An adaptive management approach to recovering burrowing owl populations and restoring a grassland ecosystem in San Diego County

A proposal for funding to the San Diego Foundation

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Executive summary

We propose to develop a model program to assist in the recovery of Western burrowing owls (*Athene cunicularia hypugaea*) and their grassland ecosystem in San Diego County (see Appendix 1 for a review of threats to California grasslands and burrowing owls). We will use an adaptive management approach wherein the outcome of management actions is documented scientifically, and there is continuous feedback between science and management. Using this approach, each lesson learned is incorporated into the next steps for both research and management, enabling constant adaptive revision of methods while maintaining a focus on a few key overarching goals (see Appendix 2 for a review of the adaptive management context of this work).

Because the California ground squirrel (*Spermophilus beecheyi*) is a "keystone" species that helps engineer California grassland ecosystems and provides critical resources for burrowing owls, re-establishment of this species is a crucial component of any recovery plan for burrowing owls and the larger ecosystem (see Appendix 3 for a review of the ecological role of ground squirrels; see Appendix 4 for a discussion of our approach for developing an optimal and ecologically relevant translocation programs for ground squirrels).

Our primary objective is to help establish a model conservation program—with sufficient documentation and validation—on how to manage local grassland habitat for burrowing owls, and other species integral to this ecosystem. The result will be a set of protocols and strategies that can be adopted by managers and researchers in San Diego and in other areas where burrowing owl conservation management is warranted. Our second objective is to assist in the establishment of a more natural grassland ecosystem in San Diego County by re-establishing ground squirrels and, ultimately, burrowing owls. The proposed work is for the first year of a long-term program.

Collaborative project development and stakeholder participation

This proposed Scope of Work provides an overview of the goals, objectives and methods of the San Diego Zoo Institute for Conservation Research (ICR) burrowing owl (BUOW) management and science program for southern San Diego

County. The goals of this project were developed in consultation with an interagency group of south county land managers, scientists, and regulators (USFWS, CDFG, SANDAG, SDSU, and ICR). The tasks were co-developed by SDSU and ICR and are interdependent. SDSU will evaluate habitat utilization and prey availability and will collaborate with ICR to conduct and evaluate the efficacy of habitat enhancements. ICR's focus will be on behavioral and ecological studies of burrowing owls using GPS tracking, and establishing a successful ground squirrel translocation program to create self-sustaining burrowing owl habitat. We will also collaboratively track nesting success of the existing population as a joint task and conduct data analyses with SDSU based on a common database and shared expertise. The experimental design for all aspects of this adaptive management program will be co-developed to ensure that the projects and resulting data can be seamlessly integrated. At critical junctures during program development, works-in-progress will be shared with the full stakeholder group for input.

Project goals in broader context

We begin with the premise that long-term success depends on (a) focusing first on restoring habitat that will better support BUOW and (b) understanding the consequences of management activities so that management can proceed adaptively (see Appendix 1). To a certain extent, this is a "build-it-and-they-will come" experiment. Our efforts to create more suitable habitat for BUOW, particularly burrows and more open vegetation, may attract nearby BUOW to settle. However, this is not the primary intent of our work and not the metric of success that we will use. In the 1-year period covered in this grant proposal, we seek primarily to create suitable BUOW habitat that can be more self-sustaining. Any natural BUOW immigration will be an added benefit. The results will help us understand whether translocation is needed and, in the future, may allow us to compare passive versus active relocation strategies.

Moreover, the presumption is that this is Year 1 of a multi-year effort. The full ramifications of the management actions taken here will require years to document through continued monitoring. More importantly, future management actions will be necessary to achieve long-term goals related to improved ecosystem function and BUOW recovery.

San Diego Zoo's Institute for Conservation Research will invest considerable resources in this program, both in San Diego County and in other areas outside the scope of this proposal. In addition to time and resources provided by administrative staff, we have established a postdoctoral program to examine some of the wider regional conservation issues in Southern California (a commitment of $250,000 over 3 years). Dr. Paquita Hoeck has accepted an offer for this position and will commence work in early 2011. This program will interact synergistically with the proposed program in San Diego County.

