MENEKEN, B. M., A. C. S. KNIPPS, J. N. LAYNE, AND K. G. ASHTON. 2005. *Neoseps reynoldsi*. Longevity. Herpetological Review 37:164–165.

MORTON, S. R., AND C. D. JAMES. 1988. The diversity and abundance of lizards in arid Australia: a new hypothesis. American Naturalist 132:237–256.

MYERS, C. W., AND S. R. TELFORD JR. 1965. Food of *Neoseps*, the Florida Sand Skink. Quarterly Journal of the Florida Academy of Sciences 28:190–194.

PIANKA, E. R. 1986. Ecology and Natural History of Desert Lizards. Princeton Univ. Press, Princeton, NJ.

ROFF, D. A. 1992. The Evolution of Life Histories: Theory and Analysis. Chapman and Hall, New York.

SHINE, R., AND A. E. GREER. 1991. Why are clutch sizes more variable in some species than in others? Evolution 45:1696–706.

SMITH, C. R. 1982. Food resource partitioning of fossorial Florida reptiles. *In* N. J. Scott (ed.), Herpetological Communities, pp. 173–78. Wildlife Research Report 13, U.S. Department of the Interior, Washington, DC.

STEARNS, S. C. 1992. The Evolution of Life Histories. Oxford Univ. Press, Oxford.

SUTTON, P. E. 1996. A Mark and Recapture Study of the Florida Sand Skink, *Neoseps reynoldsi*, and a Comparison of Sand Skink Sampling Methods. Unpubl. master's thesis, Univ. of South Florida, Tampa.

SUTTON, P. E., H. R. MUSHINSKY, AND E. D. MCCOY. 1999. Comparing the use of pitfall drift fences and cover boards for sampling the threatened sand skink (*Neoseps reynoldsi*). Herpetological Review 30: 149–151.

TELFORD JR., S. R. 1959. A study of the sand skink, *Neoseps reynoldsi* Stejneger. Copeia 1959:110–119.

———. 1969. *Neoseps reynoldsi*. Catalogue of American Amphibians and Reptiles 80:1–2.

———. 1998. Monitoring of the sand skink (*Neoseps reynoldsi*) in Ocala National Forest. Final project report, USDA Forest Service, Ocala National Forest, FL.

TINKLE, D. W., H. M. WILBUR, AND S. G. TILLEY. 1970. Evolutionary strategies in lizard reproduction. Evolution 24:55–74.

VITT, L. J. 1992. Diversity of reproductive strategies among Brazilian lizards and snakes: the significance of lineage and adaptation. *In* W. C. Hamlett (ed.), Reproductive Biology of South American Vertebrates, pp. 135–149. Springer-Verlag, New York.

ZAR, J. H. 1996. Biostatistical Analysis. 3rd ed. Prentice Hall, Upper Saddle River, NJ.

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Microhabitats and Population Densities of California Legless Lizards, with Comments on Effectiveness of Various Techniques for Estimating Numbers of Fossorial Reptiles

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ABSTRACT.—**We studied the cryptic fossorial legless lizard (*Anniella pulchra*) in a 1.57-ha area of sand dune on the coast of central California. This is the largest and most dense population of *A. pulchra* (N = 3,582; 0.228/m^2) known to date. We documented distribution of animals through systematic removal and relocation of lizards at the site and with GIS analyses. Lizard density was high near shrubs and where soil moisture was greater but lower in disturbed soils and in iceplant. We also conducted time-constrained searches and coverboard surveys to analyze the efficacy of standard survey methods for legless lizards. Moderate-impact time-constrained searches were more effective in establishing presence of lizards when compared to low-impact time-constrained searches and coverboard surveys. Our data show that standard methods may not be effective in establishing presence or absence of this lizard at low densities. None of the survey methods was effective in predicting the density of lizards actually present.**

California Legless Lizards (*Anniella pulchra*) are fossorial animals that typically inhabit sand or loose soils within a variety of environments including coastal dunes, oak woodlands, and montane forests (Miller, 1944; Hunt, 1983; Jennings and Hayes, 1994). They are endemic to California and northern Baja California (Stebbins, 1954; Gorman, 1957; Hunt, 1984; Bury, 1985; Jennings, 1987). *Anniella pulchra* are most commonly found within 100 km of the coast (Jennings and Hayes, 1994; Hunt, 1997). Because of extensive loss of

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habitat resulting from urban and agricultural development, *A. pulchra* is listed as a Species of Special Concern by the California Department of Fish and Game (2004).

