estimated demographic parameters, including growth rate, sex ratio, fecundity, survival rate, annual population growth rate (λ), population size, density, and mean distances moved sex ratio, survival rate and reproduction. In order to calculate these estimates I live-trapped the *D. v. venustus* population from April to September 2001 and May to September 2002 and used mark-recapture techniques to analyze the data. Most parameter estimates were similar to those reported in the literature for the endangered congener, *D. stephensi*. However, due to a high adult survival rate, annual population growth estimates were markedly higher for *D. v. venustus* than those reported for *D. stephensi*. Previous studies suggest that congener population dynamics are driven by precipitation patterns. To better assess temporal variability of the demographic parameters of this population, additional years of monitoring are needed.

INTRODUCTION

Habitat for the Santa Cruz kangaroo rat (*Dipodomys v. venustus*) has diminished at an alarming rate over the last quarter century. Recent studies suggest that *D. v. venustus* may currently be restricted to a single site in the Santa Cruz Mountains in

Central California (see Chapter 3). Molecular evidence suggests that the population at that site may further suffer from low genetic diversity (see Chapter 2). Despite indications that the long-term persistence of the taxon is at risk, little information exists regarding *D. v. venustus* life history and demographics.

Dipodomys v. venustus occurs in association with a unique assemblage of northern maritime chaparral plant species, referred to as “silverleaf manzanita chaparral” (Marangio and Morgan 1987), found only in the Santa Cruz Mountains. This vegetation community is restricted to inland marine deposits that occur within the Zayante soil series. Like most *Dipodomys* (kangaroo rats), *D. v. venustus* is nocturnal, primarily granivorous, and is adapted to living in a relatively arid environment (Ingles 1965, Schmidly et al. 1993, Reichman and Price 1993).

The California Department of Fish and Game (CDFG) and the United States Fish and Wildlife Service (USFWS) have been approached by local wildlife biologists and land-use planners concerned about the potential impacts that land-use change has on the Zayante sand hills ecosystem and *D. v. venustus*. These wildlife agencies are responsible for assuring the long-term survival of California's unique natural heritage through the development of conservation strategies.

Detailed demographic information is an important component of formulating a conservation strategy for imperiled species (Gilpin and Soulé 1986). However, most of the information available regarding demographic parameters of *D. v. venustus* has been extrapolated from that available for other species of *Dipodomys* (Best 1992). In addition,

several unpublished studies on this taxon have relied heavily on the interpretation of limited data sets to derive demographic estimates.

Existing population size estimates

Observation suggests that *D. venustus* may always occur in low numbers (J. L. Patton, pers. comm.). Trapping efforts on the Hastings Reserve in Carmel Valley consistently yielded low numbers of the subspecies, *D. v. sanctiluciae* (Heske et al. 1997); 25 individuals were captured in 22 years on one trap-line that was 35 stations long (3 snap traps per station) and set twice a year.

In areas where *D. v. venustus* presence has been documented, population sizes and densities evidently have always been quite low. At Wilder Ranch State Park in Santa Cruz County, Axtell (1990) trapped a total of 15 individuals in 888 trap nights (2.8 % success). Using the Schnabel method, Axtell estimated that 18.9 ± 12.7 kangaroo rats (95% confidence interval) occurred within the 1.82 ha study area, or between 3 and 17 ind/ha. Assuming a homogenous distribution Axtell (1990) extrapolated that if all 20 ha of potentially suitable habitat were occupied, the population size would be about 200 animals (range 60 to 340).

