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Microhabitats and home range of the California legless lizard using biototelemtry

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MICROHABITATS AND HOME RANGE OF THE CALIFORNIA LEGLESS LIZARD USING BIOTELEMETRY

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ABSTRACT

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by Linda Ann Kuhnz

Microhabitat utilization and home range of the fossorial legless lizard (*Anniella pulchra*) were studied in 4 hectares of sand dune in central California. Methods were developed using Passive Integrated Transponders (PIT-tags) and underground biotelemetry to track movements within microhabitats, in response to disturbance, and to determine home range and dispersal ability. This is the most abundant population of *A. pulchra* known (n = 3,582; 0.228/m^2). Abundance was greater in quality habitat (e.g. near yellow lupine bushes) and with greater soil moisture, but lower in disturbed soils. They were routinely found at temperatures below 20°C and were active day and night. The average home range was 71 m^2 (std. dev. = 87.2). In the laboratory, *Anniella* moved underground through a system of persistent burrows and vertically migrated to a depth of 46 cm. PIT-tags were a viable method for tracking *Anniella* and could be used with other small fossorial animals.

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I. INTRODUCTION

The California legless lizard (*Anniella pulchra* Gray 1852; Sauria: Anniellidae) is a fossorial (burrowing) animal that typically inhabits sand or loose soil (Fig. 1). They are nearly endemic to California, but also found in northern Baja California (Stebbins 1954, Hunt 1984, Bury 1985, Jennings 1987, Jennings and Hayes 1994). State agencies regard *Anniella pulchra* as a Species of Special Concern because of human impacts to coastal dune habitats (Jennings and Hayes 1994, California Department of Fish and Game 2000).

Two unofficial designations for *A. pulchra* primarily reflect differences in dorsal coloration and distribution (Hunt 1983, Hunt and Zander 1997). Very dark animals are commonly called black legless lizards (subspecies *A. p. nigra*), and most workers refer to lighter colored adults as silvery legless lizards (subspecies *A. p. pulchra*). Genetic studies are inconclusive, especially those comparing populations in central California (Murphy and Smith 1985, Jennings 1987, Hunt and Zander 1997). Proposed amendments to the nomenclature (addition of subspecies designations) remain unchanged.

Knowledge of the longevity, movement, and microhabitats of these lizards was incomplete because studying them in situ, in their underground habitat, has been difficult. Workers have investigated this cryptic animal for many years, using the best methods available. Until now, the accepted method for tracking legless lizards consisted of placing wood coverboards on the soil surface, then periodically digging under them to check for the presence of lizards (Hunt and Zander 1997). Although this is a low-impact, cost-effective sampling method, it cannot be used to determine population size, home range, or microhabitat selection.

At my study site where the abundance of lizards was known, coverboards were ineffective for detecting the presence or determining the density of lizards (pers. observ.). External methods of tagging legless lizards using India-ink or permanent ink marker have been effective only short-term, or unreliable (Ruth, pers. comm.; pers. observ.). Other common methods of marking lizards and snakes (e.g., toe and scale clipping) were not possible given *Anniella's* morphology.

I employed new technology to track the movements of legless lizards. The use of PIT-tags (Passive Integrated Transponder) in terrestrial field biology usually has been limited to the identification of manually recaptured animals (Camper and Dixon 1988, Germano and Williams 1993, Paramenter 1993, Jemison et al. 1995). The methods developed for this study allowed me to track the activity of individual animals in their subterranean environment without recapturing them, conceivably with less bias toward slow or easily captured lizards. Using a mobile scanner modified for use in the field, lizards were found in many different microhabitats and as deep as 11.5 cm in the soil, within the depth they presumably reside most of the time (Miller 1944, Smith 1946, Hunt 1984). Failure of PIT-tags is rare and can be readable for 15-20 years; the tags required no battery or other power source (Camper and Dixon 1988, Germano and Williams 1993, Paramenter 1993, Jemison et al. 1995).

This study was conducted at Moss Landing on the coast of central California (Fig. 2). Moss Landing Marine Laboratories, on the shores of Monterey Bay, were destroyed in the Loma Prieta earthquake of 1989. Surveys of the new construction site confirmed a population of legless lizards. In 1997-1998, the 1.57 hectare site was searched and more than 3,500 *Anniella* were moved to an adjacent area of sand dune habitat. The recovery of nearly every lizard within the building footprint also provided an extraordinary opportunity to assess lizard density relative to microhabitats. This work was required because *Anniella pulchra* was protected locally and its status as a federally listed endangered species was pending. Therefore, research protocols for these studies were under the direction and supervision of the California Department of Fish and Game (CDF&G). When the project began, there was a proposed federal rule to list the black California legless lizard as an endangered species. Although subsequent evaluation of the lizards recovered during this study indicated they probably are an intergrade between black and silvery lizards, it was not certain that black legless lizards were absent on Moss Landing Hill; some local lizards were 70% black (Miller 1943). Withdrawing the proposed rule in August 1998, the U.S. Fish and Wildlife Service stated that intervention was unnecessary because ongoing dune restoration, preservation projects, and protection from urbanization on public lands were protecting habitat (Federal Register 1998). Both morphotypes remain protected as a California Species of Special Concern.

This work was a rare opportunity to increase our knowledge of the life history of a fossorial animal, and PIT-tag technology capabilities. A clearer understanding of legless lizard microhabitat associations will allow biologists and regulators to design appropriate recovery and relocation strategies as mitigation for development and anthropogenic damage to coastal dune ecosystems. This type of research also enhances our understanding of the dispersal capabilities and home range of *Anniella*, which is essential when addressing management issues. Long-term monitoring will provide new insights into population redistribution, the effects of habitat heterogeneity on movement, and the longevity of legless lizards.

II. MICROHABITATS

Introduction

Anniella inhabit diverse environments including coastal dunes, oak woodlands, and montane forests (Miller 1944, Hunt 1983, Jennings and Hayes 1994, Hunt and Zander 1997). Although more commonly found within 100 km of the coast (Antioch, CA to northern Baja), they live at elevations as high as 1800 m in the western foothills of the Sierra Nevada (Jennings and Hayes 1994, Hunt 1997). Two common habitat characteristics are mature leaf litter and a high fraction of sand in the soil. Hunt (1997) aptly described *Anniella* as a habitat generalist and a microhabitat specialist.

Although legless lizards are highly fossorial, they use the ecotone at the soil/leaf litter interface for feeding, and probably mating (pers. observ.). Based on my field observations, vegetation is important in assessing microhabitat selection. I analyzed the relationship between vegetation quality and lizard density. For coastal scrub ecosystems, I speculated that the highest quality habitat for legless lizards was perennial shrubs. Shrubs produce leaf litter beneath the canopy which probably attracts insect prey and mediates temperature change and soil moisture loss. On Moss Landing Hill, high quality habitat includes yellow bush lupine (*Lupinus arboreus*), silver bush lupine (*Lupinus chamissonus*), and mock heather (*Ericameria ericoides*). Non-native annual grasses and forbs, with their ephemeral root structure, provide some soil aeration, litter, and attraction of insects but probably are low-average quality habitat. I considered iceplant (*Carpobrotus edulis*), with its poor root structure, reduced insect fauna, and smothering cover, inadequate habitat.

The characteristics of soil and associated environmental conditions influence microhabitat selection in this and other highly fossorial animals (Stebbins 1954, Hunt 1997). The amount of organics in soils may change moisture retention, compactness of the soil, and influence temperature. Moss Landing Hill consisted of a number of different soil types. The soil in some areas was very dark gray to black with abnormally high amounts of organic material and high amounts of charcoal due to pre-modern human activity (middens). These soils were slightly more compacted than non-midden soils. Shallow depressions accumulated and held soil moisture, forming preferred microhabitats for legless lizards. Milliken et al. (1999) characterized the major soil type within the lizard recovery area as fine-grained, loosely compacted, loamy sand. Moderate amounts of organic material from plant oils have mixed with nearly all of the sand, making it slightly hydrophobic. Along the perimeter of the hill, there was a band of cemented sand with a clay and silt component (Milliken, pers. comm., pers. observ.).

Methods

Between 23 September and 30 December 1997, all recoverable legless lizards were collected from one-quarter of the hill slated for construction (collection site). Legless lizards, to a depth of 20 to 60 cm, were removed from the remaining area between March and November 1998. The entire collection site was 1.57 hectares.

Search methods required the careful raking of the sandy soil with a mulch rake. To ensure the removal of all recoverable lizards, the entire area was raked multiple times (up to five in areas where large numbers of lizards were found).

Once uncovered, lizards were captured quickly because they rapidly burrowed back into the soil. When a legless lizard was found, it was held carefully to avoid caudal autotomy, a common predatory defense mechanism. Following an inspection of the animal's condition, it was placed in a plastic bag, along with a handful of sand and duff from the capture site. Bags were inflated with air, closed, and labeled with a unique number. Lizards were kept out of direct sunlight at all times and in a cooler for return to the lab. The cooler was maintained at 5-15 C° using "blue ice" wrapped in a towel. For each lizard, I recorded the date, time, and one of seven common microhabitats: blackberry, grass/forbs, iceplant, mock heather, silver bush lupine, yellow bush lupine, or other. Due to habitat disturbance and the possibility of a lizard moving away (horizontally or vertically) from an area in response to searcher activity, we also recorded which lizards were captured in their undisturbed microhabitat during the first raking.

Each capture location was flagged. A Topcon automatic surveyor's level was used to document the position of the first 14% of lizards. The Theodolite readings were ground-truthed using known locations of three separate benchmarks. Readings were translated into geographic coordinates. The remaining positions were recorded using a Trimble Pro-XR differentially correcting global position system (DGPS). Seven and one-half percent of positions were excluded due to flagging errors or missed recordings. Most of the lizards were held in the lab an average of three days, long enough to gather meristic data: length to the nearest mm of snout-vent (SVL), tail length, re-grown tail length, and weight to the nearest 0.1 g. Modifications of Miller's (1944) age categories were used for estimating age classes based on SVL.

Lizards were released within an adjacent 2.43 hectare area of dune habitat undergoing restoration. Restoration included the elimination of weeds, which facilitated the recolonization of native plants. Planting silver bush lupine, California poppy, lizard tail, several species of buckwheat, and 15,000 yellow bush lupines also enhanced the habitat. In addition, seeds of native annuals (spineflower, sand gilia, popcorn flower, fiddleneck, and phacelia) were sown over 0.4 hectares.

Within the collection site, the vegetation type was documented in 90 randomly placed quadrats (0.25 m^2), each containing 10 randomly placed points. The percentage cover of plant species was based on the percentage of points in contact with each species. I also noted all other plants within the quadrat but not contacted by a point. All plant species were assigned to one of the seven microhabitat categories where individual lizards were captured.

Only lizards collected on the first raking were used to calculate the number of lizards in each microhabitat. The expected number of lizards within each microhabitat was calculated by multiplying all lizards captured by the percentage area of each microhabitat category.

To determine associations between lizards and soil type, a map of soil types (provided by Far Western Anthropological Research Group, Inc., 1998) was digitized and then georeferenced using a digital orthophoto quadrangle from the United States Geological Service and TNTmips v6.0 (1998, Fig. 3). Positions where lizards were captured were plotted and then counted within the boundaries of each soil type. Soil types intergrade on a scale of meters and lizards probably did not move this far in response to searcher activities, so all available lizard positions were used in the analysis (n = 3,314).

The expected number of lizards in each soil category was calculated by multiplying all lizards captured by the percentage covered by each soil type.

To test the effects of soil moisture on lizard distribution, a georeferenced aerial photo, field observations, and a 3-D digital elevation model (DEM) were used to delineate depressions (swales) in the topography within the lizard recovery area (Fig. 4). The soil in these swales accumulated and held moisture longer than other areas on the hill (pers. observ.). I developed the 3-D DEM using TNTmips v6.0 (1998) and contour data obtained from WWD Engineering (1994).

Lizard density within the swales was analyzed by plotting lizard capture positions, and then counting the number of lizards found in each swale. The expected number of lizards in swale and non-swale habitats were based on the total area of each category. A log-likelihood ratio for goodness of fit test was used to compare the observed vs. expected frequencies in all three of the microhabitat analyses (Zar 1984).

Results

Three-thousand five hundred and eighty-two *Anniella* were recovered from a 15,719 m^2 area (1.57 hectares), a density of 0.228 lizards/m^2. The greatest density, 1.67 lizards/m^2, was found under a yellow lupine bush (17 lizards in 10.17 m^2). Other yellow and blue lupines supported up to 0.78 lizards/m^2. Fifty-six percent (n = 2,006) of lizards had intact tails, and were measured for average length and mass of animals (Table 1). Fifty-eight percent of lizards measured for SVL (n = 3,518) were adults, with about equal numbers of juveniles and sub-adults (Table 2). Seven percent (n = 232) were yearlings.

Twenty-eight plant taxa (26 species and 2 genera) were identified in quadrats (Table 3). Lizards (n = 1,714) were not distributed randomly among vegetation types ($G_{(0.05,6)} = 1049.7$; $p < 0.001$). Significantly more lizards were recovered near high quality habitat (e.g. silver bush lupine, mock heather, and yellow lupine) than expected by chance alone (Fig. 5). As predicted, there were fewer lizards than expected in low to average quality areas that contained grass, forbs, and iceplant. Blackberry vines were apparently adequate lizard habitat, supporting the expected number of lizards.

Most of the study site was yellow sand overlain by 20 to 40 cm of dark brown A horizon (Table 4). There was a non-random distribution of animals among soil types ($G_{(0.05,7)} = 1,350.5$ n = 3,314, $p < 0.001$). Disturbed sands (charcoal infused and yellow sand with brown A horizon) supported fewer lizards than expected, whereas undisturbed (yellow sands with brown A horizon and charcoal infused sands) supported more than expected (Fig. 6). The proportion of lizards found in sterile, disturbed yellow sand equaled the number estimated. Lizards also were found in the proportion expected in the most compact sands (cemented sand, clay, and silt).

There were significantly more lizards in swales (0.407 lizards/m^2) than in drier areas (0.190 lizards/m^2, $G_{(0.05,1)} = 242.21$, $p < 0.001$, n = 3,314; Table 5). The increased density of animals in swales was not related to any specific soil type within the swales. Most of the swale area consisted of yellow sands with brown A horizon (1,150 m^2, 77%), and the remaining area was disturbed yellow sand and cemented sand, both supporting less densities of lizards. The density of 0.407 lizards/m^2 in swales was greater than the density in yellow sands (0.283 lizards/m^2).

Discussion

Bury (1985) estimated the density of legless lizards on Moss Landing Hill in 1984, and based on that density I expected 170 lizards ($0.011/m^2$) might live within the collection site. Miller (1944) described the density of lizards on this hill as low, having found 26 lizards per 0.93 hectares. I found 3,582 lizards ($0.228/m^2$) at this site making it the largest population known. It may be that the cryptic nature of *Anniella* does not allow investigators to infer population size correctly based on prior searching techniques. Hunt (in ABA 1998) stated that high density may be an evolutionary correlate of fossorial existence and cites other cases where reptiles and amphibians were found in high abundance. Alternatively, there may have been unique physical and ecological events on Moss Landing Hill that allowed what may be an unusually large population. Nutrient laden soil may allow uncommonly vigorous plant growth due to the high organic content of the soil and may retain moisture without decreasing the amount of air in the interstitial spaces (Miller 1944). Lizards were found in moist soil more often than dry soil. *Anniella* drink water directly from the soil and may do this more efficiently when the soil contains more moisture (Fusari 1985). The highly organic soil, and associated vegetation and insect fauna, may result in a large carrying capacity for *Anniella*. The organic content of the soil also may provide a medium that is slightly more compact, and thus amenable to lizard burrowing.

In coastal dune habitat, *A. pulchra* live near and around bush lupine (*Lupinus* spp.) and other bushes that support a variety of arthropod prey (Miller 1944, Bury 1985). My field observations confirm that at this site, *Anniella* are found in greater abundance in those microhabitats. Legless lizards are found in grass and forbs in greater abundance during the spring growing season compared with other times of the year (pers. observ.). This may be because the annual pulse of sub-surface growth sustains greater numbers of insects and insect pupae.

Human impacts to coastal dune systems encourage the colonization of invasive plant species like ripgut brome and European dune grass, lowering the quality of habitat (Slobodchikoff and Doyen 1977) and possibly extirpating lizards. The grass and forbs microhabitat category used here includes many invasive species besides ripgut. Most of the plant species were non-native annuals, which generally did not provide good root structure. Non-natives are inferior to natives in their ability to enrich the soil and prevent erosion (Rein 1999). This may lead to localized soil disturbance.

Large iceplant mats were purposely planted along the California coast to stabilize disturbed dune systems (Bury 1985), and this practice continues today (pers. observ.). These monospecific mats can spread quickly and over-grow mock heather over a meter tall. The presence of iceplant on dunes also produces a very moist spongy layer beneath the mat which supports few arthropods (Bury 1985, pers. observ.). Greater than normal salt levels in the soil also may negatively affect native plants and their natural insect populations (Bury 1985). Small numbers of legless lizards can be found under iceplant, mostly in swales. These areas may attract lizards which only temporarily reside there in order to drink interstitial soil moisture.

Some areas on Moss Landing Hill have been disturbed often in the last century. A dairy farm existed on this site from the late 1890's into the 1930's. In the early 1940's, the army placed an artillery gun and barracks on the hill. The water tower and the concrete pad under it were built in 1962, and a part of the hill was bulldozed for fire control in 1988 (ABA 1992). Most of the recently disturbed soils supported fewer lizards.