Project locations

We propose to implement this model adaptive management program in Otay Mesa, southwestern San Diego County. This portion of the County appears to contain the largest remaining population of burrowing owl. Working with our partners and stakeholders, we have identified several parcels of land that are part of a contiguous network of newly protected areas that hold great promise for grassland restoration and burrowing owl recovery. A few burrowing owls currently occupy several artificial burrows on a parcel managed by Caltrans. California ground squirrels have **not** been documented on the property but have been observed nearby. Additional sites that have been proposed and will be investigated include Rancho Jamul and Pamo Valley in Ramona. If these sites appear suitable and are approved by the San Diego BUOW Partnership and responsible land managers (e.g., Cal Trans), we will implement this program across these diverse geographic sites. The advantage of this broader landscape approach is that results will be more generalizable and robust, aiding in the development of optimal strategies for grassland restoration to support BUOW in the region.

Task 1. Coordinate project start-up
Schedule: January 2011-April 2011

- Recruit and hire postdoctoral researcher and research technician(s) to conduct research related to translocation of ground squirrels and burrowing owls.
- In collaboration with partners, refine methodology and research questions reviewed in this Scope of Work.
- Develop inventory and begin equipment purchase.
- Train project staff in capture and handling of animals and data collection methodology.
- Apply for all local, State and Federal permits required to study, handle, and place tracking devices on owls and squirrels.
- In collaboration with SDSU and other partners, identify specific locations for up to 9 experimental sites where ground squirrels will be released and an equal number of control sites where no ground squirrels will be released (See SDSU proposal to SANDAG for details). Vegetation manipulations, conducted by SDSU, will be the same at all control and experimental sites.
- Coordinate with SDSU, the BUOW Partnership, and property managers at release site(s) to prepare site for receiving squirrels (and BUOW via natural dispersal). Explore potential for partners to establish standardized brush and/or rock piles to enhance habitat for ground squirrels and other fossorial mammals at all experimental and control sites.
- Initiate ground squirrel survey with the goal of building a predictive habitat model for ground squirrel presence specifically for San Diego County.

Deliverables:
ICR will provide a brief report detailing methodological and analytical approach, including a status update for all permits and preliminary data summary for the ground squirrel survey.

Task 2. Burrowing owl spatial ecology
Schedule: March 2011-December 2011

- Capture nearby resident burrowing owls and fit with GPS transmitters for study.
- Collect systematic behavioral, ecological, and spatial data on resident owls, with the primary goal of establishing ranging and migratory patterns and foraging ecology.
- Coordinate with SDSU to establish prey base surveys to determine prey abundance and seasonal patterns of prey availability for burrowing owls.
- Collaborate with SDSU to determine how prey base distribution and foraging behavior influences spatial movements.
- BUOW will be fitted with GPS transmitters for approximately two months in the spring nesting season and for another two months in the Fall, with the goal of establishing movement and foraging patterns during the period that may limit population growth (nesting season) and during the season when food resources may be limiting (Fall dry season).
- Use these data to obtain insights into BUOW carrying capacity and to provide recommendations for locations to establish additional nearby BUOW groups, where resource availability and conspecific competition will not impede chances of success.

Deliverables:
ICR will provide a brief summary of project status, including data summary, recommendations, and a discussion of problems, obstacles, and suggested solutions.

Task 3. Burrowing owl nesting ecology
Schedule: March 2011-July 2011

- As part of the goal to understand spatial movements and resource use by BUOW in the nesting season, we will install remote-access video cameras in BUOW nests.
- Parental care, including prey provisioning of offspring, will be documented and the rate of food delivery (and prey type and size) will be evaluated with regard to offspring development and survival.

Deliverables:
ICR will provide a brief summary of project status, including data summary, a discussion of problems, obstacles, and suggested solutions, and a digital copy of edited video highlights for illustrative and/or public relations purposes.

Task 4. Ground squirrel translocation
Schedule: June 2011-December 2011

- Establish artificial burrows and above-below ground acclimation enclosures to provide temporary refuge for translocated ground squirrels.
- Capture and relocate a minimum of 100 California ground squirrels (*Spermophilus beecheyi*) to the designated and approved release sites. Target number is 33 squirrels per experimental replicate (habitat restoration site) across 9 sites, for a total of 297 translocated squirrels. Release group will be comprised of adult males and females with dependent offspring and will be distributed in a balanced fashion across the 3 experimental habitat treatments (mow, mow plus soil aeration, control).
- Fit subset of squirrels with VHF radiocollars, release, and observe post-release behavior.
- Collect systematic data on behavior, movements, survival and reproduction.
- Document effects of squirrels on burrow availability, BUOW prey base diversity and abundance, and (with SDSU as lead) vegetation structure.
- Document any use of experimental and control sites by BUOW.