On a site referred to as the “Save-the-Redwoods-League” (SRL) parcel, Biosearch Wildlife Surveys (1996) sampled 13 trap-lines between July and September 1996, a total of 4,200 trap nights yielded 43 *D. v. venustus* individuals (1.0 % success). Using the Schnabel method to evaluate this dataset, I estimated that 33 kangaroo rats (23 to 47, 95% CI) occurred within their study (Bean, unpub.). The study area for each transect was approximately 1.08 ha. Using these data, the density estimate for *D. v. venustus* on the

SRL site in 1996 was 2.4 ind/ha (range 1.59 - 3.26 ind/ha). However, it should be noted that the Schnabel estimator provides conservative estimates (Davis and Winstead 1980). A decade earlier, Roest (1984) captured three kangaroo rats in a 0.46 ha area (737 trap nights; 6.5 ind/ha). Roest (1984) also conducted a live trapping study at the former Olympia Quarry property where she trapped a total of 7 individuals in a 1 ha study area during 737 trap nights (1.2% success). Based on these data, *D. v. venustus* density in her study area was 7 ind/ha.

Mean and maximum density estimates can be misleading, however, Price and Endo (1989) present data from repeated censuses of the Federally listed, endangered Stephen's kangaroo rat (*Dipodomys stephensi*) in southern California that indicate apparent population density of kangaroo rats can vary more than 10-fold in response to rainfall. The authors estimate that *D. stephensi* density ranged from about 3 ind/ha to about 53 ind/ha over their four-year study period (Price and Endo 1989). Because minimum population densities dictate long-term survival, Price and Endo contend that effective conservation strategies should be based on minimum population densities rather than averages.

Fragmented habitat, ongoing local threats, and historically low population density combine three known correlates of extinction (Lande 1999), leading to the conclusion that *D. v. venustus* may be at risk. This study was designed to determine whether *D. v. venustus* merits protection pursuant to the Federal (FESA) and/or California Endangered Species Act (CESA). The goals were 1) to estimate population dynamics of the subspecies in the

single remaining site (the SRL property) and 2) to compare key demographic parameters for this population with published demographic parameters for congeners.

METHODS

Study Sites

The SRL parcel represents one of the largest undisturbed parcels of Zayante sand-related habitats remaining in Santa Cruz County. The property encompasses 124 ha of undeveloped land in the central portion of the County. It is bordered on the south by Henry Cowell Redwoods State Park, on the east by Graham Hill Road, on the west by the Southern Pacific Railroad Tracks and on the north by Roaring Camp Railroad (Figure 4-1). The site ranges from 95 to 220 m elevation and supports a variety of habitats including northern maritime chaparral, silver-leaf manzanita chaparral with a scattered ponderosa pine/ knobcone pine canopy, sand parkland, mixed evergreen forest, and redwood forest. The chaparral-type communities occur with variable density throughout the site.

Data Collection

Kangaroo rats were censused using two line transects of 50 Sherman live-traps (Model XLK). Each trap station consisted on two traps placed ca 10 m apart, perpendicular to the transect. Trapping grids were not established because of habitat sensitivity and rugged topography. Trapping was conducted for four consecutive nights at monthly intervals from April to September 2001 and May to September 2002. However, Line 1 was not trapped during May 2001; instead a temporary third line was placed in another portion of the site to assess distribution on the property.

Traps were baited with dried millet seed and a paper towel was placed in the trap to provide bedding material during cold weather. Traps were opened and baited between 1800 h and 2000 h and checked the following morning between 0600 h and 0800 h. Each individual *D. v. venustus* trapped was permanently marked with a numbered ear tag. Standard measurements (mass, head-body length, tail length, ear [from notch], hind foot) and sex, reproductive condition (scrotal, lactating, non-reproductive), and age class (juvenile, adult) were recorded before releasing individuals at the point of capture.

Estimating population dynamics

In order to assess population vigor, I estimated basic demographic parameters of *D. v. venustus* including juvenile growth rate, sex ratio, fecundity, survival rate, annual population growth rate (λ), population size, density, and mean distances moved.

Juvenile Growth Rate: In order to determine the growth rate of the juveniles, the mass of each individual juvenile was plotted over time. Growth rate was based on nine animals that were caught on more than one occasion. Of those nine, six were caught more than two times.

Sex Ratio: Sex ratios for both adults and juveniles were estimated by comparing the number of males captured to the number of females captured. Sex ratio is expressed as the proportion of males per female (male: female).