Although *A. pulchra* are rarely observed above ground, they use the ecotone at the soil/leaf litter interface for feeding (Miller, 1944; Kuhnz, 2000a) and apparently for mating (Kuhnz, 2000a). Legless lizard movement, foraging, and reproductive behaviors are closely tied to microhabitat features such as mature leaf litter, a high fraction of sand in the soil, and below-ground root structure. Presumably, this species is negatively impacted by complete alteration of suitable habitat and by degradation of habitats through the loss of native plant communities and the introduction of exotic weeds.

In the central California coastal dune setting, perennial shrubs such as bush lupine (*Lupinus arboreus*, *Lupinus chamissonus*), and mock heather (*Ericameria ericoides*) produce abundant leaf litter beneath the canopy and have strong root systems. These features may attract insect prey, moderate temperature, and reduce soil moisture loss and erosion. Annual grasses and forbs do not produce abundant mature litter and have ephemeral root structures and, therefore, may offer little protection from higher ground temperatures and soil desiccation (Slobodchikoff and Doyen, 1977). Monocultural mats of South African iceplant (*Carpobrotus edulis*) may dramatically reduce soil temperature and water loss, but they offer poor root structure and low soil aeration and may not support a suitable insect prey base (Rein, 1999; Tassan et al., 1982; Powell, 1978).

Physical characteristics of soils may be important components in habitat suitability for legless lizards. For example, organic composition may affect compaction, temperature, and the moisture retention capacity of soil. Grain size distribution can also affect the degree of substrate compaction, and topography may affect water flow and retention.

We examined the relationship between microhabitat characteristics (i.e., vegetation, soil type, and topography) and legless lizard densities in a coastal dune setting in central California in conjunction with a large construction project that required translocation of California Legless Lizards. The project also gave us the opportunity to evaluate common techniques used to survey for this species and directly measure population densities within a constrained area.

Prior survey methods for legless lizards include coverboard surveys (Hunt and Zander, 1997), time-constrained searches (Bury and Raphael, 1983; Bury, 1985), fixed-area plot sampling (Szaro et al., 1988), and pit-fall or funnel traps (Block et al., 1988). The sensitivity of these sampling techniques at varying population densities has been uncertain, and this investigation provided a unique opportunity to understand the efficacy of various methods because we removed all of the lizards within the study area and, therefore, quantified the entire population. In this study, we used the most common techniques to survey for legless lizards in areas of the undisturbed construction site and then compared the results to our estimate of the total number of lizards, derived from depletion surveys of the site.

Materials and Methods

Study Area.—We conducted this study on a coastal dune at Moss Landing, California, in conjunction with construction of the new Moss Landing Marine Laboratories, which replaced the facilities destroyed in the Loma Prieta earthquake of 1989. Vegetation at this site was predominantly nonnative weeds and short-lived native shrubs. R. Milliken, J. Nelson, W. Hildebrandt, and P. Mikkelson (unpubl., 1999) characterized the major soil type within the construction area as fine-grained, loosely compacted, loamy sand containing moderate amounts of organic material from plant oils. Preconstruction surveys confirmed the presence of California Legless Lizards at the site.

Removal and Translocation of Lizards.—From September through December 1997 and between March and November 1998, the nearly 1.6-ha construction site was searched to depletion, and all legless lizards were translocated to an adjacent undeveloped section of the dune. Prior to depletion surveys, we constructed an impenetrable perimeter barrier around the exterior and subsections of the site, buried upright to a depth of 55 cm.

The capture, temporary housing, and release of legless lizards followed protocols approved by the San Jose State University Institutional Animal Care and Use Committee (Protocol 764), and we obtained state and federal permits. We systematically searched individual plots five to seven times using 12–15 people who carefully raked the sandy soil with a mulch rake. Plots were considered depleted of legless lizards when one or fewer legless lizards were found per 40 hours of search effort. We documented the type of vegetation under which each lizard was found. Because of habitat disturbance and the possibility of a lizard moving away (horizontally or vertically) in response to activity or searchers, we also recorded which lizards were captured in undisturbed habitat during the first raking. We recorded capture locations with a Trimble Pro-XR differentially correcting global position system (DGPS). We documented snout–vent length (SVL), tail and regrown tail lengths, plus mass to the nearest 0.1 g. To date, there are no published data regarding growth rates and ages of California Legless Lizards, and we could not document male to female ratios because they are not externally sexually dimorphic (Hunt, 1984). We used modifications of Miller's (1944) age categories for estimating age classes based on SVL.