III. METHODS DEVELOPMENT: PASSIVE INTEGRATED TRANSPONDERS AND GLOBAL POSITIONING SYSTEM

Introduction

PIT-tags were chosen for this study because they were small, passive and did not require an internal battery that must periodically be changed. The life expectancy of the tag probably exceeds the life expectancy of the lizards, making long-term study possible. Legless lizards near Monterey Bay reportedly burrow in the upper few cms of the soil (Miller 1944), allowing detection with a tag reader most of the time. Each glass-encased tag has a unique 10-digit alphanumeric sequence encoded into it that allows identification of relocated lizards.

Intra-abdominal placement of PIT-tags for long-term marking is essential for animals that live in a fossorial environment. Placement in the peritoneum increases the probability of injury to the animal, however via friction, the loss of tags is unacceptably great when placed subcutaneously (Germano and Williams 1993, Jemison et al. 1995). Subcutaneously placed tags fail because of breakage, and can easily be lost through skin lesions (Camper and Dixon 1988, Germano and Williams 1993). Visceral protrusion is a problem with intra-abdominal placement (Keck 1994).

Tracking the movements of legless lizards in the field requires finding individuals in their subterranean environment and recording their positions accurately. For an animal with potentially limited dispersal ability, knowing the precision of tracking equipment is essential. I conducted sensitivity range tests with the PIT-tag reader and positional accuracy tests with GPS equipment to determine their optimal use and level of data accuracy.

Methods

I observed the health and survival of a group of 25 legless lizards tagged in October 1997 to determine the feasibility of tagging. Lizards were chosen randomly for tagging from among animals with a SVL > 110 mm and mass >2.5 g. This size class was selected based on an evaluation of the internal anatomy and assessment that tagging smaller lizards could be detrimental. I did not tag some animals fitting these criteria if the diameter of the animal appeared too small to accommodate the tag without risk of injury. PIT-tagging techniques specific to *A. pulchra* were developed with Dr. Norman Scott, National Biological Services, Piedras Blancas Field Station, San Simeon, CA in consultation with Dr. James R. Dixon. Dr. Scott has extensive experience PIT-tagging snakes, lizards, and turtles, and Dr. Dixon helped develop initial protocols for PIT-tag use in the field of herpetology. Dr. Stephen B. Ruth provided information regarding legless lizard anatomy.

PIT-tags (11.5 mm x 2.1 mm, 0.06 g) coated in antibiotic ointment were injected intra-abdominally in legless lizards using the tip of a 12-gauge needle. The safest place to insert the tag was posterior to the lungs and liver and anterior to the gonads. To facilitate tissue closure, the incision was held together for 10 to 20 seconds. This technique was modified after several tagging sessions. Subsequent procedures involved inserting the needle only far enough to create a small opening in the peritoneum, creating a significantly smaller incision. Instead of using the syringe plunger to introduce the tag into the abdomen, the tag was manually massaged into place. This new procedure lessened the trauma to lizards and reduced the number of lizards with visceral protrusion.

I held PIT-tagged individuals for a minimum of three-weeks post-procedure, inspecting each animal daily for the first week. Lizards were held separately in plastic boxes (35 cm L x 20 cm W x 10 cm H) with mesh-covered lids for air circulation. Each box contained ~15 cm depth of sieved sand from the capture site and 1 to 2 small rocks for the lizard to rub against to aid molting. To provide a heterogeneous habitat, sand in one half of the box was kept moist and the other dry. The room temperature fluctuated with ambient air temperature; heaters prevented the temperature from dropping below approximately 13 C°. Fans circulated air and prevented the temperature from increasing above ~ 27 C°. Light was controlled via timers set to a 12D:12N cycle. I also constructed glass terrariums measuring 60 x 100 x 6 cm, containing sand 46-cm deep. Six sets of four lizards each were observed within these tanks for various time periods (3 to 10 months each) during a 16-month period. Because there has been at least one report of aggression between lizards housed together (Miller 1944), I carefully inspected each of them for scars and scale irregularities before releasing them into the terrariums. Multi-day time-lapse video recordings were made of several groups of lizards.

The external PIT-tag scanning device was an AVID Power Tracker II, normally used as a hand-held tag detector. The reader emits an electromagnetic field that activates the tag so that the unique alphanumeric code is transmitted back to the scanner. Modifications for use in the field included the addition of a 1.5 m extendable aluminum pole, addition of a reset switch on the pole, and a revision to the power source to accommodate a double external Nicad battery. A pivot was placed at the base of the pole so that the orientation of the reader could be changed for working on slopes. To search for lizards, the reader was swept as close to the ground as possible without causing disturbance. Circular movements were used to minimize the effects of tag orientation on sensitivity. When a lizard was located, its position was determined by triangulating the signal with the reader.

To evaluate the effects of tag orientation on tag delectability and to ensure that all tags could be located from the same distance, loose unburied tags were tested with the scanner from a constant distance. PIT-tags were placed in the sand in horizontal, vertical, and diagonal positions during testing.

The depth at which loose buried tags could be detected underground was assessed by burying PIT-tags in dry sand and recording the deepest depth that the tag could be detected. The effect of moisture was tested in the same manner by placing tags in wet sand. Tags also were tested for sensitivity variability in duff-covered sand and duff-covered wet sand.

I placed PIT-tagged lizards in a small plastic container that prevented them from moving but did not interfere with the signal range of the reader. The containers were buried under progressively deeper sand (dry and wet) until the tag could no longer be detected. All detection depths were recorded to the nearest 0.5 cm.

In April 1999, twelve geographic locations on Moss Landing Hill were used to test the difference between positions recorded with a Trimble ProXR GPS unit with real-time differential correction (DGPS) vs. positions recorded, and then post-processed for differential correction in the lab. Each position was recorded for 45 seconds. For post-processing I used Trimble's Pathfinder Office software and files collected by a differential correction base station located at California State University Monterey Bay, about 9.6 km away. The DGPS positions and the post-processed positions were plotted together in Pathfinder Office and the distances between each pair was measured in cm.

I tested the difference between post-processed positions and positions recorded in phase processing mode. Phase processing is highly accurate, and involves placing the GPS unit on a tripod so there is no movement of the antenna. The unit is stationary for 20 minutes, registering and averaging 1200 positional data points. At three sites, the GPS unit was used to record the position for 45 seconds in normal mode and then without moving the unit, for an additional 20 minutes in phase processing mode. These phase-processed positions were treated as the actual geographic position.

Two consecutive searches were conducted of the accessible habitat semi-annually. Each tagged lizard located in the field was weighed, measured, and released in the same location. I also recorded information on each lizard's general health: (a) did the lizard defecate (an indication that it recently fed), (b) did the ventral side of the animal look full or concave, (c) was there evidence of reproductive activity (gravid or pregnant), (d) was the tail thin (indicating the loss of energy reserve), (e) had the tail been recently lost (caudal autotomy; this information is important if the mass of the animal was less than at a previous capture), (f) the condition and visibility of the tagging scar, and (g) other information about the general appearance of the lizard.

Results

In late spring 1998, six months after the injection of PIT-tags, 24 of the original 25 captive tagged lizards appeared healthy, well-fed, and experiencing no detrimental effects. One lizard died 2 months after the tagging procedure was performed. An additional 630 lizards (wt. range = 2.6 - 7.3 g, 0 = 4.7 g, std deviation = 0.83; SVL range = 112 - 172 mm, 0 = 133 mm, std deviation = 8.6) were tagged in spring 1998 over a 30-day period. Approximately

93% of the lizards showed no sign of distress or complication. Lizards experiencing visceral extrusion or signs of infection received subcutaneous injections of 1 mg/ml Amikacin (5 mg/kg wt.) using a 28-gauge sterile needle. Betadine was used as a topical antiseptic. If a lizard appeared moribund, I euthanized it with chloroform. Overall, mortality was 4.9%. Lethal injuries consisted of visceral protrusion (intestinal or post-caval vein, 4.2%), wound infection (0.3%), and bowel obstruction (0.1%). Mortality rate was 6% for lizards tagged during the first four tagging days, 3% for days 5 and 6, and 0% in the last five sessions. Lizards suspected of being in an early reproductive state (enlarged ovaries or testes) had greater abdominal turgor and greater than average mortality.

Tagged lizards were held in the lab for at least three weeks before release. Movement and speed were not affected, spontaneous tag loss in the lab was < 1%, and none of the tags malfunctioned or broke. No tags were expelled or broken in lizards held in the lab for > 2 years.

In glass terraria, PIT-tagged lizards could be located at any depth (0 to 46 cm) within the tank, without being seen and without disturbing them. They moved easily through the sand, creating a system of discrete burrows (persistent tunnels). The sand around the burrows only occasionally re-consolidated and new tunnels quickly replaced them. Most burrows were nearly horizontal. Within burrows near the glass, lizards moved forward and backward with apparently equal ease at all speeds. Some lizards were active, whereas others moved to the bottom of the terrarium and remained there for weeks at a time. Overall, the frequency of movement markedly increased in March-May in both years. When small lupines were growing in the terrarium, lizards burrowed vertically, head up, next to the root ball of the plant.

Occasionally lizards fed on mealworms (*Tenebrio molitor*) or sowbugs (*Armadillidium* sp.) from within these vertical burrows. Through time, multiple lizards occupied many of the same tunnels, but never at the same time. No scars, wounds, or aggressive behavior were observed for lizards housed together. Lizards were almost equally distributed throughout the terrarium at all times, except during mating season (March-April), when they were routinely found next to each other. During visual observations and time-lapse recordings, lizards were rarely on the soil surface, even when the surface was covered with leaf litter. Only lizards that were dying were found at the surface and dead lizards always were found on top of the sand. In April 2000, however, time-lapse video revealed lizards moving on the soil surface, mostly at night. Within two days, two lizards were observed mating at the surface.

Due to the size and shape of the electromagnetic field produced by the tag reader, there was a potential 6-cm horizontal error in the estimated location from the actual position of the lizard. This problem was overcome by triangulating the position with the reader, resulting in an error smaller than the size of an individual lizard.

Loose tags (not implanted in lizards), placed horizontally and diagonally in air were detected by the reader from the same distance with almost no variability (Table 6). Loose tags in dry sand were detected to 12 cm depth in the horizontal position (0 = 10.4 cm) but were detected to only half that depth (0 = 5.2 cm) when in a vertical orientation. Tags in a horizontal orientation in wet sand also could be detected to 12 cm depth, but the mean was slightly greater (10.7 cm) than for dry sand. Loose tags in the horizontal position in dry and wet sand covered with a 1.5 cm duff layer were detected to a mean depth of 10.5 cm. Tags in lizards were detected in dry and wet sand to a depth of 11.5 cm.

Post-processed GPS data had a mean error of only 24.3 cm (range = 16.2 to 39.1, std. deviation = 12.8) when compared with phase-processed data. The average distance between the 12 locations recorded with DGPS and post-processed positions was 45.1 cm (range = 4.3 to 74.7 cm, std. deviation = 20.6 cm).

Early DGPS data were not post-processed. The positional error for those data were ~ 70 cm, which included the DGPS vs. post-processing error and the error from the phase processing position. All post-processed data were assumed correct to within ~ 24 cm.

One hundred forty-six tagged lizards were recaptured between 9 and 21 months post-release (17 in March 1999, 27 in November 1999, 102 in March 2000). All but 3 were active, well fed, and had PIT-tag wounds that were completely healed, leaving little or no scarring. Three lizards appeared thin and under-active. Only 22 of the lizards were recaptured twice; 17 gained mass by the second recapture (0.2 to 1.0 g), one lost its tail so mass change was unknown, and 4 lost between 0.2 and 0.4 g. In March 2000, 46% of the 102 recaptured tagged lizards appeared reproductive.

Discussion

The health and vigor of the recaptured lizards indicated the overall success of PIT-tagging *Anniella*. When workers with experience tagged lizards, injury and mortality were reduced. There were no visible effects on the movement of tagged lizards compared with un-tagged lizards. No significant speed differences or mass changes were detected in PIT-tagged vs. non-tagged animals in a prior study of neonatal snakes (Keck 1994).

Tag detection could be improved with development of a better tag reader with deeper tag detection ranges so that a greater percentage of lizards could be detected and vertical migration information obtained. Faber (1997) obtained a 15-cm range using similarly sized transponders, and Destron Ferring, Inc. recently produced a new reader that may detect lizards as deep as 21 cm below the soil surface. The detection range for lizards in a vertical position is highly variable and generally less than for lizards in a horizontal position. Lab observations, however, indicated that lizards probably remain in a horizontal position except when very near the surface, increasing the probability of detection with the reader.

Tagging techniques could be improved by applying biocompatible glue to help seal the incision following tag insertion. To avoid problems with high abdominal turgor, food should be withheld from lizards for more than one week, and lizards with any visible signs of enlarged gonads should not be tagged. Previous research projects involving the PIT-tagging of snakes, lizards, turtles, and anurans have not included anesthesia as a part of the protocol (Camper and Dixon 1988, Germano and Williams 1993, Parmenter 1993, Keck 1994, Jemison et al. 1995). This presumably was because the pain caused by injecting a PIT-tag was considered ephemeral and because the use of anesthetics on small animals can present complications, delaying recovery or causing death. No published information exists about previous uses of anesthesia for legless lizards. There has been some success using flurothane vapor, but this method was rejected because the fumes are toxic to the liver of workers breathing the vapor (Margaret Fusari pers. comm.). The decision was made to forgo anesthesia as it was considered too risky (N. Scott and J. Dixon, pers. comm.). Later, in an effort to develop methods for the safe administration of anesthetic for legless lizards, we enlisted the assistance of Dr. Michael Murray, D.V.M. a reptile veterinarian at the Avian and Exotic Pet Clinic in Monterey. In consultation with nationally recognized reptile veterinarian and author of Reptile Medicine and

Surgery (1996), Dr. Douglas Mader, D.V.M in Key West, Florida, the anesthetic Telazol was tested. After extensive testing with increasing concentrations, lizards were successfully anesthetized. Future PIT-tagging procedures should thus include administering 0.04 cc of Telazol 10 mg/ml injected subcutaneously dorsolaterally, approximately 2-3 cm behind the skull and near the heart.

Miller (1944) believed legless lizards had limited ability for dispersal. If this is true, then our understanding of the limitations of this technology and the amount of error produced is essential because of the need to accurately measure small increments of movement. Post-processed positions were nearly twice as accurate and therefore, an essential protocol.

These methods represent a unique application of a new technology, and can be used in other investigations of fossorial or cryptic animals. The procedures for remotely detecting animals may benefit researchers already using PIT-tag technology. Some of these studies may be compromised when manually recaptured PIT-tagged animals become skittish or sensitized to handling.

IV. UNDERGROUND BIOTELEMETRY

Introduction

PIT-tagged lizards were released in a series of experiments designed to assess short-term and long-term movement patterns. The frequency and extent of legless lizard movement among microhabitats was previously unknown. Heterogeneity in vegetation indicates below-ground variation, such as root structures and prey availability. Soil also provides habitat heterogeneity; highly compacted soil may preclude lizard burrowing (Hunt 1997), and moist soil may attract lizards (Bury and Balgooyen 1976, Fusari 1984). Because lizards are ectothermic, I expected that behavioral thermoregulation affected the activities of legless lizards (e.g. vertical movement), although perhaps not as much as in their non-fossorial counterparts. The specific heat of moist sand is greater than air and thus moist sand insulates legless lizards. In addition, these lizards are capable of maintaining their standard metabolic rate at low temperatures (Brattstrom 1965, Withers 1981, Fusari 1984). This may allow *Anniella* to actively forage during colder night hours and throughout seasonal temperature changes (Fusari 1984). Legless lizards occur at 5.2 to 31.2 C°, with 40 C° being lethal (Miller 1944, Gorman 1957, Fusari 1984).

In prior studies, the fossorial nature of *Anniella* made it difficult to determine the effects of increased disturbance to coastal dune habitats, and to estimate home-range and dispersal ability. The Moss Landing site, with its sandy soil and varied vegetation cover, provided suitable conditions to test these aspects of the life history of legless lizards. Hunt (1984) completed an exhaustive study of *Anniella* and found no external sexual dimorphism.

nor are there any known behavioral differences. Because of this, and because all tagged lizards were adults, I did not test for gender or ontogenic differences.

To detect microhabitat selection and responses to disturbance and other lizards, short-term surveys (24-48 hours) were conducted, which consisted of releasing animals under various environmental conditions. Long-term (24 months) monitoring involved releasing a large number of lizards throughout the 2.43 hectare study site, and tracking them on a weekly to monthly basis. This portion of the study focused on the broader goals of estimating home range and dispersal ability. These studies were undertaken to (i) test the hypothesis that legless lizards moved in directed ways within microhabitats, (ii) evaluate lizards responses to disturbance, (iii) estimate home-range area, and (iv) determine dispersal ability.

Methods

Lizards were provided food and water until their release. Individual PIT-tagged legless lizards were randomly selected and transported to the field in plastic containers containing soil. They were released at a starting location, and tracked with the PIT-tag reader. I placed small plastic bags filled with sand and marked with the lizard's unique number on the soil's surface above lizard positions each time a lizard was detected. The lizards were not captured. The reader operator systematically searched an area by extending the tag reader in front, thereby avoiding walking on any un-searched ground. To avoid foot-fall disturbance, all other measurements were made after the operator searched the area. I conducted more directed searches as I approached a previous position of a lizard, moving the reader in concentric circles (a 1 to 2 m^2 area) radiating from the bag. In addition, as each experiment progressed, I tested an increasingly larger area outside the perimeter of the release area.