Fecundity: The number of times a female gave birth during the study period was derived by assuming that either one or two months of observed enlarged or swollen mammary glands reflected one litter; three or four consecutive months of enlarged glands indicated 2 litters and 5 or 6 months were correlated with 3 litters. This methodology is

based roughly on the approach used by Price and Kelly (1994). Gestation was assumed to last 30 days, as it does in congeners (Jones 1985), and weaning was assumed after 30 days. I compared the mean number of litters per year using a two-way ANOVA including year and age-class as independent variables.

Due to the fact that young of the year have lower reproductive rates (fewer possible litters per year), juvenile reproduction was estimated separately from adult reproduction. To estimate fecundity, I multiplied the estimated number of litters per female by the estimated number of females per litter and the estimated birth to weanling survival rates as follows:

$$\text{Fecundity} = (\text{litters/year})(\text{female pups/litter})(\text{survival from pup to weanling})$$

Because some of these estimates are not available for *D. v. venustus*, litter size and survival rate for *D. stephensi* were substituted as rough approximations, recognizing that the more temperate climate of Southern California may allow for higher productivity in this species. Lackey (1967) reported 2.67 pups per litter (=1.33 female pups per litter) for *D. stephensi* and Price and Kelly (1994) estimated that survival rates from birth to weanling for *D. stephensi* was 25% in 1990 and 39% in 1991. I thus used a mean survival rate of 32% the first age class (pup to weanling). I further assumed a 1:1 sex ratio at birth.

Survivorship: Survival rates were estimated using the program MARK (White and Burnham 1999), which calculates survival rate estimates from marked animals when they are reencountered at a later time. I used the Cormack-Jolly-Seber Model to estimate survival probabilities from the field data (Cormack 1964, Jolly 1965, Seber 1965).

Models tested included both recapture and survival rates as a function of the following: 1) group, 2) time, 3) group crossed with time, and 4) constant (null model). Each model was tested for each group.

Annual Population Growth Rate: In order to calculate yearly population growth rate (λ), the ratio of population sizes at time t and one year earlier, I calculated the greatest positive eigenvalue from a two-stage population matrix (Caswell 2002). I used a female only age-structured model with juveniles and adults as the two stages. While *D. venustus* undoubtedly has more complex population dynamics than are exhibited by this simple model, the paucity of data only allowed for a limited analysis. The simplified life history allows juveniles to reproduce the first year (F_j) and juveniles become adults the next year with a probability of one if they survive (S_j). Adults may die or survive (S_a) and reproduce with probability F_a .

I used MATLAB version 6.5 (The Mathworks, Inc. 2003) to calculate λ using the best estimated survival values from the program MARK and fecundity values described above. I used the upper and lower confidence limit survival values to get a sense of the range of possible λ values. I used the upper and lower confidence limit survival estimates one at a time to see how λ changed. In addition, I performed a simple sensitivity analysis, evaluating how much each parameter would have to change to lead to a stable population ($\lambda = 1$).

The two-stage population model I employed to derive estimates of population growth rate is based on the following assumptions: 1) individual demographic characteristics are related to age, 2) there is little variation among individuals of the same

age, 3) the population is closed, 4) there is no stochasticity, and 5) there is no density dependence.

Population Size: I calculated Jolly-Seber population estimates for each permanent transect at SRL for the two-year study period (Jolly 1965). The Jolly-Seber model is an open population model for multiple mark-recapture samplings that estimates population size at each sampling time. An open model was selected because the sampling regime disallowed assumptions of closed models concerning mortality or recruitment. The underlying principles of this method are that the proportion of marks in a recapture sample is an estimate of the proportion of marks in the population. A 95 % confidence interval for the combined mean population estimates was derived from Ricker's (1975) estimates of confidence limits for small value variables based on a Poisson frequency distribution.

