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Megan,

Attached are staff's comments on the TDS and Rugged Biological Resources Reports. Please let us know if you have any questions prior to the scheduled 10/28 working meeting.

Thanks,

Ashley

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Wildlife Conservation and Solar Energy Development in the Desert Southwest, United States

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Large areas of public land are currently being permitted or evaluated for utility-scale solar energy development (USSED) in the southwestern United States, including areas with high biodiversity and protected species. However, peer-reviewed studies of the effects of USSED on wildlife are lacking. The potential effects of the construction and the eventual decommissioning of solar energy facilities include the direct mortality of wildlife; environmental impacts of fugitive dust and dust suppressants; destruction and modification of habitat, including the impacts of roads; and off-site impacts related to construction material acquisition, processing, and transportation. The potential effects of the operation and maintenance of the facilities include habitat fragmentation and barriers to gene flow, increased noise, electromagnetic field generation, microclimate alteration, pollution, water consumption, and fire. Facility design effects, the efficacy of site-selection criteria, and the cumulative effects of USSED on regional wildlife populations are unknown. Currently available peer-reviewed data are insufficient to allow a rigorous assessment of the impact of USSED on wildlife.

Keywords: solar energy development, Mojave Desert, Sonoran Desert, wildlife, desert tortoises

The United States is poised to develop new renewable energy facilities at an unprecedented rate, including in potentially large areas of public land in the Southwest. This quantum leap is driven by escalating costs and demand for traditional energy sources from fossil fuels and by concerns over global climate change. Attention is focused largely on renewable forms of energy, especially solar energy. The potential for utility-scale solar energy development (USSED) and operation (USSEDO) is particularly high in the southwestern United States, where solar energy potential is high (USDOI and USDOE 2011a) and is already being harnessed in some areas. However, the potential for USSEDO conflicts with natural resources, especially wildlife, is also high, given the exceptional biodiversity (Mittermeier et al. 2002) and sensitivity (Lovich and Bainbridge 1999) of arid Southwest ecosystems, especially the Mojave (Randall et al. 2010) and Sonoran Deserts, which are already stressed by climate and human changes (CBI 2010). In addition, the desert Southwest is identified as a "hotspot" for threatened and endangered species in the United States (Flather et al. 1998). For these reasons, planning efforts should consider ways to minimize USSEDO impacts on wildlife (CBI 2010). Paradoxically, the implementation of large-scale solar energy development as an "environmentally friendly" alternative to conventional energy sources may actually increase environmental degradation on a local and on a regional scale (Bezdek 1993, Abbasi and Abbasi 2000) with concomitant negative effects on wildlife.

A logical first step in evaluating the effects of USSEDO on wildlife is to assess the existing scientific knowledge. As renewable energy development proceeds rapidly worldwide, information is slowly accumulating on the effects of USSEDO on the environment (for reviews, see Harte and Jassby 1978, Pimentel et al. 1994, Abbasi and Abbasi 2000). Gill (2005) noted that although the number of peer-reviewed publications on renewable energy has increased dramatically since 1991, only 7.6% of all publications on the topic covered environmental impacts, only 4.0% included discussions of ecological implications, and less than 1.0% contained information on environmental risks. A great deal of information on USSEDO exists in environmental compliance documents and other unpublished, non-peer-reviewed "gray" literature sources. Published scientific information on the effects on wildlife of any form of renewable energy development, including that of wind energy, is scant (Kuvlesky et al. 2007). The vast majority of the published research on wildlife and renewable energy development has been focused on the effects of wind energy development on birds (Drewitt and Langston 2006) and bats (Kunz et al. 2007) because of their sensitivity to aerial impacts. In contrast, almost no information is available on the effects of solar energy development on wildlife.

From a conservation standpoint, one of the most important species in the desert Southwest is Agassiz's desert

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tortoise (*Gopherus agassizii*; figure 1). Distributed north and west of the Colorado River, the species was listed as *threatened* under the US Endangered Species Act in 1990. Because of its protected status, Agassiz's desert tortoise acts as an "umbrella species," extending protection to other plants and animals within its range (Tracy and Brussard, 1994). The newly described Morafka's desert tortoise (*Gopherus morafkai*; Murphy et al. 2011) is another species of significant conservation concern in the desert Southwest, found east of the Colorado River. Both tortoises are important as ecological engineers who construct burrows that provide shelter to many other animal species, which allows them to escape the temperature extremes of the desert (Ernst and Lovich 2009). The importance of these tortoises is thus greatly disproportionate to their intrinsic value as species. By virtue of their protected status, Agassiz's desert tortoises have a significant impact on regulatory issues in the listed portion of their range, yet little is known about the effects of USSEDO on the species, even a quarter century after the recognition of that deficiency (Pearson 1986). Large areas of habitat occupied by Agassiz's desert tortoise in particular have potential for development of USSED (figure 2).

Figure 1. Agassiz's desert tortoise (Gopherus agassizii). Large areas of desert tortoise habitat are developed or being evaluated for renewable energy development, including for wind and solar energy. Photograph: Jeffrey E. Lovich.

In this article, we review the state of knowledge about the known and potential effects, both direct and indirect, of USSEDO on wildlife (table 1). Our review is based on information published primarily in peer-reviewed scientific journals for both energy and wildlife professionals. Agassiz's desert tortoise is periodically highlighted in our review because of its protected status, wide distribution in areas considered for USSEDO in the desert Southwest, and well-studied status (Ernst and Lovich 2009). In addition, we identify gaps in our understanding of the effects of USSEDO on wildlife and suggest questions that will guide future research toward a goal of mitigating or minimizing the negative effects on wildlife.

Background on proposed energy-development potential in the southwestern United States

The blueprint for evaluating and permitting the development of solar energy on public land in the region, as is required under the US National Environmental Policy Act (USEPA 2010), began in a draft environmental impact statement (EIS) prepared by two federal agencies (USDOI and USDOE 2011a). The purpose of the EIS is to "develop a new Solar Energy Program to further support utility-scale solar energy development on BLM [US Bureau of Land

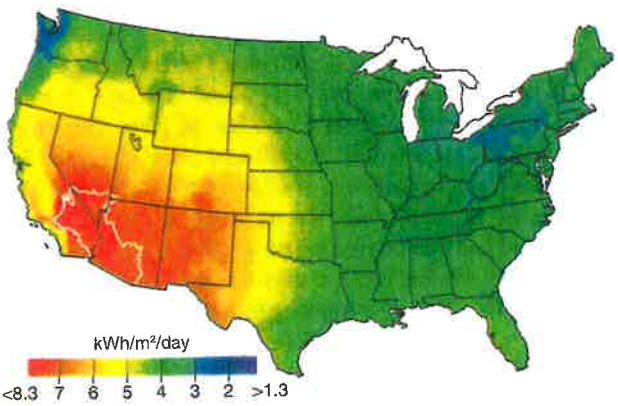

Figure 2. Concentrating solar energy potential (in kilowatt-hours per square meter per day [kWh/m²/day]) of the United States. The map shows the annual average direct normal solar resource data based on a 10-kilometer satellite-modeled data set for the period from 1998 to 2005. Refer to NREL (2011) for additional details and data sources. The white outline defines the approximate composite ranges of Agassiz's (west of the Colorado River) and Morafka's (east of the Colorado River) desert tortoises (Murphy et al. 2011) in the United States, both species of significant conservation concern. This figure was prepared by the National Renewable Energy Laboratory for the US Department of Energy (NREL 2011). The image was authored by an employee of the Alliance for Sustainable Energy, LLC, under Contract no. DE-AC36-08GO28308 with the US Department of Energy. Reprinted with permission from NREL 2011.

Table 1. List of known and potential impacts of utility-scale solar energy development on wildlife in the desert Southwest.

Impacts due to facility construction and decommissioning	Impacts due to facility presence, operation, and maintenance
Destruction and modification of wildlife habitat	Habitat fragmentation and barriers to movement and gene flow
Direct mortality of wildlife	Noise effects
Dust and dust-suppression effects	Electromagnetic field effects
Road effects	Microclimate effects
Off-site impacts	Pollution effects from spills
Destruction and modification of wildlife habitat	Water consumption effects
	Fire effects
	Light pollution effects, including polarized light
	Habitat fragmentation and barriers to movement and gene flow
	Noise effects

Management] -administered lands... and to ensure consistent application of measures to avoid, minimize, or mitigate the adverse impacts of such development" (p. ES-2). As of February 2010, the BLM had 127 active applications for solar facilities on lands that the BLM administers. According to USDOI and USDOE (2011a), all of the BLM-administered land in six states (California, Arizona, Utah, Nevada, New Mexico, and Colorado) was considered initially, for a total of 178 million hectares (ha). Not all of that land is compatible with solar energy development, so three alternative configurations are listed by USDOI and USDOI (2011a) for consideration, ranging from 274,244 to 39,972,558 ha. The larger figure is listed under the *no action alternative* where BLM would continue to use existing policy and guidance to evaluate applications. Of the area being considered under the two action alternatives, approximately 9 million ha meet the criteria established under the BLM's preferred action alternative to support solar development. Twenty-five criteria were used to exclude certain areas of public land from solar development and include environmental, social, and economic factors. The preferred alternative also included the identification of proposed *solar energy zones* (SEZs), defined as "area[s] with few impediments to utility-scale production of solar energy" (USDOI and USDOE 2011a, p. ES-7). By themselves, these SEZs constitute the nonpreferred action alternative of 274,244 ha listed above. Maps of SEZs are available at *http://solareis.anl.gov/documents/dpeis/index.cfm.*

Several sensitive, threatened, or endangered species are being considered within the EIS, but Agassiz's desert tortoise is one of only four species noted whose very presence at a site may be sufficient to exclude USSED in special cases (see table ES.2-2 in USDOI and USDOE 2011a). The potential effects of USSEDO are not trivial for tortoises or other wildlife species. Within the area covered in the draft EIS by USDOI and USDOE (2011a), it is estimated that approximately 161,943 ha of Agassiz's desert tortoise habitat will be directly affected. However, when including direct and indirect impacts on habitat (excluding transmission lines and roads that would add additional impacts; see Lovich and Bainbridge 1999, Kristan and Boarman 2007), it is estimated that approximately 769,230 ha will be affected. Some SEZs are adjacent to critical habitat designated for the recovery of Agassiz's desert tortoise, and this proximity is considered part of the indirect impacts.

On 28 October 2011, while this paper was in press, the BLM and US Department of Energy released a supplement to the EIS (USDOI and USDOE 2011b, 2011c) after receiving more than 80,500 comments. The no action alternative remains the same as in the EIS. The new preferred alternative (slightly reduced to 8,225,179 ha as the modified program alternative) eliminates or adjusts SEZs (now reduced to 115,335 ha in 17 zones as the modified SEZ alternative) to ensure that they are not in high-conflict areas and provides incentives for their use. The new plan also proposes a process to accommodate additional solar energy development outside of SEZs and to revisit ongoing state-based planning efforts to allow consideration of additional SEZs in the future.