Distance, from its previous position or from a central location, to the nearest 5 cm, and the bearing to the nearest 5° was recorded for each lizard position. Because of the size of the location marker and rounding procedures, lizard positions within 20 cm of a previous position were recorded as the same geographic location (i.e. no movement). Positional data were converted to geographic coordinates using MATLAB (1998). Experiments were designed to test 3 parameters: distance, time, and turning angle for each step in a movement path. Sampling periods were spaced 4 to 6 hours apart to avoid over-sampling and to ensure that each step in a path was independent and not autocorrelated.

I measured site fidelity by comparing the actual movements of lizards with 100 random paths in a Monte Carlo simulation. To create random paths, randomly generated angles were produced and combined with randomly chosen (without replacement) distances between successive steps in the actual path (Spencer et al. 1990). Mean squared distance (MSD) measured the dispersion around the animal's center of activity, with low MSD indicating greater site fidelity. An animal's movements were considered non-random when the MSD of the actual path was less than 95% of the MSD's for the randomly generated paths. I produced actual and random MSD's using the Animal Movement Analyst Extention (AMAE) program for ArcView (Hooge and Eichenlaub 1997). Only animals with 3 or more recorded positions were used in analyses. All other statistical analyses were done using Systat 9.0 (1999) unless otherwise noted.

I released 20 PIT-tagged lizards in each of three microhabitats at random distances and bearings within a 15-m diameter experimental area. This area contained 1) yellow lupine bushes, 2) grass/forbs, and 3) open sand. The grass/forbs category specifically included California poppy, mugwort, phacelia, creeping wild rye, oats, annual fescue, ripgut brome, wire lettuce, and sow thistle. The 60 lizards were released on 26 June 1998 between 1630 h and 1700 h; the first sampling period started at 1800 h. Every 4 hours a search of the area was conducted during a 48 hour period after release. As each lizard was located, the position was marked and time, date, soil temperature (surface, at 2.5 cm, and 10 cm depth), and habitat data (bush, grass/forbs, or sand) recorded. Air temperature was recorded at the start of each period. I measured soil compaction at 8 cm and 15 cm depth using a Soil Compaction Tester (SCT; Dickey-John Corporation). This instrument measures the pounds/square inch (psi) of pressure exerted as it is pushed downward into the soil, and has markings on the steel rod indicating the depth being measured. To avoid injuring buried lizards, I slowly inserted the thermometer and SCT probes into the soil ~1 to 1.5 cm away from their known location. Distance and bearing were recorded from the lizard's previous position.

Nine temperature monitoring stations were positioned within the experimental area, three placed randomly in each of the three microhabitats. Following the procedures outlined above, soil temperature data were collected during each sampling period; the mean temperatures from these stations were compared with the mean temperatures at the sites where lizards were detected. After ensuring that sample variances were equal with an F test (Zar 1984), I used a two-sample t-test to compare the means for each habitat type. I log (X+1) transformed data with unequal variances.

I used a subset of lizards (n = 34) for statistical analysis of microhabitat and movement patterns. Only data from lizards detected more than 2 times after release were used in analyzing site fidelity. Six other extremely sedentary lizards were excluded because the analysis required independence of position between steps. Movement between microhabitats was assessed by comparing the original microhabitat at release with the habitat each lizard eventually moved into by the end of the 48 hours.

I tested the effects of soil moisture on habitat selection by producing wet and dry areas and by comparing the movement patterns of lizards between them. To moisten the soil to a depth of ~10 cm, 1.3 cm diameter irrigation drip line was used 24 hours before the start of the experiment. I constructed an array consisting of a 12.5-m long irrigation hose with six additional 3-m long irrigation segments running at 90° on alternating sides of it (3 each side). Three randomly chosen "dry" segments were fitted with plugs, so that no water flowed from them. The center hose supplied water to the "wet" segments, but emitted no water. Low, dry grass covered the ground under the array. On 22 July 1998, I released 8 lizards, simultaneously, at the center of each segment. I searched for the 48 lizards every 6 hours for 48 hours.

To test the effect of lizard density on movement, I tracked lizards in small groups of 8 lizards and large groups of 20 lizards. Three sets of each group were released in similar habitat no less than 5 m apart. Beginning 22 July 1998, I monitored the movements of these 84 lizards every 6 hours for 48 hours.

Between 18 June and 03 July 1998, I released groups of 10 to 12 PIT-tagged lizards at 23 randomly chosen, widely-spaced locations. To test for home range and long-term movement patterns, I monitored, for 24 months, the activities of these 238 animals, and all free-roaming lizards released in controlled experiments (478 total lizards). Because large areas of the site were covered in dense bushes and berry thickets, only about 45-55% of the 2.43 hectare habitat was accessible. The amount of accessible area varied seasonally. Workers searched the accessible areas weekly from July through November 1998, bi-weekly from December through September 1999, and monthly thereafter. Searches were directed, i.e. I purposely searched on days with higher temperatures and during the particular time of day I thought I would find the maximum number of lizards.

Positions (DGPS) of lizards were recorded with a Trimble ProXr unit and, after April 1999, were post-processed as described previously. Time of day, weather, soil moisture, and habitat (sand, grass, lupine, etc.) were recorded. The lizards and the habitat were disturbed as little as possible. Lizards that stayed in the same position for more than two consecutive sampling periods were excavated to test whether the signal was coming from a loose PIT-tag.

I calculated the home range for individual lizards meeting three criteria: (i) the animal was successfully tracked for >180 days, (ii) at least four geographic positions were obtained, and (iii) the lizard did not die or leave behind a loose tag during the sampling period.

Two home range estimators, kernel home range (KHR) and minimum convex polygon (MCP) were calculated using the Animal Movement Analyst Extention (AMAE) program for ArcView (Hooge and Eichenlaub 1997). I calculated the 95% and 50% utilization distributions (UD) for kernel home range using fixed kernels with a smoothing factor calculated with the ad hoc value, as suggested by Hooge and Eichenlaub (1997) and Worton

(1989). The 95% UD is the area an animal actively uses, whereas the 50% UD establishes the core area of activity for each lizard.

Because spontaneous tag loss was low in the lab, I assumed that loose PIT-tags found in the field indicated the death of the animal. I also assumed that all loose tags were found. The finite survival rate (FSR) was calculated for lizards released in the field between 18 June 1998 and 08 September 1998, and for tagged lizards held as controls in the lab (Krebs 1999).

Results

All lizards quickly burrowed upon release and were completely buried within approximately 10 seconds. At no time were healthy lizards, tagged or untagged, seen above ground. I also noticed that lizards found near lupines and other bushes were more frequently located at the drip-line around the outer perimeter of the bush vs. the interior areas of the canopy. The maximum observed speed for these lizards was 1.96 m/hr (4.9 m in 2.5 hours).

It took approximately 2 hours to complete searches during each sampling period for the study of microhabitats. Forty-eight of the 60 lizards (80%) were detected with the reader at least once in 48 hours. Of those found, 53% were located ≥ 3 times up to a maximum of 9 times (Fig.7a). Lizards were located in almost equal numbers on the first and second days.

Thirty-two percent of the lizards stayed within the same habitat as where they were released. Fifty percent of lizards stayed in or traveled into bushes, 38% into grass, but only 12 % for sand (Fig. 7b). Eleven lizards were sedentary, remaining in the same location (from 2 to 9 times) for multiple sampling periods. The maximum time a lizard was stationary was 43 hours. Twenty-seven of the 34 lizards exhibited random movement. Twenty-one percent of the lizards originating in bushes showed site fidelity, as did 33% for grass, but only 9% for those in sand.

Lizards actively moved during day and night; sedentary behavior occurred in daytime as often as night (Fig. 8). Almost 48% of the lizards were detected between the hours of 1400 h and 1800 h (Fig. 9a), which coincided with the greatest average soil temperatures at sites where lizards were found (Fig. 9b).

Maximum number of detections of lizards occurred at about 15-20 C° for all soil depths (Fig. 10). Lizards were found within 11.5 cm of the surface at all times of the day as air temperatures ranged from 11 to 25 C°. The surface of the soil where lizards were found had a much greater range of temperatures than the air, apparently gaining and then retaining heat. Temperature extremes were mediated at 2.5 cm depth, showing less variation that at the surface (13 to 34 C°), and at 10 cm, temperatures were even more homogenous (10 to 32 C°). Lizards were routinely found when the full range of temperatures from all depths near the lizard were below 20 C° (Appendix 1).

Under bushes, temperature (surface and 2.5 cm depth) where legless lizards were found was greater than controls. Lizards were found at positions under bushes where mean temperature at the surface was 20.05 C° (standard dev = 4.77), significantly greater than 18.00 C° (standard deviation = 4.40) at the control stations ($p = 0.04$). This same pattern held for lizard detections at a depth of 2.5 cm (0 = 19.97 C°, standard dev. = 4.25) when compared with the control stations (0 = 18.24, standard deviation = 2.71; $p = 0.03$). There was no statistical difference in the means between lizard locations and control stations under bushes at

10 cm. For grass/forb and sand habitats, there were no significant differences in mean soil temperatures where lizards were found compared with the control stations (Table 7).

Loose soil (0 to 50 psi) occurred at 8-cm depth around the perimeter of yellow lupine bushes and some forbs (mugwort in particular, Fig. 11). In some cases, this phenomenon persisted to a depth of 15 cm. Deeper soils were generally more solid, and areas of open sand were very compact, up to 160 psi at 15 cm.

The number of lizards detected (48, 100% of those released) at wet release sites was equal to the number detected at dry release sites. More than half of the animals (26) stayed near their original release habitat (Fig.12). Eight lizards moved from their original habitat into wet areas, but five moved from wet habitat into dry habitat. Eight additional lizards moved into lupine bushes just outside the experimental area.

Data for 34 animals met the requirements for site-fidelity analysis; twenty-five of them (74.5%) exhibited non-random movement. Lizards released in dry areas displayed site fidelity more often (76.9%) than those released in wet areas (50%).

Twenty-three of 24 lizards released in low-density groups were detected at least twice (95.8%). More than 28% (17 of 60) of the lizards released in high density groups quickly dispersed out of range, either vertically or horizontally, and were never found during the experimental period. Of those that were located, they were found less often compared with those released in low density groups.

Data for 37 animals met the requirements for site-fidelity analysis comparing density. Lizards released in low density groups displayed site fidelity 37.5% of the time vs. 33.3% of those released in high density groups. However, only a third of the high density lizards were located often enough to be used in this analysis.

Individual lizards were located 868 times during 2 years of long-term monitoring. Four-hundred and fifteen of the 478 (86.8%) free-roaming lizards were found at least once, and new animals continue to be found that have not been located since their release. Two animals were recently found whose last known position was recorded nearly 2 years ago. Fifty-seven of the animals were located on 4 or more occasions and one was found 12 times (Fig. 13). There was no apparent seasonal pattern in the number of lizards found per hour of effort, except that in March 2000 102 lizards were located, many of them appearing gravid. A greater percentage of legless lizards under bushes were found near the drip line (71%) vs. the near the roots (3%) or in the interior of the canopy (26%).

Forty-one lizards, tracked for 243 to 671 days, were used in home range analyses (Appendix 2). The number of geographic positions recorded per individual was 4 to 12, and the maximum distance traversed was 34.8 m in 305 days (11.4 cm/day). I noted no homing tendency (i.e. no lizards were observed making straight-line paths toward their original capture location).

For the kernel home range analysis, the mean 95 % UD estimate was 71.0 m^2 (standard deviation = 87.2), and the mean 50% UD was 15.8 m^2 (standard deviation = 21.3). The large variances in the home range estimates were attributed to 5 extremely sedentary lizards (95% UD < 10 m^2) and 3 lizards with 95% UD's >225 m^2 (Figs. 14, 15, 16). The mean size of home range UD's did not increase with the length of time lizards were tracked or sample size (Fig. 17). The MCP home range was 0.33 to 70.96 m^2 (0 = 13.30 m^2, standard deviation = 16.97).

Some lizards moved between 10 and 20 m within the first month after being released, then occupied a smaller area, indicating a month may be needed for lizards to re-stabilize after the disturbance of being moved.

During summer 1998, 568 tagged lizards were released. Between 30 June 1998 and 30 June 1999, 12 loose tags were found (FSR for year 1 = 97.9%). An additional 26 loose tags were located the following year (FSR for year 2 = 95.4%, overall FSR = 93.3%). Only five tags had animal tissue still attached to them, so approximating the date of death was not practical. Of 530 lizards that presumably survived through 30 June 2000, 44% of them (232) were located within the prior six months. The FSR for tagged control lizards held in the lab was 90.4% for year 1, 84.2% for year 2, with an overall FSR of 80.9%.

An owl pellet containing a PIT-tag from a legless lizard was found 800 m away from the lizard's release site, and a second loose tag was found a similar distance from its lizard's origin. Five tags were found in scats of *Felis catus*. A robin (*Turdus migratorious*) captured but did not kill 2 legless lizards, a hawk was seen flying with a live legless lizard in its beak, and a partially digested lizard was found in a bolus, presumably from a marsh hawk (*Circus cyaneus*).

Discussion

All experimental sites supported an existing population of un-tagged legless lizards, which may have affected results. I assumed that lizards acted independently, that is the effects of other lizards on results were not known but likely equal among test groups. All experiments were conducted at one site with presumably high habitat value.

Searching for lizards may have resulted in changes in lizard movement patterns. I attempted to test the effects of human foot-falls by removing ground vibration caused by walking. I simultaneously released 8 lizards in the center of a 9 m^2 area. The area was bounded by a "catwalk" made of four 3m-long wood boards supported by four hay bales. Movements of lizards were monitored from atop the catwalk without entering the area on foot. I repeated the experiment twice with inconclusive results.

On the first occasion, lizards were released in an area vegetated with small yellow lupine bushes. I tracked their movements every 15 minutes for 24 hours, and found that although the lizards moved often, they did not move far, remaining under or around the bushes. This could have indicated that lizards move less after eliminating vibration from foot traffic. On the second occasion, the area contained only grass and forbs. Within 12 hours, 7 of 8 lizards made long movements out of the area below a large blackberry (*Rubus ursinus*) patch to the southwest. The overall conclusion is that lizards seek and settle into quality habitat. Effects of foot-fall disturbance, however, remains undetermined.

In all of the short-term experiments, I carefully transported animals, allowed them to acclimate at the site within their individual containers, and handled them as little as possible. Initial movements, however, were probably enhanced in response to their handling and disturbance (Turchin 1998).

Individuals undetected during experiments were an indication that (i) the lizard had moved into an un-searchable area, (ii) it had burrowed deeper than 10 to 11.5 cm, or (iii) the lizard was near the surface, but was in a vertical position such that the tag did not reflect the reader signal. These limitations created a bias toward animals that remained near the surface or those that remained in a more horizontal position and reduced overall sample size and increased the variability in the number of detections per lizard.

I did not collect detected lizards, and so did not determine their depth in the soil. Therefore, soil temperature was only known to within 10 cm of the actual position of the lizard, and soil compaction is only known to within 15 cm.

Because only adult lizards were large enough to tag, the movement patterns of younger lizards was not tested. Because lizards were not sexually dimorphic, I could not test differences between male and female activities. Unless a lizard remained in the same location more than twice, I assumed that the lizard was alive.

The high percentage of lizards relocated was encouraging, and because I continue to find lizards that have not been located for long periods, I should be able to refine home range estimates through time. Although some lizards may frequent shallower burrows more often, the recapture probability was not biased toward slow or easily captured animals.

Anniella is almost exclusively fossorial, therefore, I assumed that all movements occurred underground. In the field, animals were never seen on the surface and laboratory observations, including time-lapse video, support this finding. Lizards probably used the soil interface for feeding and for mating when there was sufficient leaf litter to conceal them.

My observations also indicated that lizards routinely occupied deeper soil than was previously reported. "Missing" lizards often re-appeared in the same spot, indicating that they migrated deeper and then returned to the shallower location. Although results may be an artifact of the terrariums used, lab observations clearly indicated that lizards were capable of burrowing to at least 46 cm depth. Soil compaction readings in the field indicated that *Anniella* can burrow in relatively compact sand. A review of the literature revealed several ideas about the way that these lizards move within their subterranean environment. Miller (1944) mentioned burrow systems, and Fusari (1984) and Kamel and Gatten (1983) identified *Anniella* as a sand swimmer, indicating that soil re-consolidates behind the animal as it moves underground. My lab observations confirm that legless lizards build elaborate, persistent burrow systems. These burrows, and the low soil compaction that indicated their presence, may provide a new tool in the difficult task of detecting the presence of *Anniella*. This burrowing may play an important role in the ecosystem by increasing soil aeration and drainage. The influence of burrows between roots could be important to plants and their subterranean insect fauna (Maron 1998).

Lizards actively moved day and night in all of the short-term tracking studies. A high percentage of lizards were found between 1400 h and 1800 h when soil temperatures were greatest, indicating that lizards used the temperature gradient of the soil to thermoregulate. *Anniella* does not avoid temperatures below 20 C°, as indicated by the thermal gradients used by Bury and Balgooyen (1976). Although I found lizards in soil 27 C°, I was unable to establish an actual upper temperature limit. This is because lizards were not collected and I did not know the exact temperature at the exact depth each was found. In selecting areas under bushes with higher soil temperatures, lizards may take advantage of the sunnier sides of the vegetation for basking.

Short-term movements may not be a response to immediate needs for resources such as food or water. Animals were fed and well hydrated when they were released. Overall, nearly half of the animals used in the test of short-term site fidelity had random movement paths. *Anniella pulchra* has a relatively low standard metabolic rate, 54-81% of the mean for other reptiles of the same size (Kamel and Gatten 1983), and may not feed often (Hunt pers. comm.). Still, lizards released in bushes tended to stay there, whereas lizards released in sand eventually traversed into grass or bushes. Many of the lizards released in grass also moved under yellow lupines where arthropod prey density may be greater. Lizards had no immediate need to find soil moisture; animals released in dry areas did not necessarily seek soil moisture horizontally nor did they vertically migrate to moisture below the surface.