Density: In order to estimate density, the geographic area sampled by each trap-line was calculated. The distance between each trap station and each trap was approximately 10 m. Since each trap-line likely attracted animals from the surrounding area a buffer area based on average distances moved by adult males was added to calculate the entire area sampled by each transect. Male movements were used since on average they move slightly farther than females (Price and Kelly 1994). The population size estimates were then divided by the size of the area sampled to estimate the number of kangaroo rats per hectare per trap-line.

Distances Moved: Estimates of distances moved were based on the average of all individual movements between traps. One average was calculated for each kangaroo rat. Mean movement distances were log transformed to reduce skewness and were compared between males and females using a t-test.

RESULTS

A total of 766 captures of 73 kangaroo rats was recorded over the two-year trapping period (4,200 tn, 18.2% trap success, Table 4-1). Of the 39 individuals captured in 2001, 17 kangaroo rats (43%) were captured again during 2002 (Figure 4-2). Although data are quite limited, all juveniles that survived to be recaptured in 2002 were first captured between June and August 2001. Of the five juveniles captured in September 2001, none were recaptured.

Juvenile Growth Rate: A plot of juvenile mass over time indicated that mass rapidly increased to 55-60 g then leveled off (Figure 4-3). Consequently, I classified animals ≤ 55 g as juveniles.

Sex ratio: Of the 73 kangaroo rats trapped, 34 were adult males and 20 were adult females, making the overall adult population sex ratio 1.7 males to every one female (1.7:1) (Table 4-1). The sex ratio of the juveniles captured (12 males to 7 females) was also 1.7:1. Interestingly, although numbers were small, the sex ratio of both juveniles and adults appeared to be generally more even on Line 1 than Line 2.

Fecundity: Using months each female lactated during the sample period as a metric, the mean number of litters per year per adult female was estimated to be 1.43, with 0.4 litters per year for juvenile females based on 2001 data alone (2001: adult n=5,

juvenile $n=5$; 2002: adult $n=9$, juvenile $n=0$) (Figure 4-4). The estimated mean fecundity was 0.61 for adult females and 0.17 for juvenile females (Figure 4-5). Litters per year per adult female were significantly higher ($P=.008$) in 2001 than 2002 and the number of litters per juvenile female in 2001 was significantly lower ($P=.001$) than for adults in 2001.

Survivorship: Survival rates were obtained from MARK with standard error and 95% confidence limits (Figure 4-6). The most parsimonious model indicated that survival (ϕ in MARK notation) varied among age and gender classes (Figure 4-6). Female adult survival rate was the highest (0.953) followed by male adult survival rate (0.945). As can be expected, juvenile survival was much lower with 0.749 estimated for males and 0.694 estimated for females.

Annual Population Growth Rate: Over the course of this two-year trapping study, the population grew. The total number of new individual kangaroo rats trapped during 2001 was 39 and the total of new animals trapped in 2002 was 34. In addition, 17 animals that were tagged in 2001 were captured again in 2002. Therefore, total captures in 2002 (51 individuals) were significantly higher than in 2001 (39 individuals).

My analysis indicates that using the best-fit demographic parameters, population growth is strong ($\lambda = 1.29$, Table 4-2). Using the confidence limits (Figure 4-6) one at a time to test the uncertainty in my estimate, I got a range of values from 1.11 to 1.37. Looking at the worst-case scenario, by running the model with the lowest survival rates for adults and juveniles, a growth rate (λ) of 1.11 was generated. This is still a healthy growth rate. Using fecundity values for *D. stephensi* (Price and Kelly 1994) as a rough

check on my results, I calculated a similar growth rate as I found using estimates of fecundity for *D.v.venustus*.

The demographic model was highly robust to both adult and juvenile fecundities and to juvenile survival. In order to reduce population growth to a stable population ($\lambda=1$) both fecundities and juvenile survival needed to be reduced to extremely low values (Figure 4-7). In fact, even with juvenile fecundity set to zero, λ was still very high ($\lambda=1.27$). The model was most sensitive to adult survival. Only a moderate survival rate reduction ($S_a=.68$) dropped λ to one.