The impacts of USSED on wildlife: Effects due to construction and decommissioning

The construction and eventual decommissioning of solar energy facilities will have impacts on wildlife, including rare and endangered species, and on their habitats in the desert (Harte and Jassby 1978). These activities involve significant ground disturbance and direct (e.g., mortality) and indirect (e.g., habitat loss, degradation, modification) impacts on wildlife and their habitat (Kuvlesky et al. 2007). Solar energy facilities require large land areas to harness sunlight and convert it to electrical energy. According to Wilshire and colleagues (2008), photovoltaic panels with a 10% conversion efficiency would need to cover an area of about 32,000 square kilometers, or an area a little smaller than the state of Maryland, to meet the current electricity demands of the United States. Many of the areas being considered for the development of solar energy in the Mojave and Sonoran Deserts are, at present, relatively undisturbed (USDOI and USDOE 2011a).

The extent of surface disturbance of USSED is related to the cooling technology used. Because of the scarcity of water in the desert Southwest region, dry-cooling systems, which consume 90%–95% less water than wet-cooling systems (EPRI 2002), are becoming a more viable option for concentrating solar facilities. Although wet-cooling systems are more economical and efficient, they consume larger amounts of water per kilowatt-hour (Torcellini et al. 2003). Unlike wet-cooling systems, dry-cooling systems use ambient air, instead of water, to cool the exhaust steam from the turbines. However, to achieve a heat-rejection efficiency similar to that in a wet-cooling system, Khalil and colleagues (2006) estimated that a direct dry-cooling system will require a larger footprint and would thus affect more wildlife habitat.

Although we found no information in the scientific literature about the direct effects of USSED on wildlife, the ground-disturbance impacts are expected to be similar to those caused by other human activities in the desert (Lovich and Bainbridge 1999).

Dust and dust suppressants. USSED transforms the landscape substantially through site preparation, including the construction of roads and other infrastructure. In addition, many solar facilities require vegetation removal and grading. These construction activities produce dust emissions, especially in arid environments (Munson et al. 2011), which already have the potential for natural dust emission. Dust can have dramatic effects on ecological processes at all scales (reviewed by Field et al. 2010). At the smallest scale, wind erosion, which powers dust emission, can alter the fertility and water-retention capabilities of the soil. Physiologically, dust can adversely influence the gas exchange, photosynthesis, and water usage of Mojave Desert shrubs (Sharifi et al. 1997). Depending on particle size, wind speed, and other factors, dust emission can physically damage plant species through root exposure, burial, and abrasions to their leaves and stems. The physiological and physical damage to plant species inflicted by dust emissions could ultimately reduce the plants' primary production and could indirectly affect wildlife food plants and habitat quality.

From an operational perspective, dust particles reduce mirror and panel efficiency in converting solar energy into heat or electricity. To combat dust, solar energy facilities apply various dust suppressants to surfaces with exposed soil (e.g., graded areas, areas with vegetation removed, roads). There are eight categories of common dust suppressants used for industrial applications: water, salts and brines, organic nonpetroleum products, synthetic polymers, organic petroleum, electrochemical substances, clay additives, and mulch and fiber mixtures (reviewed in Piechota et al. 2004). In a study conducted in the Mojave Desert in which the hydrological impacts of dust suppressants were compared, Singh and colleagues (2003) reported that changes did occur in the volume, rate, and timing of runoff when dust suppressants were used. In particular, petroleum-based and acrylic-polymer dust suppressants drastically influenced the hydrology of disturbed areas by increasing runoff volume and changing its timing. When it is applied to disturbed desert soils, magnesium chloride ($MgCl_2$), a commonly used salt-based dust depressant, does not increase runoff volume but does, however, increase the total suspended solids loads in runoff (Singh et al. 2003).

Others have highlighted the fact that there is a dearth of scientific research and literature on the effects of dust suppressants on wildlife, including the most commonly used category of dust depressant: brines and salts (Piechota et al. 2004, Goodrich et al. 2008). However, the application of $MgCl_2$ to roads was correlated with a higher frequency of plant damage (Goodrich et al. 2008). Because chloride salts, including $MgCl_2$, are not confined to the point of application but have the ability to be transported in runoff (White and Broadly 2001), the potential exists for a loss of primary production associated with plant damage in the habitats surrounding a solar facility, which could directly affect wildlife habitat.

Mortality of wildlife. We are not aware of any published studies documenting the direct effects of USSED on the survival of wildlife. However, subterranean animals can be affected by USSED, including species that hibernate underground. In the Sonoran Desert portion of California, Cowles (1941) observed that most reptiles in the Coachella Valley hibernated at depths of less than 33 centimeters (cm), with many at considerably shallower depths. Included in his observations were flat-tailed horned lizards (*Phrynosoma mcallii*)—a species of special concern in the region because of solar energy development (USDOI and USDOE 2011a)—and the federally protected Coachella Valley fringe-toed lizard (*Uma inornata*). Even lightweight vehicles like motorcycles are capable of causing greatly increased soil density (soil compaction) at a depth of 30–60 cm as their tires pass over the surface (Webb 1983). These observations suggest that vehicular activities in the desert have the potential to kill or entrap large numbers of subterranean animals (Stebbins 1995) through compressive forces or burrow collapse. Similar or greater impacts would be expected from the heavy equipment associated with the construction activities at an energy facility.

Destruction and modification of wildlife habitat. Despite the absence of published, peer-reviewed information on the effects of USSED on wildlife and their habitats, a considerable body of literature exists on the effects of other ground-disturbing activities on both ecological patterns and processes that are broadly comparable. Ground-disturbing activities affect a variety of processes in the desert, including soil density, water infiltration rate, vulnerability to erosion, secondary plant succession, invasion by exotic plant species, and stability of cryptobiotic soil crusts (for reviews, see Lovich and Bainbridge 1999, Webb et al. 2009). All of these processes have the ability—individually and together—to alter habitat quality, often to the detriment of wildlife. Any disturbance and alteration to the desert landscape, including the construction and decommissioning of utility-scale solar energy facilities, has the potential to increase soil erosion. Erosion can physically and physiologically affect plant species and can thus adversely influence primary production (Sharifi et al. 1997, Field et al. 2010) and food availability for wildlife.

Solar energy facilities require substantial site preparation (including the removal of vegetation) that alters topography and, thus, drainage patterns to divert the surface flow associated with rainfall away from facility infrastructure (Abbasi and Abbasi 2000). Channeling runoff away from plant communities can have dramatic negative effects on water availability and habitat quality in the desert, as was shown by Schlesinger and colleagues (1989). Areas deprived

of runoff from sheet flow support less biomass of perennial and annual plants relative to adjacent areas with uninterrupted water-flow patterns.

The impacts of roads. Roads are required in order to provide access to solar energy infrastructure. Both paved and unpaved roads have well-documented negative effects on wildlife (Forman and Alexander 1998), and similar effects are expected in utility-scale solar energy facilities. Although road mortality is most easily detected on the actual roadway, the effects of roads extend far beyond their physical surface. In a study of the effects of roads on Agassiz's desert tortoise populations in southern Nevada, von Seckendorff Hoff and Marlow (2002) examined transects along roads with traffic volumes varying from 25 to 5000 vehicles per day. Tortoises and tortoise sign (e.g., burrows, shells, scat) decreased with their proximity to a road. On roads with high traffic volumes, tortoises and tortoise sign were reduced as far as 4000 meters from the roadside. Roads with lower traffic volumes had fewer far-reaching effects.

Another effect of roads in the desert is the edge enhancement of plants and arthropod herbivores (Lightfoot and Whitford 1991). Perennial plants along the roadside are often larger than those farther away, and annual plant germination is often greatest along the shoulders of roads. It is possible that increased runoff due to impervious pavement or compacted soil contributes to this heterogeneity of vegetation in relationship to a road. Agassiz's desert tortoises may select locations for burrow construction that are close to roads, perhaps because of this increased productivity of food plants (Lovich and Daniels 2000). Although this situation suggests potentially beneficial impacts for herbivorous species of wildlife, such as tortoises, it increases their chance of being killed by vehicle strikes, as was shown by von Seckendorff Hoff and Marlow (2002).

Off-site impacts. Direct impacts on wildlife and habitat can occur well outside the actual footprint of the energy facility. Extraction of large amounts of raw materials for the construction of solar energy facilities (e.g., aggregate, cement, steel, glass); transportation and processing of those materials; the need for large amounts of water for cooling some installations; and the potential for the production of toxic wastes, including coolants, antifreeze, rust inhibitors, and heavy metals, can affect wildlife adjacent to or far from the location of the facility (Abbasi and Abbasi 2000). Abbasi and Abbasi (2000) summarized data suggesting that the material requirements for large-scale solar facilities exceed those for conventional fossil-fuel plants on a cost-per-unit-of-energy basis. In addition, water used for steam production at one solar energy facility in the Mojave Desert of California contained selenium, and the wastewater was pumped into evaporation ponds that attracted birds that fed on invertebrates. Although selenium toxicity was not considered a threat on the basis of the results of one study, the possibility exists for harmful bioaccumulation of this toxic micronutrient (Herbst 2006). In recognition of the hazard, Pimentel and colleagues (1994) suggested that fencing should be used to keep wildlife away from these toxic ponds.

The impacts of USSED on wildlife: Effects due to operation and maintenance

This category includes the effects related to the presence and operation of the solar facility, not the physical construction and decommissioning of the same. Some of the effects (e.g., mortality of wildlife and impacts caused by roads) are similar to those discussed previously for construction and decommissioning and are not discussed further.

Habitat fragmentation. Until relatively recently, the desert Southwest was characterized by large blocks of continuous and interconnected habitat. Roads and urban development continue to contribute to habitat fragmentation in this landscape. Large-scale energy development has the potential to add to and exacerbate the situation, presenting potential barriers to movement and genetic exchange in wildlife populations, including those of bighorn sheep (*Ovis canadensis*), deer (*Odocoileus* spp.), tortoises, and other species of concern and social significance. Research conducted on the effects of oil and gas exploration and development (OGED) on wildlife in the Intermountain West provides a possible analog to USSEDO, since comparable data are not available for the desert Southwest. The potential effects on mule deer (*Odocoileus hemionus*) and other wildlife species include impediments to free movement, the creation of migration bottlenecks, and a reduction in effective winter range size. Mule deer responded immediately to OGED by moving away from disturbances, with no sign of acclimation during the three years of study by Sawyer and colleagues (2009). Some deer avoidance resulted in their use of less-preferred and presumably less-suitable habitats.

Despite a lack of data on the direct contributions of USSEDO to habitat fragmentation, USSEDO has the potential to be an impediment to gene flow for some species. Although the extent of this impact is, as yet, largely unquantified in the desert, compelling evidence for the effects of human-caused habitat fragmentation on diverse wildlife species has already been demonstrated in the adjacent coastal region of southern California (Delaney et al. 2010).