Captured lizards were released into an adjacent 2.43-ha area of dune, which we were actively restoring by removing weeds and by planting and allowing the regrowth of native coastal scrub vegetation. We eliminated weeds, which facilitated the recolonization of the native plant community, in large part by planting silver bush lupine, California poppy, lizard tail, several species of buckwheat, and 15,000 yellow bush lupines (Slattery et al., 2003). We used microchips (Passive Integrated Transponders) to tag nearly 600 lizards prior to their release (Kuhnz, 2000a,b).

We surveyed the vegetation within the undisturbed construction site at 90 randomly placed quadrats (0.25 m^2), each containing 10 randomly placed points. We based estimates of the percent coverage of plant species on the number of points in contact with each plant and noted other plant species that were not contacted by a point. We confirmed sitewide estimates of vegetation cover using two additional methods: (1) by recording DGPS coordinates to calculate the area of vegetation stands; and (2) by measuring the areal extent of each plant category from color aerial photographs (scale 1:1239). We only used animals collected during the first rakings to estimate number of lizards associated with each plant type.

A map of soil types (R. Milliken, J. Nelson, W. Hildebrandt, and P. Mikkelson, unpubl., 1999) was digitized and georeferenced using a digital orthophoto quadrangle from the United States Geological Service and TNTmips v6.0 (Micro Images, Lincoln, Nebraska, 1998). We plotted capture positions on this base map and counted the number of lizards associated with each soil type.

We used a georeferenced color aerial photograph (scale 1:1239) with field observations and created a 3-D digital elevation model (DEM) to delineate depressions (swales) in the topography within the study area. We counted the number of lizards found in swales.

A log-likelihood ratio for goodness-of-fit test was used to compare the observed versus expected frequencies (Zar, 1984). The expected number of legless lizards in individual vegetation, soil, and swale categories was calculated by dividing the total number of lizards by the percent area each individual category constituted within the site.

Survey Methods.—We tested time-constrained searches within each plot while varying the level of impact to the habitat. Five trained workers conducted 30-min surveys. Using no tools, searchers conducting low-impact time-constrained searches looked for legless lizards within a plot boundary, on the surface, under dried vegetation or objects, and to a depth of 5–7 cm below the surface, while minimizing disturbance of vegetation. We restored disturbed materials, as close as possible, to presampling conditions. Moderate-impact time-constrained searches involved more extensive disturbance of vegetation and duff layers. Searchers used hand tools and surveyed for lizards to a depth of 15 cm below the surface by removing patches of annual vegetation and by pushing aside, but not uprooting, larger perennial plants.

We installed and monitored 38 randomly placed 60 × 60 cm wood coverboards for 37 months. Monthly, we surveyed the coverboards by searching under them and digging to 15 cm. To estimate the population of legless lizards in the coverboard area, we extrapolated the mean density of legless lizards removed from the construction area and added the number of animals relocated to the site. We also used the results of a mark-recapture study at this site to validate the population estimate (Kuhnz, 2000a).

Results

Removal and Translocation of Lizards.—Overall 3,582 California Legless Lizards were removed from 1.57 ha, with a mean density of 0.228 lizards/m^2. We recorded the geographic location of 3314 captured lizards. With complete removal of vegetation, the mean catch per effort was 0.3 lizards per person-hour (1572 person-hours) for a typical 0.219 ha area yielding 475 lizards. When considering all lizard captures, 57.3% were taken in the first raking, an additional 25.5% were removed in the second raking, followed by 9.8% for rake three, 4.5% for rake four, 2.3% for rake five, 0.5% for rake six, and 0.1% for rake seven. The greatest single density, 1.67 lizards/m^2, was found under a yellow lupine bush (17 lizards in 10.17 m^2). We also found other yellow and blue lupine bushes with high densities of up to 0.78 lizards/m^2.

Fifty-six percent of the animals ($N = 2006$) had intact tails, allowing us to calculate mean total body length (173.7 ± 35.1 mm, range 50–294 mm), SVL (113.2 ± 20.6 mm, range 31–172 mm), tail length (60.5 ± 17.5 mm, range 31–122 mm), and mass (3.3 ± 1.3 g, range 0.6–8.5 g) with a large sample. The majority of the 3518 lizards we measured were adults (SVL > 120 mm, 57.6%), with about equal numbers of juveniles (SVL 83–100 mm, 18.2%) and subadults (SVL 111–120 mm, 17.6%); 6.6% were yearlings (SVL < 83).