Population size: The Jolly-Seber estimates of population size at each trap-line for each sample period reached peak numbers in the Fall of 2001 and 2002 and in the Spring in 2002. These peaks appear to be consistent with juvenile dispersal events. The peak population estimate on Line 1 was greater in Spring 2002 (17.67 individuals) than it was in Fall 2001 (12.75 individuals) (Figure 4-8). For Line 2, the highest estimated population of 27.19 individuals occurred in Fall 2001 (95% CI: 17.8- 39.2). The average population throughout the season on both trap-lines increased from 2001 to 2002 (Figure 4-9). Line 1 increased from a population size of ~13 to ~15 individuals and Line 2 increased from ~14 to ~20 individuals. Overall, combined averages on each trap-line were in the range of 13 to 17 ind/line.

Density: The total area sampled on each trap-line was estimated to be 1.08 ha. This was calculated by determining the size of the linear grid (10 m by 240 m and adding a 15 m buffer = 40 m X 270 m). Density estimates ranged from 12 ind/ha to 20 ind/ha with a combined mean density of 12 ind/ha on Line 1 and 16 ind/ha on Line 2 (Figure 4-10).

Due to low confidence in the estimate of the mean, no significant difference was detectable. The density of kangaroo rats appeared to increase during the study period, however, differences were not statistically detectable.

Distances moved: Mean distance moved was significantly greater for males ($P=.036$ for log transformed data; $d=15.6$ m, $n=30$) than females ($d=10.4$ m, $n=24$). The longest movement within a trap-line by a male Santa Cruz kangaroo rat was 100 m, whereas the furthest distance moved by a female was only 50 meters; however, one female did shift from Line 1 to Line 2 when she was a juvenile. Her dispersal movement was a distance of ca. 300 m. Most individuals were recaptured most often within 10 m of their first point of capture.

DISCUSSION

One of the propositions of conservation biology is that populations have demographic and genetic thresholds below which random forces prevail over deterministic forces (Soulé 1986). Predicting the extinction of single populations requires ecological and evolutionary information (Lande 1988). The main purpose for monitoring this population for two years was to determine the degree of endangerment *D. v. venustus* faces due to demographic processes. Given the fact that this subspecies has a narrow geographic range (see Chapter 2), specialized habitat requirements, and is only known to occur in small populations, it appears that there is a high probability of near-term extinction for *D. v. venustus*.

Unfortunately, sampling probabilities are used to determine the persistence of small populations (Caughley and Gunn 1996). The effective population size may be

greater or less than the census population size both in terms of sex ratio and age distribution (Caughley and Gunn 1996). The true test of the value of a long or short term monitoring effort, however, is the degree to which one can have confidence in the estimates of the various demographic processes. This information is critical to land managers and it is important to explore options for investigating population dynamics in order to assess endangerment and the value of land management activities.

One way to assess the health of this Santa Cruz kangaroo rat population is to compare demographic estimates with those of other kangaroo rat species. Based on this study, many parameters of the *D. v. venustus* population at the SRL site are comparable to demographic measurements for another species in the genus, *D. stephensi*, with the exception of the adult survival, and thus population growth rate, which were notably higher in *D. v. venustus*. However, as discussed below, this may be due to typical boom-bust cycles observed in rodent populations.

Juvenile Growth rates: An analysis of the growth rate of *D. v. venustus* was essential for making a determination regarding the size distinction between the juvenile and adult age classes. Separating the population sampled into age classes was a critical first step to assessing the demographic parameters of *D. v. venustus*.

D. v. venustus growth rates, based on weight gain, appear to be consistent with those of *D. stephensi*. Lackey (1967) determined that juvenile animals attained 70 % of adult weight by 63 days of age. The growth rate for the animals in this study became asymptotic at around 90 days, after an animal weighed ~55g (Figure 4-3), similar to Price and Kelly's (1994) *D. stephensi* findings.