The extent to which lizards avoid each other is unknown. Lizards held in the laboratory were normally well-spaced, and there were no signs of aggression among them. When placed in greater densities, they dispersed more than lizards released at low density.

I observed that lizards tended to select the outer perimeter of the canopy of bushes. More of the lizards found under bushes were located at the drip line and low soil compaction readings at these areas indicated a large number of burrows. The drip line may provide more moisture than surrounding sand, greater soil temperature, or there may be other unseen differences at this ecotone.

Home range is usually described as the area an individual uses for feeding, mating, retreat, basking, and other normal activities and excludes occasional sallies to explore new habitat (Burt 1943). Kernel density estimators, non-parametric approaches to determining home range area, are considered robust, and are becoming widely used (Worton 1987, Worton

1989, Seaman and Powell 1996, Hansteen et al. 1997). My small sample size probably biased the results by overestimating the true home range size (Worton 1987, Seaman and Powell 1996). Even given this flaw, the kernel estimator model provides a plausible home range estimate.

MCP home-range estimation is an older, commonly used test in early studies of reptiles. It is very sensitive to sample size: as sample size increases, so does the size of the home range (Worton 1987, Boulanger and White 1990, White and Garrot 1990). This explains the small mean MCP of 13.30 m^2. MCP home range was determined by drawing a polygon which encompasses all of the known positions for an animal and calculating the total area within it. Utilization distributions are more effective for estimating the habitat animals use because they are probabilistic; each known position has an "associated probability that the animal is in that location" (Hooge and Eichenlaub 1997).

Home range sizes varied greatly among individual lizards in this study. It is possible that some of the variation in home range size was attributed to differences in ranging distances between genders. This is a common phenomenon in terrestrial lizards. Turner et al. (1969) summarized home ranges for 14 different insectivorous lizards, and found that females had much smaller ranges (15 to 1000 m^2) than males (10,000 to 20,000 m^2).

Some lizards moved 10 to 25 m within the first month after release before settling into a smaller area. This may be the time it takes for lizards to readjust to their surroundings after the disturbance of being moved. The small mean home range for this population of *A. pulchra* (71.0 m^2, 95% UD) may be due to a high abundance of food, soil moisture, and other required resources.

Animals found moving into higher quality habitat may be seeking less patchily distributed resources. *Anniella* feeds on beetle larvae, adult beetles, insect pupae, spiders, sow bugs, ants, and termites, many of which are probably abundant on Moss Landing Hill (Coe and Kunkel 1906, Miller 1944, pers. observ., Fusari pers. comm.). Hunt (1984) stated that food was probably not a limiting factor in the size of legless lizards populations. Home range size can change through time due to resource availability and population density, so I will continue to monitor this population of *A. pulchra* to gain insights into the status of the relocated lizards.

Although no consistent pattern of seasonal activity has emerged, the large pulse of apparently gravid lizards found during March indicated that perhaps reproduction activity can be monitored in the future.

There are no data on longevity for *A. pulchra*. This lizard exhibits low fecundity (1-4 live-born young) and has a low metabolic rate, so it may be a long-lived species (Miller 1944, Goldberg 1985, pers. observ.). Lizards can live as long as 7.5 years under laboratory conditions (Krieberg pers. comm.). The presence of loose tags in the field was probably a good indication of mortality because spontaneous tag loss was low under laboratory conditions. The mortality rate, however, may be underestimated. Ailing and dying lizards have a strong tendency to come to the soil surface (pers. observ., Krieberg pers. comm.). This means that the tags left behind after the carcass of a lizard decomposes are very likely to be near the soil surface where they can be found with the reader. However, mortality may be greater than I can calculate because predators carry animals, with their tags, to inaccessible places. Mortality in the laboratory was greater than field mortality, and may indicate not all dead animals were identified in the field.

Domestic cats are a problem in developed areas and readily dig for lizards (Hunt and Zander 1997, pers. observ.). Other likely predators present on the site include 6 to 8 local raptors, deer mice, skunks, opossums, gray fox, red fox, weasels, coyotes, and dogs.

Determining home range and long-term dispersal ability for a population is an important step toward resource management and for planning future translocation projects. Based on my findings, populations of *A. pulchra* are capable of dispersing into surrounding habitats. Barriers to dispersal include inappropriate or poor quality habitat and development. Mitigation for habitat destruction could include relocating animals from developed sites to large contiguous areas of quality habitat with some likelihood that they would eventually occupy new sites.

Relocation methods should be thoughtfully considered. Workers should exercise care when releasing animals of indistinguishable gender and small home range into large areas. Inadvertently releasing large numbers of all male or all female animals at widely spaced intervals may cause a population decline as animals travel greater than normal distances to find mates.

The implications of releasing lizards into areas already populated by resident lizards are unknown. In an experiment in progress (begun two years ago), I released different densities of PIT-tagged animals into field enclosures. These experiments were designed to test carry capacity and will continue for five years.

In conclusion, average habitat use for individuals was 71 m^2. Legless lizards moved underground through a system of tunnels, vertically migrated often, and may burrow deeper than previously reported. Some animals moved in directed, non-random paths, although initial movements may be attributable to agitation dispersal. Legless lizards actively moved during day and night. They were found moving at least 5 m in 2.5 h, and up to 35 m per year, and thus are capable of long-term dispersal in quality habitat. Although lizards selected warmer areas when under bushes, they also were routinely found at temperatures below 20 C°. The ability to maintain metabolic rate at lower temperatures may allow these lizards to remain active during colder times of the day and in cold, wet seasons. Although the number of deaths is likely greater, I have confirmed mortality in less than 7% of tagged lizards after 24 months post-release.

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Appendix 1. Temperature data from the short-term microhabitat experiment.

Lizard	Date	Time	Temp (C^0) Surface	Temp (C^0) 2.5 cm	Temp (C^0) 10 cm	Min Temp (C^0)	Max Temp (C^0)
6133	27-Jun-98	1400	38.5	32.5	24	24.0	38.5
2260	27-Jun-98	1400	38.5	30.5	25	25.0	38.5
9552	27-Jun-98	1400	38	27	21	21.0	38.0
1456	27-Jun-98	1000	35	24	24	24.0	35.0
9131	27-Jun-98	1400	34.5	34	27	27.0	34.5
9165	27-Jun-98	1000	34	24.5	21.5	21.5	34.0
5264	27-Jun-98	1400	34	26	22	22.0	34.0
5273	27-Jun-98	1400	33	31	22	22.0	33.0
1224	27-Jun-98	1000	33	32	24	24.0	33.0
8695	27-Jun-98	1400	33	32	25.5	25.5	33.0
1150	27-Jun-98	1400	30	33	25.5	25.5	33.0
6311	27-Jun-98	1400	32.5	27	24.5	24.5	32.5
9260	26-Jun-98	1800	23	31	32	23.0	32.0
2260	28-Jun-98	1400	31.5	24	20	20.0	31.5
3550	28-Jun-98	1400	31	25	20.5	20.5	31.0
3597	27-Jun-98	1000	31	26	21.5	21.5	31.0
1150	27-Jun-98	1000	31	26	22.5	22.5	31.0
8334	27-Jun-98	1400	30.5	27	23.5	23.5	30.5
2734	28-Jun-98	1400	30	23	18.5	18.5	30.0
1253	28-Jun-98	1400	30	24	20	20.0	30.0
6223	28-Jun-98	1400	29.5	28.5	16	16.0	29.5
6133	28-Jun-98	1400	29	28	15	15.0	29.0
9552	28-Jun-98	1400	29	24	19.5	19.5	29.0
9260	28-Jun-98	1400	29	23.5	20.5	20.5	29.0
3497	28-Jun-98	1400	20	28.5	15.5	15.5	28.5
7250	27-Jun-98	1000	28	23	20.1	20.1	28.0
6323	26-Jun-98	1800	21	24	28	21.0	28.0
7093	27-Jun-98	1400	28	24	22	22.0	28.0
7125	26-Jun-98	1800	26	27	28	26.0	28.0
6623	26-Jun-98	1800	21.5	23	27	21.5	27.0
4516	26-Jun-98	1800	25	27	23	23.0	27.0
6133	27-Jun-98	1800	26	27	23	23.0	27.0
3490	27-Jun-98	1800	27	26	23.5	23.5	27.0
7125	28-Jun-98	1400	26.5	25	19.5	19.5	26.5

Appendix 1 cont. Temperature data from the short-term microhabitat experiment.

Lizard	Date	Time	Temp (C^0) Surface	Temp (C^0) 2.5 cm	Temp (C^0) 10 cm	Min Temp (C^0)	Max Temp (C^0)
3525	27-Jun-98	1000	26.5	23.0	20.5	20.5	26.5
9131	26-Jun-98	1800	21.5	25.0	26.5	21.5	26.5
1210	27-Jun-98	1400	26.0	23.0	21.0	21.0	26.0
5264	27-Jun-98	1800	22.5	22.0	26.0	22.0	26.0
8334	27-Jun-98	1800	24.0	26.0	22.0	22.0	26.0
2666	27-Jun-98	1800	24.5	26.0	23.5	23.5	26.0
1150	27-Jun-98	1800	23.0	24.0	25.5	23.0	25.5
3490	27-Jun-98	1400	25.0	19.0	15.5	15.5	25.0
1150	28-Jun-98	1400	25.0	23.0	20.0	20.0	25.0
5140	28-Jun-98	1400	25.0	24.5	20.0	20.0	25.0
1210	27-Jun-98	1000	25.0	21.5	20.5	20.5	25.0
9346	28-Jun-98	1400	25.0	22.5	20.5	20.5	25.0
1224	27-Jun-98	1800	21.0	25.0	23.5	21.0	25.0
2232	27-Jun-98	1800	24.0	25.0	21.0	21.0	25.0
5273	27-Jun-98	1000	25.0	21.5	21.5	21.5	25.0
7794	27-Jun-98	1800	24.0	25.0	21.5	21.5	25.0
7674	26-Jun-98	1800	24.0	25.0	24.0	24.0	25.0
3550	26-Jun-98	1800	25.0	25.0	24.0	24.0	25.0
6311	28-Jun-98	1400	24.5	21.0	19.5	19.5	24.5
9165	28-Jun-98	1400	24.0	21.0	18.0	18.0	24.0
4511	28-Jun-98	1400	24.0	22.0	18.5	18.5	24.0
8695	26-Jun-98	2200	19.5	21.5	24.0	19.5	24.0
4511	27-Jun-98	1800	24.0	23.0	20.0	20.0	24.0
2260	26-Jun-98	1800	20.5	23.5	24.0	20.5	24.0
3597	26-Jun-98	1800	22.5	24.0	24.0	22.5	24.0
9165	27-Jun-98	1800	23.0	23.5	20.0	20.0	23.5
1461	27-Jun-98	1400	23.0	20.0	15.5	15.5	23.0
6323	26-Jun-98	2200	18.0	20.0	23.0	18.0	23.0
6623	28-Jun-98	1400	23.0	22.0	18.5	18.5	23.0
3525	27-Jun-98	1800	23.0	22.0	20.0	20.0	23.0
3597	27-Jun-98	1800	23.0	22.0	20.0	20.0	23.0
3310	28-Jun-98	1400	23.0	22.0	20.5	20.5	23.0
4711	26-Jun-98	1800	22.5	23.0	21.0	21.0	23.0
1680	26-Jun-98	1800	22.0	23.0	22.0	22.0	23.0

Appendix 1 cont. Temperature data from the short-term microhabitat experiment.

Lizard	Date	Time	Temp (C^0) Surface	Temp (C^0) 2.5 cm	Temp (C^0) 10 cm	Min Temp (C^0)	Max Temp (C^0)
9237	26-Jun-98	2200	15.0	18.0	22.0	15.0	22.0
3497	27-Jun-98	1400	22.0	20.5	15.5	15.5	22.0
9622	28-Jun-98	1400	21.5	22.0	18.0	18.0	22.0
9552	27-Jun-98	1800	18.5	22.0	21.0	18.5	22.0
1461	27-Jun-98	1800	22.0	21.0	19.0	19.0	22.0
8334	26-Jun-98	2200	19.5	22.0	22.0	19.5	22.0
2734	26-Jun-98	1800	22.0	21.0	20.5	20.5	22.0
9622	27-Jun-98	2200	20.5	22.0	21.0	20.5	22.0
2260	27-Jun-98	1800	21.5	22.0	22.0	21.5	22.0
9622	28-Jun-98	200	16.5	21.5	19.0	16.5	21.5
9752	28-Jun-98	1400	21.5	20.0	18.0	18.0	21.5
9552	26-Jun-98	1800	21.5	21.0	19.0	19.0	21.5
7674	27-Jun-98	2200	19.0	21.5	19.5	19.0	21.5
9752	26-Jun-98	1800	20.5	21.0	16.0	16.0	21.0
5185	28-Jun-98	1400	21.0	20.0	16.5	16.5	21.0
3310	26-Jun-98	1800	21.0	20.0	20.0	20.0	21.0
1150	26-Jun-98	1800	20.5	21.0	20.0	20.0	21.0
7250	26-Jun-98	1800	21.0	21.0	20.0	20.0	21.0
7093	27-Jun-98	1800	21.0	21.0	20.5	20.5	21.0
3597	27-Jun-98	2200	21.0	21.0	21.0	21.0	21.0
6323	27-Jun-98	200	15.5	17.0	20.5	15.5	20.5
9165	27-Jun-98	1400	20.5	18.5	17.0	17.0	20.5
6323	27-Jun-98	2200	17.5	20.5	20.0	17.5	20.5
7794	26-Jun-98	1800	18.0	20.5	20.0	18.0	20.5
6133	27-Jun-98	2200	19.0	20.5	19.0	19.0	20.5
3310	26-Jun-98	2200	20.5	19.5	20.0	19.5	20.5
1461	27-Jun-98	1000	20.0	18.0	17.0	17.0	20.0
9237	28-Jun-98	1000	20.0	19.0	17.0	17.0	20.0
1224	28-Jun-98	200	17.5	20.0	19.0	17.5	20.0
1210	26-Jun-98	2200	18.0	20.0	20.0	18.0	20.0
7674	28-Jun-98	1000	20.0	20.0	18.0	18.0	20.0
4511	27-Jun-98	1000	20.0	19.0	18.5	18.5	20.0
1253	28-Jun-98	200	18.5	20.0	18.5	18.5	20.0
7250	26-Jun-98	2200	19.5	19.0	20.0	19.0	20.0

Appendix 1 cont. Temperature data from the short-term microhabitat experiment.

Lizard	Date	Time	Temp (C^0) Surface	Temp (C^0) 2.5 cm	Temp (C^0) 10 cm	Min Temp (C^0)	Max Temp (C^0)
9260	27-Jun-98	2200	20.0	20.0	20.0	20.0	20.0
2260	28-Jun-98	1000	19.5	19.0	16.5	16.5	19.5
3597	26-Jun-98	2200	18.0	19.5	19.0	18.0	19.5
9690	26-Jun-98	1800	18.0	19.5	19.5	18.0	19.5
6623	27-Jun-98	1800	19.0	19.0	19.5	19.0	19.5
6623	27-Jun-98	200	12.0	16.0	19.0	12.0	19.0
7093	28-Jun-98	1000	19.0	18.5	15.5	15.5	19.0
2260	27-Jun-98	2200	16.0	19.0	16.5	16.0	19.0
9690	26-Jun-98	2200	16.0	17.5	19.0	16.0	19.0
9260	28-Jun-98	1000	19.0	19.0	16.0	16.0	19.0
3497	26-Jun-98	1800	19.0	19.0	18.0	18.0	19.0
1461	26-Jun-98	2200	19.0	19.0	19.0	19.0	19.0
2260	28-Jun-98	200	15.5	18.5	18.5	15.5	18.5
1253	28-Jun-98	600	17.0	18.5	15.5	15.5	18.5
9622	28-Jun-98	600	17.0	18.5	16.0	16.0	18.5
9165	28-Jun-98	1000	18.0	18.5	16.0	16.0	18.5
1253	28-Jun-98	1000	18.5	18.5	16.0	16.0	18.5
9622	28-Jun-98	1000	18.5	18.5	16.0	16.0	18.5
4711	27-Jun-98	1800	17.5	18.5	16.5	16.5	18.5
4511	28-Jun-98	1000	18.5	18.5	16.5	16.5	18.5
5595	27-Jun-98	1000	18.5	18.5	18.0	18.0	18.5
1150	27-Jun-98	200	13.0	15.0	18.0	13.0	18.0
2232	27-Jun-98	600	16.0	18.0	18.0	16.0	18.0
4511	28-Jun-98	200	16.5	18.0	17.0	16.5	18.0
6133	27-Jun-98	600	16.5	17.0	18.0	16.5	18.0
6797	28-Jun-98	200	16.5	18.0	16.5	16.5	18.0
5140	28-Jun-98	600	18.0	18.0	16.5	16.5	18.0
6623	27-Jun-98	2200	17.0	18.0	17.0	17.0	18.0
7794	27-Jun-98	2200	17.0	18.0	18.0	17.0	18.0
7093	26-Jun-98	1800	18.0	17.5	17.5	17.5	18.0
6133	28-Jun-98	1000	17.5	17.0	15.0	15.0	17.5
6623	28-Jun-98	1000	17.5	17.0	15.0	15.0	17.5
9165	28-Jun-98	600	16.0	17.5	15.0	15.0	17.5
9552	28-Jun-98	200	16.0	17.5	15.0	15.0	17.5

Appendix 1 cont. Temperature data from the short-term microhabitat experiment.