Deliverables:
A digital copy of all behavioral, ecological, spatial and other data collected. A brief summary of project status, including a discussion of problems, obstacles, and suggested solutions.

Task 4. Data analysis and synthesis
Schedule: December 2011-March 2012

- Coordinate with SDSU to compile and analyze project data in combined, compatible databases. This analysis will include
    - An evaluation of population dynamics, habitat suitability, and the prey base at existing nesting sites.
    - An evaluation of habitat enhancement experiment to identify potential interactions of vegetation composition, habitat structure, and squirrel presence and activity.
    - Recommended protocols for re-establishing ground squirrels as ecosystem engineers and managing grassland habitat for BUOW in San Diego County.

Deliverables:
ICR will provide a final report detailing all inferential and descriptive statistics obtained from the project, biological conclusions, and suggestions for the next most productive steps to be taken, including specific management actions and scientific validation.

Budget justification

This is an ambitious startup project and an investment in future burrowing owl and grassland management. This species and ecosystem is knowledge-deficient and management actions require careful evaluation to determine what is working and design better, more cost-effective strategies for the future. Our ultimate objective is not just re-establishing burrowing owls, but working to restore a more intact, functional ecosystem that can be cost-effectively self-sustaining, with minimal human intervention.

Many of the costs borne in year 1 will not be required in subsequent years. Most of the equipment purchased will remain functional for future work and will not require replacement. Once we determine how best to translocate ground squirrels, efforts will be greatly reduced and not require post-release monitoring. Failure to monitor translocations at this stage will mean a lost opportunity to understand the consequences of this management action and increase future costs. One should keep in mind that we aim to re-establish viable ground squirrel populations at 9 locations (18 including control sites) and will attempt to capture, relocate, and establish nearly 300 animals. Gaining access to lands to trap this many squirrels will require considerable planning, coordination, and communication prior to commencing with trapping. Cross-study analyses show that the size of the release group is one of the most powerful predictors of reintroduction success.

This project will also leverage significant additional funding and effort by ICR and San Diego Zoo Global. This project is a catalyst mobilizing our organization to address burrowing owl and grassland conservation in San Diego County and throughout California. Most importantly, we have obligated approximately $250,000 of our own operational funds over the next three years to support a postdoctoral research fellow program and will work with this individual to secure further funding elsewhere in support of these efforts. The focus of this will work will not be confined to San Diego County, but will address larger landscape ecology and genetics issues throughout the range of burrowing owls in California, with one key goal of informing a broader conservation strategy for the species in California. This work will entail a great deal of collaboration and synergy with the proposed project and we estimate that this individual may devote as much as 20% of her time directly to San Diego burrowing owl conservation. In addition, the requested support ($20,000) will not cover all the labor costs required for the PIs to develop and direct the project, so some of their time is also leveraged by this project.

ICR and San Diego Global have considerable expertise and intellectual resources that they will bring to bear in this nascent burrowing program. Although we have been planning for three years, this will be the first of an estimated decade-long effort supported by our organization at all levels (the project was recently given "top 10" status— out of more than 100 SDZG conservation projects— by an internal evaluation process). These activities can be considered a further "match" for the proposed work. Within the Applied Animal Ecology Division of ICR we have several

staff, in addition to the listed PI's, who will contribute labor for this program: 2 spatial ecology specialists, 3 reintroduction specialists, and a conservation ecologist with raptor experience. Collaborations are also planned with our bird curatorial department, veterinary services, and several ICR Divisions. For example, the Genetics Division will implement a landscape and population genetics program and the Physiology Division may develop a non-invasive assay to monitor corticoid metabolites (stress hormones) in feces as a measure of post-release stress following translocation. ICR also has its own conservation education program that will develop outreach programs for this species and its habitat, and San Diego Zoo Global Public Relations Department, with its considerable reach, will likewise assist with publicity to support these conservation efforts. It is difficult to calculate the value of these contributions, but we estimate that several hundred thousand dollars of labor resources will be expended on burrowing owl and grassland conservation over the coming years.