Sex Ratio: The male bias in the sex ratio is not unexpected. Price and Kelly (1994) found that live trapping *D. stephensi* generally results in a male bias. This bias is possibly due to the fact that the males are likely to have larger home ranges than females during the breeding season (Price and Kelly 1994). However, genetic drift is minimized when the sex ratio is 1:1 (Caughley and Gunn 1996). If the observed sex ratio accurately reflects that of the population, this skew towards males may reduce effective population size.

Fecundity: The fecundity rates observed in adult *D. v. venustus* appear to be consistent with fecundity estimates developed by Price and Kelly (1994) for *D. stephensi* ($F_a=0.699$). However, my study may underestimate the number of litters a female could raise each year because my sampling period started a month or two after the onset of breeding.

Survival Rates: A difference between *D. v. venustus* and *D. stephensi* demographic parameters can be seen in a comparison of adult survival rates. The survival rate estimates for *D. v. venustus* adults were approximately 95% from 2001 to 2002 (Figure 4-6), whereas, based on their 18-month live trapping study, Price and Kelly (1994) calculated that only 18% of *D. stephensi* adults persisted for 12 months after initial capture.

Annual population growth rate (λ): My estimates of *D. v. venustus* demographic rates led to a high growth rate estimate ($\lambda=1.29$). However, kangaroo rats can be subject to dramatic population fluctuations and thus wide swings in population growth rates (Goldingay et al. 1997). High population growth rates can be commensurate

with recovery from a decline, and environmental and demographic variability might result in very different growth rate estimates over time. In fact, Goldingay et al. (1997) suggests that conservation of the *Dipodomys* genus be elevated in priority for several reasons including the fact that their populations exhibit extremely variable demographics.

Price and Kelly (1994) found that the actual proportional change in *D. stephensi* population size at their study area was $\lambda=1.06$. The demographics model they developed, however, predicted much lower values ($\lambda=0.82$). This may have been due to several reasons including underestimated survival and fecundity values (Price and Kelly 1994). Compared with either λ estimate calculated for *D. stephensi* by Price and Kelly (1994), the λ estimate derived for *D. v. venustus* was substantially higher. This can be attributed to the difference in adult survival rate estimates.

Data on precipitation in Santa Cruz in the years 2000 and 2001 show that annual rainfall was less than average (76 % of normal in 2000 and 90 % of normal in 2001). Since rainfall can be expected to be a major environmental factor affecting population growth rates of kangaroo rats (Price and Kelly 1994), this population may be recovering from a low rainfall/low population growth year.

In addition, some of the model assumptions were undoubtedly violated by this data set. For instance, due to the fact that the data were collected over a two-year period, the population may have experienced immigration and emigration, thereby violating the assumption of a closed population. However, the limited extent of available habitat in concert with strong site fidelity and limited female movement suggests that this violation would only marginally influence overall population growth within the area trapped.

Whether or not my data violated other assumptions, such as lack of density-dependence, is harder to judge.

It is impossible to know with certainty why this population experienced such a significant growth rate between 2001 and 2002, and whether it would continue to do so into the future in the face of a changing environment. Limited haplotype diversity of this population suggests that it has experienced extreme fluctuations in the past (see Chapter 2). Assumptions about the relative viability of this small population that may experience dramatic fluctuations would be highly inaccurate based on a data set this small and therefore should not be attempted. However, this population growth data may indicate that this population has the capacity to recover rapidly if it does experience a perturbation.

Population Size Estimates: The population size estimates generated by the Jolly Seber model were very close to the actual number of animals trapped and marked. This is not unusual given the small sample size and stability of home ranges within the species. Indeed, it is likely that the number of kangaroo rats observed represented a very close approximation of the population within the area of each trap-line. Population estimates increased during the last trap set of each year, likely reflecting juvenile dispersal.

This study did not quantify habitat affinities of *D. v. venustus*. However, based on field observations, the habitat appears to be heterogeneous. Therefore, the density of individuals would be expected to vary within the mosaic of intermingled high and low quality habitat throughout the site and extrapolation of these densities to larger areas

would not be justified. Population sizes of other kangaroo rat species usually are expressed as density estimates (ind/ha). Therefore, population cannot be compared to congeners of *D. v. venustus*.

