Desert Tortoise Habitat Model

City of Tucson Southlands HCP Area


Prepared for

City of Tucson
Office of Conservation and Sustainable Development
201 North Stone Avenue, 3rd Floor
Tucson, Arizona 85726

Prepared by

RECON Environmental, Inc.
525 West Wetmore Road, Suite 111
Tucson, AZ 85705
P 520.325.9977 F 520.293.3051

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Dr. Philip C. Rosen
Research Scientist
University of Arizona
School of Natural Resources & Environment

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Left: Desert tortoise on rocky slope, Martina Mountain (this site is not in the study area).
Right: Unconsolidated alluvial soil with caliche caves utilized by tortoises near Pantano Wash.

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Abstract

This study used an expert field team and repeatable methods to evaluate the City of Tucson/Pima County Geographic Information System (GIS) habitat model for the desert tortoise (*Gopherus agassizii*) in the Tucson Southlands Habitat Conservation Plan (HCP) planning area. Our evaluation is based on fieldwork conducted in the context of the GIS layers used to create the model. The study area extended from Pantano Wash near Vail, south across Interstate 10 to the Forest Service boundary at the north fringe of Santa Rita Mountains, and from Davidson Canyon on the east to Interstate 19 on the west. We recorded 105 instances of desert tortoise detection. Of these, seven were found south of Interstate 10 (6.7%, including three live tortoises) and 98 to its north (93.3%, including 20 live tortoises). The detections included unambiguously identifiable desert tortoise sign comprising burrows (40), scat (38), skeletal remains (1), and tracks (2).

The model, developed primarily as part of the Sonoran Desert Conservation Plan (SDCP), included large areas of middle bajada and valley flats that we determined to be incorrectly included. Other large areas of modeled habitat were also found to be non-habitat for the desert tortoise. Further, our survey indicated that substantial areas of modeled habitat on rocky slopes may be too high in elevation and too dissimilar from Sonoran desertscrub to support tortoises. Some modeled habitat within rocky slope environments, typically considered as characteristic desert tortoise habitat, was found to lack suitable rock characteristics and soil friability for shelter requirements of tortoises in the Sonoran Desert. By contrast, areas with suitable caliche formations on bajadas well away from rocky slopes provided desert tortoise habitat ranging from poor to exceptionally high quality.

An extensive, abundant population of desert tortoises was found along Pantano Wash, in close proximity but mostly not within the modeled habitat. Despite the problems with the model, it represents an improvement over earlier attempts. It may be possible to make revisions to establish a usable habitat model for the tortoise in this, and perhaps other, regions where occupancy of bajada xeroriparian wash margins and caliche caves are critical habitat elements.

Executive Summary

The City of Tucson/Pima County Desert Tortoise Geographic Information System (GIS) habitat model is insufficient in a number of key regards, but may be repaired and refined in useful ways for future use. The habitat modeling objective is to guide conservation and urbanization patterns for this species, which is large and has unique and stringent habitat requirements.

We found the desert tortoise (*Gopherus agassizii*) extremely rare in the Tucson Southlands south of Interstate 10 (I-10), which we here call the Santa Rita Region of the study area. We found three desert tortoises and four additional sign records in the vicinity of the desert tortoises, all on the outlying hills and upper bajadas of the Santa Rita Mountains. Neither records nor potentially suitable habitat was found in the large area of flats, rolling lower bajada hills, or lower to middle bajada desertscrub central to the Southlands HCP planning area. In this latter habitat type, especially, the model is inaccurate and needs to be re-configured.

Five of the seven Santa Rita Region desert tortoise records occurred outside of currently modeled habitat. In the southeastern parts of this region, desert tortoises and their sign were completely absent, yet much of the surveyed part of that region was also modeled habitat. Structurally optimal boulder slopes, sandy, boulder-strewn flats and washes, and footslope canyons—all within modeled habitat—consistently lacked evidence of tortoise presence. Vegetation in these areas was predominantly semi-desert grassland, which, although occupied by tortoises in areas adjacent to large Sonoran desertscrub desert tortoise populations, is apparently not suitable for desert tortoises on its own. This must also be accounted for in any further habitat model iterations.

Further, in the Santa Rita Region—particularly the eastern edge of the study area west of and along Davidson Canyon and State Highway 83, and the southeastern corner of the region, as well—hard ground and unsuitable rock characteristics rendered habitat largely unsuitable for the desert tortoise, even in well-developed, rocky Sonoran desertscrub. No animals or sign were detected in these environments, yet much of this area had also been modeled as habitat. Again, this points toward the need for a new refinement and ground-truthing to construct an adequate tortoise habitat model for the HCP planning area.

Most striking in our results was the large number of desert tortoise records, indicative of exceptionally dense and extensive populations, in the Pantano Wash–Cienega Creek environs (referred to here as the Pantano Region). Desert tortoises and their sign were consistently found in all survey areas in the complex gravelly bluff system near to the actual canyon-channel of Pantano Wash–Cienega Creek occurring regularly although with generally decreasing abundance in surveys moving southward up the draws away from the mainstem wash channel. This pattern represents, at this local scale, an inverse relationship between actual habitat and the desert tortoise habitat model, which does not include the areas close to Pantano Wash.

The explanation for most of these deviations of the habitat model from actual habitat involves the way the Sonoran desert tortoise uses bajada environments. Specifically, there is growing evidence, including results recorded in these surveys, that this desert tortoise has an important bajada xeroriparian habitat component. This habitat component is tightly, if not invariably, related to the presence of hard shelters along arroyo embankments of moderately to deeply incised bajadas. The desert tortoise populations in the Tucson Southlands HCP planning area that we surveyed were 98 percent associated with substantial to major outcropping systems of "caliche" (which are valley fill sediments cemented by infiltrated calcium carbonate) that had usable cave shelters of appropriate size for desert tortoises at heights above the flash-flood zone.

This habitat discussion highlights the changes needed for correct modeling or empirical delineation of desert tortoise habitat in the Tucson Southlands HCP planning area. The distribution of suitably sized, properly situated, and adequately abundant caliche formations must be known to properly understand and manage the desert tortoise in the Tucson Southlands HCP planning area.

While it might be necessary to simply survey the landscape for desert tortoise habitat, modeling efforts remain a reasonable approach. Model re-configuration may be possible by more carefully designed use of the hardpan GIS layer that was used in the first attempt that proves to have been overly simplistic. Supplemental information will be needed, including (1) closely defined slope parameters (for Santa Rita Region) and (2) gully depth characteristics (for Pantano Region) to (3) parse caliche characteristics more closely and redefine the bajada aspect of tortoise habitat. It would then be essential to field-test the new model, first by examining the extent to which it accurately predicts and describes caliche conditions, and secondly, by verifying that tortoise populations correlate with the caliche model and other information presented here. The results of another iteration would likely be more specific, original, and useful than most GIS-based niche models for animals.

Other fieldwork that is likely to assist model-building and tortoise management in the HCP area may include:

1. Additional surveys in the Santa Rita Region to determine if there is actually a viable or even reproducing population of the desert tortoise south of I-10. Although the findings suggest this possibility, the desert tortoise's presence that was detected may reflect former immigration (see Edwards *et al.* 2004a&b) from exceptionally strong populations in the Pantano Region and Rincon Mountains, now obstructed by I-10 and other barriers.

2. A survey further south around the Santa Rita Mountains, especially into the Santa Rita Experimental Range, to test a revised caliche model and evaluate pre-existing distributional records of the desert tortoise there.

3. A formal and more extensive survey of the Pantano Region desert tortoise population to determine its full extent both upstream and downstream of Vail, the variability of desert tortoise abundance on the two sides of the cañada, and desert tortoise occurrence as a function of distance from the bluffs facing the broad washbed in the arroyo bottom. It seems clear that this major population overlaps the intensely urbanizing environment north and west of Vail.

To be useful for HCP planning, the outcome of another iteration of the model may still need to be evaluated in relation to modes by which human populations can exist with and adjacent to desert tortoise populations.

1.0 Introduction

1.1 City of Tucson HCP Planning Effort

The City of Tucson is working on a Habitat Conservation Plan (HCP) to balance future urbanization and conservation within its boundaries and on lands in surrounding areas of eastern Pima County. There are two primary planning areas in the HCP effort: Avra Valley (west of the city) and the Tucson Southlands (east and south of the city). This study is focused on the Tucson Southlands.

Federally listed (threatened or endangered) species and species that may become federally listed under the Endangered Species Act (ESA) are of particular importance in the HCP planning process. The completed HCP would become a permit for urbanization processes that may negatively impact species and natural environments but can be planned to minimize impacts or, potentially, to produce compensatory conservation gains as mitigation. The first steps in the planning process involve defining the presence, distribution, habitat, and ecological needs of species potentially subject to mandatory ESA regulations. The desert tortoise (*Gopherus agassizii*) is one such species.