Lizard	Date	Time	Temp (C^0) Surface	Temp (C^0) 2.5 cm	Temp (C^0) 10 cm	Min Temp (C^0)	Max Temp (C^0)
4516	26-Jun-98	2200	16.0	17.0	17.5	16.0	17.5
6797	27-Jun-98	2200	16.0	16.5	17.5	16.0	17.5
9622	27-Jun-98	600	16.0	17.0	17.5	16.0	17.5
1210	27-Jun-98	600	15.0	16.0	17.0	15.0	17.0
1210	28-Jun-98	1000	17.0	17.0	15.0	15.0	17.0
3490	27-Jun-98	600	15.5	16.0	17.0	15.5	17.0
3497	27-Jun-98	2200	16.0	17.0	15.5	15.5	17.0
1210	27-Jun-98	2200	16.5	17.0	15.5	15.5	17.0
7093	28-Jun-98	200	16.5	17.0	15.5	15.5	17.0
7093	27-Jun-98	2200	17.0	16.5	17.0	16.5	17.0
1461	27-Jun-98	200	14.0	16.5	16.5	14.0	16.5
3310	27-Jun-98	600	14.0	16.0	16.5	14.0	16.5
4490	27-Jun-98	200	14.5	16.5	16.5	14.5	16.5
3497	27-Jun-98	600	15.0	16.0	16.5	15.0	16.5
8334	27-Jun-98	200	15.0	16.5	16.5	15.0	16.5
1210	28-Jun-98	600	16.0	16.5	15.0	15.0	16.5
3497	28-Jun-98	1000	16.5	16.5	15.0	15.0	16.5
2260	28-Jun-98	600	13.0	16.0	16.0	13.0	16.0
4516	28-Jun-98	1000	15.0	16.0	14.0	14.0	16.0
9552	27-Jun-98	600	14.5	15.0	16.0	14.5	16.0
6623	28-Jun-98	600	15.5	16.0	14.5	14.5	16.0
7093	28-Jun-98	600	15.0	15.5	10.0	10.0	15.5
3497	28-Jun-98	600	15.0	15.5	14.0	14.0	15.5
4516	28-Jun-98	600	14.5	15.0	14.0	14.0	15.0
7093	27-Jun-98	200	12.0	14.0	14.5	12.0	14.5
5264	27-Jun-98	200	13.0	14.0	14.5	13.0	14.5
7093	27-Jun-98	600	13.0	13.0	14.5	13.0	14.5
7794	27-Jun-98	200	12.0	13.5	14.0	12.0	14.0

Appendix 2. Lizards used in the analysis of mean home range for this population of *Anniella*. KHR = Kernel Home Range

Lizard	Sample Size	Total Distance (m)	Duration (days)	Distance/Day (cm)	KHR 95	KHR 50
121793	5	10.8	338	3.2	46.3	10.3
125650	6	28.2	549	5.1	91.1	16.3
149453	4	6.6	645	1.0	29.5	6.3
151116	6	9.9	616	1.6	25.5	5.0
151167	4	6.5	243	2.7	33.2	6.9
151680	5	9.2	644	1.4	41.5	11.6
152520	4	12.1	342	3.5	108.8	21.0
152590	5	4.1	658	0.6	8.2	2.5
154644	13	14.8	552	2.7	10.1	2.3
155491	5	6.7	603	1.1	9.8	2.5
156657	5	7.1	568	1.2	12.1	2.2
157126	5	8.1	645	1.3	25.5	5.0
157316	8	15.1	243	6.2	24.6	4.0
157753	7	33.5	465	7.2	165.9	29.6
159513	5	7.2	258	2.8	29.6	4.8
161796	5	20.3	615	3.3	353.8	107.5
162352	5	14.8	629	2.4	100.9	23.1
163457	5	8.0	243	3.3	25.7	3.8
166140	5	6.5	568	1.2	20.9	5.0
245165	6	5.3	647	0.8	13.6	2.0
246316	7	10.2	236	4.3	7.2	1.2
253263	6	7.8	279	2.8	22.2	3.6
253685	4	7.0	645	1.1	29.1	5.7
256740	5	7.3	656	1.1	22.4	3.5
259525	5	20.5	617	3.3	171.3	36.6
261160	9	14.6	559	2.6	74.2	15.0
566147	6	8.5	631	1.3	14.8	4.0
568096	8	22.5	581	3.9	93.1	13.7
569471	5	20.4	568	3.6	147.5	43.0
575515	6	12.0	558	2.1	37.5	16.4
575585	5	15.3	647	2.4	121.3	36.7
609332	6	25.4	671	3.8	187.6	34.2
612467	4	3.8	632	0.6	10.5	3.6
856740	7	17.0	616	2.8	53.7	10.2
859696	6	8.1	285	2.8	20.7	5.6

Appendix 2. Cont.

Lizard	Sample Size	Total Distance (m)	Duration (days)	Distance/Day (cm)	KHR 95	KHR 50
865510	5	4.1	633	0.7	6.9	1.0
872565	5	8.4	645	1.3	40.6	8.0
874690	5	11.3	309	3.6	48.1	13.4
911093	5	34.8	305	11.4	371.2	73.8
911470	5	25.0	568	4.4	229.9	45.7
913462	6	11.4	633	1.8	24.6	7.3

Table 1. Mean, standard deviation, and range of mass, length of snout-vent, tail length and total length for lizards with intact tails (n = 2006).

Measurement	Mean	Std. Deviation	Range
Mass (g)	3.3	1.3	0.6 - 8.5
Snout-vent length (mm)	113.2	20.6	31 -172
Tail length (mm)	60.5	17.5	31- 122
Total length (mm)	173.7	35.1	50-294

Table 2. Age class distribution of recovered lizards based on Miller's (1944) snout-vent lengths.

Age Class	Snout-Vent Length (mm)	No. Lizards
Yearling	< 83	232
Juvenile	83-110	640
Sub-adult	111-120	620
Adult	>120	2,026
Total		3,518

Table 3. Percentage cover of plant taxa occurring in 90 quadrats within the lizard recovery area.

Species	% Cover	Species	% Cover
Bromus diandrus		*Carpobrotus edulis*	
Ripgut Brome	27.06	Iceplant	22.55
Montia perfoliata		**Total Iceplant**	**22.55**
Miners Lettuce	4.83		
Vulpia sp.		*Lupinus chamissonus*	
Annual Fescue	4.28	Silver Bush Lupine	8.28
Chorizanthe cuspidata		**Total Silver Bush Lupine**	**8.28**
Monterey Spineflower	3.17		
Marah fabaceus		*Rosa californica*	0.28
Man Root	2.39	California Rose	
Avena barbata			
Wild Oat	2.33	*Marrubium vulgare*	*
Chenopodium californicum		Common Horehound	
California Goosefoot	2.28		
Amsinckia spectabilis		Duff	0.44
Fiddleneck	1.00	Bare Sand	6.56
Phacelia spp.		**Total Other**	**7.28**
Phacelia	1.00		
Raphanus sativus		*Rubus ursinus*	
Wild Radish	1.00	California Blackberry	3.61
Stellaria media		**Total Blackberry**	**3.61**
Chickweed	1.00		
Artemesia douglasiana		*Lupinus arboreus*	
California Mugwort	0.61	Yellow Bush Lupine	3.45
Eschscholzia californica		**Total Yellow Bush Lupine**	**3.45**
California poppy	0.44		
Lactuca serriola		*Ericameria ericoides*	
Prickly Lettuce	0.22	Mock Heather	2.72
Achillea millefolium		**Total Mock Heather**	**2.72**
Common Yarrow	0.11		
Conium maculatum			
Poison Hemlock	0.11		
Sinapis arvensis			
Mustard	0.11		
Sonchus oleraceous			
Common Sow Thistle	0.11		
Lotus spp.			
Deerweed	0.06		
Cryptantha leiocarpa			
Popcorn Flower	*		
Leymus triticoides			
Creeping Wild Rye	*		
Total Grass and Forbs	**52.11**		

*Present in low abundance within quadrats, not reflected in counts

Table 4. Area (m^2), percentage cover, and density of lizards (#/m^2) by soil type within the study area.

Soil Category	Area (m^2)	% Cover	Density (liz/m^2)
Charcoal Infused Sand: Midden Sand infused black with charcoal dust to 2 m	2,631	16.74	0.314
Charcoal Infused Sand: Disturbed Sand infused black with charcoal dust depth varies, disturbed or redeposited	3,048	19.39	0.184
Cemented Sand/Clay/Silt Medium brown cemented sands, clay/silt clay/silt cement, 10-30 cm dark brown organic A horizon	1,023	6.51	0.213
Yellow Sands with Brown A Horizon Yellow sands overlain by 20-40 cm dark brown organic A horizon	6,628	42.17	0.283
Yellow Sands: Disturbed Yellow sands disturbed and redeposited	1,253	7.97	0.207
Yellow Sands with Brown A Horizon: Disturbed Yellow sands and brown sediments disturbed and redeposited	599	3.81	0.022
Unknown	537	3.42	0.127
Total	15,719	100.00	0.211

Table 5. Area (m^2), percentage cover, number of lizards found, and density (#lizards/m2) in areas of moisture accumulation (swales) and drier habitats within the study zone.

Category	Area (m^2)	% Cover	No. Lizards	Density (liz/m^2)
Swales				
Depressions where soil moisture accumulates	1,493	9.50	607	0.407
Non-Swale	14,226	90.50	2,707	0.190
Drier habitat; better drained				
Total	15,719	100.00	3,314	0.213

Table 6. Mean, standard deviation, range of depths, and number of trials (n) that PIT-tags were detected under various conditions (loose, buried in sand, implanted in lizards) and in different orientations. Tags were implanted in lizards two weeks before testing.

Tag-Sand Condition	Orientation	n	Mean (cm)	Std. Deviation	Depth Range (cm)
Loose, unburied	Horizontal	15	10.5	0.129	10.0-10.5
Loose, unburied	Diagonal	15	10.5	0	10.5-10.5
Loose, buried, dry sand	Horizontal	15	10.4	0.594	9.5-12.0
Loose, buried, dry sand	Vertical	15	5.2	3.015	2.0-10.5
Loose, buried, wet sand	Horizontal	15	10.7	0.523	10.0-12.0
Loose, buried, duff-covered, dry sand	Horizontal	15	10.5	0.327	9.5-11.0
Loose, buried, duff-covered, wet sand	Horizontal	15	10.5	0.129	10.0-10.5
Implanted in lizard, dry sand	Horizontal	6	10.5	0.949	9.0-11.5
Implanted in lizard, wet sand	Horizontal	6	10.7	0.683	10.0-11.5

Table 7. Mean, standard deviation, sample size (n) and probability of a difference for comparing the soil temperatures where lizards were detected and at control stations for three habitat types.

Habitat Type	Sample Type	Sample Locations	Mean Temp (°C)	Standard Dev.	N	Prob.
Bushes	Surface	Lizards	20.05	4.77	55	0.04*
		Controls	18.00	4.40	33	
	2.5 cm	Lizards	19.97	4.25	55	0.03*
		Controls	18.24	2.71	33	
	10 cm	Lizards	17.75	2.81	55	0.17
		Controls	17.01	2.12	33	
Grass/Forbs	Surface	Lizards	22.63	5.49	64	0.32
		Controls	21.35	6.22	33	
	2.5 cm	Lizards	22.37	3.79	64	0.25
		Controls	21.32	4.50	33	
	10 cm	Lizards	20.49	3.01	64	0.35
		Controls	19.87	3.14	33	
Sand	Surface	Lizards	21.01	7.27	45	0.83
		Controls	21.41	8.89	33	
	2.5 cm	Lizards	20.47	4.42	45	0.48
		Controls	21.26	5.16	33	
	10 cm	Lizards	19.43	4.09	45	0.28
		Controls	20.38	3.59	33	

* = significant results

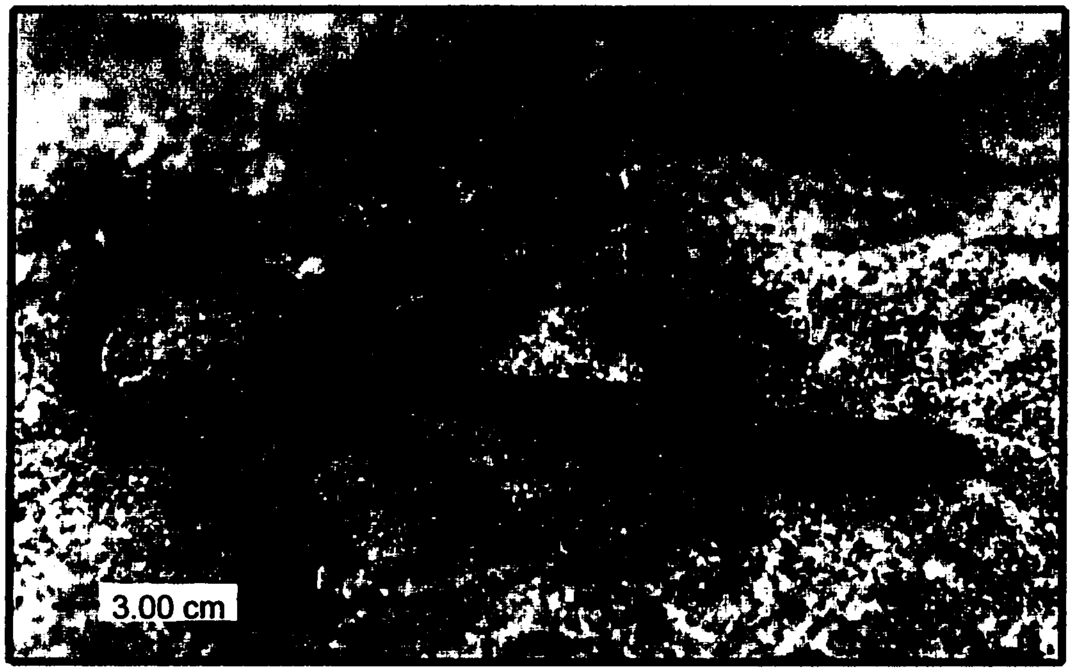

Figure 1. California legless lizard (*Anniella pulchra*) on the sand surface with beach burr, a fore dune plant. These lizards are nearly exclusively fossorial.

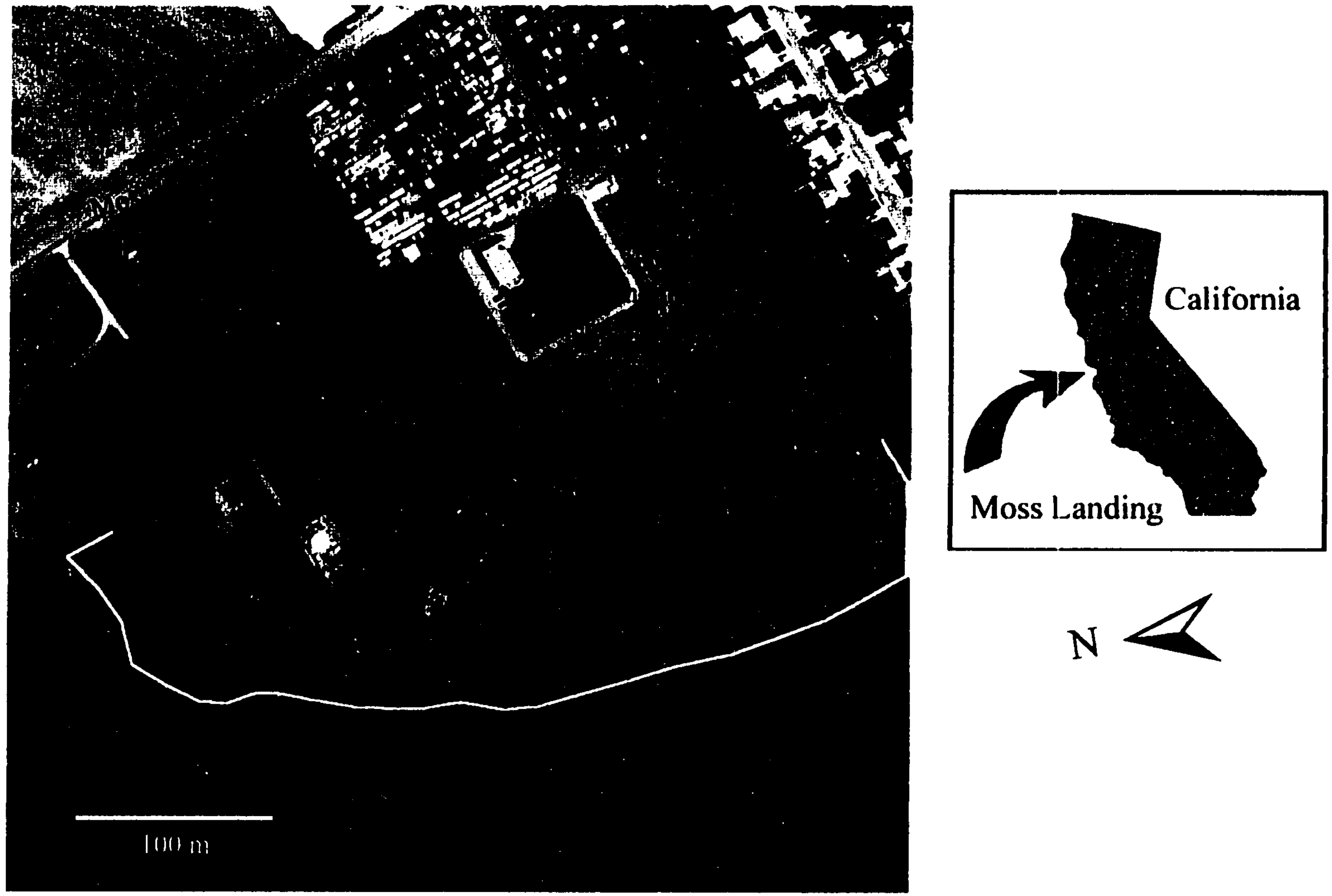

Figure 2. Study site. The red outline shows the 1.6 hectare collection site. Legless lizards were released in the 2.4 hectares shown inside the white line. Vegetation in this habitat was enhanced during the study.