Appendix 1. Status and threats to California native grasslands and burrowing owls

Native grasslands of California

The native grasslands of the Western United States, and California in particular, are among the most endangered ecosystems in the temperate world (Samson & Knopf 1996). In California approximately 90% of species listed in the Inventory of Rare and Endangered Species can be found in grasslands (Barry *et al.* 2006). Grasslands support both high wildlife abundance and diversity and are one of the signature ecosystems of the west. Due to their suitability for grazing, agriculture and housing developments, grasslands are also among the most favored ecosystems for human use. Grasslands also are vulnerable to invasion by exotic plants, particularly if disturbed. In California, many native bunch grass systems have been invaded by annual grasses, mainly Mediterranean in origin. It is not surprising that remaining native grasslands in California support a number of species of conservation concern. One of the most notable species is the charismatic and highly visible burrowing owl. Another signature species of this ecosystem, the California ground squirrel, is not threatened with extinction, but is an integral component of this ecosystem.

Threats to burrowing owls

Western burrowing owls (*Athene cunicularia hypugaea*) face increasing threats to their survival, causing this once common grassland species to become a U.S. Fish and Wildlife Service Bird of Conservation Concern (USFWS 2002; Klute *et al.* 2003) and listed as endangered by both Canada and Mexico (Holroyd *et al.* 2001). In southern California, encroachment of urban development has resulted in the loss of suitable habitat, population declines, and local extinctions (Center for Biological Diversity 2003; Lincer & Bloom 2007). Breeding locations have been severely limited to a few small isolated patches. Other threats include reduced availability of burrows due to decreases in fossorial mammal populations, anthropogenic disturbances to nesting sites, increased predation, decreased prey availability, and other anthropogenic mortality such as ingestion of rodenticides, pesticides, or other toxins used in pest eradication programs, strike hazards, and direct take (Center for Biological Diversity 2003; Klute *et al.* 2003; Lincer & Bloom 2007).

While this situation is extremely critical for burrowing owl survival, there exists considerable potential for recovery. As their natural grassland habitat has diminished, burrowing owls have adapted to human landscapes, using habitat edges along roadsides, agricultural areas, parks, golf courses, levees, and vacant/undeveloped lots, despite close proximity to urban development. Burrowing owls also have a relatively high reproductive ability compared to other raptors, and can lay up to 11 eggs/clutch, with an average clutch size of 7-9 eggs (Ehrlich et al. 1988). These factors make burrowing owl populations more resilient and increase the likelihood for successful recovery.

Unfortunately, recovery has been made problematic by lack of critical information coupled with human population pressures on owl habitat. Because burrowing owl habitat within San Diego County's Multiple Species Conservation Program (MSCP) has yet to be thoroughly surveyed, their current status is unknown (Winchell *et al.* 2008). Furthermore, preserved grasslands in San Diego County may be unsuitable habitat for burrowing owls due to dense exotic vegetation, decreased prey base, and lack of burrows needed for breeding (Winchell *et al.* 2008). Well-intentioned management activities have been conducted with little knowledge on their effects. For example, owls have been evicted from their burrows for passive relocation, yet the survivorship and impact of these evicted owls on the remaining resident owl population are unknown. Also, artificial burrows have been deployed without addressing the underlying issue of habitat unsuitability and the need for burrowing mammals as a sustainable source of owl breeding sites. Obstacles such as these need to be overcome to reverse the rapid decline of burrowing owl populations.

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Appendix 2. An adaptive management framework for the long-term goals of grassland restoration and burrowing owl recovery

Looking ahead to embrace a multi-year program, we propose an adaptive management approach to conservation of burrowing owls in San Diego County. Adaptive management, the systematic reduction of uncertainty by carrying out (controlled) management actions, is the best way forward. Adaptive management begins with a set of goals — crafted jointly by researchers and managers — that articulate specific hypotheses (Walters 1986; Schreiber *et al.* 2004; Nichols & Williams 2006). Confidence in the course of management increases as plans are revised to incorporate "lessons learned" from monitoring and evaluation of results. While widely advocated in conservation biology, in reality adaptive management is rarely implemented (Sutherland 2006). All too often there is a disconnect between science and management, wherein researchers proceed in one direction, collecting data that may or may not be useful for management, and managers proceed in another, managing without the benefit of scientifically acquired knowledge. Adaptive management does *not* mean waiting until "all the science is in" and is not intended to cause delays to active on-the-ground management.