1.2 Desert Tortoise

The desert tortoise is an emblematic desert species for both the Sonoran Desert of Arizona and the Mojave Desert of southern California and southern Nevada and Utah. In the Mojave Desert, its precipitous decline has led to federal listing as threatened under the ESA. In the Sonoran Desert, the tortoise has fared better, primarily because the rocky habitats it uses here are less disturbed by urbanization and other human impacts than suitable habitat in the Mojave Desert. While the decline in the Mojave Desert has been astonishingly marked and rapid (Luke *et al*. 1991; Berry 2003; Tracy *et al.* 2004), recent trends in the Sonoran Desert also suggest a decline (Boarman and Kristan 2008) associated with drought (personal observations; Vaughn *et al.* 2008), leading to a petition to list the Sonoran Desert tortoise populations under the ESA (WildEarth Guardians and Western Watersheds Project 2008).

1.2.1 Conservation Status

Considering the species' long life cycle (US Fish & Wildlife Service [USFWS] 2008) and former abundance, declines can be slow and nonetheless represent significant threats. Despite an age at maturity near 15 years (later than in humans!) and a generation time likely near twice that, many—indeed most—formerly robust populations in Mojave Desert have declined from the range of 100–200 individuals per square mile to less than a tenth of that over the course of the past 25–35 years—about in a single generation. Sonoran Desert populations have declined by around half on average (Boarman and Kristan 2008), although this decline might be a natural function of drought. For the Sonoran Desert population, evaluation of the severity of threat depends on (1) the extent to which burgeoning urbanization impacts tortoise habitat and (2) relationships among drought, anthropogenic climate change, and tortoise population dynamics (Rosen 2008).

Although a decision evaluating the ESA listing petition for the Sonoran Desert tortoise has yet to be reached, this tortoise is likely to remain a high conservation priority for many decades and may be expected to be considered for listing again, if the current petition is rejected. This likelihood reflects the unique ecological requirements of the desert tortoise compared to other relatively abundant desert animals and the difficulty tortoises have living in close proximity to people.

1.2.2 Natural History and Impacts

Photograph 1. Desert tortoise entering a caliche cave near Pantano Wash.

The desert tortoise is the largest reptile in the Sonoran–Mojave desert system, not only in weight, but, notably, in width and height. Despite its shell, it is susceptible to attack from large animals such as cougars, which can crush the shell, coyotes, which can bite and gnaw the animal, and smaller animals like raccoons, which may be able to pry out and chew limbs. Thus, in addition to needing burrow refuges from desert heat and winter cold, the tortoise requires shelter to protect it from predation. As a result, its habitat is especially tightly constrained by the need for suitable shelters of sufficient size. In the Sonoran Desert, this apparently requires rock with soil that is friable enough for the tortoises to modify pre-existing shelters, dig additional more temporary ones, and dig nest holes in or near burrow entrances for their eggs (Photograph 1). In addition, this tortoise is active at high environmental temperatures and may suffer from drought and very high temperatures. Thus, tortoise habitat is limited by several factors, which combine to make its distribution and abundance local, discontinuous, and variable within the Sonoran Desert. This puts the animal at risk both from direct human landscape modification and from anthropogenic climate change during the 21st century, which, for the American

Southwest (Seager *et al*. 2007), is projected to produce a hotter, drier climate that would be less suitable for the desert tortoise.

The desert tortoise also faces other direct and unintended consequences of human population increase in its inhabited landscapes—incidental impacts of automobiles, dogs, and exotic tortoises that can transmit disease. Lowe (1990) observed that people 'love them to death'; this may include collecting tortoises, bringing them into households as pets, and thereby removing them from native populations. These other direct and unintentional impacts result in steady decline in tortoise populations near people, even where suitable habitat for the tortoise is saved. The captive tortoise population, while a potentially significant conservation resource, is not exposed to ecological and evolutionary pressures that maintain the fitness of the species as a wild animal, making conservation in the wild an optimal strategy.

Desert tortoise habitat in Sonoran Desert settings has not been fully understood and described. After an extended period of misunderstanding, it was recognized only about three to four decades ago that the desert tortoise extensively occupied rocky boulder slopes, particularly in the Sonoran Desert of Arizona, rather than primarily sandy flats as seen in the Mojave Desert. For the Sonoran Desert, this new finding has become dogma, and only during the past couple of decades has it begun to become clear that extensive habitat for tortoises in the Sonoran Desert occurs along bajada washes at distance from rocky hills and mountainsides.

1.2 Study Purpose

This study presents an initial attempt to understand the desert tortoise and its habitat within the Tucson HCP context, and specifically, in the Tucson Southlands. Empirical field data are used to evaluate a Geographic Information System (GIS) model of desert tortoise habitat developed for the Sonoran Desert by Arizona Game and Fish Department (AGFD) and others and modified by Pima County for the Sonoran Desert Conservation Plan (SDCP) in eastern Pima County. This GIS model was based on known habitat features determined by expert consultation, including slope, elevation, and rock outcrops, with a hardpan GIS layer added as a surrogate for caliche formation in non-montane environments (Julia Fonseca, pers. comm., 2009). The results of this study are intended to evaluate the current desert tortoise habitat model and propose modifications that may be necessary to increase its accuracy and better inform planning and mitigation in the Southlands to better preserve and protect the desert tortoise.

2.0 Study Area

2.1 Study Area Location

The study area for this project includes the Tucson Southlands, which is bisected by Interstate 10 (I-10), with the Pantano Region to the north (bounded by the Pantano Wash) and the Santa Rita Region to the south (Figure 1). The Tucson Southlands includes the northern and northwestern footslopes and bajadas of the Santa Rita Mountains, and extends east to Davidson Canyon and west to the Santa Cruz River floodplain. The Pantano Wash corridor runs generally from Pima County's Ciénega Creek County Preserve, east of Vail along a major rail corridor, and continues northwest across Houghton Road into the intensively urbanized area of southeastern Tucson.

2.2 Study Area Description

2.2.1 Elevation

The maximum elevation in the study area is approximately 5,085 feet (ft) on peaks north of Mount Fagan, in the north end of the Santa Rita Mountains. The study area slopes down to the north to Pantano Wash and Ciénega Creek at low point elevations of approximately 2,941 and 3,281 ft at the west and east study area boundaries, respectively. It slopes WSW and then west toward the Santa Cruz River floodplain near Old Nogales Highway and I-10 at minimum elevations (on the bajada near the east-side river floodplain margin) of 2,589–2,661 ft.

2.2.2 Habitat Assessment

Vegetation in the study area ranges from semi-desert grassland at the higher elevations to paloverde–saguaro–mixed cactus at the lower elevations. Here the Arizona Upland Subdivision of the Sonoran Desert is transitional in many regards to Chihuahuan desertscrub, especially in the northeastern part of the Southlands. The northern end of the Santa Rita Mountains is characterized by steep slopes with scattered outcrops of granitic, rhyolitic, and metamorphic rock; there are outlying large and small hills extending out on the bajada to the north, some with large granitic boulders and outcrops as well as metamorphic and limestone rock types. Beyond the hills and mountains, sandy–gravelly bajadas extend to the north, with transitions from mesquite–prickly pear–cholla landscapes on upper and middle bajadas to mixed desertscrub with mesquite, creosotebush, diverse subshrubs, and diverse forbs on stony, calcium-infused hills and

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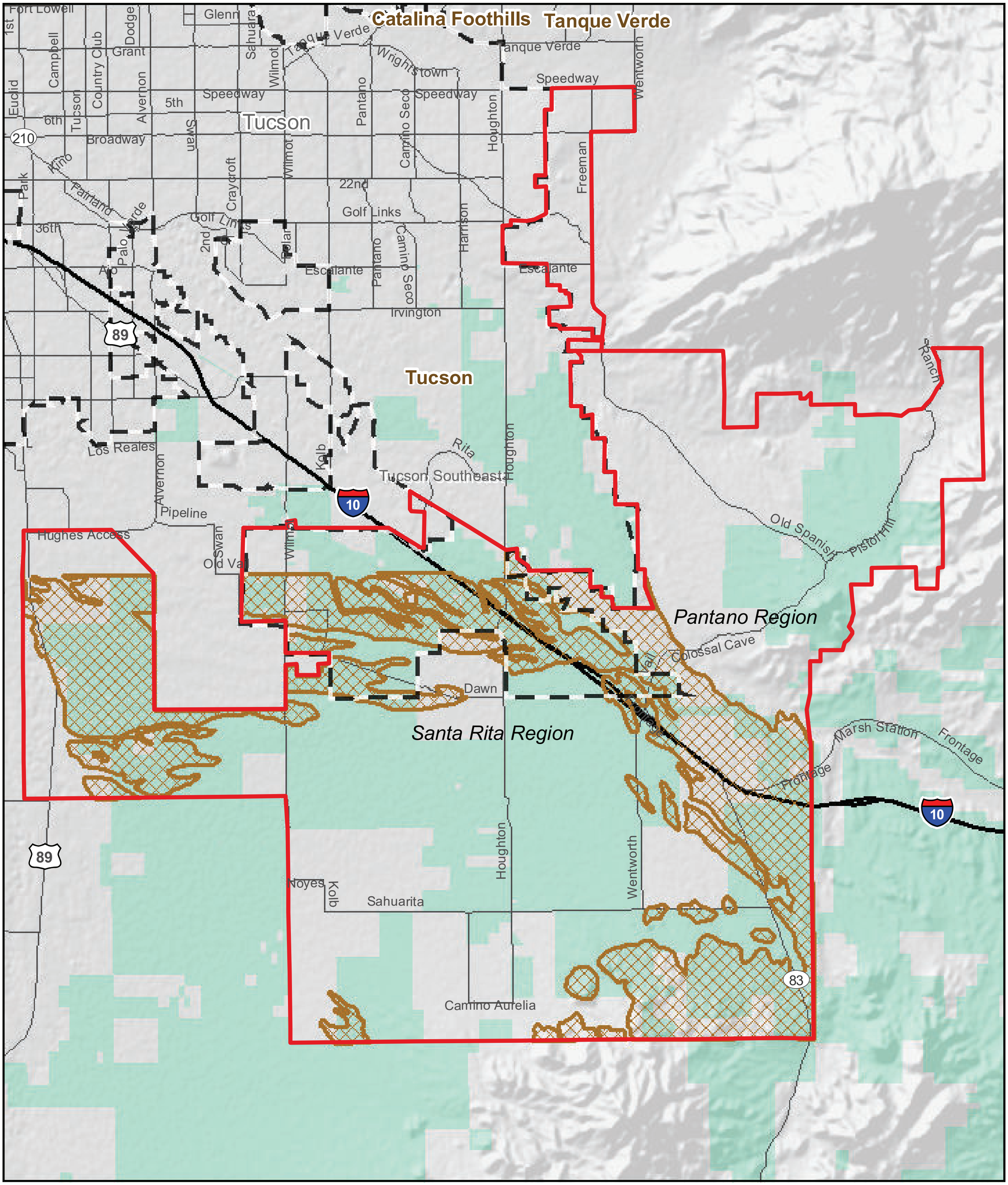