We found 28 plant species in 90 quadrats (Table 1). Legless lizards ($N = 1714$ located during the first raking session) were not distributed randomly among vegetation categories ($G_{0.05,6} = 1049.7$; $P < 0.001$). Significantly more

TABLE 1. Percent ground cover occurring in 90 random quadrats (0.25 m^2) at the Moss Landing, California, site for 10 randomly placed points. Total reported cover for seven major categories is reported (*).

Species	Common name	% Cover
Bromus diandrus	Ripgut Brome	27.1
Montia perfoliata	Miner's Lettuce	4.8
Vulpia bromoides	Six-week Fescue	4.3
Chroizanthe p. pungens	Monterey Spineflower	3.2
Marah fabaceus	Man-root	2.4
Avena barbata	Wild Oat	2.3
Chenopodium californicum	California Goosefoot	2.3
Amsinckia spectabilis	Fiddleneck	1.0
Phacelia distans	Phacelia	1.0
Raphanus sativus	Wild Radish	1.0
Stellaria media	Chickweed	1.0
Artemesia douglasiana	Mugwort	0.6
Eschscholzia californica	California Poppy	0.4
Lactuca serriola	Prickly Lettuce	0.2
Achillea millefolium	Common Yarrow	0.1
Conium maculatum	Poison Hemlock	0.1
Sinapis arvensis	Mustard	0.1
Sonchus oleraceus	Common Sow Thistle	0.1
Lotus scoparius	Deerweed	0.1
Cryptantha leoicarpa	Popcorn Flower[a]	—
Leymus triticoides	Creeping Wild Rye[a]	—
	*Total Grass/Forbs	52.1
Carpobrotus edulis	Iceplant	22.6
	*Total Iceplant	22.6
Lupinus chamissonus	Silver Bush Lupine	8.3
	*Total Silver Bush Lupine	8.3
Rubus ursinus	California Blackberry	3.6
	*Total Blackberry	3.6
Lupinus arboreus	Yellow Bush Lupine	3.5
	*Total Yellow Bush Lupine	3.5
Ericameria ericoides	Mock Heather	2.7
	*Total Mock Heather	2.7
Rosa californica	California Rose	0.3
Marrubium vulgare	Horeghound[a]	—
	Duff	0.3
	Bare Sand	6.6
	*Total Other	7.2

[a] Present in low abundance within quadrats, not quantified.

animals were found near shrubs (e.g., silver bush lupine, mock heather, and yellow lupine) than expected by chance (Fig. 1). There were fewer legless lizards than expected in areas dominated by grasses, forbs, and iceplant.

Most of the site had a base of yellow sand overlain by 20–40 cm of dark brown A horizon, yet there were surface outcrops of yellow sand, charcoal-infused sand (midden) and cemented clay/silt-rich sand, along with areas where these soils had been mixed by disturbance. We found that legless lizards were not randomly distributed among these soil types ($G_{(0.05,7)} = 1350.5$ $N = 3{,}314$, $P < 0.001$). Disturbed sands (charcoal-infused and yellow sand with brown A horizon) contained fewer lizards than expected, whereas undisturbed substratum (yellow sands with brown A horizon and charcoal infused sands) contained more animals than expected (Fig. 2).

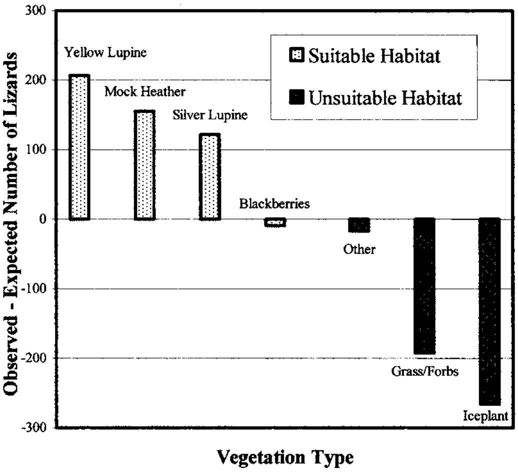

FIG. 1. Legless lizard distribution among vegetation categories for lizards found during initial depletion searches at Moss Landing, California, in 1997 and 1998 ($N = 1714$). Habitat quality is based on the difference between the log-likelihood ratio for goodness-of-fit test, expected versus observed frequencies of animals for each category.