Adaptive management is a good approach to adopt for burrowing owls in San Diego County. There are active and emerging science and management programs in place, and these should be brought together more formally. Notably lacking is a comprehensive strategic plan, which typically sets the stage for adaptive management. We advocate beginning an adaptive management approach without further delay because management is "happening" and a more scientific approach is needed to guide this management. Failure to adopt an adaptive management approach can be costly in terms of financial and staff resources if ineffective management actions are perpetuated without adequate evaluation. Although not yet articulated in a strategic plan, habitat enhancement and translocation will clearly be a component of the plan. Indeed, they are a prominent component of other plans, such as the one proposed for North America (Holroyd *et al.* 2001). Hence, we advocate that we start on these goals and modify plans and actions accordingly if and when a strategic plan is written. Our results can likewise inform and contribute to the strategic plan.

A strategic plan should be a "living document" that can be modified based on new lessons learned from science and management actions. Similarly, our proposed research and management actions must remain flexible to incorporate new knowledge. This makes it difficult to articulate specific objectives that we will address, for example, in 2 years' time. In fact, articulating overly specific objectives would constrain the course of management and science, reducing the ability of both to adapt to reality. Thus, the approach may need to be modified to incorporate unanticipated contingencies, while maintaining the same overall goals. These goals include:

1. Restore native grassland plant communities.

2. Increase our understanding of the role California ground squirrels play in "engineering" grassland ecosystems and burrowing owl habitat.
3. Develop an effective strategy for re-establishing ground squirrels in areas where they have been extirpated.
4. Increase conservation-relevant knowledge of burrowing owl ecology and behavior in San Diego County.
5. Develop an optimal strategy for translocating or encouraging relocation of burrowing owls as a conservation tool.

At least five other complimentary goals should be pursued as part of a larger strategic plan:

1. Determine the distribution and abundance of burrowing owls in San Diego County.
2. Assess the spatiotemporal dynamics of burrowing owls and current population trends.
3. Identify key habitat characteristics and interspecific ecological relationships associated with burrowing owl occupancy to develop a habitat suitability model at a local and landscape scale.
4. Evaluate the population-genetic structure and management implications.

SANDAG and its consultants have begun on the first three goals. ICR is developing an indendent project to address the fourth goal. By pursuing the goals we propose here we will be addressing 8 of the 13 management actions that Holroyd and colleagues (2002) have recommended in their conservation plan, including reintroduction techniques, translocation outcome follow-up, and ground squirrel conservation.

Our ultimate objective is not just re-establishing burrowing owls, but working to restore a more intact, functional ecosystem that can be cost-effectively self-sustaining, with minimal human intervention. This long-term goal is an expression of our commitment that extends well beyond the scope of work in this proposal. Because long-term ecological research holds cumulative value much greater than its annual rate of return, we embrace an approach that commits our research team well into the future (Swaisgood *et al.* 2010a; Swaisgood *et al.* 2010b).

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Appendix 3. The ecological role of ground squirrels and burrow requirements of burrowing owls

California ground squirrels as ecosystem engineers

"Because Burrowing Owls nest in burrows of prairie dogs, ground squirrels, and other fossorial mammals, the owls' future is tied to the conservation of these mammals and their native habitats" (p. 402, Holroyd *et al.* 2002).

Given the mounting evidence showing that California ground squirrels (and other burrowing mammals elsewhere) play a key role in engineering grassland ecosystems, it is surprising how little attention this species has received in conservation planning and policy. Fitch (1948) and Linsdale (1946) long ago noted the diversity of animal life associated with ground squirrel burrow systems. More recent quantitative research has substantiated these observations. Sites with ground squirrel colonies have greater diversity of reptiles, amphibians, insects and birds than sites where squirrels are absent (Lenihan 2007). Similarly, black-tailed prairie dogs on the Great Plains are associated with higher bird diversity (Smith & Lomolino 2004) and other plant and animal diversity (Kotliar *et al.* 1999). It is also possible that ground squirrels are a "keystone" species responsible for maintaining the vegetation community itself. Kangaroo rats play this role in Arizona where investigators found that their removal resulted in the invasion of annual grasses into the native shrub habitat (Brown & Heske 1990).