Noise effects. Industrial noise can have impacts on wildlife, including changes to their habitat use and activity patterns, increases in stress, weakened immune systems, reduced reproductive success, altered foraging behavior, increased predation risk, degraded communication with conspecifics, and damaged hearing (Barber et al. 2009, Pater et al. 2009). Changes in sound level of only a few decibels can elicit substantial animal responses. Most noise associated with USSEDO is likely to be generated during the construction phase (Suter 2002), but noise can also be produced during operation and maintenance activities. Brattstrom and Bondello (1983) documented the effects of noise on Mojave

Desert wildlife on the basis of experiments involving off-highway vehicles. Noise from some of these vehicles can reach 110 decibels—near the threshold of human pain and certainly within the range expected for various construction, operation, and maintenance activities (Suter 2002) associated with USSEDO. This level of noise caused hearing loss in animals, such as kangaroo rats (*Dipodomys* spp.), desert iguanas (*Dipsosaurus dorsalis*), and fringe-toed lizards (*Uma* spp.). In addition, it interfered with the ability of kangaroo rats to detect predators, such as rattlesnakes (*Crotalus* spp.), and caused an unnatural emergence of aestivating spadefoot toads (*Scaphiopus* spp.), which would most likely result in their deaths. Because of impacts on wildlife, Brattstrom and Bondello (1983) recommended that "all undisturbed desert habitats, critical habitats, and all ranges of threatened, endangered, or otherwise protected desert species" (p. 204) should be protected from loud noise.

Although many consider solar energy production a "quiet" endeavor, noise is associated with their operation. For example, facilities at which wet-cooling systems are used will have noises generated by fans and pumps. As for facilities with dry-cooling systems, only noise from fans will be produced during operation (EPRI 2002). Because of the larger size requirements of dry-cooling systems, there will be more noise production associated with an increase in the number of fans.

Electromagnetic field generation. When electricity is passed through cables, it generates electric and magnetic fields. USSEDO requires a large distribution system of buried and overhead cables to transmit energy from the point of production to the end user. Electromagnetic fields (EMFs) produced as energy flows through system cables are a concern from the standpoint of both human and wildlife health, yet little information is available to assess the potential impact of the EMFs associated with USSEDO on wildlife. Concerns about EMFs have persisted for a long time, in part because of controversy over whether they're the actual cause of problems and disagreement about the underlying mechanisms for possible effects. For example, there is presently a lack of widely accepted agreement about the biological mechanisms that can explain the consistent associations between extremely low-frequency EMF exposure from overhead power lines and childhood leukemia, although there is no shortage of theories (Gee 2009).

Some conclude that the effects of EMFs on wildlife will be minor because of reviews of the often conflicting and inconclusive literature on the topic (Petersen and Malm 2006). Others suggest that EMFs are a possible source of harm for diverse species of wildlife and contribute to the decline of some mammal populations. Balmori (2010) listed possible impacts of chronic exposure to athermal electromagnetic radiation, which included damage to the nervous system, disruption of circadian rhythm, changes in heart function, impairment of immunity and fertility, and genetic and developmental problems. He concluded that enough evidence exists to confirm harm to wildlife but suggested that further study is urgently needed. Other authors suggest that the generally inconsistent epidemiological evidence in support of the effects of EMFs should not be cause for inaction. Instead, they argue that the precautionary principle should be applied in order to prevent a recurrence of the "late lessons from early warnings" scenario that has been repeated throughout history (Gee 2009).

Magnetic information is used for orientation by diverse species, from insects (Sharma and Kumar 2010) to reptiles (Perry A et al. 1985). Despite recognition of this phenomenon, the direct effects of USSEDO-produced EMFs on wildlife orientation remains unknown.

Microclimate effects. The alteration of a landscape through the removal of vegetation and the construction of structures by humans not only has the potential of increasing animal mortality but also changes the characteristics of the environment in a way that affects wildlife. The potential for microclimate effects unique to solar facilities was discussed by Pimentel and colleagues (1994) and by Harte and Jassby (1978). It has been estimated that a concentrating solar facility can increase the albedo of a desert environment by 30%–56%, which could influence local temperature and precipitation patterns through changes in wind speed and evapotranspiration. Depending on their design, large concentrating solar facilities may also have the ability to produce significant amounts of unused heat that could be carried downwind into adjacent wildlife habitat with the potential to create localized drought conditions. The heat produced by central-tower solar facilities can burn or incinerate birds and flying insects as they pass through the concentrated beams of reflected light (McCrary et al. 1986, Pimentel et al. 1994, Tsoutsos et al. 2005, Wilshire et al. 2008).

A dry-cooled solar facility—in particular, one with a concentrating-trough system—could reject heated air from the cooling process with temperatures 25–35 degrees Fahrenheit higher than the ambient temperature (EPRI 2002). This could affect the microclimate on site or those in adjacent habitats. To our knowledge, no research is available to assess the effects of USSEDO on temperature or that of any other climatic variable on wildlife. However, organisms whose sex is determined by incubation temperatures, such as both species of desert tortoises, may be especially sensitive to temperature changes, because small temperature changes have the potential to alter hatchling sex ratios (Hulin et al. 2009).

Pollutants from spills. USSEDO, especially at wet-cooled solar facilities, has a potential risk for hazardous chemical spills on site, associated with the toxicants used in cooling systems, antifreeze agents, rust inhibitors, herbicides, and heavy metals (Abbasi and Abbasi 2000, Tsoutsos et al. 2005). Wet-cooling solar systems must use treatment chemicals (e.g., chlorine, bromine, selenium) and acids and bases (e.g., sulfuric acid, sodium hydroxide, hydrated lime) for the prevention of fouling and scaling and for pH control of the water used in their recirculating systems (EPRI 2002).

Solar facilities at which a recirculating system is used also have treatment and disposal issues associated with water discharge, known as *blowdown*, which is water with a high concentration of dissolved and suspended materials created by the numerous evaporation cycles in the closed system (EPRI 2002). These discharges may contain chemicals used to prevent fouling and scaling. The potentially tainted water is usually stored in evaporative ponds, which further concentrates the toxicants (Herbst 2006). Because water is an attraction for desert wildlife, numerous species could be adversely affected. The adverse effects of the aforementioned substances and similar ones on wildlife are well documented in the literature, and a full review is outside the scope of this article. However, with the decreased likelihood of wet-cooling systems for solar facilities in the desert, the risk of hazardous spills and discharges on site will be less in the future, because dry-cooling systems eliminate most of the associated water-treatment processes (EPRI 2002). However, there are still risks of spills associated with a dry-cooling system. More research is needed on the adverse effects of chemical spills and tainted-water discharges specifically related to USSEDO on wildlife.

Water consumption (wet-cooled solar). The southwestern United States is a water-poor region, and water use is highly regulated throughout the area. Because of this water limitation, the type of cooling systems installed at solar facilities is limited as well. For example, a once-through cooling system—a form of wet cooling—is generally not feasible in arid environments, because there are few permanent bodies of water (i.e., rivers, oceans, and lakes) from which to draw cool water and then into which to release hot water. Likewise, other wet-cooling options, such as recirculating systems and hybrid systems, are becoming less popular because of water shortage issues in the arid region. Therefore, the popularity of the less-efficient and less-economical dry-cooling systems is increasing on public lands. Water will also be needed at solar facilities to periodically wash dust from the mirrors or panels. Although there are numerous reports in which the costs and benefits were compared both environmentally and economically (EPRI 2002, Khalil et al. 2006) between wet- and dry-cooled solar facilities, to our knowledge no one has actually quantified the effects of water use and consumption on desert wildlife in relation to the operation of these facilities.

Fire risks. Any system that produces electricity and heat has a potential risk of fire, and renewable energy facilities are no exception. Concentrating solar energy facilities harness the sun's energy to heat oils, gases, or liquid sodium, depending on the system design (e.g., heliostat power, trough, dish). With temperatures reaching more than 300 degrees Celsius in most concentrated solar systems, spills and leaks from the coolant system increase the risk of fires (Tsoutsos et al. 2005). Even though all vegetation is usually removed from the site during construction, which reduces the risk of a fire propagating on and off site, the increase of human activity in a desert region increases the potential for fire, especially along major highways and in the densely populated western Mojave Desert (Brooks and Matchett 2006).

The Southwest deserts are not fire-adapted ecosystems: fire was historically uncommon in these regions (Brooks and Esque 2002). However, with the establishment of numerous flammable invasive annual plants in the desert Southwest (Brown and Minnich 1986), coupled with an increase in anthropogenic ignitions, fire has become more common in the deserts, which adversely affects wildlife (Esque et al. 2003). For Agassiz's desert tortoise, fire can translate into direct mortality at renewable energy facilities (Lovich and Daniels 2000) and can cause reductions in food and habitat quality. To our knowledge, however, there is no scientific literature related to the effects of USSEDO-caused fire on wildlife.

Light pollution. Two types of light pollution could be produced by solar energy facilities: ecological light pollution (ELP; Longcore and Rich 2004) and polarized light pollution (PLP; Horváth et al. 2009). The latter, PLP, could be produced at high levels at facilities using photovoltaic solar panels, because dark surfaces polarize light. ELP can also be produced at solar facilities in the form of reflected light. The reflected light from USSEDO has been suggested as a possible hazard to eyesight (Abbasi and Abbasi 2000). ELP could adversely affect the physiology, behavior, and population ecology of wildlife, which could include the alteration of predation, competition, and reproduction (for reviews, see Longcore and Rich 2004, Perry G et al. 2008). For example, the foraging behavior of some species can be adversely affected by light pollution (for a review, see Longcore and Rich 2004). The literature is limited regarding the impact of artificial lighting on amphibians and reptiles (Perry G et al. 2008), and, to our knowledge, there are no published studies in which the impacts on wildlife of light pollution produced by USSEDO have been assessed. However, light pollution is considered by G. Perry and colleagues (2008) to be a serious threat to reptiles, amphibians, and entire ecological communities that requires consideration during project planning. G. Perry and colleagues (2008) further recommended the removal of unnecessary lighting so that the lighting conditions of nearby habitats would be as close as possible to their natural state.

Numerous anthropogenic products—usually those that are dark in color (e.g., oil spills, glass panes, automobiles, plastics, paints, asphalt roads)—can unnaturally polarize light, which can have adverse effects on wildlife (for a review, see Horváth et al. 2009). For example, numerous animal species use polarized light for orientation and navigation purposes (Horváth and Varjú 2004). Therefore, the potential exists for PLP to disrupt the orientation and migration abilities of desert wildlife, including those of sensitive species. In the review by Horváth and colleagues (2009), which was focused mostly on insects but included a few avian references, they highlighted the fact that anthropogenic products that produce PLP can appear to be water bodies to wildlife and can become ecological traps for insects and, to a lesser degree, avian species. Therefore,

utility-scale solar energy facilities at which photovoltaic technology is used in the desert Southwest could create a direct effect on insects (i.e., ecological trap), which could have profound but unquantified effects on the ecological community surrounding the solar facility. In addition, there may be indirect effects on wildlife through the limitation of plant food resources, especially if pollinators are negatively affected. As was stated by Horváth and colleagues (2009), the population- and community-level effects of PLP can only be speculated on because of the paucity of data.