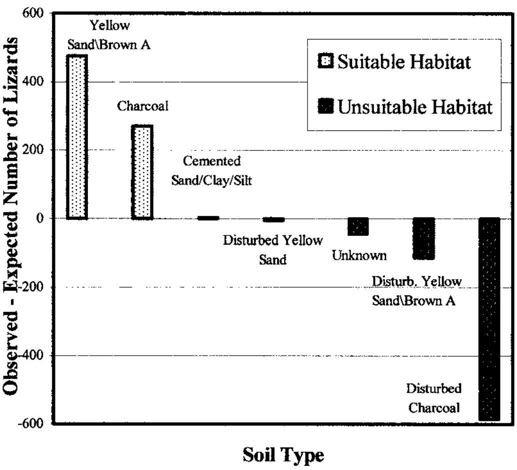

FIG. 2. Legless lizard distribution among soil categories for lizards found during depletion searches at Moss Landing, California, in 1997 and 1998 ($N = 3314$). Habitat quality is based on the difference between the observed versus expected frequencies of animals for each category.

TABLE 2. We conducted low and moderate habitat impact surveys in undisturbed plots and then removed all legless lizards to depletion. Plot size, number of legless lizards removed during depletion raking, density calculated as number of individuals/100 m^2, and numbers and percent of legless lizards captured during surveys at Moss Landing, California, in 1998 are shown.

Plot size (m^2)	# Removed lizards at depletion	Density (#/100 m^2)	# Lizards low-impact search	% Lizards located low-impact	# Lizards moderate-impact search	% Lizards located moderate-impact
501	7	1	0	0	0	0
980	77	8	6	7.8	8	10.4
622	71	11	3	4.2	5	7
929	109	12	7	6.4	7	6.4
746	200	27	6	3	14	7
1773	701	40	5	0.7	9	1.3
366	166	45	4	2.4	13	7.8
675	332	49	7	2.1	12	3.6
213	114	54	8	7	16	14
369	213	58	3	1.4	12	5.6

The proportion of lizards found in sterile, disturbed yellow sand was consistent with the expected number. The density of legless lizards found in compact sands (cemented sand, clay, and silt) was also close to the overall average density.

The density of legless lizards was significantly greater in swales (0.407 lizards/m^2) than in nonswale areas (0.190 lizards/m^2, $G_{0.05,1}$ = 242.21, $P < 0.001$, $N = 3314$). The high density of animals in swales was not related to soil type within the swales. Most of the swale area consisted of yellow sands with a brown A horizon (1150 m^2, 77%), with the remaining areas being comprised of disturbed yellow sands and cemented sands. The average density of 0.407 legless lizards/m^2, calculated from the number of animals found within the swale areas, was greater than the densities calculated for legless lizards found in yellow sands (0.283/m^2), disturbed yellow sands (0.207/m^2), or cemented clay/silt-rich sands (0.213/m^2).

Survey Methods.—On average, moderate-impact time-constrained searches revealed twice as many legless lizards (mean ± SD = 9.6, ± 4.9, 2.5 person-hours) than did low-impact time-constrained searches (4.9 ± 2.4, 2.5 person-hours), a difference that was statistically significant (T_9 = 4.10, $P = 0.002$; Table 2.). At very low densities (about one animal/100 m^2), we did not detect any legless lizards with either sampling method. At slightly higher densities (eight to 12 animals/100 m^2), we found five to nine animals with moderate-impact area searches and three to seven animals with the low-impact method. In plots supporting the highest densities (40–58 individuals/100 m^2), we found seven to 13 animals with moderate-impact sampling, whereas three to eight were found with the low-impact method. We found no correlation between the number of legless lizards detected during time-constrained searches and the number of animals actually present or the density of legless lizards removed during depletion raking.

We found 100 legless lizards under coverboards in 1292 searches over a 37-month period; sampling effort totaled 323 person-hours. The number of animals detected under coverboards ranged from zero to 10 per month (2.94 ± 2.32). Given a total estimated population of 9000 lizards, the mean percent found under coverboards in a given month was 0.03 (SD = 0.03).