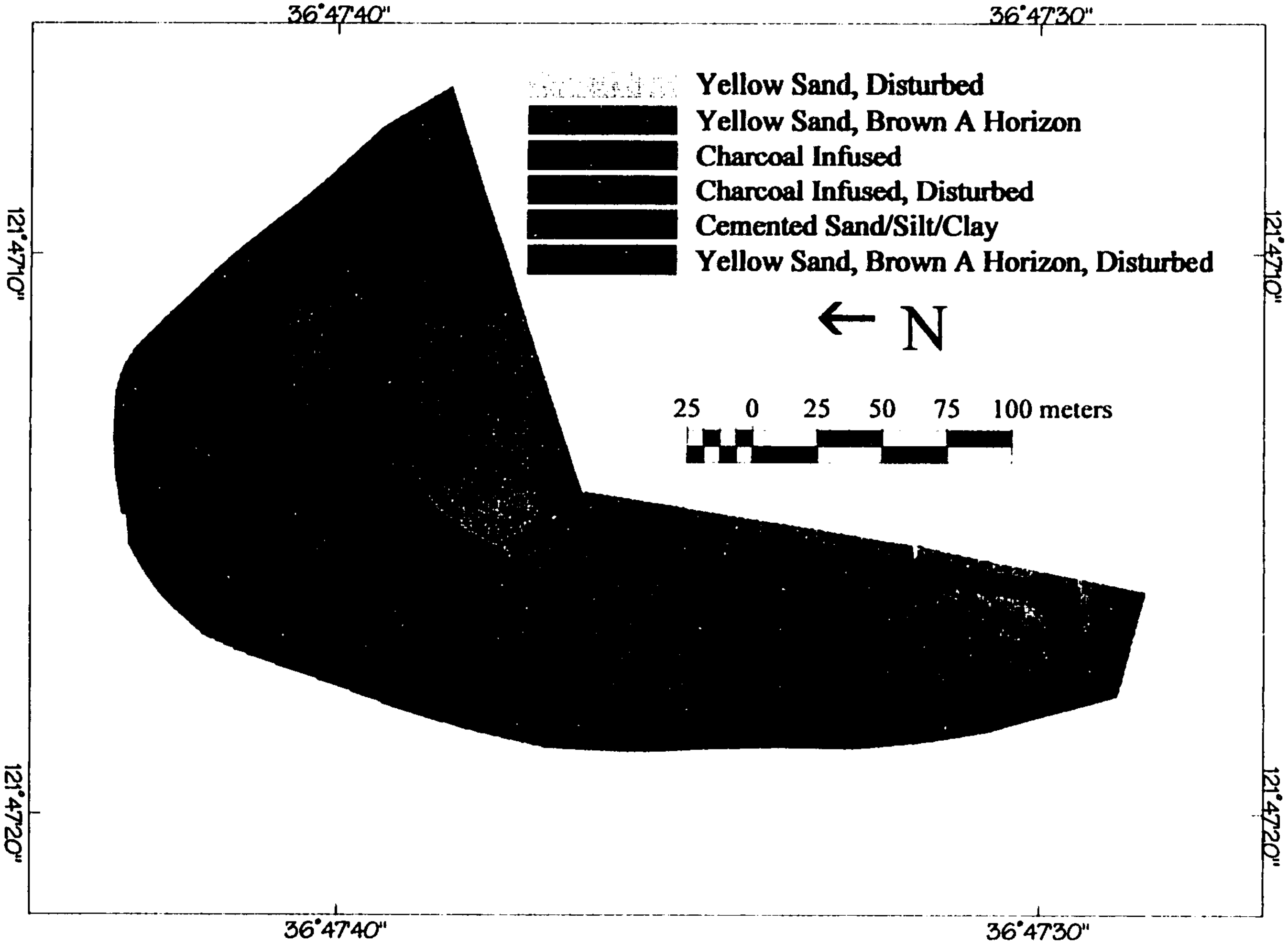

Figure 3. Soil types within the study area where lizards were captured. Area of defined soils is 15,182 m2.

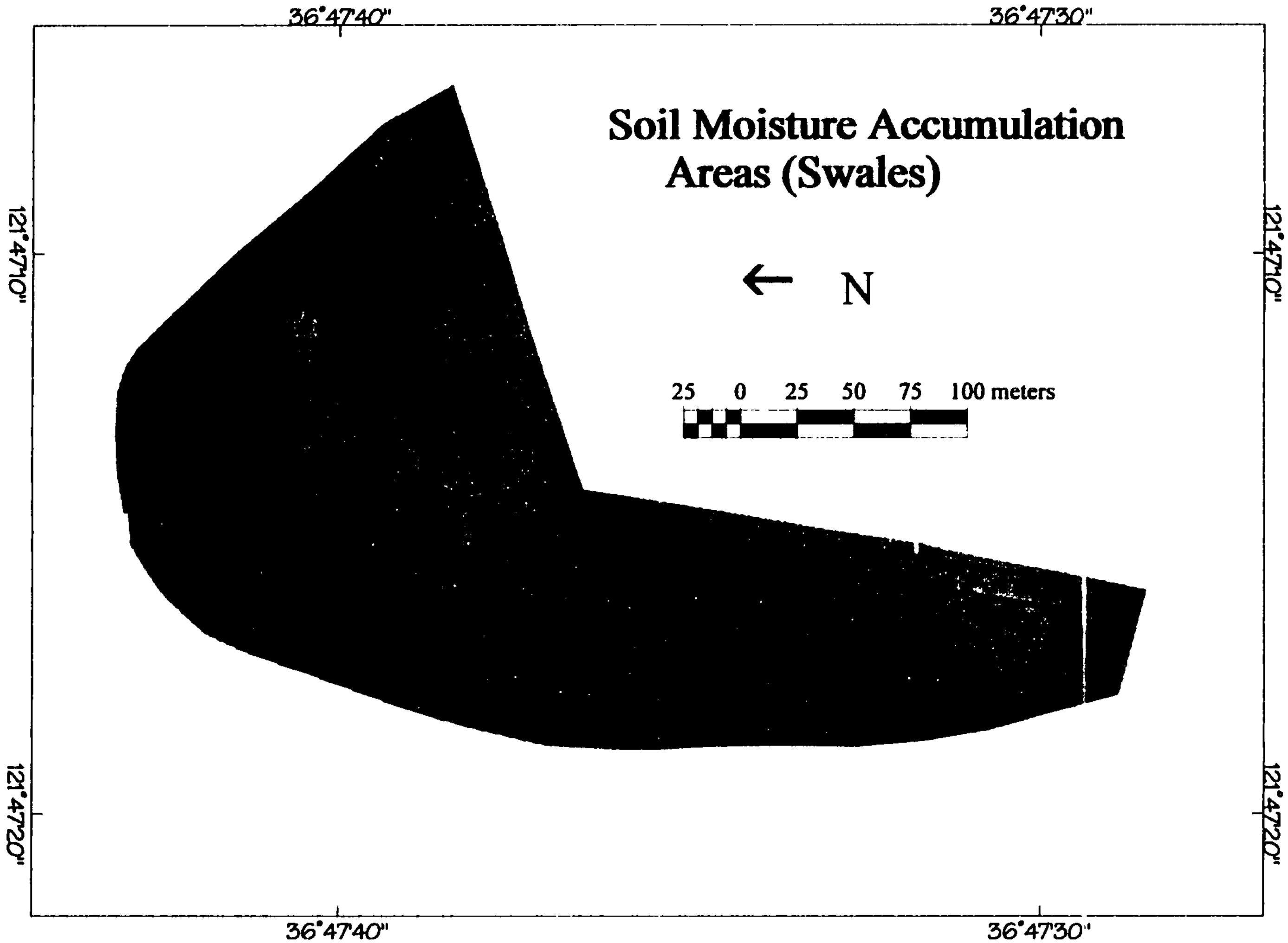

Figure 4. Topographic map of Moss Landing Hill showing areas of moisture accumulation. Swales (9.5% of the area) are depicted as dark polygons within the collection site (red outline).

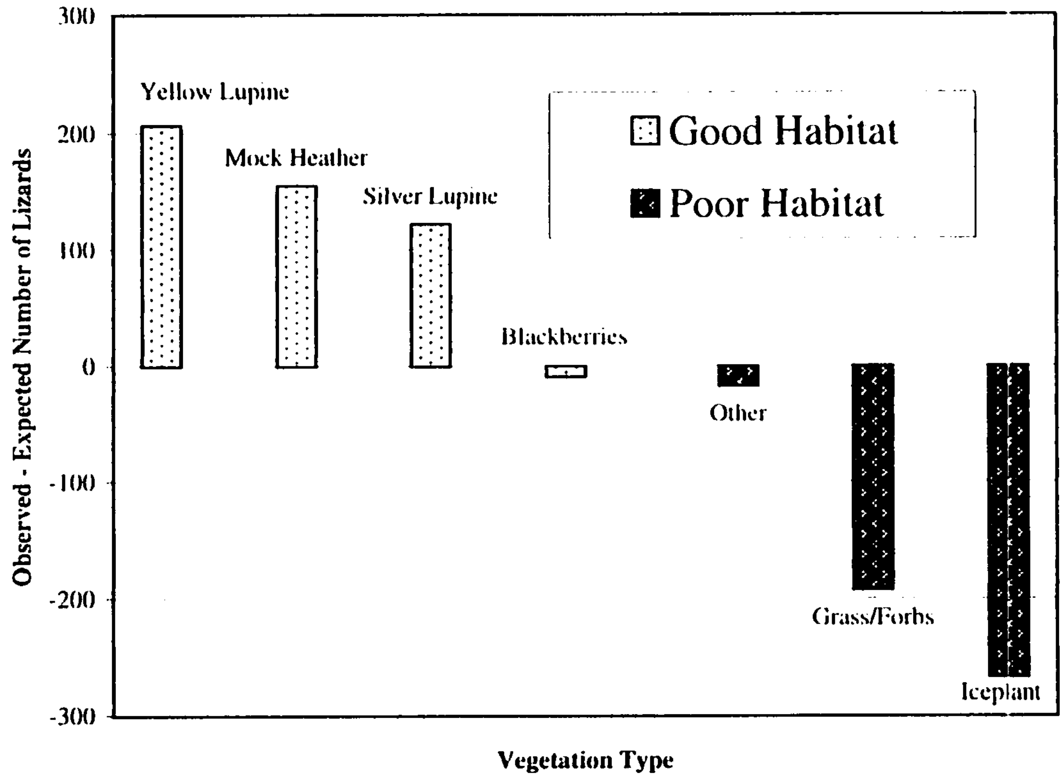

Figure 5. Lizard distribution among vegetation types for lizards found during initial recovery searches (n = 1,714). Habitat quality is based on the difference between the observed vs. expected frequencies of animals for each category.

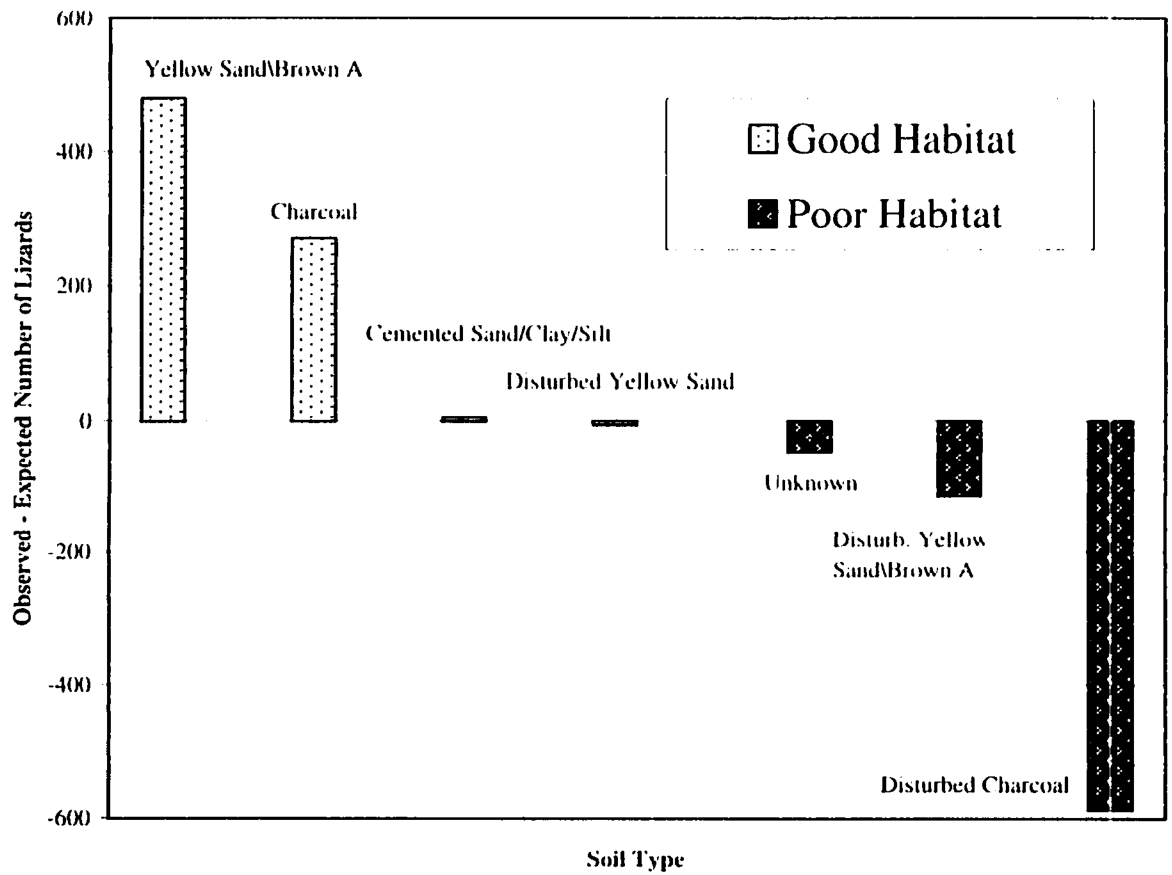

Figure 6. Lizard distribution among soil categories (n = 3,314). Categories described in more detail in Table 2. Habitat quality is based on the difference between the observed vs. expected frequencies of animals for each category.

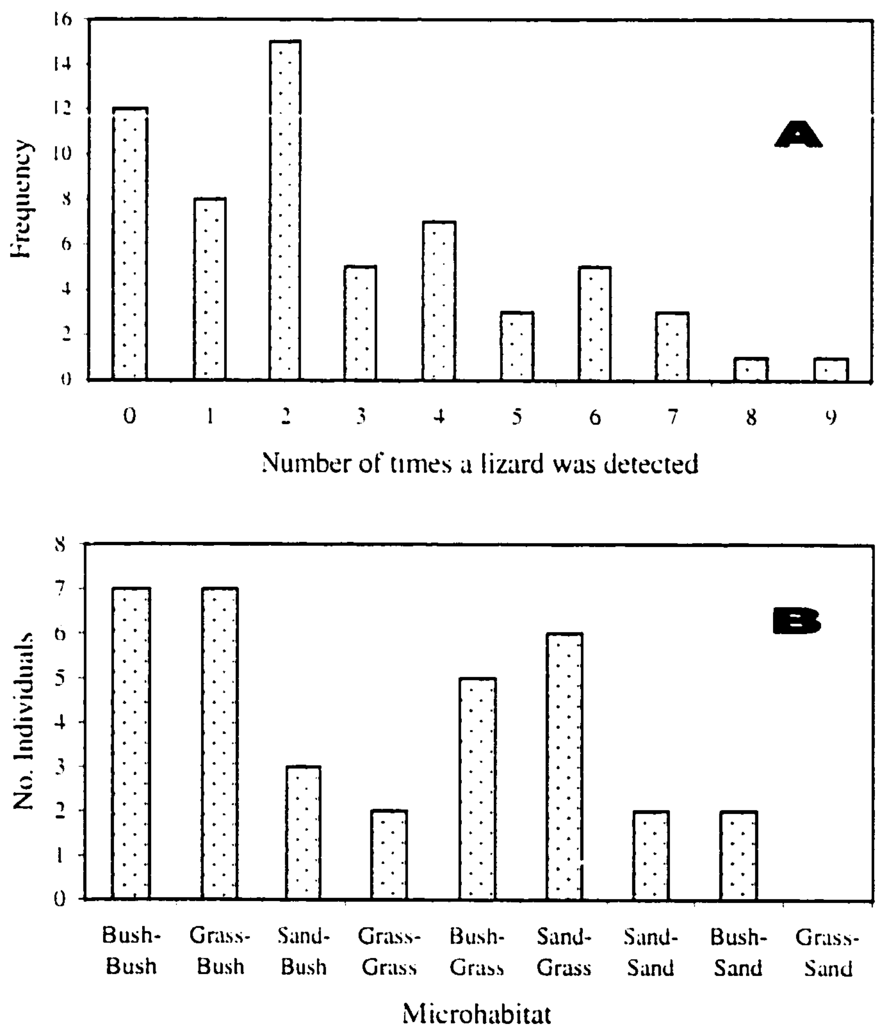

Figure 7 a).The number of times (frequency) a lizard was detected in the short-term microhabitat experiment. Eighty percent of the animals were located at least once (n = 60). b). Change in microhabitat for lizards, reported as the original habitat and ending habitat category. The grass category included forbs. This classification includes only those animals used for statistical analysis (n = 34).