Density: Price and Endo (1989) estimated densities for *D. stephensi* of 5.2 and 4.9 ind/ha in February 1987 and March 1998, respectively. While my estimates are substantially higher (Figure 4-10), previous estimates of density for the SRL *D. v. venustus* population (Bean unpub., Roest 1984) were similar to Price and Endo's (1989), again suggesting that this population may be recovering from a recent period of decline. Price and Endo (1989) documented substantial temporal variation in their populations and were able to correlate these fluctuations with rainfall.

Distances moved: Male Santa Cruz kangaroo rats moved greater distances than females, mirroring observations by Price et al. (1994) for Stephen's kangaroo rat. Price and Kelly (1994) found that the majority of *D. stephensi* individuals maintained an average home range corresponding to a circle with a radius of 20 m. Although data obtained at SRL do not allow us to estimate home range size, average distance moved between traps of *D. v. venustus* suggests a similar pattern to that observed by Price et al. (1994).

CONCLUSION

Although the population appeared to grow during the study period, demographic variability has immediate implications for the influence of stochastic events on population viability (Pimm et al. 1988). The duration of this study prevented estimation of the variance of demographic parameters through time. Many rodent species

experience dramatic inter-annual variation in densities. This population has experienced high adult survivorship and high population density during the study period. However, due to the small population size and the relatively small patch of habitat within which this population of *D. v. venustus* persists, it is likely susceptible to stochastic effects, both environmental and demographic. Evidence of extreme fluctuations in the past is provided by the limited haplotype diversity that was documented in this population (see Chapter 2). Dramatic fluctuations in population density have been documented in some congeners (Price and Endo 1989), and it is likely that this taxon would experience similar responses to environmental variability over time.

As the only known population of *D. v. venustus*, this population requires both protection and ongoing monitoring in the hope that in time we can better understand how best to manage the species so that it may persist. Combined with information developed regarding the limited genetic diversity (see Chapter 2) and the current distribution (see Chapter 3) of this species, this study further supports the finding that *D. v. venustus* should be protected pursuant to the either FESA or CESA.

ACKNOWLEDGEMENTS

This work would not have been possible without the help of many volunteer field assistants who attended early morning trap checks over the two-year period to record data. In addition, David Laabs was instrumental in helping to set up this study and Jacob Pollock provided invaluable assistance with the data analysis. I also wish to thank my advisor, Dr. Rachel O'Malley and my committee members, Dr. Patrick Kelly, Dr. Doug Kelt, and Dr. Jim Patton for their thorough review of this manuscript.

LIST OF FIGURES

Figure 4-1: Silverleaf manzanita chaparral habitat patch on the Save-the-Redwoods League parcel with two permanent trap-line locations shown.

Figure 4-2: *D. v. venustus* tagged in 2001 that were recaptured in 2002.

Figure 4-3: Change in juvenile *D. v. venustus* mass over first 20 months of life.

Figure 4-4: Number of litters per year for adult and juvenile female *D. v. venustus* in 2001 and 2002 showing 95% confidence intervals.

Figure 4-5: Estimated fecundity of adult and juvenile *D. v. venustus* females expressed as number of female offspring that survive to the juvenile age class in years 2001 and 2002.

Figure 4-6: Survival rate estimates for adult and juvenile *D. v. venustus* obtained using the program MARK. Error bars represent 95% confidence intervals.

Figure 4-7: Sensitivity of λ to changes in demographic rates.

Figure 4-8: Monthly population estimates for *D. v. venustus* on Lines 1 and 2 during 2001 and 2002.

Figure 4-9: Mean population estimate for *D. v. venustus* on Lines 1 and 2 for 2001 and 2002 showing 95% confidence intervals.

Figure 4-10: Mean densities for *D. v. venustus* on Lines 1 and 2 for 2001 and 2002. Error bars represent 95% confidence intervals.