DISCUSSION

In preliminary nondepletion studies of the Moss Landing dune, Bury (1985) estimated the density of legless lizards to be about 11 animals per 1000 m^2 (0.011/m^2, 1 person-hour) and Miller (1944) found 26 animals per 0.93 ha (no number of lizards/person-hour reported). Based on these estimates, we expected that about 170 legless lizards might live within the 1.57-ha construction site, but we removed 3582. This is the largest and most dense legless lizard population known. The large difference between the estimated and actual population size suggests that either this population had grown unusually large since Bury (1985) or Miller (1944) last surveyed the site or the methods that have been used to survey for this secretive animal are insufficient for estimating population size.

There are several physical and biotic factors at this site that may be unique, thus allowing what may be an unusually high population of legless lizards. For example, humans have occupied this particular locale for nearly 8000 yr and their middens resulted in very high nutrient levels within the coastal dune soils, which are normally nutrient deprived (R. Milliken, J. Nelson, W. Hildebrandt, and P. Mikkelson, unpubl., 1999). These nutrient-laden soils have allowed uncommonly vigorous plant growth, resulting in a rich vegetative cover, thick duff layers, and a rich invertebrate prey base. High nutrient soil and the resulting insect fauna produces robust animal populations. Alternatively, the topography along with the organic and granular composition of the dunes may result in the retention of unusually high or persistent levels of water, which might have enhanced the substrate both as a space to move through and as a source of metabolic water. In addition, the cessation of some of the more intensive disturbance imposed on this site in the past may have allowed some of these factors to aid the recovery of dune vegetation and soils over the past two or three decades, thereby enabling the legless lizard population to grow beyond previously reported estimates.

Results of this study demonstrate that legless lizards at this site are more abundant among the native yellow lupine, mock heather, and silver lupine bushes, and they are far less abundant among the nonnative grasses, forbs, and iceplant (Fig. 2). Yet at the time we conducted the depletion surveys, only about 40% of the site was covered with native vegetation, and the three plants that were associated with the highest legless lizard densities (yellow lupine, mock heather, and silver lupine) comprised only 14.5% of the vegetative cover. Nearly 50% of the site was covered by ripgut brome and iceplant which are the habitats associated with the lowest legless lizard densities we observed.

Given these results, it seems unlikely that the vegetation itself could account for what might be an unusually large legless lizard population. On the other hand, the degraded state of the vegetation was at least partially the result of bull dozing disturbance in the late 1980s, and it is possible that the large number of legless lizards could have been a remnant population from an earlier time when the dune was prime habitat.

The topography and soils of the dune have been repeatedly disturbed over the last century through activities associated with a dairy farm, an artillery gunnery and barracks, a municipal water tank, and fire suppression. The disturbed soils at this site were occupied by fewer legless lizards than were the undisturbed soils (Fig. 2). By far, the greatest densities of legless lizards were in the charcoal-infused sands of the ancient midden and the yellow sands overlain by brown A horizon, suggesting a strong association between legless lizards and soils that have remained relatively undisturbed. We also found lizards at relatively high densities in the compacted clay/silt-rich sands. Clearly legless lizards are using the noncompacted organic rich soils preferentially but are also finding suitable habitat in the slightly cemented clay/silt-rich sands.

Finally, the topography of the dunes may provide some benefit, particularly concerning water retention in the swales between the dune peaks. We found nearly twice the expected density of legless lizards in the moist soils of swales, which may capture and retain water runoff from the peaks. Swales may benefit legless lizards by providing access to interstitial drinking water (Fusari, 1985) or by increasing plant production, which would in turn lead to greater deposition of a duff layer and a subsequent increase in insect prey populations. Swale habitats occupied only about 9.5% of the total area from which we removed legless lizards and represented habitat for only about 22% of the animals we found. Access to swale habitat, therefore, does not in itself account for the unusually large lizard population.

None of the microhabitat conditions alone can accurately explain this large population. Therefore, we suggest that either there are factors that are important to legless lizards that are highly available at this site, which we did not identify or recognize (i.e., the synergistic effect of identified factors), or that the population dynamics of this species are poorly understood, leading to inaccuracies in population size estimates. Because of the lack of studies from comparable sites, neither one of these conclusions can be evaluated.

The failure of the current and past surveys to correlate with the known minimum total population at this site indicates that results derived from standard survey methods are inaccurate. Survey data from Miller (1944) and Bury (1985) suggested a very low population density at this site. A similar interpretation of the results of our own surveys would have erroneously lead to the same conclusion.