Lenihan (2007) also found that the presence of ground squirrels may be a prerequisite for burrowing owls in her study area in northern California: only those sites with ground squirrels had burrowing owls. The decline of fossorial mammals has also been implicated as a key factor for the decline of burrowing owls in British Columbia (Howie, 1980), the Great Plains of the U.S. (Kotliar *et al.* 1999; Desmond *et al.* 2000; Smith & Lomolino 2004), Argentina (Machicote et al. 2004) and here in San Diego County (Lincer & Bloom 2007). Human development of burrowing owl habitat is obviously responsible for the loss of many burrowing owl breeding sites in San Diego, but the loss of burrowing owl populations in undeveloped areas, such as Camp Pendleton and Warner Ranch, cannot be explained by habitat destruction. Elimination of ground squirrels or crushing of burrows may have made these areas unsuitable as burrowing owl breeding sites (Lincer & Bloom 2007).

The case for burrowing owl dependency on ground squirrels is strong. In addition to supplying burrows that are required for successful breeding, ground squirrels' digging and foraging keeps the vegetation low (Evans & Holdenried 1943; Brown & Heske 1990), which is favored by burrowing owls (Green & Anthony 1989; Clayton & Schmutz 1999). Ground squirrels' "ecosystem engineering" also increases availability of some burrowing owl prey species, such as ground beetles and centipedes (Lenihan 2007). Finally, ground squirrels may serve as antipredator sentinels, since both squirrels and owls fall prey to the same predators. Ground squirrels are highly vigilant animals and use antipredator vocalizations and visual

displays to maintain an early warning system for predator detection and deterrence (Owings & Hennessy 1984; Loughry & McDonough 1988; Swaisgood *et al.* 1999). By "eavesdropping" on these antipredator alarms, burrowing owls may avoid predation, as suggested by lower levels of predation on burrowing owls living in association with black-tailed prairie dogs (Desmond *et al.* 2000).

Despite these significant positive impacts on grassland ecosystems and key species of conservation concern, the role of ground squirrels remain a neglected aspect of conservation action in California. This can perhaps be attributed to the commonly held belief that ground squirrels are a "pest" species and are commonplace. However, because they are viewed as a nuisance "…eradication campaigns have poisoned California ground squirrels by foot, horse, vehicles, and aircraft using a variety of chemical toxicants…, anticoagulants…, and burrow fumigants" (Lenihan 2007). These continued efforts at eradication keep ground squirrels at 10-20% of their historical carrying capacity (Marsh 1987) in numbers too low to adequately perform their role as ecosystem engineer.

Clearly, burrowing owls can thrive in the absence of ground squirrels if their habitat needs are met artificially. Burrowing owls are commonly found in agricultural systems, where they benefit from the abundant agricultural pests that serve as prey, the high proportion of bare ground and low vegetation, and nesting opportunities afforded by irrigation pipes and other artificial shelter. However, relying on such artificial systems to prevent extirpation of burrowing owls is risky, as land management practices are at the whim of the private landowner. Also, these artificial systems do little to conserve the wider grassland ecosystem. Currently, more than 70% of California's burrowing owls reside in Imperial County in these artificial agricultural systems.

Artificial versus natural burrow systems

Why not just construct artificial burrows for burrowing owls? To be sure, artificial burrows can be used to solve short-term conservation problems (e.g., (Trulio 1995; Lincer & Bloom 2007), but is a conservation strategy overly reliant on artificial burrows sustainable? Winchell (2010 presentation to San Diego County landmanagers and other BUOW stakeholders) has shown that continued dependence on human management action is precarious. While creation of artificial burrows and signing the location of active burrows to deter inadvertent destruction resulted in an increase in population size, the population returned to baseline as soon as these management actions were discontinued. In an era of uncertain funding, relying on continued human management appears risky.

We may also underestimate the number of artificial burrows needed to adequately support a population of burrowing owls. Detailed observations have shown that burrowing owls often distribute their chicks across multiple burrows, which may reduce chances of losing the entire brood to a predator (Desmond *et al.* 2000).