Unanswered questions and research needs

In our review of the peer-reviewed scientific literature, we found only one peer-reviewed publication on the specific effects of utility-scale solar energy facility operation on wildlife (McCrary et al. 1986) and none on utility-scale solar energy facility construction or decommissioning. Although it is possible that we missed other peer-reviewed publications, our preliminary assessment demonstrates that very little critically reviewed information is available on this topic. The dearth of published, peer-reviewed scientific information provides an opportunity to identify the fundamental research questions for which resource managers need answers. Without those answers, resource managers will be unable to effectively minimize the negative effects of USSEDO on wildlife, especially before permitting widespread development of this technology on relatively undisturbed public land.

Before-and-after studies. Carefully controlled studies are required in order to tease out the direct and indirect effects of USSEDO on wildlife. Pre- and postconstruction evaluations are necessary to identify the effects of renewable energy facilities and to compare results across studies (Kunz et al. 2007). In their review of wind energy development and wildlife, with an emphasis on birds, Kuvlesky and colleagues (2007) noted that experimental designs and data-collection standards were typically inconsistent among studies. This fact alone contributes measurably to the reported variability among studies or renders comparisons difficult, if not impossible. Additional studies should emphasize the need for carefully controlled before-after-control-impact (BACI) studies (Kuvlesky et al. 2007) with replication (if possible) and a detailed description of site conditions. The potential payoff for supporting BACI studies now could be significant: They could provide answers for how to mitigate the negative impacts on wildlife in a cost-effective and timely manner.

What are the cumulative effects of large numbers of dispersed or concentrated energy facilities? Large portions of the desert Southwest have the potential for solar energy development. Although certain areas are targeted for large facilities because of resource availability and engineering requirements (e.g., their proximity to existing transmission corridors), other areas may receive smaller, more widely scattered facilities. A major unanswered question is what the cumulative impacts of these facilities on wildlife are. Would it be better for wildlife if development is concentrated or if it is scattered in smaller, dispersed facilities? Modeling based on existing data would be highly suspect because of the deficiency of detailed site-level published information identified in our analysis. Except for those on habitat destruction and alteration related to other human endeavors, there are no published articles on the population genetic consequences of habitat fragmentation related to USSED, which makes this a high priority for future research.

What density or design of development maximizes energy benefits while minimizing negative effects on wildlife? We are not aware of any published peer-reviewed studies in which the impacts on wildlife of different USSED densities or designs have been assessed. For example, would it benefit wildlife to leave strips of undisturbed habitat between rows of concentrating solar arrays? Research projects in which various densities, arrays, or designs of energy-development infrastructure are considered would be extremely valuable. BACI studies would be very useful for addressing this deficiency.

What are the best sites for energy farms with respect to the needs of wildlife? The large areas of public land available for renewable energy development in the desert Southwest encompass a wide variety of habitats. Although this provides a large number of choices for USSED, not all areas have the same energy potential because of resource availability and the limitations associated with engineering requirements, as was noted above. Detailed information on wildlife distribution and habitat requirements are crucially needed for proper site location and for the design of renewable energy developments (Tsoutsos et al. 2005). Public-resource-management agencies have access to rich geospatial data sets based on many years of inventories and resource-management planning. These data could be used to identify areas of high value for both energy development and wildlife. Areas with overlapping high values could be carefully studied through risk assessment when it appears that conflicts are likely. Previously degraded wildlife habitats, such as old mine sites, overgrazed pastures, and abandoned crop fields, may be good places to concentrate USSED to minimize its impacts on wildlife (CBI 2010).

Can the impacts of solar energy development on wildlife be mitigated? The construction of solar energy facilities can cause direct mortality of wildlife. In addition, building these facilities results in the destruction and fragmentation of wildlife habitat and may increase the possibility of fire, as was discussed above. Beyond these effects, essentially nothing is known about the operational effects of solar energy facilities on wildlife. Current mitigation strategies for desert tortoises and other protected species include few alternatives other than translocation of the animals from the footprint of the development into other areas. Although this strategy may be appealing at first glance, animal translocation has a checkered history of success, especially for reptiles and amphibians (Germano and Bishop 2008, CBI 2010). Translocation

has yet to be demonstrated as a viable long-term solution that would mitigate the destruction of Agassiz's desert tortoise habitat (Ernst and Lovich 2009, CBI 2010).

Conclusions

All energy production has associated social and environmental costs (Budnitz and Holdren 1976, Bezdek 1993). In their review of the adverse environmental effects of renewable energy development, Abbasi and Abbasi (2000) stated that "renewable energy sources are not the panacea they are popularly perceived to be; indeed, in some cases, their adverse environmental impacts can be as strongly negative as the impacts of conventional energy sources" (p. 121). Therefore, responsible, efficient energy production requires both the minimization of environmental costs and the maximization of benefits to society—factors that are not mutually exclusive. Stevens and colleagues (1991) and Martín-López and colleagues (2008) suggested that the analyses of costs and benefits should include both wildlife use and existence values. On the basis of our review of the existing peer-reviewed scientific literature, it appears that insufficient evidence is available to determine whether solar energy development, as it is envisioned for the desert Southwest, is compatible with wildlife conservation. This is especially true for threatened species such as Agassiz's desert tortoise. The many other unanswered questions that remain after reviewing the available evidence provide opportunities for future research, as was outlined above.

The shift toward renewable energy is widely perceived by the public as a "green movement" intended to reduce greenhouse-gas emissions and acid rain and to curb global climate change (Abbasi and Abbasi 2000). However, as was noted by Harte and Jassby (1978), just because an energy technology is simple, thermodynamically optimal, renewable, or inexpensive does not mean that it will be benign from an ecological perspective. The issue of wildlife impacts is much more complex than is widely appreciated, especially when the various scales of impact (e.g., local, regional, global) are considered. Our analysis shows that, on a local scale, so little is known about the effects USSEDO on wildlife that extrapolation to larger scales with any degree of confidence is currently limited by an inadequate amount of scientific data. Therefore, without additional research to fill the significant information void, accurate assessment of the potential impacts of solar energy development on wildlife is largely theoretical but needs to be empirical and well-founded on supporting science.

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FOUR NEW SPECIES OF CALIFORNIA LEGLESS LIZARDS (*ANNIELLA*)

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A . A previous genetic study of the California legless lizard (*Anniella pulchra*) revealed five deep genetic lineages and alluded to morphological differences among them. Here we show that three of these genetic lineages can be readily diagnosed from topotypic *A. pulchra* through a combination of coloration, scalation, and skeletal characters (trunk vertebra number). A fourth lineage is cryptic, but can be diagnosed from *A. pulchra* by its karyotype. We argue that these genetic clades of *A. pulchra* are strong candidates for species recognition because they exhibit properties that corroborate the DNA evidence for lineage separation. We therefore hypothesize that each of the five genetic clades of *A. pulchra* ("*Anniella* clades A–E") are distinct species and so describe four new species (*Anniella alexanderae*, sp. nov., *Anniella campi*, sp. nov., *Anniella grinnelli*, sp. nov., and *Anniella stebbinsi*, sp. nov.). In naming these new species we have chosen to honor four natural historians whose contributions to the study of California's vertebrate biodiversity are an ongoing inspiration for students of natural history and natural history museum curators. Two of these new species have small and poorly characterized ranges in the San Joaquin Valley and Carrizo Plain (*A. alexanderae* and *A. grinnelli*). A third restricted-range species (*A. campi*) is known from just three sites in the eastern Sierra Nevada. The fourth new species (*A. stebbinsi*) is a wide-ranging cryptic lineage that occurs throughout Southern California and into Baja California, Mexico. The limited distribution and fragile habitats occupied by the new species of *Anniella* warrant additional scientific research and conservation attention.

K : *Anniella pulchra*; California; conservation; lizard; new species

INTRODUCTION

The genus *Anniella* Gray, 1852, includes limbless lizards endemic to western North America. *Anniella* is the last survivor of an anguimorph lineage that first appeared in the Eocene of the western interior (Gauthier, 1982; Smith, 2011). From the Miocene on, the fossil record is restricted to within the known range of extant *Anniella* in California and Baja California, Mexico (Gauthier, 1980; Bell *et al.*, 1995; Hunt, 2008a). The populations traditionally assigned to the type species, *Anniella pulchra* Gray, 1852, occur

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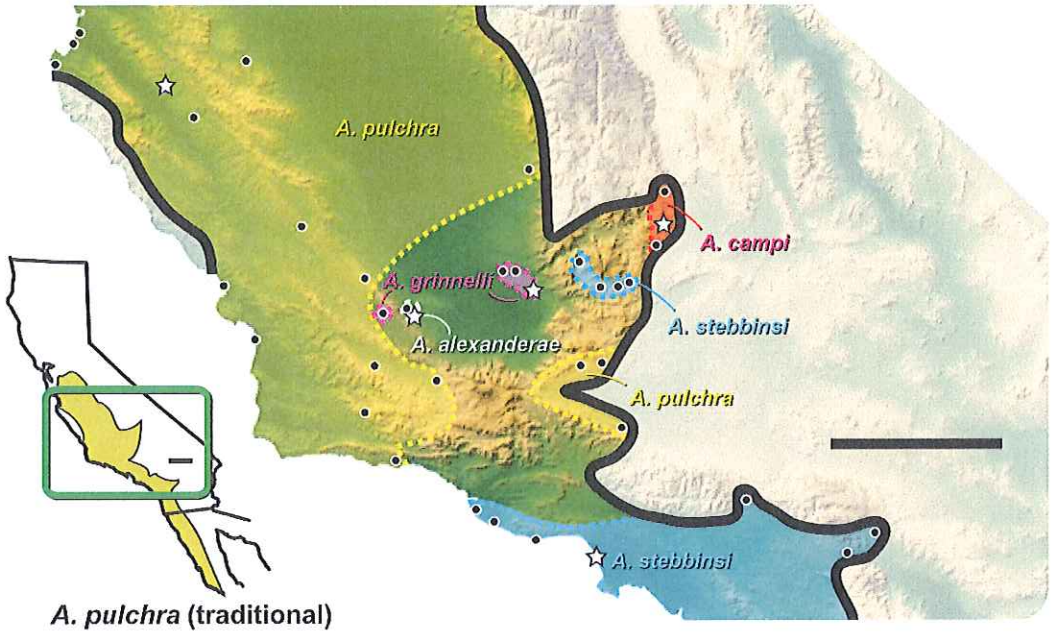

Figure 1. Map showing the traditional (inset) distribution of *Anniella pulchra* and a detail (main) showing the hypothesized distribution of the newly described species. White stars indicate type localities, black dots show referred specimens used in this study. Color-shaded areas are speculated based on the distribution of museum specimens and genetic clades (Parham and Papenfuss, 2009) updated through the addition of MVZ 172784 from the southern Sierra Nevada (*A. campi*, referred by morphology) and two genetically characterized specimens of *A. pulchra sensu stricto*: 1) SBMNH HE-2448 from within the Santa Barbara city limits; 2) MVZ 13376 (*A. pulchra sensu stricto*) based on data from Pearse and Pogson (2000). Contact zones between *A. pulchra* and the newly described species in the Carrizo Plain, San Joaquin Valley, Transverse Ranges, and Sierra Nevada are uncertain and so are not shaded. Scale bars = 100 km.

from northwest Baja California, to the eastern San Francisco Bay Area (Stebbins, 2003; Hunt, 2008c; Fig. 1). A second species, *Anniella geronimensis* Shaw, 1940, is restricted to coastal sand dunes in northwest Baja California, Mexico. There is a limited area of sympatry in Baja California in the vicinity of San Quintin Bay (Shaw, 1953; Hunt, 2008b).