Although inadequate for estimating population density, time-constrained searches proved to be the most reliable method for detecting the presence of legless lizards over a wide range of population densities and vegetation types. Moderate-impact timed-constrained searches revealed more animals than the other survey methods and can be conducted more quickly. Although we typically found twice as many legless lizards with moderate-impact time-constrained searches versus low-impact time-constrained searches, low-impact time-constrained searches proved equally effective at revealing the presence of legless lizards. This is important because it allows the searcher to apply the technique in sensitive habitats such as an undisturbed dune or at a restoration site. Neither of these survey methods revealed the presence of legless lizards at extremely low population densities (about one animal/100 m^2).

We rarely detected legless lizards with coverboards, having sampled 34 times over a 37-

month period. Because we created an artificially high density of legless lizards in the study area, had a large array of coverboards compared to other studies, and sampled over an unusually long period, we expected to find higher numbers of lizards under coverboards. Results from this study indicate that coverboards were a poor indicator of population size or density. The majority of the 1292 coverboards had no lizard underneath them; this method could fail to establish the presence of lizards if used in short-term studies where small population size and a low number of coverboards may be used. At our site, coverboards did not become "seasoned" through time (i.e., they did not become more effective the longer they remained in place) and they provided consistently low yields that required a very large effort.

These results provide evidence that coverboard surveys and pitfall trap arrays do not accurately determine the presence (or absence when used for habitat management decisions) of this species, and we suggest that these methods be avoided when surveying for California Legless Lizards as a predevelopment or predisturbance mitigation. In situations where it is essential to know whether legless lizards are present, a full depletion survey should be conducted in a discrete area within the habitat.

This investigation suggests that California Legless Lizards may be more locally abundant in some areas than had been previously suspected. However, urbanization of coastal areas continues to encroach on the very specific microhabitats required to support legless lizards. We found a strong correlation between native vegetation, coastal dune topography, and the level of substrate disturbance and high legless lizard population densities, suggesting that the loss of native coastal dune vegetation and disturbance of dune soils may impact this sensitive species by reducing appropriate microhabitat. Restoration of habitat is essential; replacing stands of exotic plants with native plant communities may allow higher carrying capacities and, thus, larger populations of this protected species.

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Literature Cited

Block, W. M., M. L. Morrison, J. C. Slaymaker, and G. Jongejan. 1988. Design considerations for the study of amphibians, reptiles, and small mammals in California's oak woodlands: temporal and spatial patterns. *In* Proceedings of the Symposium on Management of Amphibians, Reptiles, and Small Mammals in North America, pp. 247–253. U.S. Department of Agriculture General Technical Report RM-166, Washington, DC.

Bury, R. B. 1985. *Anniella pulchra nigra*, Black Legless Lizard (Anniellidae: Sauria) in Central California. Office of endangered species, U.S. Fish and Wildlife Service, Washington. DC.

Bury R. B., and M. G. Raphael. 1983. Inventory methods for amphibians and reptiles. *In* Proceedings of an International Conference on Renewable Resource Inventories for Monitoring Changes and Trends, pp. 83-14. Society of American Foresters, Bethesda, MD.

California Department of Fish and Game. 2004. Amphibian and Reptile Species of Special Concern in California. California Department of Fish and Game, Sacramento.

Fusari, M. H. 1985. Drinking of soil water by the California Legless Lizard, *Anniella pulchra*. Copeia 1985:981–986.

Gorman, J. 1957. Recent collections of the California Limbless Lizard, *Anniella pulchra*. Copeia 1957: 148–150.

Hunt, L. E. 1983. A nomenclatural rearrangement of the genus *Anniella* (Sauria: Anniellidae). Copeia 1983:79–89.

———. 1984. Morphological Variation in the Fossorial Lizard *Anniella*. Unpubl. master's thesis, Univ. of California, Berkeley.

———. 1997. Geostatistical modeling of species distributions. Geostatistics for Environmental Applications 427–438.

Hunt, L. E. and M. Zander. 1997. Status of the Black Legless Lizard (*Anniella pulchra nigra*) on the city of Marina lands, Monterey County California. City of Marina Planning Department, Marina, CA.

Jennings, M. R. 1987. Annotated check list of the amphibians and reptiles of California. 2nd rev. ed. Southwestern Herpetologists Society, Special Publications 3:1–48.

Jennings, M. R., and M. P. Hayes. 1994. Amphibian and reptile species of special concern in California. California Department of Fish and Game, Inland Fisheries Division, Sacramento.