In addition to the quantity of burrows, the quality of the habitat around the burrows may be an issue. In the absence of ground squirrels further management may be necessary, for example, to keep the vegetation low. It is even possible that establishing artificial burrows in areas that are otherwise ecologically unsuitable will serve as an "ecological trap" (Schlaepfer *et al.* 2002) attracting owls but not adequately supporting survival and reproduction. In fact, burrowing owls in Argentina appear drawn to just such a trap (Machicote *et al.* 2004). Nesting failures were common when owls nested in burrows excavated by armadillos, probably because, unlike the other locally abundant fossorial mammal (vizcachas), armadillos do not remove vegetation from around their burrows. Good burrows surrounded by poor habitat, therefore, can cause more harm than good. Use of an artificial burrow by burrowing owls does not guarantee its conservation value.

Our goal is the re-establishment of self-sustaining ecosystem processes that are less reliant on constant human intervention and will be more cost-effective in the long-term.

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Appendix 4. Bringing ground squirrels back to re-engineer suitable burrowing owl habitat

Reversing these trends for ground squirrels will be a necessary component of any strategy to bring back our native grasslands and their inhabitants to more natural balance. One might reasonably believe that re-establishing a "pest" species will be easy, but they would be wrong. As noted by Salmon & Marsh (1981), "Our experience has been that California ground squirrels released into an area will rarely stay." In one study, 83% of translocated ground squirrels immediately abandoned the release site (Van Vuren *et al.* 1997).

As a means to improve grassland habitat for burrowing owls and other species of concern, we propose to develop a scientific, ecologically relevant, strategy for relocating California ground squirrels.

Understanding ground squirrel habitat requirements

To increase our ability to successfully translocate ground squirrels, we must first understand better their habitat needs. Surprisingly little research has been conducted on the habitat requirements of California ground squirrels. One study, albeit in the Sierra Nevada mountains, showed that California ground squirrels are associated with open canopies, rocky terrain, bare ground, and hard substrate (Coppeto *et al.* 2006). We will conduct surveys for ground squirrels in San Diego County and examine habitat covariates to gain a better understanding of the factors influencing the distribution and abundance of ground squirrels. There is currently no scientific basis for understanding why ground squirrels are locally abundant at some sites and absent at many others. If we do not understand this relationship, we may be unsuccessful at selecting sites that will support sustainable burrowing owl populations dependent on ground squirrel burrows. Indeed it is possible that some selected mitigation sites will never support burrowing owls without continued human intervention in the form of burrow creation, if the habitat will not support ground squirrels. Thus, better knowledge of ground squirrel habitat requirements will be instrumental in guiding any burrowing owl translocation program and may radically alter how mitigation sites are selected.

The goal of these surveys is not to estimate population size, but to determine the ecological variables that affect distribution and relative abundance. To better understand the relationship between occupied and unoccupied habitat, we will develop habitat suitability models based on habitat data collected at areas where ground squirrels are known to occur. Using presence-only models, such as HABITAT or SVM, we will be able to begin to identify key habitat variables for ground squirrels and broadly predict their distribution ((Pearce & Boyce 2006). The results can then be used to define key habitat factors and help identify critical habitat in San Diego County for both ground squirrels and burrowing owls.

Ground squirrel translocation strategy

While the research effort and criteria for success will not be as high as with translocation of burrowing owls or other conservation-dependent species, it is clear that research is required to develop a reliable, cost-effective method of translocating ground squirrels. Many translocation programs are unsuccessful or marginally successful because of high mortality and post-release dispersal away from the release site. Post-release monitoring, attention to release group composition, and ecologically relevant modifications to the post-release habitat and social environment can have profound effects on the success of translocation programs (Stamps & Swaisgood 2007; Swaisgood 2010). Such methods have been established for black-tailed prairie dogs by a member of our team (Shier 2006; Shier & Owings 2006) and we will apply some of the lessons learned from her work to California ground squirrels. In some cases, these "ecologically relevant" modifications to the post-release environment can increase survival and reproduction by at least 5- to 10-fold (up to 24-fold for kangaroo rats). Thus, investing a limited amount of resources into developing a ground squirrel translocation strategy will be cost-saving even in the near term.

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