Tucson City Limit

Greater Southlands HCP Area

Modeled Desert Tortoise Habitat

State Trust Land

0 Miles 3

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FIGURE 1

Regional Location

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on fine soils of level distributary floodplains to the WNW and west. The eastern margins of the study area slope NNE from the north end of the Santa Rita Mountains across stony bajadas and hills toward, and in places including, Davidson Canyon, a major tributary to Ciénega Creek.

Higher elevations of the study area, in the northern foothill mountains of the Santa Rita Mountains, are primarily covered by semi-desert grassland, which may be occupied by the desert tortoise where it is adjacent to Arizona Upland Sonoran Desertscrub occupied by abundant tortoises. This vegetation also occurs on bajadas adjoining the higher rock slopes, as well as on many lower slopes and even outlying hills, particularly south of the community of Corona de Tucson and to the ENE of Mt. Fagan. Rock outcrops and boulders suitable for the desert tortoise are found in varying abundance across this environment.

There are a couple of outlying hills and a local sandy bajada area NE of Mt. Fagan, near the alignment of Wentworth Road, that have extremely well-developed granitic boulder fields configured suitably for desert tortoise habitat and vegetated with open stands of semi-desert grassland with Sonoran Desert plants included. To the east, the environments generally near State Highway 83 and associated with Davidson Canyon have hard, shallow soils, small rocks, and few outcrops with little habitat suitable for tortoises.

SE of Corona de Tucson, there are also smaller mountains and lower slopes supporting Arizona upland Sonoran desertscrub, with included dry tropical scrub (thornscrub) and semi-desert grassland floristic elements. Upper and middle bajadas in this area support Arizona upland Sonoran desertscrub, primarily in transitional phases with a few semi-desert grassland elements, and notably including huge stands of Englemann prickly pear (*Opuntia phaeacantha*), brown-spined prickly pear (*Opuntia phaeacantha*), chollas (*Cylindropuntia* spp.), and velvet mesquite (*Prosopis velutina*). In places there are stands of saguaro (*Carnegiea gigantea*), the emblematic plant of the Arizona Upland subdivision of the Sonoran Desert.

Middle to lower bajadas to the north and east of the Santa Rita Mountains support Sonoran desertscrub with notable Chihuahuan characteristics such as very abundant ocotillo (*Fouquieria splendens*), yucca (*Yucca* spp.), and primarily non-Sonoran shrubs including mariola (*Parthenium incanum*) and desert zinnia (*Zinnia acerosa*). A diversity of small cacti, including rare and unusual species such as needle-spined (*Echinomastus erectocentrus* var. *erectocentrus*) and Pima pineapple (*Coryphantha scheeri* var. *robustispina*) cacti; the flat, low-growing MacDougal's nipple cactus (*Mammillaria gummifera* [*heyderi*]); and beehive cactus (*Coryphantha vivipara*), which are not often so abundant in the Sonoran Desert, are prominent in this environment, which extends down to Pantano Wash. The low, rolling stony bajada terrain of the large central lowlands of the Southlands, WNW and west of the Santa Rita Mountains, supports similar vegetation. None of these environments has shelter sites suitable for tortoises.

The wide, braided, low-gradient, distributary floodplain drainages WNW and west of the Santa Ritas support a distinctive grassy, herbaceous, and shubtree vegetation in an open desert tree formation dominated by mesquite and other desert trees. There are several perennial grasses, including tobosa (*Pleuraphis mutica*), and a variety of unusual forbs such as Arizona foldwing (*Dicliptera resupinata*), few-flower beggarticks (*Bidens leptocephala*), Arizona sunflowerweed (*Tithonia thurberi*), and crested anoda (*Anoda cristata*), some of which are found in the west branch of the Santa Cruz River and in subtropical desertscrub and thornscrub in Sonora. Some of these arroyos are somewhat to extremely incised and have cut down to newly exposed beds of caliche and unconsolidated gravels (Photograph 2). We found no habitat for the desert tortoise in these environments.

Photograph 2. Exposed caliche in the central Lee Moore Wash basin portion of the study area. The incision is recent, having downcut along a utility line road, first through soft, very fine sandy loam, then into the cemented caliche below. These recent exposures of caliche lack caves that could be used as shelters by desert tortoises, and such areas offer no habitat for them.

Photograph 3. Caliche cave shelter in use by a desert tortoise near Pantano Wash. Note the friable, loose alluvial soil, which is suitable for digging. Desert tortoises modify the floors of hard shelters and dig shallow "pallet" burrows of approximately a half-meter depth, and also may dig deeper burrows in this and other friable soil types.

Elsewhere, most bajada wash bottomlands support characteristic Sonoran Desert, shrubtree-dominated xeroriparian thornscrub. These washes are slightly incised into the surrounding bajada uplands (which supports Arizona Upland vegetation) and thus have few exposures of caliche in most places. Local areas south, southeast, and southwest of Corona de Tucson have more markedly dissected bajadas with abundant caliche potentially suitable for the desert tortoise, but there is little caliche north of Sahuarita Road, none of which was found suitable for the desert tortoise.

The environs of Pantano Wash and Ciénega Creek present a unique aspect. This major riparian corridor is incised about 30–50 ft into the gravelly lower bajada through which it passes. The incision forms steep, loose, gravelly–stony bluffs with scattered, major exposures of caliche at various elevations, and the incision extends deeply south into the bajada to form steep, deep, narrow draws with exposed soil and caliche that provide ideal habitat for the desert tortoise (Photographs 3 and 4).

Photograph 4. A major side canyon extending south from the Pantano Wash mainstem. This environmental type supports a thriving tortoise population, anchored by extensive caliche formations the animals use as hard shelters. The horizontal slot visible in the upper center of the photo is an example of a major outcrop of caliche in which erosive processes have produced large, deep shelters used by tortoises.

3.0 Methods

3.1 Validation of Habitat Model

This study was designed to provide solid, although not—due to budgetary constraints—exhaustive, survey data. The original intent was to “validate” the existing desert tortoise habitat model. After some of the fieldwork had been complete, it became clear that the model required too much modification to justify formal validation.

For validation, we recommended that an Occupancy Model approach might be considered as the most efficient means to achieve results that would stand the intense scrutiny that land use decisions might entail. We retained much of the study design intended to establish a data baseline for computation of occupancy model parameters. However, it became evident that the intensive, formal census methods for the occupancy model design would be a waste of time if applied to the very large areas of what we identified as clearly unsuitable habitat (i.e., non-habitat) that the model identified as habitat.

3.2 Survey Locations

The study area was classified into six survey regions for operational purposes: Corona de Tucson, vicinity of Copper Cut Road, Pantano, Sonoita Highway, Santa Rita Experimental Range (SRER), and lowland non-habitat.