Aerial by AirPhoto USA
Imagery date: June, 2000

0 290 580 870 1,160
Feet

Legend

- Parcel Boundary
- Silver Leaf Manzanita Chaparral

Figure 4.1

Figure 4-2

Figure 4-3

Figure 4-4

Figure 4-5

Figure 4-6

Figure 4-7

Figure 4-8

Figure 4-9

Figure 4-10

TABLES

Line	Year	Adult			Juvenile			Total individuals trapped
		Male	Female	Sex ratio (M:F)	Male	Female	Sex ratio (M:F)	
1	2001	4	5	0.8:1	2	5	0.4:1	16
1	2002	7	5	1.4:1	1	0	1:0	<u>13</u>
TOTALS LINE 1:		11	10	1.1:1	3	5	0.6:1	29
2	2001	10	5	2.0:1	6	2	3:1	23
2	2002	13	5	2.6:1	3	0	1:0	<u>21</u>
TOTALS LINE 2:		23	10	2.3:1	9	2	4.5:1	44
Combined totals:		34	20	1.7:1	12	7	1.7:1	73

Table 4-1. Numbers of Santa Cruz kangaroo rats captured in 2001-02 on transect Lines 1 and 2 arranged by age and sex and showing sex ratios for adults and juveniles.

	S _a		S _j	F _a	F _j	Lambda (λ)
Best fit parameters	0.953	0.694		0.61	0.17	1.29
Adult survival (S _a) at upper CL	0.977	0.694		0.61	0.17	1.32
Juvenile survival (S _j) at upper CL	0.953	0.888		0.61	0.17	1.37
Adult survival (S _a) at lower CL	0.903	0.694		0.61	0.17	1.24
Juvenile survival (S _j) at lower CL	0.953	0.393		0.61	0.17	1.16
Adult and juvenile survival at lower CL	0.903	0.393		0.61	0.17	1.11
Adult fecundity (F _a) at <i>D. stephensi</i> value	0.953	0.694		0.699	0.17	1.33
Juvenile fecundity (F _j) at <i>D. stephensi</i> value	0.953	0.694		0.61	0.098	1.28

Table 4-2. Estimates of *D. v. venustus* annual population growth (lambda) calculated using best fit parameters, upper and lower confidence limits of survival, and congener fecundity, to illustrate uncertainty in the estimates.

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**APPENDIX A. LETTER OF OFFICIAL PROTOCOL REVIEW FROM SAN
JOSE STATE UNIVERSITY INSTITUTIONAL ANIMAL CARE AND USE
COMMITTEE**

San Jose State University
Institutional Animal Care and Use Committee

LETTER OF OFFICIAL PROTOCOL REVIEW

Date: May 24, 2002

Dear Dr. O'Malley,

The animal care and use portion of your research proposal indicated below was reviewed by the Institutional Animal Care and Use Committee (IACUC). The status of your proposal is as follows:

Principal Investigator(s): Rachael O'Malley/Caitlin Bean

Protocol #: 794

Title: Taxonomy, distribution, and demographics of the Santa Cruz kangaroo rat (*Dipodomys venustus venustus*).

The application was approved without modification by the IACUC

Approval date: April 1, 2001 * Expiration Date: September 1, 2002

The IACUC must be informed in writing of any proposed changes to the approved protocol outline and approval must be granted in writing by the IACUC before any change is instituted. If you wish to continue the approved outline beyond the expiration date, it is recommended that you resubmit a renewal application by August 2002.

The protocol number (#794) may only be used by the principal investigator and participants included on the approved application form. The protocol number will be required on grant and contract proposals to fund the project. To maintain valid protocol approval, route a copy of all renewed permits, requests for permit extensions, correspondence with the P.I. and federal agencies or related business to the UAC office at extended zip 0100 to be included in your animal use file.

If you have any questions, feel free to contact me at extension 4-4929.

Larry Young, RVT, LATg
IACUC Coordinator

Cc: UAC Office
Department Chair