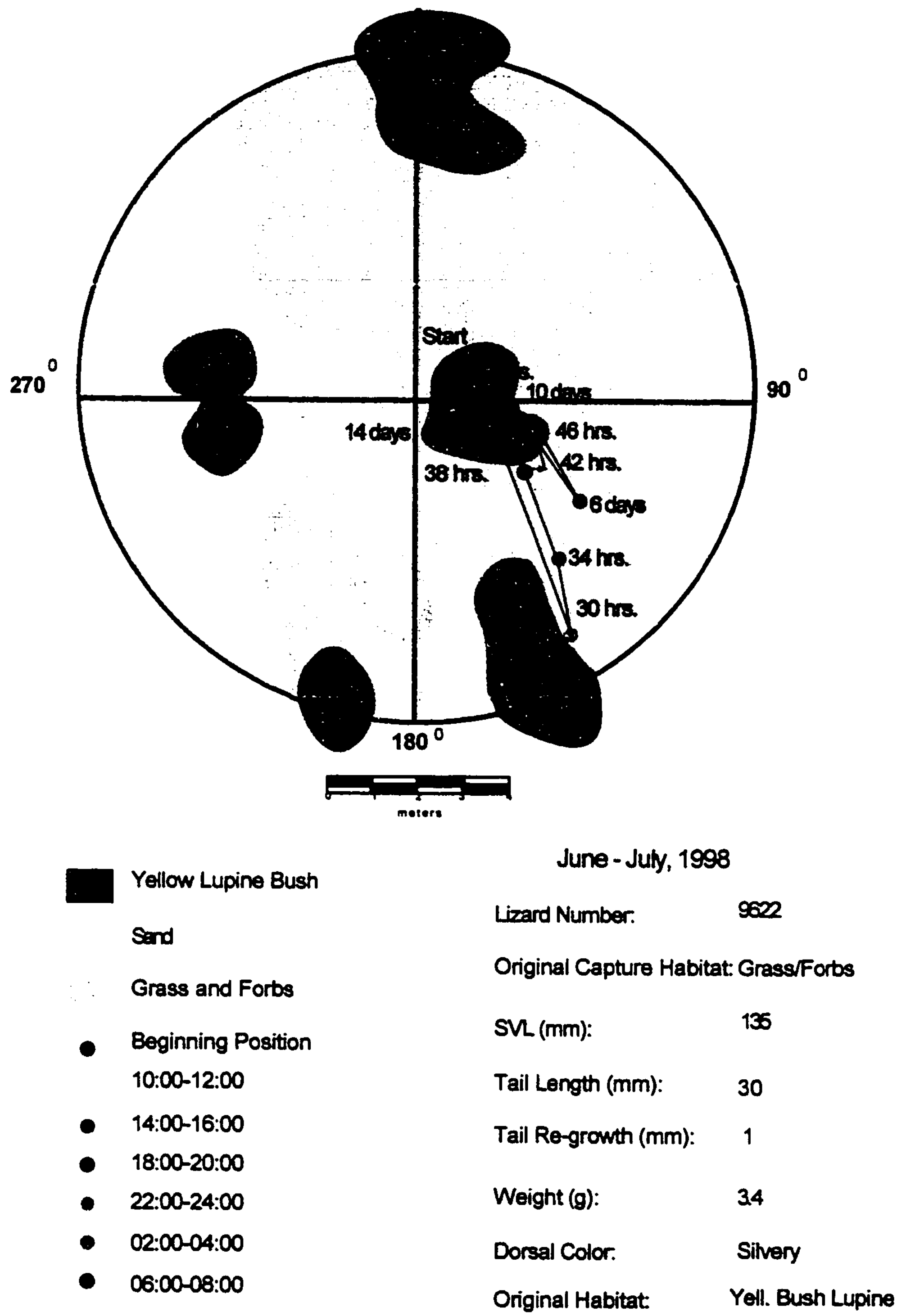

Figure 8. Sample movements of one lizard tracked for 14 days. This lizard moved during day and night, and was consistently located within 10 to 12 cm of the surface between the hours of 1400 h and 1600 h.

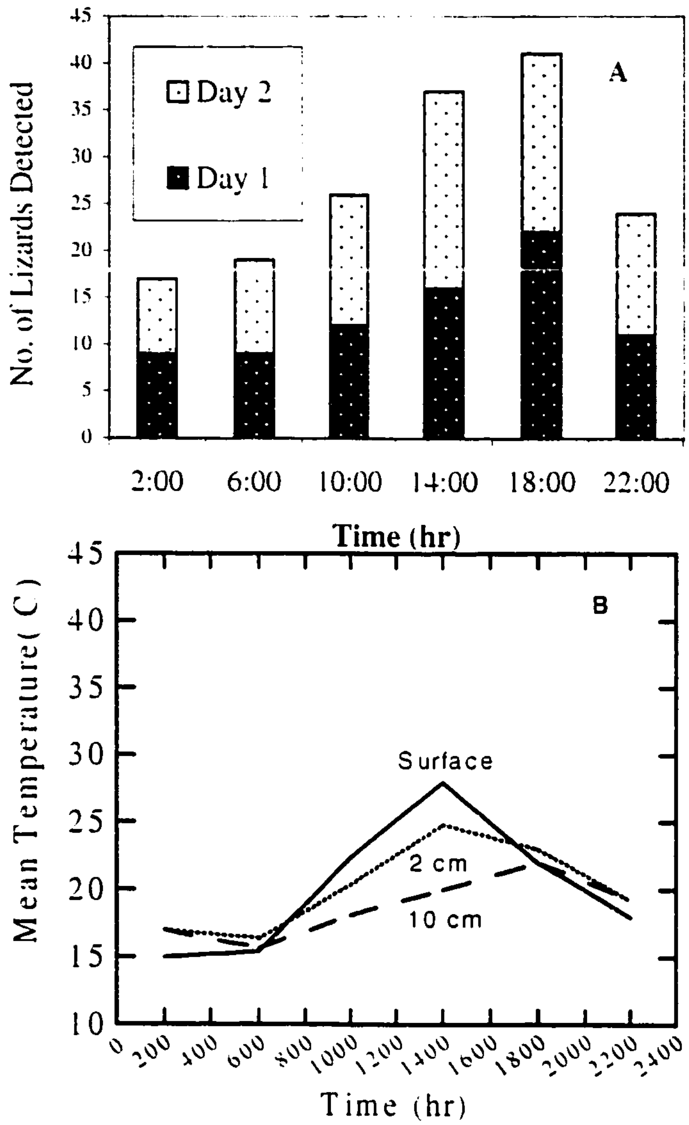

Figure 9. a) The number of lizards detected by time of day, for two days b) Mean temperatures for soil readings at the surface, 2 cm, and at 10 cm depth by time of day. These temperatures were recorded at the sites where lizards were found during short-term tracking.

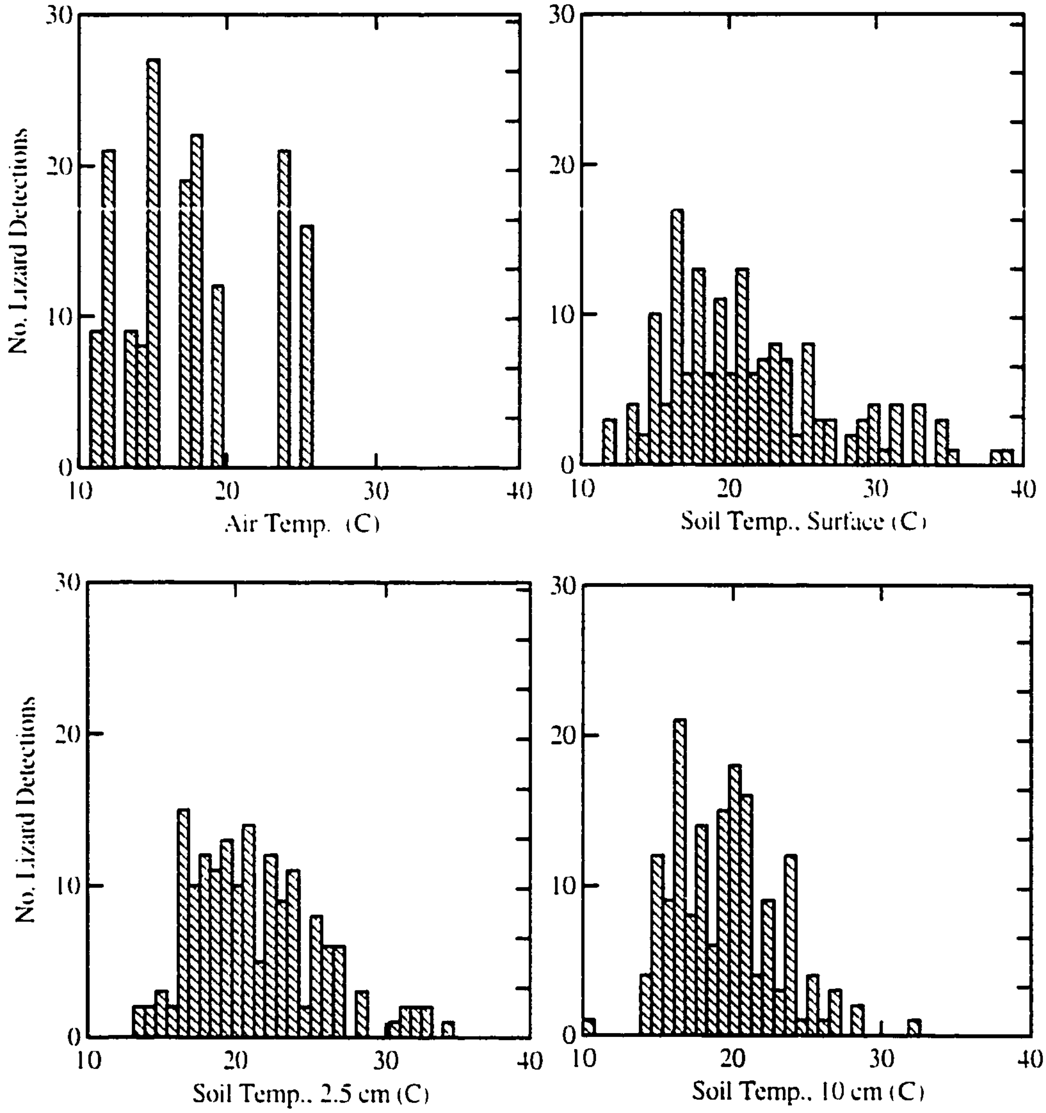

Figure 10. The number of lizard detections for air and soil temperature at 3 depths. Measurements were made at the sites where animals were found during short-term tracking.

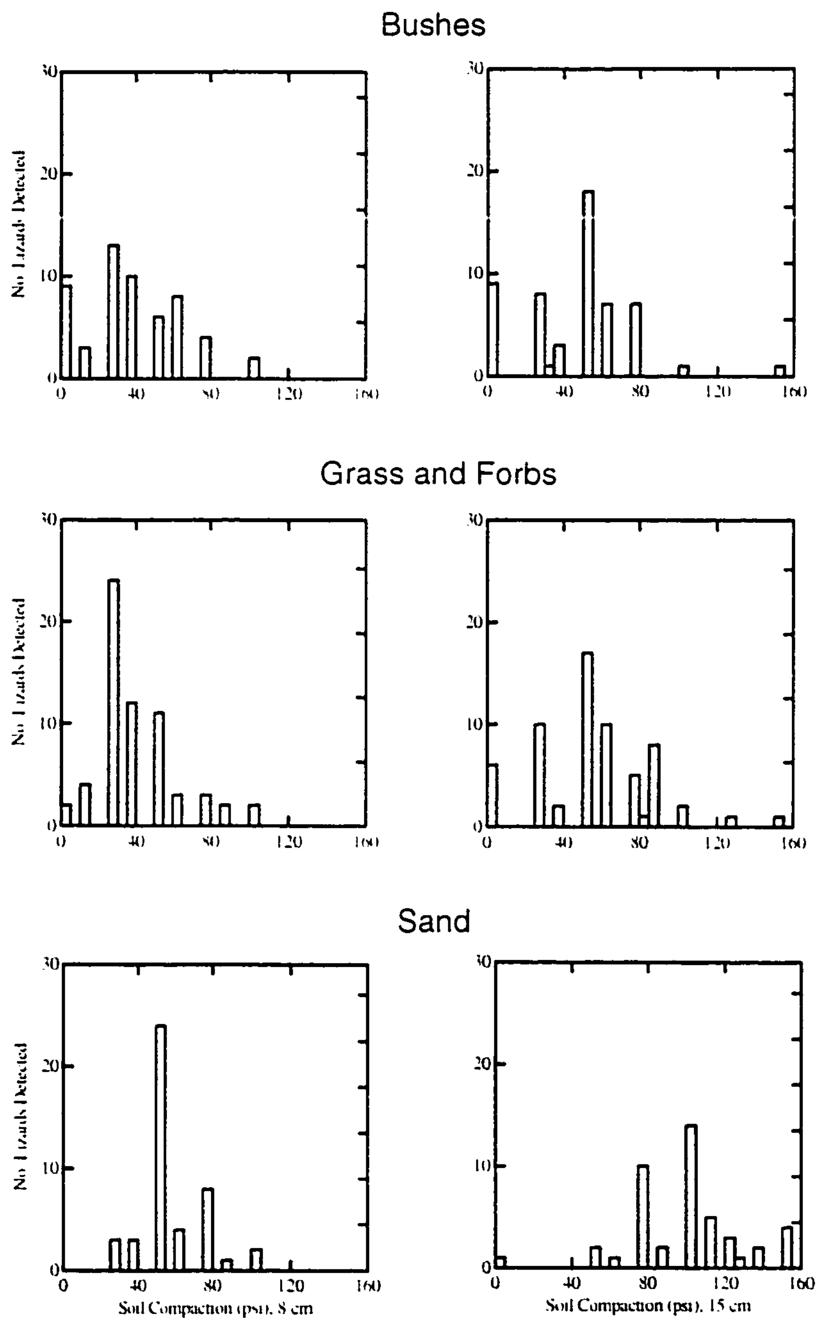

Figure 11. Number of lizards detected at different levels of soil compaction (psi) at two soil depths in 3 habitats: bushes, grass/forbs, and sand.

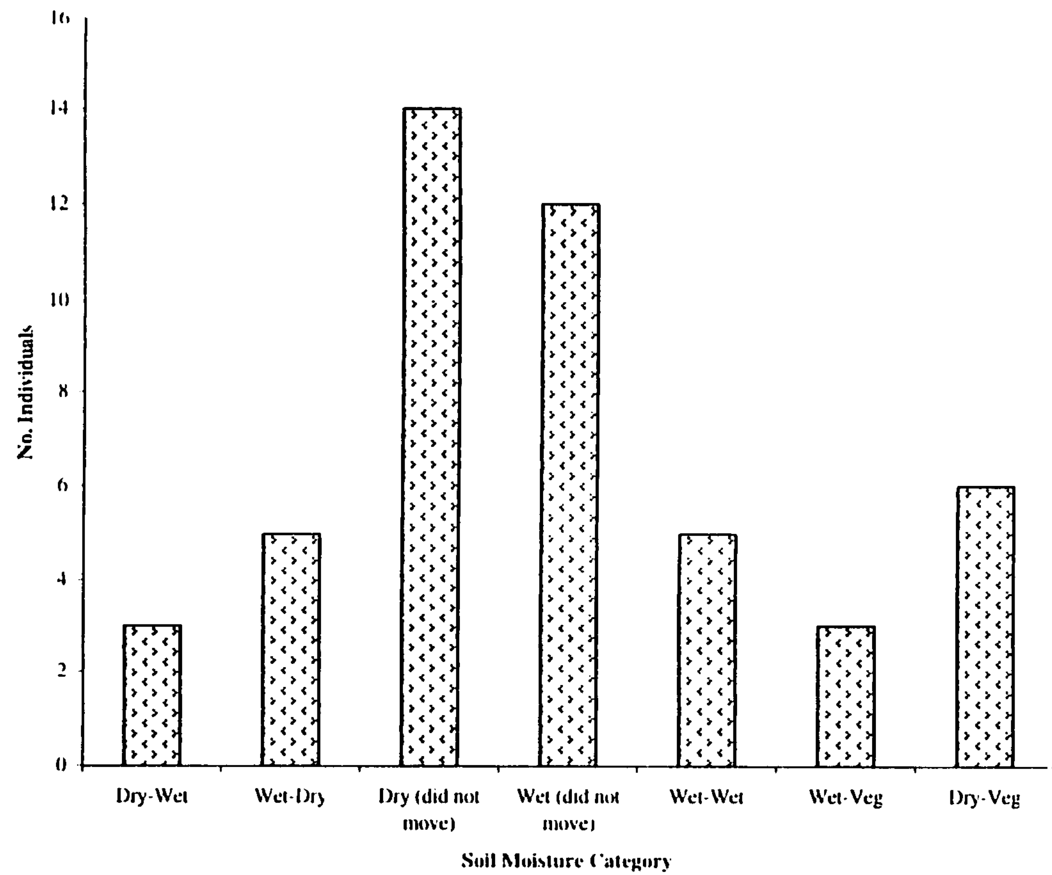

Figure 12. Change in microhabitat for lizards during tracking for 48 hours, reported as the original habitat and ending habitat category. Single habitat categories indicate individuals who remained within the same habitat throughout the experiment. The wet-wet category indicates that the animals traveled from one wet area to another (n = 48).