Kuhnz, L. A. 2000a. Microhabitats and Home Range of the California Legless Lizard Using biotelemetry. Unpubl. master's thesis, California State University, San Jose.

———. 2000b. Passive integrated transponders as a method for relocating legless lizards in underground habitats. *In* J. H. Eiler, D. J. Alcorn, and M. R. Neuman (eds.), Biotelemetry 15: Proceedings of the 15th International Symposium on Biotelemetry, Juneau, Alaska,Wageningen, The Netherlands.

MILLER, C. M. 1944. Ecological relationships and adaptations of the limbless lizards of the genus *Anniella*. Ecological Monographs 14:271–289.

POWELL, J. A. 1978. Endangered habitats for insects: California coastal sand dunes. Atala 6:41–50.

REIN, F. A. 1999. Vegetation Buffer Strips in a Mediterranean Climate: Potential for Protecting Soil and Water Resources. Unpubl. Ph.D. diss., Univ. of California, Santa Cruz.

SLATTERY, P. N., K. L. USCHYK, AND R. B. BURTON. 2003. Controlling weeds with weeds: disturbance, succession, yellow lupines and their role in the successful restoration of a native dune community. *In* C. Piosko (ed.), Proceedings of the California Invasive Plant Council Symposium. Vol. 7, p. 115. California Invasive Plant Council, Berkeley.

SLOBODCHIKOFF, C. N., AND J. T. DOYEN. 1977. Effects of *Ammophila arenaria* on sand dune arthropod communities. Ecology 58:1171–1175.

STEBBINS, R. C. 1954. Amphibians and Reptiles of Western North America. McGraw-Hill Inc., New York.

SZARO, R. C., S. C. BELFIT, K. J. AITKIN, AND R. D. BABB. 1988. The use of timed fixed-area plots and a mark-recapture technique in assessing riparian garter snake populations. *In* Proceedings of the Symposium on Management of Amphibians, Reptiles, and Small Mammals in North America, pp. 239–246. U.S. Department of Agriculture General Technical Report RM-166, Washington, DC.

R. L. TASSAN, K. S. HAGEN, AND D. V. CASSIDY. 1982. Imported natural enemies established against iceplant scales in California. California Agriculture September–October. 36:16–17.

ZAR, J. H. 1984. Biostatistical Analysis. Prentice Hall, Englewood Cliffs, NJ.

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Spatial Ecology of the Endangered Iguana, *Cyclura lewisi*, in a Disturbed Setting on Grand Cayman

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ABSTRACT.—**West Indian rock iguanas (genus *Cyclura*: Iguanidae) are among the most endangered lizards in the world, and many species will need to occupy human-modified and -occupied habitats to escape extinction. The Grand Cayman Blue Iguana, *Cyclura lewisi*, is critically endangered with fewer than 25 wild iguanas remaining. To aid the conservation of this and other iguanas, we investigated the spatial ecology of a captive-bred, released population of *C. lewisi* occupying a botanic park on Grand Cayman. Iguanas were monitored using transect walks and radio telemetry during the summer and fall of 2002. Males used larger areas and had greater movement distances than females during tracking periods in the summer but not in the fall. Overall home ranges for both seasons combined were larger in males than in females. Some home-range estimates were greater than any previously reported in *Cyclura*. Several iguanas, especially males during the breeding season, used areas outside the park where they are vulnerable to increased predation, death by vehicle, and hunting or collection by humans. This, combined with the large average home-range sizes for this species, indicate that future reserves for *C. lewisi* should be large and surrounded by buffer zones or fences.**

Rock iguanas of the genus *Cyclura* (Iguanidae, Frost and Ethridge, 1989; but see discussion of taxonomy in Hollingsworth, 2004) are a highly endangered group of lizards inhabiting islands throughout the West Indies (Alberts, 2000). These large, herbivorous iguanas are threatened by habitat loss and degradation (Alberts, 2000), competition with and predation by introduced species (Iverson, 1978; Mitchell, 1999), and hunting and collection by humans (Carey, 1966; Knapp et al., 1999; Alberts, 2000). Many populations are currently managed through captive breeding or head-starting programs, and some species will need to occupy human-modified and -occupied habitats to escape extinction.

The above circumstances apply to the endemic Grand Cayman Blue Iguana, *Cyclura lewisi*, which is critically endangered with only 7–25 individuals remaining in the wild (Burton, 2002). These iguanas remain as mostly isolated, non-reproductive individuals occupying disturbed

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