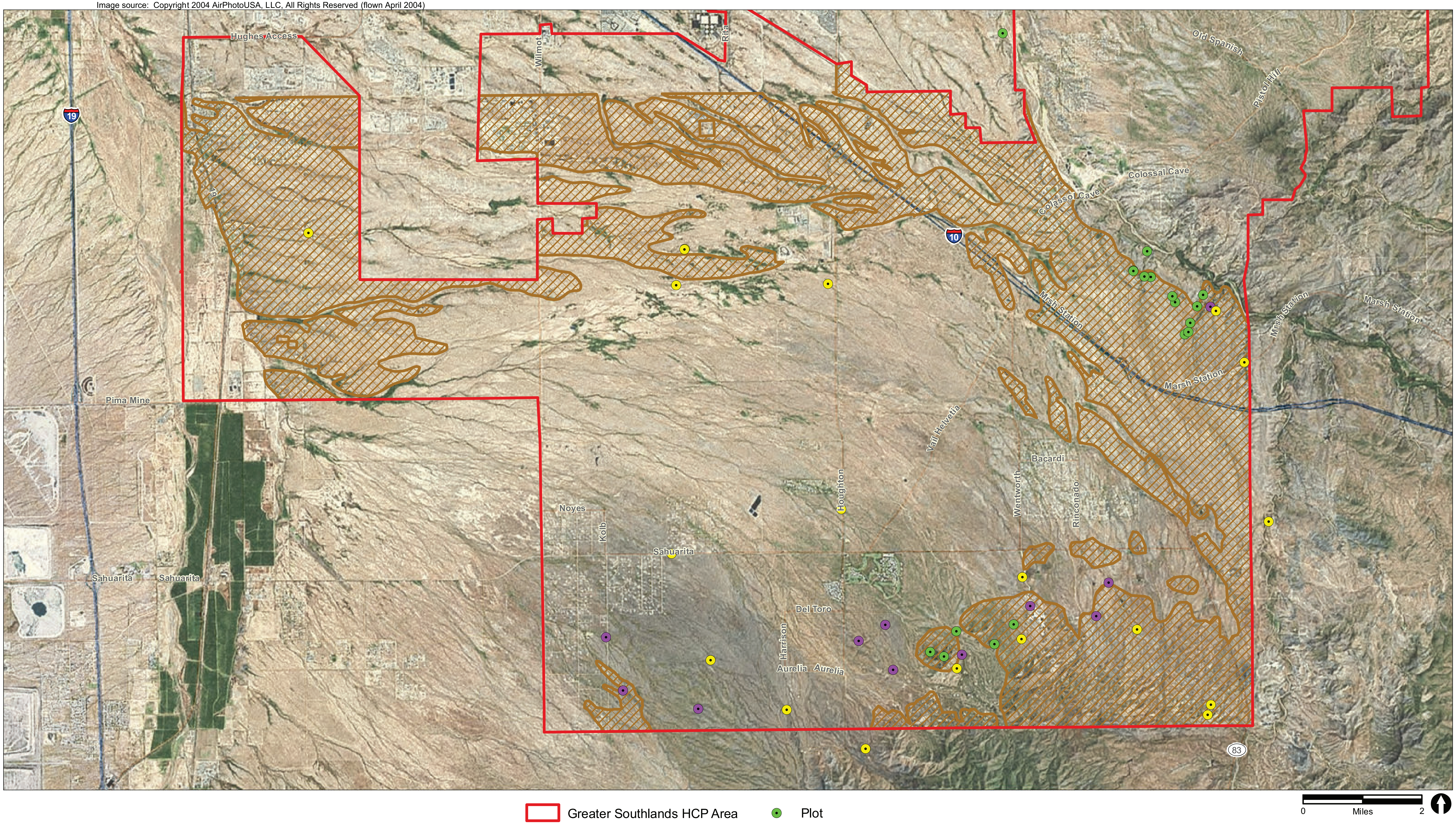
3.3 Data Collection

We collected data using three methods: (1) square plots, (2) belt transects, and (1) wide-searching, time-constrained searches (TCS) using simple visual encounter survey (VES) methods in potentially suitable habitat we identified during reconnaissance (Figure 2). Fieldwork was conducted during September and early October 2009 between 0700 and 1800 hours. Detailed plot location information is presented in appendices to this report: plot location information (Appendix A), habitat descriptions of survey areas (Appendix B), survey effort (Appendix C), and detailed tracklogs (Appendix D).

We followed Zylstra (2009) with modifications to collect occupancy model data. When conducting plot and belt transects, entire plots were surveyed in order to simultaneously obtain TCS data rather than truncating our search upon first positive tortoise detection as suggested for time efficiency in occupancy model studies.

Information collected during all surveys included:

- Global Positioning System (GPS) locations of all observations
- Field notes on all observations of live desert tortoises including:
    - life stage (juvenile, adult, and sub-adult)
    - sex



Greater Southlands HCP Area

Modeled Desert Tortoise Habitat

Plot

Time-constrained Search

Transect

See Appendix D for detailed tracklog

FIGURE 2

Locations of Plots, Transects, and Time-constrained Searches

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- midline carapace length (MCL)
- health
- growth rings for age determination (young individuals only)

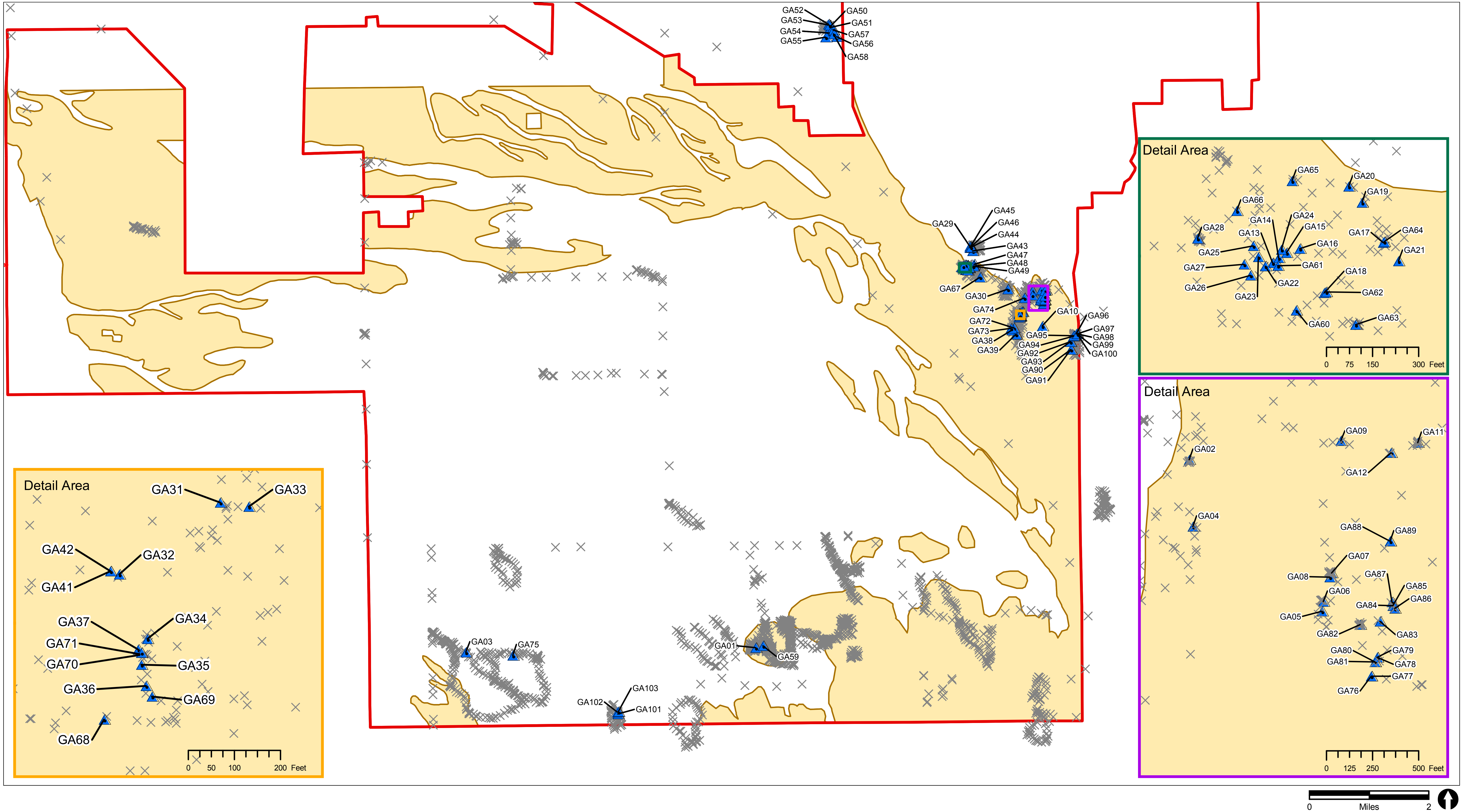
o Fieldnotes on desert tortoise sign including: active burrows, scat, tracks, and remains of dead tortoises

o Photographs including portraits of each tortoise and growth rings on two or more carapacial scutes with limited wear

Searches were performed by scanning open ground, looking under vegetation, and using mirrors or flashlights to inspect holes and crevices, with a focus on finding scat, active burrows, or tracks indicating the likely presence of an animal. If a tortoise was discovered in a hole or crevice, surveyors attempted, without risking harm or excessive disturbance to the shelter, to remove the animal by hand. Handling of tortoises was conducted only by personnel permitted by Arizona Game and Fish Department to do so and according to protocols established by the AGFD and others to protect the animals from potential disease transfer and undue stress. These precautions included wearing disposable latex gloves during handling, use of veterinary disinfectant on equipment (Arizona Interagency Desert Tortoise Team 1996), and gentle handling of tortoises without turning them onto their backs to reduce potential for fluid loss (Averill-Murray 2002a). Tortoises that lost fluid by urination during our handling were re-hydrated with saline solution via self-imbibing through the nostrils.