Like other fossorial taxa with reduced or missing limbs, *Anniella* species are morphologically conservative. Hunt (1984) performed a study of morphological variation among *A. pulchra* populations. His detailed study, combined with our own observations, confirms that there are few significant differences in scalation among populations of *A. pulchra* (Table 1). The major morphological variation within *A. pulchra* is coloration, with some coastal populations showing dorsal melanism (Hunt, 1984, 2008a,c). Previous genetic studies of *A. pulchra* show that melanistic populations do not form a monophyletic group or correspond to the deepest genetics divergences (Bezy and Wright, 1971; Bezy *et al.*, 1977; Pearse and Pogson, 2000; Parham and Papenfuss, 2009).

We would expect that the reduced vagility associated with a subterranean ecology would facilitate speciation. Indeed, numerous genetic studies have shown that other morphologically conservative, fossorial, reptile taxa harbor cryptic species (e.g., Daniels

T 1. S *A* .

Anniella spp.	No. of Scales or Scale Rows								
	Supralabials	Infralabials	Dorsal	Ant.	Mid.	Post.	A. clear	M. clear	P. clear
Hunt (1984)									
A. pulchra	5–7	5–8	198–250	31–36	28–32	22–26	4–8	4–7	3–5
A. stebbinsi	6–8	4–9	188–249	28–36	24–30	22–26	4–7	4–6	3–6
Holotypes									
A. alexanderae	6	5	257	32	26	24	6	4	4
A. campi	5	5	244	35	32	27	5	4	4
A. grinnelli	6	5	239	30	25	23	7	5	6
A. stebbinsi	6	4	215	30	28	24	6	5	5

Supralabials: number of supralabials; Infralabials: number of infralabials; Dorsal: number of dorsal scales counted along the midline; Ant.: number of anterior scale rows counted at two head lengths posterior to the interoccipital; Mid.: number of scale rows at mid-body; Post: number of posterior scale rows counted at 10 scales anterior to vent; A. clear: number of anterior clear scale rows (i.e., lacking dark pigmentation) between the dorsal and lateral stripes counted at two head lengths posterior to the interoccipital; M. clear: number of clear scale rows (i.e., lacking dark pigmentation) between the dorsal and lateral stripes at mid-body; P. clear: number of posterior clear scale rows (i.e., lacking dark pigmentation) between the dorsal and lateral stripes rows counted at 10 scales anterior to vent.

Summary of data from Hunt (1984) based on 102 *A. pulchra* and 614 *A. stebbinsi*. Data included are from the clearly designated groups in that study that do not include more than one species. For *A. pulchra*, the groups included are: 1–3, 4, 7, 10. For *A. stebbinsi*, the groups included are: 12, 14–27. The following groups were excluded because they span geographic regions that may contain more than one species: 5, 6, 8, 9, 11, 13.

Data from the holotypes of the new species described in this paper.

et al., 2009; Mott and Vietes, 2009; Heideman *et al.*, 2011). A similar pattern was not revealed in *Anniella* until our range-wide study of genetic variation among populations of *Anniella* (Parham and Papenfuss, 2009). In that paper, we reported mitochondrial and nuclear DNA sequences from 45 localities spanning the range of *A. pulchra.* Our data revealed five genetic clades that can be diagnosed with mitochondrial and nuclear DNA markers. The maximum uncorrected mitochondrial sequence divergence among the five genetic lineages of *A. pulchra* ranges from 4.3% to 9.2% (Parham and Papenfuss, 2009). This amount of divergence corresponds to species level differences of other lizard genera (reviewed by Papenfuss *et al.*, 2001). But more significantly, the genetic clades we uncovered can be diagnosed with morphological characters, including previously unreported coloration, vertebral counts from x-rays, or published karyotypic differences. Thus, unlike the aforementioned melanistic populations, the deep genetic clades of *A. pulchra* are strong candidates for species recognition because they exhibit properties that corroborate the genetic evidence for lineage separation (de Queiroz, 2007). We therefore hypothesize that each of the five genetic clades of *A. pulchra* (*Anniella* clades A–E of Parham and Papenfuss [2009]) are distinct species.

Before describing four new species, it is necessary to establish which of the five clades will remain as *A. pulchra.* Murphy and Smith (1991) designated a neotype for *A. pulchra* because of problems associated with the original description of the genus and species noticed by Hunt (1983). The neotype of *A. pulchra*, MVZ 64656, is from Pinnacles National Monument, San Benito County, California (Figs. 1, 2). A topotypic specimen, MVZ 247489, belongs to clade A, which is distributed throughout Northern California. Therefore, *A. pulchra* is now

Figure 2. A topotypic *Anniella pulchra* (MVZ 247488) in dorsal and ventral views, and the type locality for the species at Pinnacles National Monument, San Benito County, California, U.S.A.

limited to populations in clade A of Parham and Papenfuss (2009). As such, genetic clades B–E are described as new species below. In naming these new species we have chosen to honor four natural historians whose contributions to the study of California's vertebrate biodiversity are an ongoing inspiration for students of natural history and natural history museum curators.

MATERIALS AND METHODS

Museum abbreviations: CAS, California Academy of Sciences, San Francisco, California; LACM, Natural History Museum of Los

T 2. D A .
B A. .

	A. pulchra	*A. alexanderae*	*A. campi*	*A. grinnelli*	*A. stebbinsi*
Ventral color	Yellow	**Grey**	Yellow	**Purple**	Yellow
Lateral stripe	~Single	Single	**Double**	Single	~Single
Mean vertebral count	<77 (76.0)	**>81 (82.2)**	<77 (76.5)	**>81 (81.2)**	<77 (75.4)
Dorsal scales	≤250 (198–250)	**>250 (252–278)**	<250 (219–244)	<250 (234–249)	<250 (188–249)
Mean dorsal scales	222.3	**261.2**	227.6	242.4	213.7
Chromosomes	2n = 20	?	?	?	**2n = 22**
Maximum ND2 divergence from *A. pulchra* (%)	—	**8.0**	**8.4**	**9.2**	**8.7**

Max. ND2 divergence from *A. pulchra* is the maximum sequence divergence from *A. pulchra* based on the mitochondrial DNA marker used by Parham and Papenfuss (2009). See descriptions and diagnoses of each species for more details.

Angeles, Los Angeles, California; MCZ, Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts; MVZ, Museum of Vertebrate Zoology, University of California, Berkeley, California; SBMNH, Santa Barbara Museum of Natural History, Santa Barbara, California; SDNHM, San Diego Natural History Museum, San Diego, California; UCMP, University of California Museum of Paleontology, University of California, Berkeley, California. Locality data for all referenced material have been standardized into metric units and for format. Original locality information is available from the repositories.

Specimens used in the study were collected over a 14-year period. *Anniella* species are fossorial and are rarely active on the surface. Many of the sites sampled have no cover to search such as logs, stones, or leaf litter. More than 2,000 cover objects (flattened cardboard boxes and pieces of plywood) were placed at localities throughout the range of *Anniella* in California. Nearly all of the new species described here from sites north of the Transverse Ranges were found by raking in sandy soil under cover objects.

Molecular data used to delineate species here are taken from Parham and Papenfuss (2009). The samples from the Parham and Papenfuss (2009) study include all of the new holotypes and a topotype for *A. pulchra*. We refer closely related samples of each species by clade in the section called Referred Specimens (see below). We refer to the molecular marker sequenced by Parham and Papenfuss (2009), NADH dehydrogenase subunit 2 and five adjacent tRNAs (*trnWANCY*), as well as parts of cytochrome oxidase 1 and *trnM*, as "ND2" hereafter. Coloration data were taken from living specimens (Appendix) observed under a sunlight spectrum Bell & Howell lamp using a Munsell Book of Color (Munsell Color Company, 1976) and RGB Hexadecimal color conversions (Kelly and Judd, 1955) listed as "(Munsell, RGB)." Ventral coloration characters can only be observed in fresh specimens, whereas characters relating to the lateral stripes can be observed in preserved specimens. Vertebral counts were taken from x-rays (Appendix). Morphological abbreviations: SVL, snout-vent length; TL, tail length. Scale names in the descriptions are based on Smith (1946, p. 466). Scalation of the new holotypes was compared with a large survey of *A. pulchra* complex populations (Hunt, 1984; Table 1). Diagnostic characters are presented in Table 2.

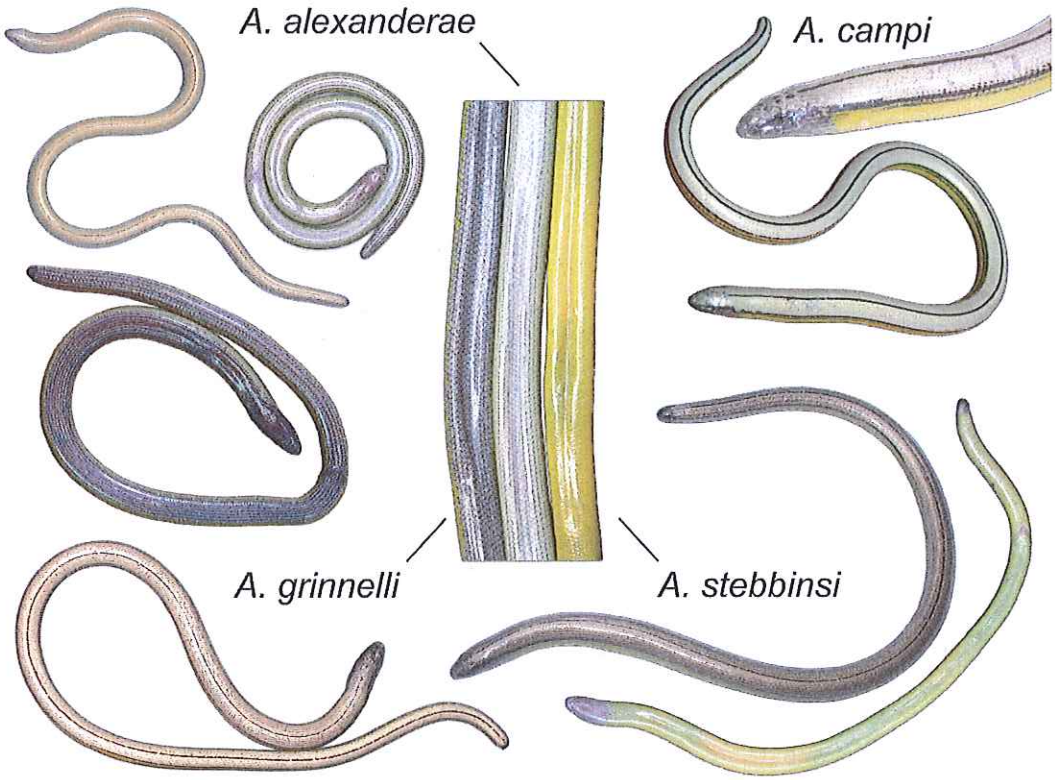

Figure 3. Four new species of *Anniella* and their diagnostic characters. Upper left, *Anniella alexanderae*: dorsal (MVZ 250549, paratype); ventral view showing the diagnostic gray coloration (MVZ 257720, paratype). Upper right, *Anniella campi*: dorsal (MCZ-R-189380, paratype); detail (MVZ 257277, holotype) showing diagnostic double dark lateral stripes. Lower left, *Anniella grinnelli*: ventral (MVZ 247487, paratype) showing diagnostic purple coloration; dorsal (MVZ 267228, paratype). Lower right, *Anniella stebbinsi*: dorsal (MVZ 250558, paratype); ventral (MVZ 267248). Center: comparison of ventral coloration from three of the new species. Left, *A. grinnelli* (MVZ 250546, paratype); center, *A. alexanderae* (MVZ 250549, paratype); right, *A. stebbinsi* (MVZ 250558, paratype).