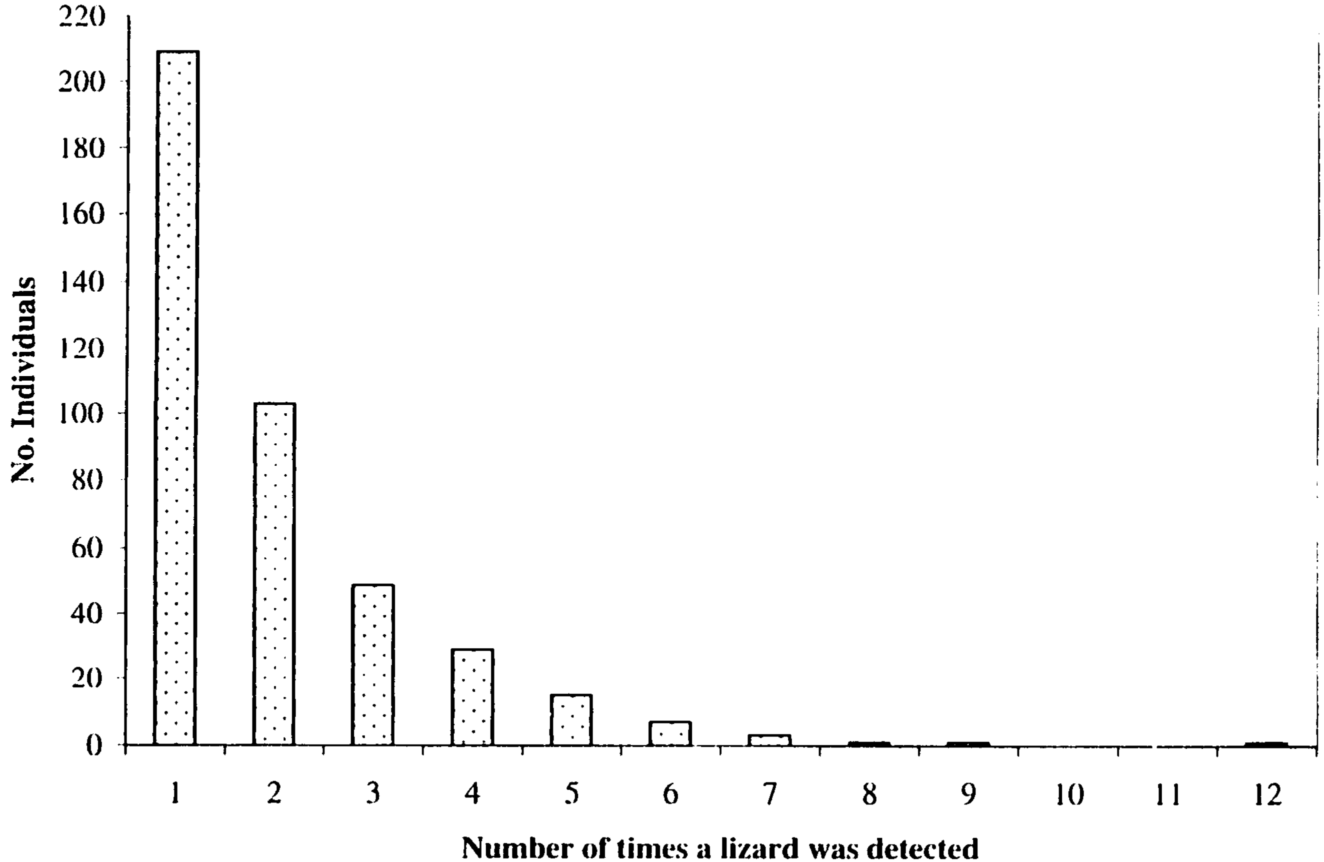

Figure 13. The number of times individual lizards were detected (n = 417), during 24 months of monitoring.

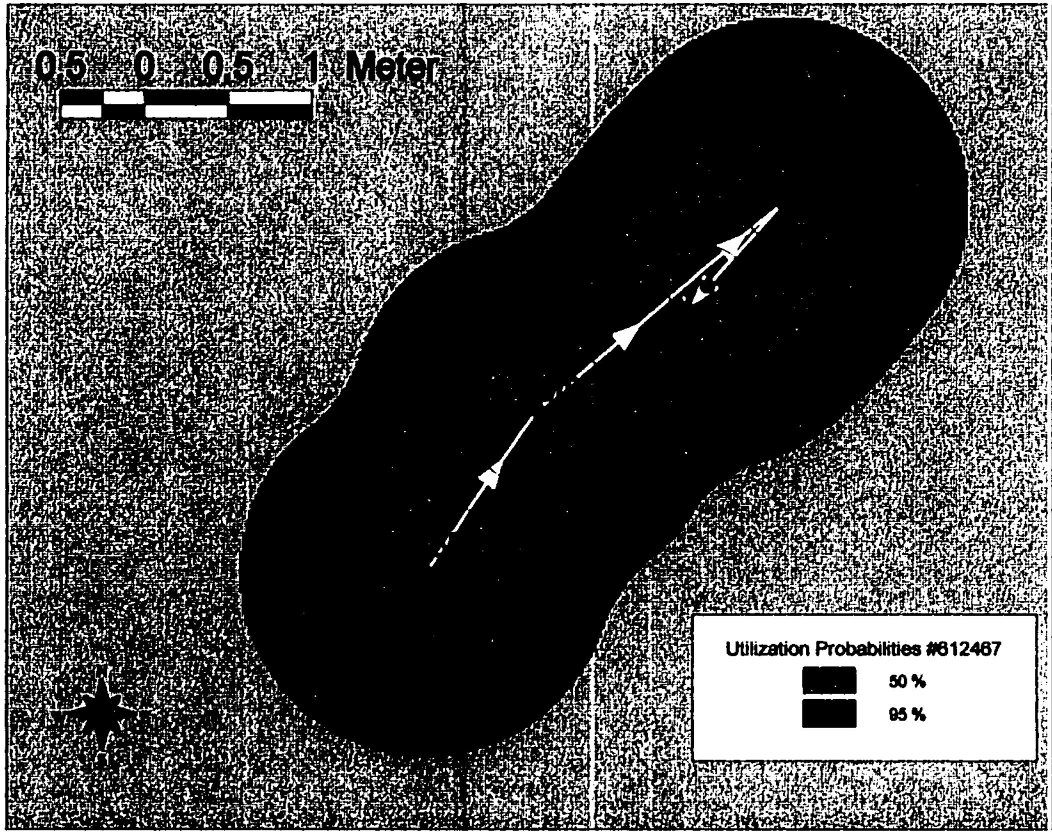

Figure 14. Example of utilization distributions for a lizard with a small home range. The 95% UD is 10.5 m^2 and the 50 % UD is 3.6 m^2. After 632 days of tracking, this animal was less than 2.5 m away from the initial release point. Error circles reflect the 70-cm detection resolution for earlier positions and the 24-cm resolution on later GPS positions.

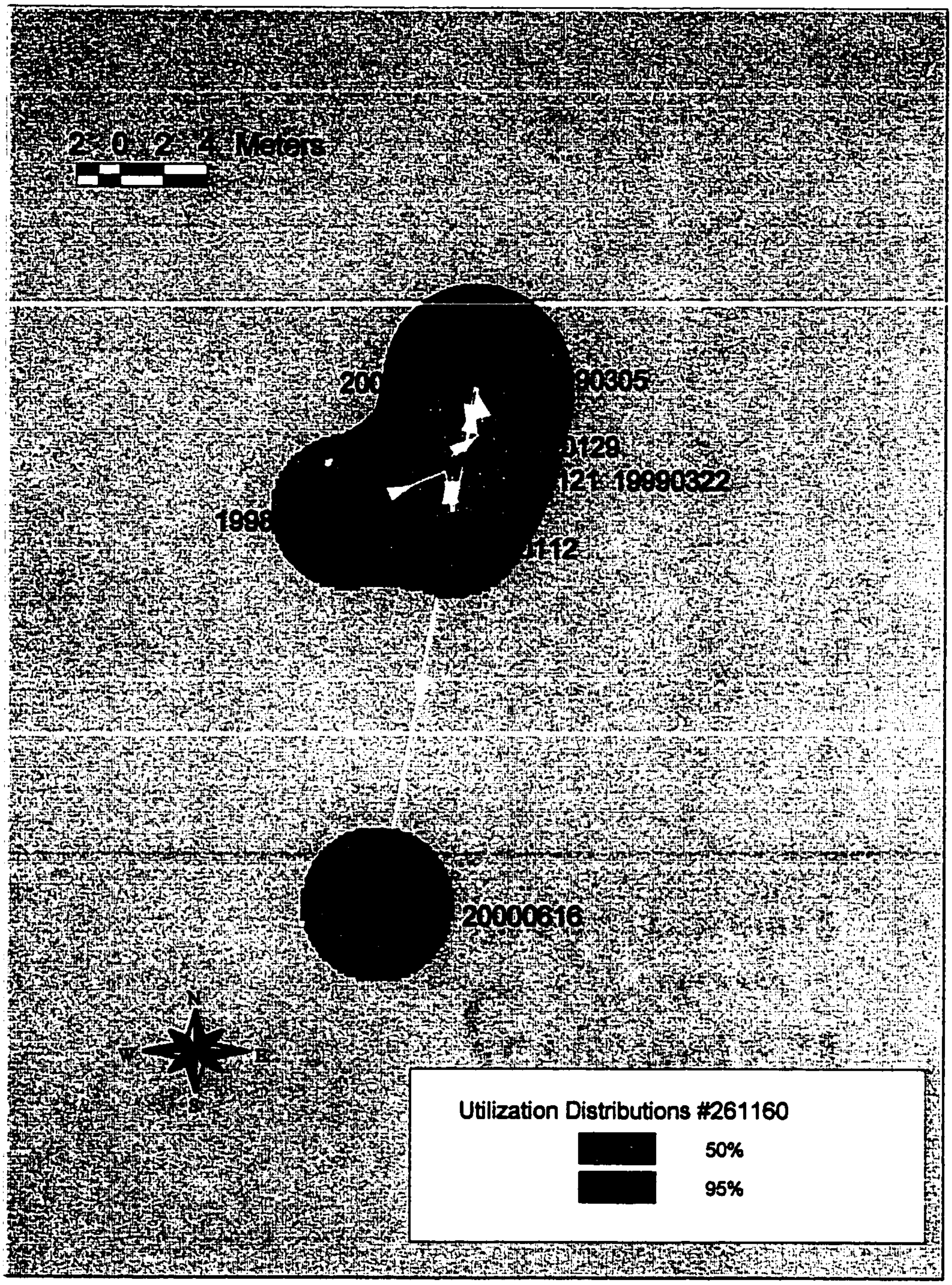

Figure 15. Utilization distributions for a lizard with an average home range. The 95% UD is 74.2 m^2 and the 50 % UD is 15.1 m^2. This animal was tracked for nearly 2 years, and was recently found 14 m away from its former center of activity.

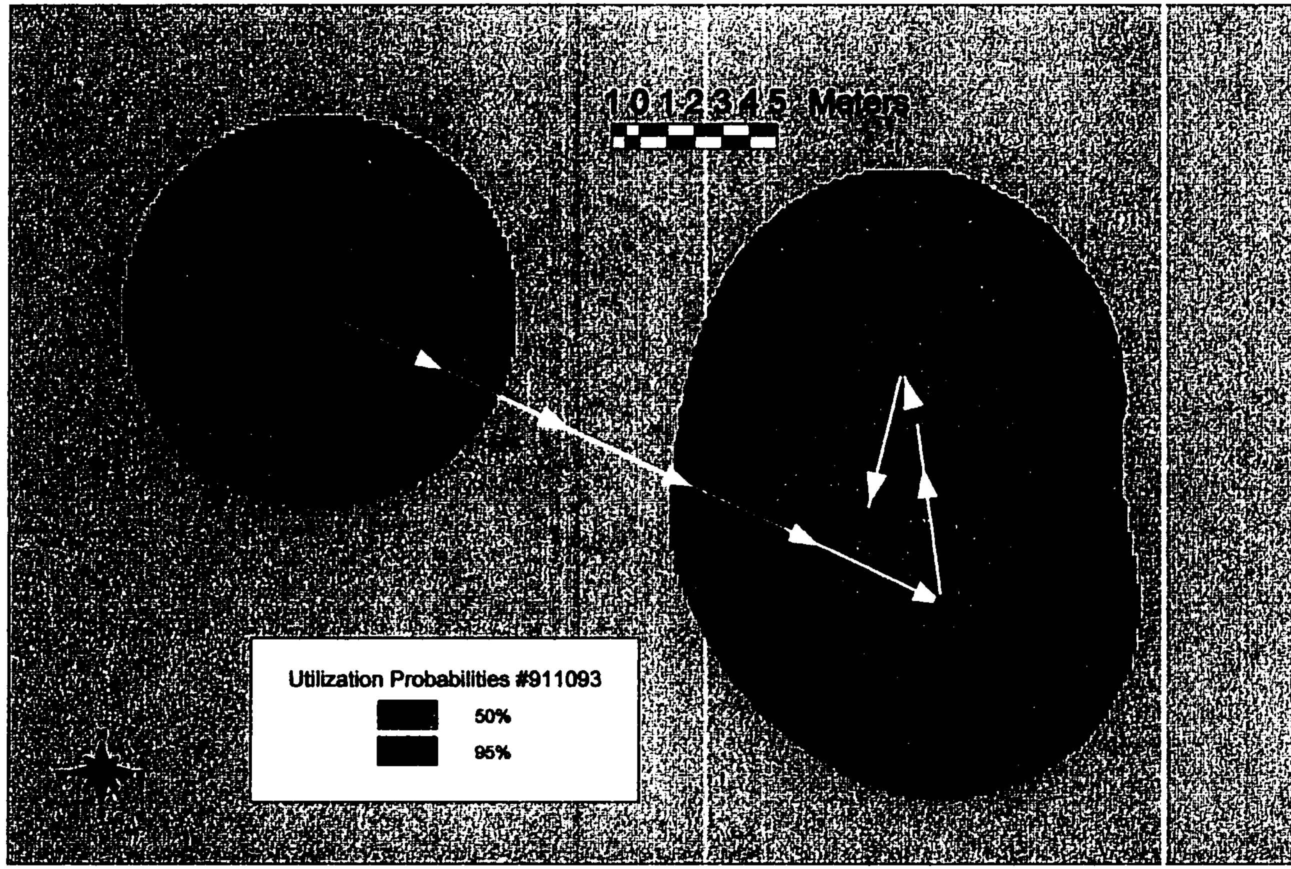

Figure 16. Utilization distributions for a lizard with a large home range. The 95% UD is 371.2 m^2 and the 50 % UD is 73.76 m^2. This lizard moved 22 m in the first month after release, then settled into a smaller area for the following 8 months.

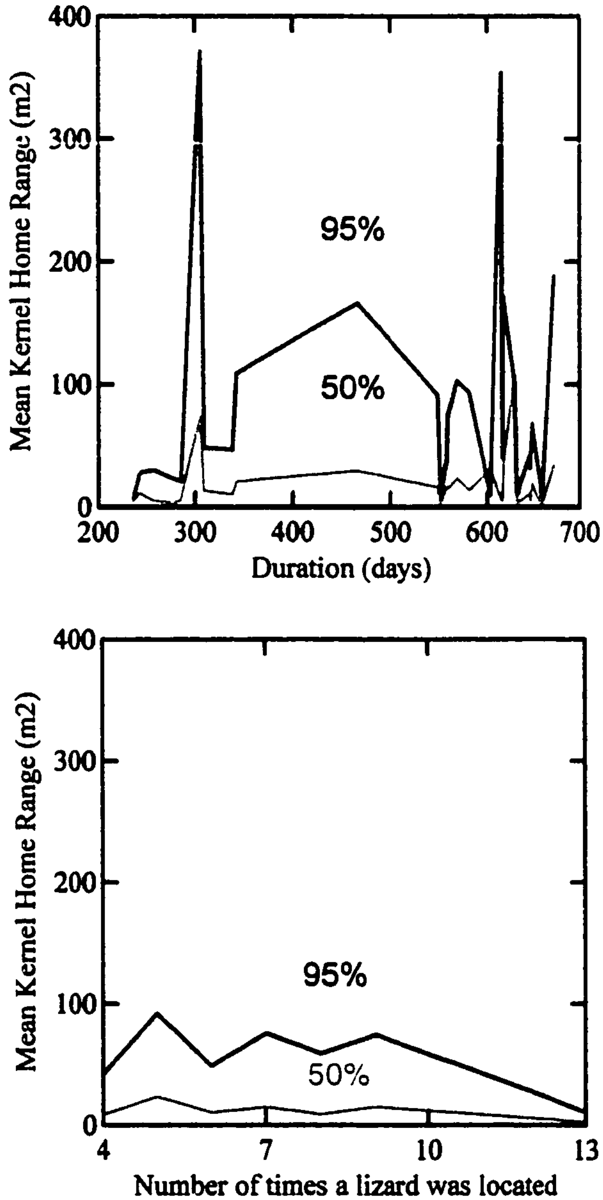

Figure 17. Mean kernel home range compared with the duration of tracking and number of times lizards were located (n = 41).