Scat was readily identifiable by grass-forb fragment remains, size, shape, and characteristic veneer. Active burrows and shelters were unequivocally identified based on shape, depth, and characteristic scuff and footprint marks left by tortoises, and by the presence of scat. Possible burrows and shelters were identified based on shape and size, but were not included as tortoise records unless tortoise sign was found in them or in the immediate vicinity. Tortoise scat lasts for weeks, months, and sometimes years in the environment, depending upon how well it is protected from rain and mechanical damage. Thus the absence of scat can be a strong indicator that tortoises are not present in an area.

Habitat conditions including soil, geology, and vegetation type were characterized (Appendix B) with special attention to the amount and nature of tortoise habitat in rocks. Surveyors noted consolidated sedimentary deposits (either conglomerate rock or calcified soil ["caliche"]), as well as limestone, granite, and igneous rock.



Greater Southlands HCP Area

Modeled Desert Tortoise Habitat

Tortoise Observation

Track Points

FIGURE 3

Desert Tortoise Observations

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3.2.1 Plots

Fourteen square 3-hectare (ha) plots (5 of which were re-surveyed for use in occupancy modeling) were surveyed (Figure 3). For plot re-surveys, we waited at least 5 days between successive surveys. The square plots were aligned N-S-E-W with the earth grid on slopes and boulder-strewn flats. Plots were surveyed by a crew of 2–5 personnel, walking in parallel lines approximately 10 meters (m) apart. Each crew member was tracked by a GPS unit (Figure 3). See Appendix C for details regarding the survey effort.

4.1 Pantano Region

The most striking results included the large number of desert tortoise observations, indicative of exceptionally dense and extensive populations, in the Pantano Wash-Ciénega Creek region of the study area (Table 1, see Photograph 4). Tortoises and their sign were consistently found in all surveyed areas in the complex gravelly bluff system near to the channel of Pantano Wash–Ciénega Creek (see Photographs 3 and 4), and tortoises and sign were often and regularly found further from the main arroyo, although with a generally decreasing abundance in surveys moving southward away from the mainstem wash bed.

These populations were intimately associated with major caliche formations with numerous small caves that frequently yielded tortoises and/or their sign. The unconsolidated sand, gravel, and cobble soils had many shallow pallet-type burrows in active use. Tortoise sign was abundant on the steep embankments of railroad grades in this region, although no concerted effort was made to investigate them. This population consisted of mixed-age animals ranging from juveniles a few years of age to old adults. Although local populations in the Rincon Mountain Unit of Saguaro National Park equal or may sometimes exceed the densities we saw (Bruce Weise, pers. comm., 2009), this newly discovered Pantano Wash population is likely among the densest tortoise populations in the Sonoran Desert of Arizona.

There is one previous report of a tortoise population along Pantano Wash, on the northwest edge of Vail in an area currently slated for urban development (Ericson and Jordan 2006). We surveyed a site 3 miles NNW of Vail and also detected tortoises and abundant sign there. Data supplied by AGFD to Pima County during tortoise habitat model development contains a record from the south side of Pantano Wash near Houghton Road, 6 miles further downstream from our lowermost site. Cecil Schwalbe (pers. comm., 2009) has reported a tortoise moving through a side arroyo on the opposite side of Pantano Wash, approximately 1.5 miles east of the AGFD record. Taken together, this information indicates that a major tortoise population occupies the south side of Pantano Wash, from at least 3 miles NNW of Vail to the Marsh Station Road bridges over the main arroyo 4 miles ESE of Vail. Presumably, this population

Table 1. Desert tortoise observations on plots, transects, and time-constrained searches during desert tortoise model evaluation study, City of Tucson Southlands HCP study area, Sept.-Oct. 2009. Second surveys of plots are shown in *underlined italics*.

Site	Live Adult	Live Juvenile	Burrow	Fresh Scat	Old Scat	Skeletal Remains	Track	**Total**
Santa Rita Region:								
01 plot	1							**1**
07.3 transect	1							**1**
19 plot				1				**1**
TCS-19							1	**1**
TCS-20	1		1		1			**3**
Pantano Region:								
09 plot				1				**1**
11 transect	4	2	1				1	**8**
12 plot 1	1*		7	7		1		**16**
12 plot 2	*1*		*2*	*4*				***7***
13 plot 1								**0**
13 plot 2	*1*							***1***
14 plot 1				3				**3**
14 plot 2								***0***
15 plot 1	2		1	2				**5**
15 plot 2	*2*		*1*	*1*				***4***
16 plot 1	1*		3*					**3**
16 plot 2								***0***
17 plot	1		4	2				**7**
18 plot	1		4	4				**9**
off-plot	2		3	2				**7**
TCS-08	1		8	5				**14**
TCS-15			5	6				**11**
Total	**20**	**2**	**40**	**38**	**1**	**1**	**2**	**104**

* Records found on adjoining off-plot locations.

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occurs also on the north side of Pantano Wash and extends east into the main body of Pima County's Ciénega Creek Preserve east of the Marsh Station Road bridges. Much of this area also supports substantial populations of the Pima pineapple cactus (Baker 2006, 2007; and our observations) as well as other uncommon smaller cactus species populations and abundant, diverse wildlife.

4.2 Santa Rita Region

South of I-10, three tortoises were observed with four additional sign records in the vicinity of the tortoises. One very large adult male tortoise and one track in a caliche cave burrow were found in a wash around the large rolling "ballena" formation of hilly, ancient dissected bajada 2–3 miles west of Corona de Tucson. A second very large and old tortoise, this one female, was found near scat, caliche, and pallet burrow records on the upper bajada SSW of Corona de Tucson in the bluffs of a side draw of deeply incised Sycamore Canyon Wash. These records were associated with the best caliche formations south of I-10. One additional tortoise, a young adult, and a single scat record, were found a mile and a half southeast of Corona de Tucson, on the largest desert mountain outlier south of I-10, on granitic boulder slopes, but plenty of additional effort spent on and around this mountain yielded no sign or tortoises. Generally, the tortoises were found in (on the granite mountain) or near (the ballena bajada) the modeled tortoise habitat, but the model was not accurate for the bajada.

Although the largest wash between Corona de Tucson and Copper Cut Road to the east also had well-developed caliche and appeared suitable, no tortoises or tortoise sign were observed. Extensive intensive searches in semi-desert grassland further east and south also yielded no evidence of tortoises despite the presence of suitable cover that could serve as shelter sites (Photograph 5) and caliche in a few places. Although tortoises on the lower Rincon Mountain slopes and in Tortolita Mountains are found in biotic communities transitional to semi-desert grassland at and above the elevations of the semi-desert grasslands we surveyed, our findings indicate that such utilization may be tortoise population spillover from desertscrub into marginal habitat. Some further investigation is needed to clarify this supposition, but these results indicate that the model requires revision to eliminate semi-desert grassland south of I-10 as well.

In the Sonoran-Chihuahuan desertscrub further east, generally associated with Davidson Canyon, there were few or no suitable shelter sites and no evidence of tortoises despite our having targeted the survey to sites with the best potential for cover and the most suitable-looking vegetation (e.g., stands of saguaro). In Davidson Canyon, little rock or caliche was found in the study area, and the best site that was investigated—most promising based on extensive visual reconnaissance—had few caliche exposures. Its few fractured metamorphic rock outcrops offered little in the way of potential cover for tortoises. Soils were hard and poorly suited for digging by tortoises.

Photograph 5. Granitic boulders with friable soil on a ridge in semi-desert grassland. Although rock and soil at this site seemed optimal for tortoises, none were found there or elsewhere in this vegetation type.

West of Davidson Canyon, rolling hills and low mountains were dominated by limestone rock, and there were no shelter sites available for tortoises. Soils were too hard for digging, and none of this area appeared suitable as tortoise habitat. Larger hills and mountains in this area were similarly unsuitable.

The extensive lowlands and hills west and north of these areas were also surveyed, large areas of which were included as potential habitat in the GIS tortoise habitat model. We found no tortoise sign and no potentially suitable habitat even in sites with exposed caliche and friable soils that tortoises could potentially dig into (see Photograph 2). Although these areas were largely included as potential habitat in the tortoise model, the results of this survey demonstrate that they are not occupied by a tortoise population.

4.3 Discussion

The tortoise habitat model performed poorly in the Pantano Wash portion of the study area, where tortoises were most abundant in the large bluffs along and extending south in draws from Pantano Wash. The modeled habitat included flatter terrain closer to I-10, and there was little overlap between the tortoise observations and the modeled habitat, although the modeled habitat was nearby. The tortoise habitat model is accurate in the inclusion of caliche as the key habitat feature for tortoises in the Southlands HCP area, but it failed to capture the actual caliche exposures or the nuances of caliche that determine whether it provides shelter sites required by tortoises.

The desert tortoise may find pre-existing shelters in great fields of granite boulders to be largely sufficient as habitat. However, even in this situation, usually, and perhaps always in other situations, this tortoise must also be able to excavate its shelters under and among the boulders. It digs secondary dens and shallow burrows (called "pallets") in friable soils as shelter from temperature, predators, and desiccation.