Anniella alexanderae, new species
Temblor Legless Lizard
Figure 3

Anniella pulchra lineage B—Parham and Papenfuss, 2009.

Holotype. MVZ 250570, an adult male from 35.2090°N, 119.5672°W (380 m elevation [elev.]; Figs. 1, 4), Shale Rd., 1.3 km S (by road) junction with Hwy. 33, Kern County, California, U.S.A., collected on February 21, 2005, by Theodore J. Papenfuss and James F. Parham.

Paratypes. CAS 238588, an adult male from 35.2101°N, 119.5670°W (375 m elev.; Figs. 1, 4), Shale Rd., 1.3 km S by road of the junction with Hwy. 33, Kern County, California, U.S.A., collected on October 2, 2007, by Theodore J. Papenfuss; MCZ R-189386 and MVZ 267237, both adult males from 35.2092°N, 119.5671°W (413 m elev.; Figs. 1, 4), Shale Rd. 1.3. km S by road of the junction with Hwy. 33 (Figs. 1, 4), Kern County, California, U.S.A., collected on April 18, 2010, by Theodore J. Papenfuss;

Figure 4. Type localities of the four new species of *Anniella*. Upper left, *Anniella alexanderae*: Shale Rd., 1.3 km S (by road) junction with Hwy. 33, Kern County, California, U.S.A. Upper right, *Anniella campi*: Big Spring, 5.8 km NW junction Hwy. 14 (by Hwy. 178) Kern County, California, U.S.A. Lower left, *Anniella grinnelli*: Jack Zaninovich Memorial Nature Trail, Sand Ridge Preserve, Kern County, California, U.S.A. Lower right, *Anniella stebbinsi*: El Segundo Dunes, Los Angeles International Airport, Los Angeles County, California, U.S.A.

MVZ 250549 (Fig. 3), an adult male from 35.2090°N, 119.5666°W (380 m elev.; Figs. 1, 4), Shale Rd. 1.3. km S by road of the junction with Hwy. 33, Kern County, California, U.S.A., collected on October 21, 2005, by Theodore J. Papenfuss; MVZ 257720 (Fig. 3), an adult, not sexed, from 35.2090°N, 119.5666°W, (380 m elev.; Figs. 1, 4), Shale Rd., 1.3 km S by road of the junction with Hwy. 33, Kern County, California, U.S.A., collected April 2, 2007, by Theodore J. Papenfuss.

Referred Specimens. Additional specimens listed in the Appendix of this study and from clade B of Parham and Papenfuss (2009; localities 22 and 23 in the appendix of that study).

Diagnosis. Distinguished from all other species of the *A. pulchra* complex by a unique ventral coloration of Light Gray (5Y 7/1, RGB #D3D3D3) that is continuous from the insertion of the lower jaw to the end of the tail. This coloration is present in all paratypes and referred specimens. It is further distinguished from *A. pulchra*, *Anniella stebbinsi*, and *Anniella campi* by its higher vertebral count (Fig. 5) and from all species of the complex by its higher dorsal scale count (Tables 1, 2). *Anniella alexanderae* shows a maximum mitochondrial

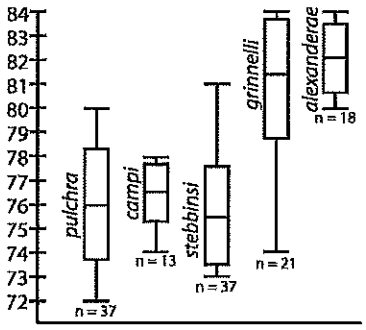

Figure 5. Box and whisker plots (range, sample standard deviation, mean) of trunk vertebral counts of *Anniella pulchra* and the four new species based on x-ray images of museum specimens. *Anniella alexanderae* and *Anniella grinnelli* show higher vertebral counts than the other three species of the *A. pulchra* complex. Note that a single outlier with a trunk vertebral count of 74 (the rest are 79–84) affects the range of *A. grinnelli*.

sequence divergence (for ND2, see Materials and Methods) from *A. pulchra* of 8.0%, from *A. grinnelli* of 6.0%, from *A. campi* of 4.9%, and from *A. stebbinsi* of 4.9% (Parham and Papenfuss, 2009).

Description (Based on Holotype). Adult male, 158 mm SVL, 81 mm TL; 81 trunk vertebrae. Coloration in life: dorsal color Pale Olive (5Y 6/4, RGB #A79367), lateral color Strong Orange (5YR 7/12, RGB #A85400), ventral color ventral Light Gray (5Y 7/1, RGB #D3D3D3); a mid-dorsal black stripe one-third scale wide is present from the parietals to the tip of the tail; lateral black stripes one-third scale wide are present from the eye to the tip of the tail.

Rostral large, visible from above; posterior tip pointed and in contact with prefrontals in a slight groove at anterior suture of prefrontals; supraoculars 3-3; preoculars 1-1; postoculars 2-2; occipitals 2-2; supralabials 6-6, first small and located directly beneath nasal with posterior edge in contact with second supralabial, second largest, third and fourth half the length of second and in contact with eye, fifth equal in size to third and fourth and in contact with postoculars; anterior two-thirds of mental contacts first pair of infralabials, posterior pointed one-third of mental inserts in a groove between postmentals; infralabials 5-5; 32 scale rows two head lengths posterior to the interoccipital, 26 scale rows at mid-body; 24 scale rows counted 10 scales anterior to vent; six clear (no dark pigment from stripes) scale rows between dorsal and lateral stripe on right side of body two head lengths posterior to the interoccipital; four clear scale rows at mid-body, four clear scale rows at a point 10 scales anterior to vent; 257 dorsal body scales counted along right side of mid-dorsal line from posterior border of interoccipital to a point above the vent.

Distribution. This species is known from two sites separated by continuous suitable habitat west of Hwy. 33. The known sites are in areas of sandy soil at the southeast base of the Temblor Range between McKittrick and Taft on the west side of the Southern San Joaquin Valley in Kern County, California (Fig. 1). All specimens have been found between California State Highway 33 and the Temblor Range. Detailed searches, including multi-year use of cover boards, have failed to yield *Anniella* in apparent suitable habitat on the floor of the San Joaquin Valley east of Highway 33.

Natural History. All specimens were found under cover boards and flattened cardboard boxes placed on sandy soil. This species is most easily found between February and March when the soil is damp. The known range is in an arid part of California (average annual rainfall at nearby McKittrick is just 184 mm).

Etymology. This species is named after the naturalist Annie Montague Alexander (1867–1950; Fig. 6), who collected thousands of botanical, paleontological, and zoological specimens from western North America and provided intellectual support and crucial endowments for both the Museum of Vertebrate Zoology and the Museum of Paleontology at

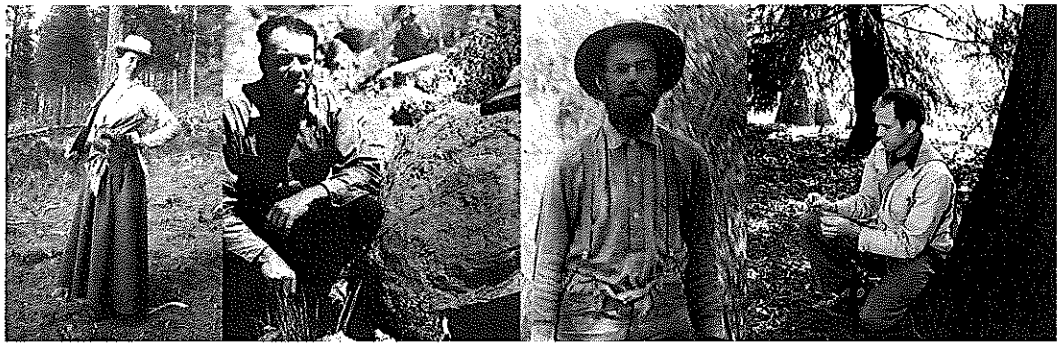

Figure 6. Four natural historians whose contributions to the study of California's vertebrate biodiversity are honored by the new species of *Anniella* described here. Left, Annie Montague Alexander (1867–1950) on expedition collecting Pleistocene fossils at Fossil Lake, Lake County, Oregon, in 1901 (from the UCMP archives). Center left, Charles Lewis Camp (1893–1974) on expedition in San Juan County, Utah, in 1942 (from the UCMP archives) next to the holotype of the Permian tetrapod *Tseajaia campi* Vaughn, 1964. Center right, Joseph Grinnell (1877–1939) on expedition collecting vertebrates in Imperial County, California, in 1910 (from the MVZ archives). Robert Cyril Stebbins (1915–) with an *Ensatina* salamander on the University of California at Berkeley campus in 1951 (from the MVZ archives).

the University of California at Berkeley (Stein, 2001).

Anniella campi, new species
Southern Sierra Legless Lizard
Figure 3

Anniella pulchra lineage D—Parham and Papenfuss, 2009.

Holotype. MVZ 257727 (Fig. 3) from 35.6251°N, 117.9581°W (1,230 m elev.; Figs. 1, 4), Big Spring, 5.8 km NW Junction Hwy. 14 (by Hwy. 178) Kern County, California, U.S.A., collected on March 31, 2006, by Theodore J. Papenfuss.

Paratypes. CAS 233827, an adult male, 233828, an adult female, from 35.6252°N, 117.9581°W (1,240 m elev.; Figs. 1, 4), Big Spring, 5.8 km NW junction Hwy. 14 (by Hwy. 178) Kern County, California, U.S.A., collected on March 31, 2006, by Theodore J. Papenfuss; MCZ R-189380 (Fig. 3), 189381, 189382, adults not sexed from 35.6252°N, 117.9581°W (1,240 m elev.; Figs. 1, 4), Big Spring, 5.8 km NW junction Hwy. 14 (by Hwy. 178) Kern County, California, U.S.A., collected on May 7, 2011, by Theodore J. Papenfuss.

Referred Specimens. MVZ 172784 (Kern County, California, U.S.A.), additional specimens listed in the Appendix of this study and from clade D of Parham and Papenfuss (2009; localities 28 and 29 in the appendix of that study).

Diagnosis. Distinguished from all other species of the *Anniella pulchra* complex by a unique color pattern consisting of continuous, double, dark lateral stripes from the side of the head to the tip of the tail. This character is present in all paratypes and referred specimens. *Anniella campi* shows a maximum mitochondrial sequence divergence (for ND2, see Materials and Methods) from *A. pulchra* of 8.4%, from *A. grinnelli* of 5.8%, from *A. alexanderae* of 4.9%, and from *A. stebbinsi* of 4.3%.

Description (Based on Holotype). Adult male, SVL 152 mm, regenerated TL 60 mm, 74 trunk vertebrae. Coloration in life: dorsal color Yellowish Gray (2.5Y 7/2, RGB #C1AE96), lateral color Vivid Yellow (5Y 7/12, #DBA600), ventral color Vivid Yellow (5Y 8/14, RGB #FBCE00).

Rostral large, visible from above. Posterior tip pointed and in contact with prefrontals

in a slight groove at anterior suture of prefrontals; supraoculars 3-3; preoculars 1-1; postoculars 2-2; occipitals 2-2; supralabials 5-5, first small and located directly beneath nasal with posterior edge in contact with second supralabial, second largest, third, fourth, and fifth half the length of second, third and fourth in contact with eye; anterior two-thirds of mental contacts first pair of infralabials, posterior pointed one-third of mental inserts in a groove between postmentals; infralabials 5-5; 35 scale rows two head lengths posterior to the interoccipital, 32 scale rows at mid-body; 27 scale rows counted 10 scales anterior to vent; five clear scale rows between dorsal and lateral stripe on right side of body two head lengths posterior to the interoccipital; four clear (no dark pigment from stripes) scale rows at mid-body, four clear scale rows at a point 10 scales anterior to vent; 244 dorsal body scales counted along right side of mid-dorsal line from posterior border of interoccipital to a point above the vent.

Distribution. Anniella campi is only known from thee localities along the western edge of the Mojave Desert in Kern and Inyo counties (Fig. 1). The Big Spring locality is a permanent spring that supports a small area of suitable habitat, estimated at less than 2 hectares, in an otherwise desert environment. The *Anniella* population here is clearly relictual since there is no other suitable habitat in the area. Parham and Papenfuss (2009) reported a second along Nine Mile Canyon Road in southern Inyo County, north of Big Spring. A third locality, south of Big Spring in Kern County is represented by a museum specimen that shows the diagnostic character of the complete double lateral stripes (MVZ 172784). Specimens have been found crossing the road at night (Robert W. Hansen, personal communication). It is likely that this species will be found in canyons between Big Spring and Nine Mile Canyon.

Natural History. This species is locally common at Big Spring, where specimens have been collected by raking under debris that has accumulated at the base of Chamisa (*Ericameria nauseosa*) that grow adjacent to the spring. Specimens have been found in April and May.

Etymology. This species is named after Charles Lewis Camp (1893–1974; Fig. 6), former student at the Museum of Vertebrate Zoology and later director of the University of California Museum of Paleontology. On a 1915 collecting expedition to Yosemite National Park with Joseph Grinnell, he discovered the Mt. Lyell salamander, *Hydromantes platycephalus* (Camp, 1916), part of a lineage that is otherwise restricted to the Old World and therefore one of the more significant herpetological discoveries in North America. Charles Camp also participated in successful paleontological expeditions throughout western North America, as well as Africa, Australia, and South America. Camp's (1923) influential "Classification of the lizards" formed the foundation for modern taxonomy of squamates (Estes and Pregill, 1988).

Anniella grinnelli, new species
Bakersfield Legless Lizard
Figure 3

Anniella pulchra lineage C—Parham and Papenfuss, 2009.

Holotype. MVZ 257714, from 35.3054°N, 118.8013°W (254 m elev.; Figs. 1, 4), Jack Zaninovich Memorial Nature Trail, Sand Ridge Preserve, Kern County, California, U.S.A., collected on April 11, 2007, by James F. Parham and Theodore J. Papenfuss.

Paratypes. CAS 234253, an adult male, CAS 234254 and 234255, both adult females, from 35.3894°N, 119.0697°W (130 m elev.), in a field 0.8 km N of Rosedale Hwy. by Fruitvale Ave then 0.3 km E of the end of Price Way, Bakersfield, Kern County, California,

collected on February 1, 2006, by James F. Parham and Theodore J. Papenfuss; MCZ R-189378, R-189379, adult males from 35.3900°N, 119.0608°W (125 m elev.), 0.65 km N of Rosedale Hwy. by Landco Dr., then 0.15 km W at end of Gilmore Ave., Bakersfield, Kern County, California, collected on April 21, 2010, by Theodore J. Papenfuss; MVZ 247487 (Fig. 3), an adult, not sexed, from 35.3894°N, 119.0697°W (120 m elev.) in a field 0.8 km N of Rosedale Hwy. by Fruitvale Ave then 0.3 km E of the end of Price Way, Bakersfield, Kern County, California, U.S.A., collected on April 27, 2002, by Theodore J. Papenfuss; MVZ 250546 (Fig. 3), an adult female from 35.3900°N, 119.0608°W (125 m elev.), 0.65 km N of Rosedale Hwy. by Landco Dr., then 0.15 km W at end of Gilmore Ave., Bakersfield, Kern County, California, collected on April 21, 2010, by Theodore J. Papenfuss; MVZ 267228 (Fig. 3), an adult, not sexed, from 35.3894°N, 119.0697°W (120 m elev.) in a field 0.8 km N of Rosedale Hwy. by Fruitvale Ave. then 0.3 km E of the end of Price Way, Bakersfield, Kern County, California, U.S.A., collected on March 17, 2005, by Theodore J. Papenfuss.

Referred Specimens. Additional specimens listed in the Appendix of this study and from clade C of Parham and Papenfuss (2009; localities 24 through 27 in the appendix of that study).

Diagnosis. Distinguished from all other species of *Anniella* by a unique ventral coloration of Grayish Red (2.5R 4/2, RGB #755A61). This coloration is continuous from the anterior end of the lower jaw to the end of the tail and is present in all paratypes and known specimens. It is further distinguished from *A. pulchra, A. stebbinsi,* and *A. campi* by its higher vertebral count (Fig. 5). *Anniella grinnelli* shows a maximum mitochondrial sequence divergence (for ND2, see Materials and Methods) from *A. pulchra* of 9.2%, from *A. stebbinsi* of 6.4%, from *A. alexanderae* of 6.0%, and from *A. campi* of 5.8%.

Description (Based on Holotype): Adult male, 148 mm SVL, 93 mm TL; 79 trunk vertebrae. Coloration in life: dorsal color Light Olive Gray (7.5Y 5/2, RGB #837A67), lateral color Strong Orange (5YR 7/12, RGB #A85400), ventral color Grayish Red (2.5R 4/2, RGB #755A61 [appears purple]); a mid-dorsal black stripe one-half scale wide is present from the parietals to the tip of the tail; lateral black stripes one scale wide are present from the eye to the tip of the tail.

Rostral large, visible from above, posterior side flat and in contact with prefrontals; supraoculars 3-3; preoculars 1-1; postoculars 2-2; occipitals 2-2; supralabials 6-6, first small and located directly beneath nasal, second largest, third and fourth half the length of second and in contact with eye; mental rounded and broadly in contact with first pair of infralabials and postmentals; infralabials 5-5; 30 scale rows two head lengths posterior to the interoccipital, 25 scale rows at mid-body; 23 scale rows counted 10 scales anterior to vent; seven clear (no dark pigment from stripes) scale rows between dorsal and lateral stripe on right side of body two head lengths posterior to the interoccipital; five clear scale rows at mid-body, six clear scale rows at a point 10 scales anterior to vent; 239 dorsal body scales counted along right side of mid-dorsal line from posterior border of interoccipital to a point above the vent.

Distribution. This known range of *A. grinnelli* is restricted to the southern San Joaquin Valley and the east side of the Carrizo Plain (Fig. 1). Specimens have been collected within the city limits of Bakersfield. During the last 10 years, two of the three known Bakersfield populations were destroyed by housing development. A protected population is located at the type locality, the

Sand Ridge Preserve. Individuals from the Carrizo Plain are similar in coloration and mitochondrial sequences to San Joaquin samples but have a nuclear genotype known only from lineage B. Parham and Papenfuss (2009) speculated that this population may be a hybrid or intergrade population, but we include Carrizo specimens in our concept of *A. grinnelli* (Fig. 1).

Natural History. All specimens were found under cover objects (plywood scraps and flattened cardboard boxes) that had been placed on sandy soil. The type locality is a stable sand dune of Pleistocene origin (Fig. 4).

Etymology. This species is named after Joseph Grinnell (1877–1939; Fig. 6), the first director of the Museum of Vertebrate Zoology at the University of California at Berkeley. Joseph Grinnell published hundreds of scientific papers based on his extensive collecting and surveys in western North America, and developed the Grinnell Method of note taking that has become the standard for natural history observations.

Anniella stebbinsi, new species
Southern California Legless Lizard
Figure 3

Anniella pulchra lineage E—Parham and Papenfuss, 2009

Holotype. MVZ 267246, from 33.9500°N, 118.4415°W (24 m elev.; Figs. 1, 4), El Segundo Dunes, Los Angeles International Airport, Los Angeles County, California, U.S.A., collected on April 20, 2010, by Theodore J. Papenfuss.

Paratypes. MVZ 267247, a subadult male collected with the holotype; MVZ 250558 (Fig. 3), a subadult male from 34.0042°N, 118.8100°W (5 m elev.), Point Dume, Los Angeles County, California, U.S.A., collected on November 24, 2005, by Theodore J. Papenfuss. MVZ 267248 (Fig. 3), from 33.9015°N, 116.7447°W (470 m elev.), 4.0 km SE (airline) of Cabazon, Riverside County, California, U.S.A., collected on March 19, 2005, by Theodore J. Papenfuss.

Referred Specimens: LACM 64583 (karyotyped specimen [Bezy *et al.*, 1977] from the type locality in Los Angeles County, California, U.S.A.), SDNHM 42040, 42041, 42876, 42878, 42879 (San Diego County, California, U.S.A.), additional specimens listed in the Appendix of this study, and from clade E of Parham and Papenfuss (2009; localities 30–45 in the appendix of that study, but excluding the *A. geronimensis* from locality 41 [Colonia Guerrero]).