The explanation of most of the deviations of the habitat model from actual habitat involves the way the Sonoran Desert tortoise utilizes bajada environments. Specifically, there is growing evidence, including results recorded in these surveys, that this tortoise has an important bajada xeroriparian habitat component. This habitat component is tightly related to the presence of hard shelters along embankments of moderately to deeply incised arroyos. Tortoise populations in the study area were 98 percent associated with substantial to major outcropping systems of "caliche" (valley fill sediments cemented by accumulated calcium carbonate) in which usable cave shelters at heights above the flash-flood zone had formed by various processes such as water erosion and animal activity.

These findings indicate that In the Sonoran Desert, desert tortoise populations only occur where hard rock shelters exist to anchor the niche. This likely reflects the more intense predation regime in Sonoran compared to Mojavean environments. In addition, the requirement for hard shelter may have a seasonal basis, particularly functioning as on winter refuges, but this is not definitely known.

This habitat discussion highlights the changes needed for correct modeling or empirical delineation of desert tortoise habitat in the Tucson Southlands HCP planning area. The distribution of suitably sized, properly situated, and adequately abundant caliche formations must be known to properly understand and manage the desert tortoise in the Tucson Southlands HCP planning area.

5.0 Recommendations

Specific recommendations for refinement of the existing desert tortoise habitat model include:

1. **Incorporating a better understanding of desert tortoise utilization of semi-desert grassland habitat.** Although tortoises on the lower Rincon Mountain slopes and in Tortolita Mountains are found in biotic communities transitional to semi-desert grassland, the findings indicate that such utilization at and above the elevations of the semi-desert grasslands that were surveyed may be a spillover from tortoise populations in desertscrub into marginal habitat. Some further investigation is needed to clarify this supposition, but these results indicate that the model requires revision in this regard.

2. **Incorporating a more detailed and accurate description of predictive substrate.** Supplemental information will be needed, including (1) closely defined slope parameters (for Santa Rita Region) and (2) gully depth characteristics (for Pantano Region) to (3) parse caliche characteristics more closely and redefine the bajada aspect of tortoise habitat. It would then be essential to field-test the new model, first by examining the extent to which it accurately predicts and describes caliche conditions and secondly by verifying that tortoise populations correlate with the caliche model and other information presented here. The results of another iteration would likely be more specific, original, and useful than most GIS-based niche models for animals.

Additional fieldwork that is likely to assist model-building and tortoise management in the HCP area may include:

1. Additional surveys in the Santa Rita Region to determine if there is actually a viable or even reproducing population of the desert tortoise south of I-10. Although our findings suggest this possibility, the desert tortoise's presence south of I-10 may reflect former immigration (see Edwards *et al.* 2004a and b) from exceptionally strong populations in the Pantano Region and Rincon Mountains, now obstructed by I-10 and other barriers.

2. Survey further south around the Santa Rita Mountains, especially into the Santa Rita Experimental Range, to test a revised caliche model and evaluate pre-existing distributional records of the desert tortoise there.

3. A formal and more extensive survey of the Pantano Region desert tortoise population to determine (1) its full extent both upstream and downstream of Vail, (2) the variability of desert tortoise abundance on the two sides of the cañada, and (3) desert tortoise occurrence as a function of distance from the bluffs facing the broad washbed in the arroyo bottom. It seems clear that this major population overlaps the intensely urbanizing environment north and west of Vail.

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APPENDICES

Appendix A: Locations of Survey Areas

Plot, transect, and time-constrained search type and location information on desert tortoise model evaluation study, City of Tucson Southlands HCP study area, Sept.-Oct. 2009.

Site no.	Sub-region	Type	Notes	Zone	Easting	Northing	Elev. (ft)
01 plot	Corona de Tucson	plot	NE corner	12R	523808	3533660	3731
01 plot	Corona de Tucson	plot	NW corner	12R	523642	3533708	3705
01 plot	Corona de Tucson	plot	SE corner	12R	523765	3533503	3915
01 plot	Corona de Tucson	plot	SW corner	12R	523611	3533538	3728
02 transect	Corona de Tucson	belt transect	transect START	12R	524739	3533560	3862
02 transect	Corona de Tucson	belt transect	transect STOP	12R	524482	3534195	3748
03 plot	Corona de Tucson	plot	NW corner	12R	524248	3533651	3940
03 plot	Corona de Tucson	plot	NW corner	12R	524042	3533662	3948
03 plot	Corona de Tucson	plot	SW corner	12R	524225	3533504	4137
03 plot	Corona de Tucson	plot	SW corner	12R	524070	3533496	4092
04 plot	Corona de Tucson	plot	NE corner	12R	524683	3534338	3684
04 plot	Corona de Tucson	plot	NNW corner	12R	524551	3534320	3730
04 plot	Corona de Tucson	plot	NW corner	12R	524554	3534324	3750
04 plot	Corona de Tucson	plot	SE corner	12R	524735	3534179	3740
04 plot	Corona de Tucson	plot	SW corner	12R	524564	3534179	3740
05 plot	vic Copper Cut Rd	plot	NE corner	12R	526287	3534352	3764
05 plot	vic Copper Cut Rd	plot	NW corner	12R	526116	3534351	3764
05 plot	vic Copper Cut Rd	plot	SE corner	12R	526287	3534180	3764
05 plot	vic Copper Cut Rd	plot	SW corner	12R	526116	3534177	3793
06 plot	vic Copper Cut Rd	plot	NE corner	12R	525749	3533826	3881
06 plot	vic Copper Cut Rd	plot	NW corner	12R	525593	3533827	3881
06 plot	vic Copper Cut Rd	plot	SE corner	12R	525744	3533667	3980

Site no.	Sub-region	Type	Notes	Zone	Easting	Northing	Elev. (ft)
06 plot	vic Copper Cut Rd	plot	SW corner	12R	525581	3533669	3976
07.1 transect	Corona de Tucson	belt transect	Transect START	12R	515058	3534099	3053
07.1 transect	Corona de Tucson	belt transect	Transect STOP	12R	515663	3533287	3123
07.2 transect	Corona de Tucson	belt transect	Transect START	12R	515506	3532653	3143
07.2 transect	Corona de Tucson	belt transect	Transect STOP	12R	516161	3531873	3228
07.2 transect	Corona de Tucson	belt transect	Transect STOP	12R	516241	3531750	3238
07.3 transect	Corona de Tucson	belt transect	Transect START	12R	517544	3532138	3328
07.3 transect	Corona de Tucson	belt transect	Transect STOP	12R	515398	3533777	3061
08 transect	Corona de Tucson	belt transect	Transect START	12R	526578	3534850	3713
08 transect	Corona de Tucson	belt transect	Transect STOP	12R	525695	3536597	3580
09 plot	Pantano	plot	Plot START	12S	531330	3543241	3287
10 (skipped)	na	na	Na	na	na	na	na
11 transect	Pantano	plot	Transect START	12S	531531	3542915	3350
11 transect	Pantano	plot	Transect STOP	12S	531546	3542894	3359
12 plot	Pantano	plot	NE corner	12S	529625	3543914	3247
12 plot	Pantano	plot	NW corner	12S	529452	3543917	3307
12 plot	Pantano	plot	SE corner	12S	529619	3543743	3251
12 plot	Pantano	plot	SW corner	12S	529451	3543743	3310
13 plot	Pantano	plot	NE corner	12S	529923	3543742	3313
13 plot	Pantano	plot	NW corner	12S	529756	3543742	3306
13 plot	Pantano	plot	SE corner	12S	529927	3543572	3318
13 plot	Pantano	plot	SW corner	12S	529754	3543567	3310
14 plot	Pantano	plot	NE corner	12S	530684	3543206	3355
14 plot	Pantano	plot	NW corner	12S	530508	3543208	3350
14 plot	Pantano	plot	SE corner	12S	530681	3543033	3369
14 plot	Pantano	plot	SW corner	12S	530509	3543038	3360
15 plot	Pantano	plot	NE corner	12S	531077	3542644	3311
15 plot	Pantano	plot	NW corner	12S	530907	3542641	3383
15 plot	Pantano	plot	SE corner	12S	531081	3542472	3353
15 plot	Pantano	plot	SW corner	12S	530910	3542470	3366
16 plot	Pantano	plot	NE corner	12S	530965	3542237	3385
16 plot	Pantano	plot	NW corner	12S	530792	3542229	3420
16 plot	Pantano	plot	SE corner	12S	530965	3542065	3385
16 plot	Pantano	plot	SW corner	12S	530794	3542059	3420
17 plot	Pantano	plot	NE corner	12S	529829	3544435	3255
17 plot	Pantano	plot	NW corner	12S	529656	3544435	3228
17 plot	Pantano	plot	SE corner	12S	529829	3544265	3205
17 plot	Pantano	plot	SW corner	12S	529655	3544266	3215

Site no.	Sub-region	Type	Notes	Zone	Easting	Northing	Elev. (ft)
18 plot	Pantano	plot	NE corner	12S	525957	3550384	2992
18 plot	Pantano	plot	NW corner	12S	525789	3550383	3008
18 plot	Pantano	plot	SE corner	12S	525958	3550213	3025
18 plot	Pantano	plot	SW corner	12S	525784	3550213	3028
19 plot	Pantano	plot	NE corner	12R	524021	3533795	3825
19 plot	Pantano	plot	NW corner	12R	523853	3533794	3773
19 plot	Pantano	plot	SE corner	12R	524023	3533626	3779
19 plot	Pantano	plot	SW corner	12R	523854	3533626	3789
20 transect	Corona de Tucson	belt transect	transect START	12R	522643	3534372	3576
20 transect	Corona de Tucson	belt transect	transect STOP	12R	523204	3533404	3697
21 transect	Corona de Tucson	belt transect	transect START	12R	522834	3533158	3674
21 transect	Corona de Tucson	belt transect	transect STOP	12R	522178	3534177	3537
22 transect	Corona de Tucson	belt transect	transect START	12R	521917	3533938	3524
22 transect	Corona de Tucson	belt transect	transect STOP	12R	522715	3533083	3691
23 transect	vic Copper Cut Rd	belt transect	transect START	12R	528367	3534565	na
23 transect	vic Copper Cut Rd	belt transect	transect STOP	12R	528327	3535486	3727
24 transect	vic Copper Cut Rd	belt transect	transect START	12R	528707	3535472	3711
24 transect	vic Copper Cut Rd	belt transect	transect STOP	12R	529285	3534252	3822
TCS 01	Corona de Tucson	TCS	search START	12R	526335	3533961	3829
TCS 01	Corona de Tucson	TCS	search STOP	12R	526337	3533332	4056
TCS 02	Corona de Tucson	TCS	search START	12R	526370	3535631	3654
TCS-03	Sonoita Hwy	TCS	search START	12R	531450	3532136	4069
TCS-03	Sonoita Hwy	TCS	search STOP	12R	531450	3532135	4056
TCS-04	Sonoita Hwy	TCS	search START	12R	531362	3531866	4235
TCS-04	Sonoita Hwy	TCS	search STOP	12R	531374	3531889	4216
TCS-05	Sonoita Hwy	TCS	search START	12R	533055	3537084	3671
TCS-05	Sonoita Hwy	TCS	search STOP	12R	533033	3537084	3672
TCS-06	SRER	TCS	search START	12R	515921	3520737	4018
TCS-06	SRER	TCS	search STOP	12R	515922	3520738	4019
TCS-07	Corona de Tucson	TCS	search START	12R	524574	3533171	3915
TCS-07	Corona de Tucson	TCS	search STOP	12R	524817	3533152	3887
TCS-08	Pantano	TCS	search START	12S	531681	3542800	3365
TCS-08	Pantano	TCS	search STOP	12S	531703	3542797	3368
TCS-09	lowland non-habitat	TCS	search START	12S	517282	3544603	2948

Site no.	Sub-region	Type	Notes	Zone	Easting	Northing	Elev. (ft)
TCS-10	lowland non-habitat	TCS	search STOP	12S	517277	3544591	2949
TCS-11	lowland non-habitat	TCS	search START	12S	517038	3543621	2949
TCS-11	lowland non-habitat	TCS	search STOP	12S	517039	3543653	2934
TCS-12	lowland non-habitat	TCS	search START	12S	521165	3543630	3087
TCS-13	lowland non-habitat	TCS	search START	12R	521466	3537521	3239
TCS-13	lowland non-habitat	TCS	search STOP	12R	521469	3537520	3244
TCS-14	vic Copper Cut Rd	TCS	search START	12R	529461	3534189	3835
TCS-14	vic Copper Cut Rd	TCS	search STOP	12R	529462	3534192	3843
TCS-15	Pantano	TCS	search START	12S	532441	3541404	3416
TCS-15	Pantano	TCS	search STOP	12S	532503	3541433	3419
TCS-16	lowland non-habitat	TCS	search START	12S	507082	3545133	2676
TCS-16	lowland non-habitat	TCS	search STOP	12S	507086	3545135	2666
TCS-17	Corona de Tucson	TCS	search START	12R	516860	3536348	3076
TCS-17	Corona de Tucson	TCS	search STOP	12R	517326	3536360	3070
TCS-18	Corona de Tucson	TCS	search START	12R	522080	3531014	3884
TCS-18	Corona de Tucson	TCS	search STOP	12R	522080	3531008	3861
TCS-19	Corona de Tucson	TCS	search START	12R	517889	3533449	3298
TCS-19	Corona de Tucson	TCS	search STOP	12R	517888	3533450	3285
TCS-20	Corona de Tucson	TCS	search START	12R	519941	3532100	3541
TCS-20	Corona de Tucson	TCS	search STOP	12R	519975	3532118	3526

Appendix B: Habitat Descriptions of Survey Areas

Habitat descriptions for plots, transects, and time-constrained searched areas for desert tortoise model evaluation study, City of Tucson Southlands HCP study area, Sept–Oct. 2009. SonD = Sonoran desertscrub, ChihD = Chihuahuan desertscrub, thornscrub = Sonoran (=Sinaloan) thornscrub (or dry tropic scrub), SD-G = semi-desert grassland.

Site No.	Tucson Southlands Sub-region	Slope Type	Vegetation Type	Shelter Types	Verbal Loc Description
01 plot	Corona de Tucson	bedrock, boulder slope	SonD & thornscrub w some SD-G	boulder and outcrop shelter sites available	W outcrops desert mountain SE CdT
02 transect	Corona de Tucson	level bajada	SonD mesquite–hackberry–prickley pear	fractured rock, few or no shelter sites	Wash between desert mountains SE CdT
03 plot	Corona de Tucson	bedrock, boulder slope	SD-G, SonD, thornscrub	boulder and outcrop shelter sites available	N Draw desert mountain SE CdT
04 plot	Corona de Tucson	rock and bedrock	SonD	outcrop shelter sites available, mostly angular, fragmented rock	smaller desert mountain SE CdT
05 plot	vic Copper Cut Rd	level middle bajada with washes	SD-G	granitic boulder shelter sites widely scattered, abundant	Outcrop Flat W Copper Cut Rd
06 plot	vic Copper Cut Rd	boulder, bedrock, and sandy loam slopes	SD-G w SonD element	granitic boulder shelter sites and friable soil very abundant	Outcrop-Boulder Hill W Copper Cut Rd
07.1 transect	Corona de Tucson	heavily rolling bajada with large washes	SonD w limited SD-G elements	widely scattered groups of caliche caves, some substantial	Bajada ballenas W CdT section 1
07.2 transect	Corona de Tucson	heavily rolling bajada with large washes	SonD w limited SD-G elements	widely scattered groups of caliche caves	Bajada ballenas W CdT section 2
07.3 transect	Corona de Tucson	heavily rolling bajada with large washes	SonD w limited SD-G elements	widely scattered groups of caliche caves	Bajada ballenas W CdT section 3

Site No.	Tucson Southlands Sub-region	Slope Type	Vegetation Type	Shelter Types	Verbal Loc Description
08 transect	Corona de Tucson	bajada wash with bluffs and outcrops	SD-G and SonD	moderately abundant good caliche cave development	Wash W of Red Hill W Copper Cut Rd
09 plot	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	caliche well developed and widespread	Pantano S bank, SE of Vail 2
11 transect	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	caliche well developed and widespread	Pantano S side, SE of Vail 6
12 plot 1	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	caliche well developed and widespread	Pantano S side, SE of Vail 1
13 plot 1	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	limited caliche	Pantano S side, SE of Vail 2
14 plot 1	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	limited caliche	Pantano S side, SE of Vail 3
15 plot 1	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	limited caliche	Pantano S side, SE of Vail 4
16 plot 1	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	caliche well developed and widespread	Pantano S side, SE of Vail 5
17 plot	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	caliche well developed and widespread	Pantano S bank, SE of Vail 1
18 plot	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	caliche well developed	Pantano S bank, NNW of Vail
19 plot	Corona de Tucson	bedrock, boulder slope	SonD & thornscrub w some SD-G	boulder and outcrop shelter sites available	NW outcrops desert mountain SE CdT
20 transect	Corona de Tucson	upper bajada medium wash	SonD	shelter marginal	Desert bajada SSE CdT 1

Site No.	Tucson Southlands Sub-region	Slope Type	Vegetation Type	Shelter Types	Verbal Loc Description
21 transect	Corona de Tucson	upper bajada medium wash	SonD	shelter marginal	Desert bajada SSE CdT 2
22 transect	Corona de Tucson	upper bajada medium wash	SonD	shelter marginal	Desert bajada SSE CdT 3
23 transect	vic Copper Cut Rd	upper bajada medium wash	SonD and SD-G	shelter marginal	lower wash2 E of Copper Cut Rd
24 transect	vic Copper Cut Rd	upper bajada medium wash	SonD and SD-G	shelter marginal	lower wash1 E of Copper Cut Rd
TCS 01	Corona de Tucson	rock slopes and canyons	SD-G w thornscrub elements	local caliche caves and boulder shelters	S base Cuprite Mine mountain
TCS 02	Corona de Tucson	rocky hill slopes	SonD	angular, fractured rock, very few shelter sites	N-most red hill W Copper Cut Rd
TCS-03	Sonoita Hwy	stony hill slopes	SD-G and SonD	loose rock, few or no shelter sites	N-side Hill W of Hwy 83
TCS-04	Sonoita Hwy	stony hill slopes and incised upper bajada washes	SonD and SD-G with thornscrub elements	scattered outcrop and caliche, few shelter sites	S-side Hill W of Hwy 83
TCS-05	Sonoita Hwy	hills and rolling bajada, large wash bluffs	SonD with ChihD elements	little caliche, rock type angular, fragmented, with poor shelter sites	Davidson Cyn, lower saguaro hill
TCS-06	SRER GOAG recc site	rolling bajada, large wash, and local rocky draws	SD-G	local areas of rock outcrop with poor shelter sites	Santa Rita Experimental Range S Huerfano Butte
TCS-07	Corona de Tucson	outcrop, boulder, and rock slope	SonD with thornscrub elements	boulders and outcrops with rock shelters available	E side desert mountain SE CdT
TCS-08	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	caliche well developed and widespread	Pantano S side, SE of Vail 7
TCS-09	lowland non-habitat	level lower bajada floodplain distributary	open mesquite, acacia, other SonD	very little caliche in arroyo cut, no shelter sites	central Lee Moore Wash basin 1
TCS-10	lowland non-habitat	level lower bajada floodplain distributary	open mesquite, acacia, other SonD	very little caliche in arroyo cut, no shelter sites	central Lee Moore Wash basin 2