Diagnosis. Distinguished by its yellow ventral coloration from *A. grinnelli*, which has a purple (grayish-red) ventral coloration and from *A. alexanderae*, which has a light gray ventral coloration. Distinguished from *A. pulchra* which also has a yellow ventral coloration by a somatic chromosome number of 2n = 20 rather than 2n = 22 (Bezy *et al.*, 1977). Distinguished from *A. campi*, which also has a yellow ventral coloration by a single dark lateral stripe on each side rather than a double lateral stripe. Some specimens of *A. stebbinsi* have a double lateral stripe, but it is never continuous or exceeds 50% of the combined body and tail length, whereas in *A. campi* it is continuous and extends to the tip of the tail. *Anniella stebbinsi* shows a maximum mitochondrial sequence divergence (for ND2, see Materials and Methods) from *A. pulchra* of 8.7%, from *A. grinnelli* of 6.4%, from *A. alexanderae* of 4.9%, and from *A. campi* of 4.3%.

Description (Based on Holotype). Adult female, SVL 132 mm, regenerated TL 81 mm, 79 trunk vertebrae. Coloration in life: dorsal color Light Olive Brown (2.5Y 5/2, RGB #8B7863), lateral color Strong Yellow (RGB #E1A129), ventral color Moderate Yellow (5Y 7/8, RGB #CFA639); mid-dorsal black stripe less than one scale wide is present from the parietals to the tip of the tail; lateral

black stripes one scale wide are present from the eye to the tip of the tail.

Rostral large, visible from above, posterior tip pointed and in contact with prefrontals in a slight groove at anterior suture of prefrontals; supraoculars 3-3; preoculars 1-1; postoculars 2-2; occipitals 2-2; supralabials 6-6, first small and located directly beneath nasal with posterior edge in contact with second supralabial, second largest, third and fourth two-thirds the length of second and in contact with eye; mental rounded, broadly in contact with first pair of infralabials and postmentals; infralabials 4-4; 30 scale rows two head lengths posterior to the interoccipital, 28 scale rows at mid-body; 24 scale rows counted 10 scales anterior to vent; six clear (no dark pigment from stripes) scale rows between dorsal and lateral stripe on right side of body two head lengths posterior to the interoccipital; five clear scale rows at mid-body, five clear scale rows at a point 10 scales anterior to vent; 215 dorsal body scales counted on right side of mid-dorsal line from posterior border of interoccipital to a point above the vent; 215 dorsal body scales counted along right side of mid-dorsal line from posterior border of interoccipital to a point above the vent.

Distribution. Throughout Southern California south of the Transverse Ranges into northern Baja California, Mexico (Fig. 1). Populations in the Tehachapi and Piute mountains of Kern County are disjunct from the main distribution of this species to the south. Therefore, the distribution of *A. stebbinsi* is presumably bisected by southern populations of *A. pulchra* ranging from the Santa Barbara region into the Antelope Valley of the western Mojave Desert (Fig. 1; Parham and Papenfuss, 2009). Based on the bulk of their hypothesized range, we recommend the common names of "Northern California legless lizard" for *A. pulchra* and "Southern California legless lizard" for *A. stebbinsi.*

Natural History. Anniella stebbinsi is found in a broader range of habitats that any of the other species in the genus. Often locally abundant, specimens are found in coastal sand dunes and a variety of interior habitats, including sandy washes and alluvial fans (Stebbins and McGinnis, 2012). Much of the coastal dune habitat has been destroyed by coastal development between Ventura County and the Mexican Border. Fortunately, a large protected population persists in the remnant of the once extensive El Segundo Dunes at Los Angeles International Airport (Fig. 4).

Anniella stebbinsi is common at the western margin of the Colorado Desert under trash dumped at the base of Mt. San Jacinto in the vicinity of Cabazon, Riverside County. Here the only large shrub is Creosote (*Larrea tridentata*). The seasonal Whitewater River provides sufficient moisture near the surface. The disjunct northern populations occur in sandy soils in the Piute and Tehachapi mountains at elevations of 400–900 m in both Oak Woodland and Mixed Conifer Forest. In the lower drainage of Caliente Creek at Caliente Post Office, individuals have been collected beneath cardboard cover placed under Scalebroom bushes (*Lepidospartum squamatum*). There is continuous sandy habitat along Caliente Creek between Caliente Post Office and Sand Ridge Preserve, the type locality for *A. grimmelli.* Additional fieldwork is needed to document the location of an almost certain contact between these two species. Contact between *A. stebbinsi* and *A. pulchra* is likely along the coast of California between the cities of Santa Barbara and Oxnard and along the southeastern slope of the Tehachapi Mountains, where *A. pulchra* is common in Joshua/Juniper woodland.

Etymology. This species is named after Robert Cyril Stebbins (1915–; Fig. 6) who was appointed the first Curator of Herpetol-

ogy at the Museum of Vertebrate Zoology in 1945. Robert Stebbins' contribution to western North American herpetology includes many scientific publications, but especially his classic, comprehensive, beautifully self-illustrated, and influential field guides (Stebbins 1951, 1954, 1960, 1966, 1972, 1985, 2003; Stebbins and McGinnis, 2012).

CONSERVATION IMPLICATIONS

The former *A. pulchra*, a species of special concern (Jennings and Hayes, 1994), is now divided into five species. This means *A. pulchra* has a smaller distribution than previously recognized, thereby enhancing concern about its conservation status. The remaining four species have even smaller ranges, some of which are degraded or threatened by human activities. Whereas much of the range of *A. stebbinsi* is already compromised by urban development, the conservation implications for the other three new species are even more striking because of their very limited distributions. *Anniella grinnelli* is known from a few sites in the southern San Joaquin Valley, an area that has been greatly modified by urban and agricultural development (PPIC, 2006; Great Valley Center, 2007). *Anniella grinnelli* persists in small patches within the Bakersfield city limits, but some of the populations we collected were extirpated by development during the course of this study. The type locality at the Sand Ridge Preserve is a secure site that will help ensure the species survival. *Anniella alexanderae* is known from two sites at the base of the Temblor Mountains, and should be considered rare pending further study. Finally, *Anniella campi* is known from just three sites. This species may be restricted to the vicinity of potentially fragile springs in canyons that open into the Mojave Desert and so warrants careful monitoring. Additional research into the distribution, contact zones, and diversity of *Anniella* is clearly needed.

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Appendix 1

The following specimens were used for the vertebral counts (shown in parentheses) summarized in Table 1 and 2: ***A. alexanderae***: CAS 238588 (82); MCZ R-189383 (84); MCZ R-189384 (83); MCZ R-189385 (82); MCZ R-189386 (82); MVZ 250528 (81); MVZ 250549 (83); MVZ 250550 (80); MVZ 250570 (81); MVZ 250573 (81); MVZ 250574(82); MVZ 250575 (83); MVZ 250576 (82); MVZ 257082 (84); MVZ 257717(84); MVZ 257718 (81); MVZ 257720 (82); MVZ 257741 (82). ***A. campi***: MCZ R-189380 (78); MCZ R-189381 (76); MCZ R-189382 (78); MVZ 104771 (76); MVZ 228817 (77); MVZ 228818 (77); MVZ 228819 (77); MVZ 228829 (78); MVZ 232844 (76); MVZ 257727 (74); MVZ 257728 (75); MVZ 257729 (78); MVZ 257730 (75). ***A. grinnelli***: MCZ R-189378 (79); MCZ R-189379 (83); MVZ 230663 (83); MVZ 230665 (74); MVZ 247487 (82); MVZ 250527 (84); MVZ 250534 (81); MVZ 250541 (81); MVZ 250542 (79); MVZ 250543 (86); MVZ 250545 (84); MVZ 250546 (83); MVZ 250547 (83); MVZ 250548 (82); MVZ 257714 (79); MVZ 257716 (80); MVZ 257724 (80); MVZ 257725 (80); MVZ 257726 (80); MVZ 257737 (82); MVZ 257738 (81). ***A. pulchra***: MVZ 27300 (73); MVZ 33793 (78); MVZ 33795 (76); MVZ 33796 (75); MVZ 33860 (73); MVZ 45612 (74); MVZ 58106 (75); MVZ 58410 (78); MVZ 60216 (74); MVZ 60292 (75); MVZ 64105 (76); MVZ 64106 (76); MVZ 71919 (75); MVZ 71920 (75); MVZ 71921 (74); MVZ 71922 (75); MVZ 84593 (73); MVZ 83594 (75); MVZ 117600 (75); MVZ 223384 (74); MVZ 227778 (73); MVZ 228815 (74); MVZ 228816 (75); MVZ 228832 (78); MVZ 247488 (72); MVZ 247489 (74); MVZ 250536 (78); MVZ 250537 (80); MVZ 250538 (79); MVZ 250539 (79); MVZ 250540 (78); MVZ 250562 (79); MVZ 250563 (78); MVZ 250564 (78); MVZ 250566 (79); MVZ 250567 (79); MVZ 250569 (79). ***A. stebbinsi***: MVZ 226854 (75); MVZ 226855 (75); MVZ 226856 (74); MVZ 226857 (77); MVZ 226859 (75); MVZ 226860 (76); MVZ 226863 (75); MVZ 228844 (75); MVZ 228861 (74); MVZ 230554 (77); MVZ 230556 (75); MVZ 230666 (76); MVZ 230667 (75); MVZ 230668 (77); MVZ 230669 (78); MVZ 230673 (81); MVZ 230674 (74); MVZ 230675 (73); MVZ 230676 (74); MVZ 230677 (74); MVZ 230678 (74); MVZ 232618 (77); MVZ 232619 (77); MVZ 232621 (76); MVZ 250552 (75); MVZ 250553 (73); MVZ 250577 (75); MVZ 250731 (74); MVZ 250732 (77); MVZ 250733 (76); MVZ 257743 (74); MVZ 257744 (73); MVZ 257745 (76); MVZ 274645 (78); MVZ 267246 (71); MVZ 267247 (71). The following specimens were used for the dorsal scale counts (shown in parentheses) summarized in Table 1 and 2: ***A. alexanderae***: MVZ 250528 (257); MVZ 250550 (255); MVZ 250570 (257); MVZ 250574 (263); MVZ 250576 (252); MVZ 257718 (268); MVZ 257720 (265); MVZ 257739 (256); MVZ 257741 (261); MVZ 267236 (278). ***A. campi***: MVZ 104771 (223); MVZ 172784 (227);

MVZ 228817 (230); MVZ 228818 (224); MVZ 228819 (222); MVZ 228820 (235); MVZ 228821 (223); MVZ 257727 (244); MVZ 257728 (219); MVZ 267231 (229). ***A. grinnelli***: MVZ 230663 (234); MVZ 250527 (246); MVZ 250527 (246); MVZ 250534 (248); MVZ 250543 (234); MVZ 250546 (243); MVZ 250547 (249); MVZ 257714 (239); MVZ 257726 (247); MVZ 257742 (238). The following specimens were used to evaluate ventral coloration (see Materials and Methods): ***A. alexanderae***: CAS 238588; MVZ 250570; MVZ 250549; MVZ 257739. ***A. campi***: MVZ 257727; MVZ 257728. ***A. grinnelli***: CAS 234252; MVZ 250546; MVZ 257718; MVZ 257737; MVZ 257738. ***A. pulchra***: MVZ 257098; MVZ 257731; MVZ 257732. ***A. stebbinsi***: MVZ 250552; MVZ 250553; MVZ 250556; MVZ 257723; MVZ 257735.

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