Site No.	Tucson Southlands Sub-region	Slope Type	Vegetation Type	Shelter Types	Verbal Loc Description
TCS-11	lowland non-habitat	level lower bajada floodplain distributary	open mesquite, acacia, other SonD	little caliche in arroyo cut, no shelter sites	central Lee Moore Wash basin 3
TCS-12	lowland non-habitat	level lower bajada floodplain distributary	open mesquite, acacia, other SonD	extensive newly exposed caliche, no shelter sites	central Lee Moore Wash basin 4 (nr Houghton Rd)
TCS-13	lowland non-habitat	lower-middle bajada	SonD with SD-G characteristics	almost no caliche or other shelt	prickley pear washes NNE CdT
TCS-14	vic Copper Cut Rd	upper bajada with mature incised washes	SD-G with strong SonD elements	friable soil, local caliche uncommon	upper wash E of Copper Cut Rd
TCS-15	Pantano	stony lower bajada with bluffs along multiple deep draws	SonD with ChihD elements	caliche widespread, not well developed	Pantano S side, SE of Vail 8
TCS-16	lowland non-habitat	lower bajada, deeply entrenched wash	mesquite bosque surrounded by SonD	deep, exposed caliche and consolidated sediment, no shelter sites	lower Lee Moore Wash, 3 mi E Santa Cruz R
TCS-17	Corona de Tucson	middle bajada, medium to large washes	SonD w SD-G elements	very few or no shelter sites	middle bajada nr Sahuarita Rd, W CdT
TCS-18	Corona de Tucson	upper bajada wash with local bluff	SonD w SD-G elements well represented	few, local groups of caliche caves	NW base Mt Fagen, S CdT
TCS-19	Corona de Tucson	heavily rolling bajada with large washes	SonD w limited SD-G elements	widely scattered groups of caliche caves	Bajada ballenas W CdT section 4
TCS-20	Corona de Tucson	upper bajada, large wash with bluffs	SonD with thronscrub and SD-G elements	large caliche caves abundant	Sycamore Cyn Wash SSW CdT

Appendix C: Survey Effort

Plot, transect, and time-constrained search work schedule on Desert Tortoise model evaluation study, City of Tucson Southlands HCP study area, Sept.–Oct. 2009. SRER is Santa Rita Experimental Range. Total person-hr search was 188.2 hr.

Site No.	Date	Start time	Stop time	Time of Study (hr)	Plot size (ha)	Belt Transect Area (km^2)	Track-log Length (m)	No. Obs.	TCS km X No. Obs.	Tucson Southlands Sub-region
01 plot	3-Sep-2009	11:10	15:16	4:06	3.0		na	1		Corona de Tucson
02 transect	3-Sep-2009	16:15	17:48	1:33		1.7	834	2		Corona de Tucson
03 plot	4-Sep-2009	9:15	12:48	3:33	3.0		na	2		Corona de Tucson
04 plot	7-Sep-2009	7:03	8:18	1:15	3.0		na	4		Corona de Tucson
05 plot	14-Sep-2009	9:26	10:16	0:50	3.0		na	2		vic Copper Cut Rd
06 plot	7-Sep-2009	9:43	10:45	1:02	3.0		na	3		vic Copper Cut Rd
07.1 transect	6-Sep-2009	8:12	9:44	1:32		4.7	1580	3		Corona de Tucson
07.2 transect	6-Sep-2009	9:44	11:18	1:34		5.0	1670	3		Corona de Tucson
07.3 transect	6-Sep-2009	11:18	13:03	1:45		9.1	3040	3		Corona de Tucson
08 transect	6-Sep-2009	14:32	16:04	1:32		7.5	2490	3		Corona de Tucson
09 plot	7-Sep-2009	12:17	14:07	1:50	3.0		na	3		Pantano
11 transect	7-Sep-2009	14:31	16:49	2:18	3.0		na	3		Pantano
12 plot	8-Sep-2009	7:32	9:16	1:44	3.0		na	3		Pantano
12 plot	15-Sep-2009	7:43	9:35	1:52	3.0		na	2		Pantano
13 plot	8-Sep-2009	9:46	10:26	0:40	3.0		na	3		Pantano
13 plot	15-Sep-2009	9:44	10:53	1:09	3.0		na	2		Pantano
14 plot	8-Sep-2009	11:25	12:56	1:31	3.0		na	3		Pantano
14 plot	15-Sep-2009	15:05	15:40	0:35	3.0		na	2		Pantano
15 plot	8-Sep-2009	12:59	13:50	0:51	3.0		na	3		Pantano
15 plot	15-Sep-2009	11:50	13:35	1:45	3.0		na	2		Pantano
16 plot	8-Sep-2009	14:00	14:54	0:54	3.0		na	3		Pantano
16 plot	15-Sep-2009	13:36	14:34	0:58	3.0		na	2		Pantano
17 plot	10-Sep-2009	7:20	9:20	2:00	3.0		na	3		Pantano
18 plot	10-Sep-2009	11:45	14:00	2:15	3.0		na	3		Pantano

Site No.	Date	Start time	Stop time	Time of Study (hr)	Plot size (ha)	Belt Transect Area (km^2)	Track-log Length (m)	No. Obs.	TCS km X No. Obs.	Tucson Southlands Sub-region
19 plot	11-Sep-2009	9:05	10:15	1:10	3.0		na	2		Corona de Tucson
20 transect	13-Sep-2009	7:30	8:13	0:43		3.3	1090	3		Corona de Tucson
21 transect	13-Sep-2009	8:42	9:28	0:46		3.9	1290	3		Corona de Tucson
22 transect	13-Sep-2009	9:42	10:58	1:16		3.7	1240	3		Corona de Tucson
23 transect	13-Sep-2009	12:30	13:23	0:53		3.2	1070	3		vic Copper Cut Rd
24 transect	13-Sep-2009	13:33	14:48	1:15		4.8	1590	3		vic Copper Cut Rd
TCS 01	5-Sep-2009	9:14	10:11	0:57			971	2	1.94	Corona de Tucson
TCS 02	5-Sep-2009	10:11	12:00	1:49			2001	2	4.00	Corona de Tucson
TCS-03	14-Sep-2009	10:53	11:40	0:47			1888	2	3.78	Sonoita Hwy
TCS-04	14-Sep-2009	11:45	13:12	1:27			3159	2	6.32	Sonoita Hwy
TCS-05	14-Sep-2009	14:16	16:00	1:44			2436	2	4.87	Sonoita Hwy
TCS-06	10-Oct-2009	17:15	18:08	0:53			1998	1	2.00	SRER
TCS-07	11-Oct-2009	13:45	15:30	1:45			2127	3	6.38	Corona de Tucson
TCS-08	11-Oct-2009	16:30	17:13	0:43			578	3	1.73	Pantano
TCS-09	12-Oct-2009	9:03	9:08	0:05			200	3	0.60	lowland non-habitat
TCS-10	12-Oct-2009	9:09	9:17	0:08			300	3	0.90	lowland non-habitat
TCS-11	12-Oct-2009	9:25	9:38	0:13			632	3	1.90	lowland non-habitat
TCS-12	12-Oct-2009	9:56	10:26	0:30			1452	3	4.36	lowland non-habitat
TCS-13	12-Oct-2009	11:17	11:58	0:41			2125	3	6.38	lowland non-habitat
TCS-14	12-Oct-2009	13:04	14:58	1:54			3946	3	11.84	vic Copper Cut Rd
TCS-15	12-Oct-2009	15:58	17:36	1:38			1891	3	5.67	Pantano
TCS-16	13-Oct-2009	9:13	10:00	0:47			1544	3	4.63	lowland non-habitat
TCS-17	13-Oct-2009	11:07	12:22	1:15			2914	3	8.74	Corona de Tucson
TCS-18	13-Oct-2009	13:15	14:47	1:32			3750	3	11.25	Corona de Tucson
TCS-19	11-Oct-2009	9:07	12:22	3:15			6617	3	19.85	Corona de Tucson
TCS-20	13-Oct-2009	15:31	17:01	1:30			1504	3	4.51	Corona de Tucson
Total Search				**71 hr 2 min**	**60.0**	**46.8**	**57.9**		**111.65**	

Appendix D:
CD containing a Detailed Track Log of Survey Effort